Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures

HELAINE SELIN (Ed.)

Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures

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With 1374 Figures and 107 Tables

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Personal Note From The Editor

Many years ago I taught African history at a secondary school in Central Africa. A few years before, some of the teachers in the country had designed a syllabus that included pre-European history, since the curriculum, left over from colonial days, did not include any mention of Africa before the Portuguese. After a year of teaching from this revised version, I asked my students what they thought was the most significant moment in African history, and virtually all of them said it was the arrival of David Livingstone.

It may well be that that was the most important moment for Africa, but it shocked me at the time that no one considered any African achievements worth mentioning. Over these years I have come to see that the dominance of the West means not only that Westerners disparage the rest of the world but also that the rest of the world sees itself as inferior to the West. This book is meant to take one step towards rectifying that, by describing the scientific achievements of those who have been overlooked or undervalued by scholars in both the West and the East.

The book is more than just a compilation of disparate articles; it is a glimpse into how people describe and perceive and order the world. I hope the reader will do some exploring. In addition to reading about Maya astronomy, one can read about Mesoamerican mathematics and medicine, as well as a general article on magic and science, because all the fields are interrelated and entwined. It might be useful to read about astronomy in Africa and in Australia, to see how similar and different these cultures are. One can travel across disciplines, following the achievements of one culture, and across cultures, comparing the same discipline. And then it would be useful to read an essay on Transmission of Knowledge, or Rationality and Method, to put the articles and their contents in a broader philosophical and social context.

My hope, and that of the advisors and contributors to the project, is that the *Encyclopaedia* will expand the horizons of scholars, teachers, and students by illustrating how extensive the accomplishments of non-Western scientists are. May our future students never believe that science is limited to a fraction of the world.

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A note about the authors' names, especially Asian ones: I made many embarrassing errors confusing peoples' surnames and given names, but I was reluctant to change authors' names to conform to the Western style, as it went against the spirit of the *Encyclopaedia*. Therefore, I have left the names as the authors wrote them.

There is no cure for curiosity.

Tim Davis, *My Life in Politics*, 2006

Dedicated with affection and admiration to Dr. Robert Friedlander, Sarajune Dagen, and the nurses in the brain surgery unit at Brigham and Women's Hospital, Boston. You saved my life.

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Introduction to the Second Edition

"Some people now incorporate bits and pieces of information about other cultures' science into their courses; we hope that in ten years, minds and curricula will have expanded to include much more of this material." That line is a quotation from the Introduction to the first edition of the *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*. Ten years has passed. What has changed?

The most dramatic change has been technological. When I began working on the first edition, in 1992, only a handful of people had email access, and that was especially true for people outside of Europe and North America. Just getting in touch with people was a major obstacle. Months, sometimes years, passed between the time an invitation was extended and accepted, and an article was sent, edited and sent back, and approved. Electronic books did not exist. Images and bibliographies were necessarily limited, as we did not want to make the encyclopaedia too large. Now we have an encyclopaedia that goes far beyond the limits imposed by print. We are in the midst of a new kind of scholarly communication.

The second change becomes apparent by looking over the scholarly literature in the field. In some disciplines, twice as many new books and articles were published in the last decade than had been published in the 10 years before the first edition. With the increase in scholarship, we find that we no longer have to defend our field of study. One of the weaknesses of the first edition was that we did not always eliminate the anti-Eurocentric language and occasionally allowed a polemical tone to come through. In the new edition, we move from advocacy to analysis.

Another advantage of the increase in relevant scholarship is that we have been able to find materials that we were unable to find before. This new edition includes sections on ceramics, architecture, water management, brewing, fishing, cosmology, and many more entries on ethnobotany, metallurgy, and on city and town planning.

What is perhaps even more interesting is that it is not just scholarly interest that has increased over this period. A lead article in the *New York Times Magazine* on February 23, 2003 discussed the field of ethnomathematics, which is a major focus of the encyclopaedia. In this area, the mathematical activities of many cultures, such as Indian geometry or mapmaking in the Marshall Islands, are recognized as mathematics, where before they were relegated to the field of anthropology and dismissed as not having any mathematical value. It is particularly relevant that educators have picked up this notion and are trying to study and teach science through the lens of culture. What a perfect time to expand the encyclopaedia and take advantage of this new interest.

The Electronic Version

The web makes a cross-cultural, cross-disciplinary comparison especially easy. A reader can search "lunar mansions" and be taken to all the mentions of lunar mansions, not just in the articles specifically devoted to that topic, but in any of the rest of the encyclopaedia, as in the chapter on Ibn Majid, an Arab navigator of the fifteenth century. It also makes it possible to connect the philosophical essays with the more empirical ones, making it easier to broaden users' views to include philosophical, social, historical, geographical, and scientific aspects. This is a conscious instrument drawn to promote cross-cultural interaction. The electronic edition has hyperlinks to other articles in the encyclopaedia, and to sites suggested by the authors. We have greatly increased the number of images. We hope to be able to continue to add to this over the years. We plan to keep the encyclopaedia updated. This means not just updating and adding to the research there, but being able to introduce new topics as they become available.

I think our prediction of 1997 has partially come true, and I hope the new edition will reach farther, dig deeper, and touch many more minds and hearts. As Tim Davis says in *My Life in Politics* (Aperture, 2006), "There is no cure for curiosity."

Abacus

Sr. Barbara E. Reynolds

In contemporary usage, the word *abacus* refers to a computational device with beads sliding on fixed rods, often associated with the Japanese or Chinese. However, the word *abacus* has Latin roots, suggesting a rich history in Western as well as Eastern cultures.

The present-day abacus, called *suan-pan* in China, *soroban* in Japan, and *schoty* in Russia is still in use by shopkeepers throughout Asia and in Chinatowns around the world. It works on a place-value or positional system of numeric notation, similar to that of our familiar Hindu-Arabic numerals. The number of beads on each rod represents the value of the digit in that place, with higher place values to the left (or, on the *schoty,* above) and lower place values to the right (or below). Numeric values are read from left-to-right (or top-to-bottom) similarly to the written numerals. For example, the numeral 341 is represented by 3 beads on the *hundreds* rod, 4 beads on the *tens* rod, and 1 bead on the *units* rod.

On Chinese and Japanese models the rods are vertical, and the beads on these rods are divided into two groups by a horizontal bar, which separates the beads into a set of one or two beads above the bar and another set of four or five beads below the bar. The beads above this horizontal bar are valued at five times the beads below the bar. Thus, for example, the number 756 is represented by 1 five-bead and 2 one-beads on the *hundreds* rod, 1 five-bead and no one-beads on the *tens* rod, and 1 five-bead and 1 one-bead on the *units* rod. To operate the abacus, first clear it by pushing all the beads away from the horizontal bar, the beads in the lower section are pushed down while those in the upper section are pushed up. This can be done quickly by tilting the abacus slightly so that all the beads slide down, then laying the abacus on a flat horizontal surface and running the index finger between the bar and beads in the upper section, pushing them away from the bar. The abacus is operated using the thumb and the index finger to push beads toward or away from the bar as values are added or subtracted. To add 341 + 756, first push the beads in place to represent 341, then push additional beads in place to represent 756. On the *hundreds* rod there will be 3 one-beads plus 1 five-bead and 2 additional one-beads; on the *tens* rod there will be 4 one-beads and 1 five-bead, and on the *units* rod there will be 1 one-bead, 1-five bead and 1 additional one-bead. The result can be read as 10 *hundreds*, 9 *tens*, and 7 *ones*. In practice this is quickly simplified by regrouping the beads to 1 *thousand,* 0 *hundreds,* 9 *tens,* and 7 *ones,* or simply 1097. That is, whenever 5 one-beads are accumulated below the bar they are exchanged for 1 five-bead above the bar, and whenever 2 five-beads are accumulated above the bar, they are exchanged for 1 one-bead in the next column to the left.

The Chinese *suan-pan*, which is first mentioned in the literature in the twelfth century, traditionally has two five-beads and five one-beads on each rod. So it is possible to accumulate a value of 15 (2 five-beads plus 5 one-beads) on each rod during the computation, and this must be simplified as described above before the result can be read out. The Japanese *soroban*, developed in the early 1930s, has shorter rods with one five-bead and four one-beads on each rod. With the *soraban* the value on any rod cannot go above 9 (1 five-bead plus 4 one-beads) so that simplifications must be carried out continuously throughout the computation. Since each bead is moved through a shorter distance, an experienced, skillful user can perform computations more quickly on the *soroban* than on the *suan-pan*.

The Russian *shoty*, developed in the 17th century, has horizontal rods, with ten beads on each rod. Numeric values are read from top down, with each rod valued at 10 times the value of the rod immediately below it. That is, the *hundreds* rod is above the *tens* rod, which is above the *units* rod. Calculating with the *shoty* resembles finger counting, each bead representing one finger, or one unit in its respective place value. If you hold your hands out in front of you with the palms away from you, your two thumbs will be side-by-side, flanked by the four fingers of each hand. Similarly, the two middle beads on each rod of the *shoty* representing the thumbs are in a contrasting color to the two sets of four beads each on either side. This makes it easier to see the values without consciously counting the beads. To clear the value on the *shoty* the beads are all pushed to the right. Beads are pushed to the left or right as numbers are added or subtracted.

Archeological evidence in the form of bead-frame calculators as well as piles of small smooth rounded stones, which could have been used as counters for reckoning, suggests that in ancient times (300 BCE to 500 AD), computations in the marketplace throughout the Roman empire were commonly worked out by casting stones (*calculi*) in the sand or on a specially marked counting table (*abax*). Lines in the sand or on the table top would mark off space for *ones*, *tens*, *hundred*s, and so on. To make the values easier to read, stones placed on the line between two spaces would denote values halfway between the lower-valued unit on the right and the higher-valued unit on the left. For example, a stone on the line between the *ones* and the *tens* would be valued as *five*, and a stone on the line between the *tens* and the *hundreds* would be valued as *fifty*.

Roman numerals could have been used to easily record the results of computations done on a sand-reckoner or counting table. The Roman numerals I, X, C, and M represent stones in the units, tens, hundreds, and thousands spaces, respectively, while V, L, and D represent values on the lines, 5, 50 and 500. On some surviving counting tables, the Roman numerals I, X, C, and M have been scratched onto the table top in the appropriate spaces, making it a simple matter to record the final result of the computation. The Roman numeral CCVIII (represented by 208 in Hindu-Arabic numerals) would be cast on the counter-top using two stones in the *hundreds* space, one stone on the line between the *tens* and the *units* spaces, and three stones in the *units* space. Similarly, the Roman numeral DCXXVIIII (or 629) would be cast using one stone on the line between the *thousands* and the *hundreds* spaces, one stone in the *hundreds* space, two stones in the *tens* space, one stone on the line between the *tens* and the *units* spaces, and four stones in *units* space. The use of a quasi-positional subtractive principle in Roman numerals – so that IIII is represented as IV and VIIII as IX – is a later development used only sparingly in ancient and medieval times.

To add CCVIII + DCXXVIIII, the person doing the calculating (probably a merchant), would first cast stones representing CCVIII, and then the additional stones representing DCXXVIIII. These would be regrouped by rearranging the stones in full view of the customer first as D CC C XX VV III IIII, and then simplified as D CCC XXX V II (or simply as 837 in our more familiar numerals).

In the early fourteenth century, bankers and merchants were still required by law to use Roman numerals to record business transactions. Since the Gutenberg printing press was not invented until about 100 years later, the majority of the population was illiterate (i.e., not taught to read the printed word). Recording the result of the previous example, DCCCXXXVII, in Roman numerals requires ten symbols, one symbol on the paper for each stone on the counting table. Recording the same result using Hindu-Arabic numerals would require only three symbols. Zero was a difficult concept, one that was not easily adopted. The Hindu-Arabic numeral 500 requires three digits, but would be represented by a single stone on the abacus, and by the single letter D using Roman numerals. Although the idea of zero as a placeholder was sometimes understood in medieval times, it simply was not needed in doing computations using an abacus. If results were recorded using Roman numerals, the clear correspondence between the stones on the counting table and the symbols on the paper was readily apparent. Thus, using Roman numerals, the customer would be assured that the merchant or banker was accurately recording the result of the transaction.

The Roman bead-frame calculators found at some archeological sites are small enough to be held in one hand and have a design similar to the Chinese *suan-pan*. This evidence suggests that the abacus was taken from Western Europe to the East by Christian migrations. In the late fourth century, Arabs brought the concept of a numeral for zero to the West from the Hindus in India.

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Abortion

Malcolm Potts

Abortion, along with circumcision, is amongst the oldest operations known to human kind. While abortion meets an extraordinarily important need of the individual, society commonly treats it differently from other aspects of medical science. Usually, there is little honor to be gained by improving abortion technologies.

The explanations and beliefs different cultures develop concerning the origin and maturation of pregnancy help determine attitudes to abortion. The *Quʾrān*, for example, describes pregnancy as a process of increasing complexity progressing from, "a drop of seed, in a safe lodging, firmly affixed" to a "lump" with "bones, clothed with flesh", and some Islamic theologians permit abortion early in pregnancy. Most abortions are performed because the woman feels she cannot support the child if born, although unmarried women, especially in non-Western traditional societies, may abort for fear of punishment. In the ancient Ugandan royal household, abortion was carried out on princesses so as not to divide the kingdom.

Abortion is known in practically all cultures from preliterate societies to the most industrialized. Abortionists are often also traditional birth attendants or medicine men. A spectrum of techniques is used which differ in their complexity and in their consequences, and which are greatly influenced by the stage of pregnancy when the procedure is carried out. In non-Western societies most techniques fall into one of three categories: herbal remedies, abdominal massage, and the insertion of foreign bodies into the uterine cavity.

In many contemporary non-Western cultures a variety of brews and potions are concocted to bring on a late menstrual period. Such methods were also widely sold in Western cultures until the reform of the abortion law. The open sale of emmenogogues (medicines to bring on a late period) in Manila, Lima, or Dacca today finds a close parallel in Boston in the nineteenth century United States, or Birmingham, England in the middle of this century. The *Jamu* remedies sold every day in Indonesia include a number of emmenogoges. The use of a tea brewed with the spiny nettle (*Urtica magellanica*) by the Aymara Indians of Bolivia living near Lake Titicaca and the juice of hibiscus leaves (*Abelomschus diversifolius*) in the Pacific islands are two examples from among many herbal remedies in preliterate societies.

The use for abortifacient medications is usually limited to the first six or eight weeks after the last menstrual period. Many do not work, but rely on the fact that spontaneous abortion is common and will often be ascribed to a traditional remedy when one has been used. Others are physiologically active, either on uterine muscle or the embryo, although they often need to be used in doses that may be toxic to the woman. In the 1970s and 1980s the Human Reproduction Program of the World Health Organization tested a number of such abortifacients from around the world, and at least one, from Mexico, underwent preliminary screening by a pharmaceutical company. The time of collection, the method of preparation, and details of use may all be critically important in determining the outcome. An alternative technique for studying traditional abortifacients was developed by Moira Gallen in the Philippines, who worked with vendors of traditional abortifacients and then followed up the women who used them. The data suggest some herbal remedies do indeed bring on a late period.

An amalgamation of Western and non-Western cultures has taken place in Brazil where the Western drug Cytotec, an oral form of prostaglandin, is sold illicitly to women with an unintended pregnancy. It is estimated there are one to four million illegally induced abortions in Brazil each year, and each woman has one to three abortions in a lifetime. Cytotec produces bleeding from the uterus which, although it does not always lead to abortion, is usually sufficient to take the woman to the hospital, where the abortion is invariably completed in the operating theater. It is relatively safe but can be very painful. Until restrictions were placed on sales in 1991, 50,000 packets a month were being sold.

The second set of abortion technologies, with a history stretching back to preliterate societies, involves physical trauma to the woman's body. Many cultures associate falls and physical violence with abortion, as did the ancient Hebrews (*Bible:* Exodus 21: 22). The oldest visual representation of an abortion anywhere in the world is on a bas relief in the great temples of Ankor Wat built by King Suryavarman II (AD 1130–1150). Massage abortion remains common from Burma, through

Thailand and Malaysia to the Philippines and Indonesia. Traditional birth attendants use their hands, elbows, bare feet, or a wooden mallet (as portrayed on the Ankor reliefs) to pound the uterus and terminate an unwanted pregnancy. Operators begin by asking the woman to empty her bladder and then try to draw the uterus from beneath the pubic bone so they can apply pressure to the abdominal wall. Sometimes these procedures lead to vaginal bleeding and abortion with relative ease; on other occasions the pain may be so severe that the operator has to stop and return some other time. A study in Thailand estimated that 250,000 such massage abortions take place in the villages of Thailand each year. Gynecologists in Malaysia have described how women are sometimes admitted to hospital for what appear to be the symptoms of appendicitis, with fever and rigidity of their abdominal muscles; when the abdomen is open, the uterus is found to be so bruised and damaged that it may be necessary to do a hysterectomy.

This specialized technique, which has to be learnt from generation to generation, is largely limited to Southeast Asia, although the American Indian Crows and Assiniboines used a board, on which two women jumped, placed across the abdomen of a recumbent pregnant woman, and Queensland native Australians used a thick twine wound around the abdomen combined with "punching" the abdominal wall.

The third types of abortion techniques are the most common and are found in all continents. They involve passing a foreign body through the uterine cervix in order to dislodge the placenta and cause an abortion. In traditional societies a twig or root may be used and it may take a day or more for the procedure to work. The major risks are infection and hemorrhage. The Smith Sound Inuit used the thinned down rib of a seal with the point cased in a protective cover of tanned seal skin, which could be withdrawn by a thread when the instrument had been inserted into the uterus. The Fijians fashioned a similar instrument from *losilosi* wood, but without the protective cover for insertion, and the Hawaiians used a wooden dagger-shaped object up to 22 cm long which was perceived as an idol Kapo. In contemporary Latin America and much of urban Africa, the commonest method of inducing abortion is to pass soft urinary catheters, or *sonda*, such as those used by doctors when men have enlarged prostates. Such catheters are readily available, although traditional abortions do not always use adequate sterile techniques and, even under the best of conditions, leaving such a catheter in place can be associated with infection.

Epidemiological studies show beyond all doubt that the safest way of inducing first trimester abortion is through the use of vacuum aspiration, and most legal abortions in the Western world are done using this technique. A small tube, varying in diameter from something slightly larger than a drinking straw to about 1 cm, is passed through the cervix, and attached to a vacuum pump. In the first three months of pregnancy such a procedure generally takes about 5 min and is commonly done as an out patient procedure under local anesthesia.

Vacuum aspiration abortion was described in nineteenth century Scotland, but the technique used today was invented in China sometime in the 1950s by Wu and Wu. The method spread across certain parts of the Soviet Union and into Czechoslovakia and some other areas of Eastern Europe. In the 1960s a nonmedically qualified practitioner from California called Harvey Karman invented a piece of handheld vacuum aspiration equipment. Karman got the idea from descriptions of procedure performed in China, Russia, and Eastern Europe, and the flow of ideas has gone full circle with the syringe equipment now being widely used in many non-Western countries, such as Bangladesh, Vietnam, and Sri Lanka.

In the Ankor reliefs the women having abortions are surrounded by the flames of hell. Although abortion was disapproved of in the East, it was still considered a crime against the family, not against the state as it is commonly perceived in the West. Abortion before the felt fetal movements was legal in Britain and all states of the United States in 1800 and illegal in those same places by 1900. With the expansion of colonialism, Western abortion laws were imposed upon all colonized nations of the Third World. The nations of the then British Empire either adopted a form of the 1861 Offenses Against the Person Act of Queen Victoria's England or a version of the Indian penal code. French colonies enacted the code of Napoleon and even countries that were not colonized, such as Thailand and Japan, adopted some form of restrictive abortion legislation in the nineteenth century derived from Western statutes.

The second half of the twentieth century has seen a reversal of many restrictive laws. The majority of the world's population now lives in countries which have access to safe abortion on request. The technologies used all over the world owe a great deal to non-Western philosophies and inventiveness.

See also: ►*Jamu*, ►Ethnobotany, ►Childbirth

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Abraham Bar Ḥiyya (Savasorda)

Tony Levy

Abraham bar Ḥiyya, also called Savasorda (latinized from the Arabic *ṣāḥib al-shurṭa* = Chief of the guard), flourished in Barcelona, in Christian Spain, but was probably educated in the kingdom (*tā'ifa*) of Saragossa, during the period in which it was ruled by the Arabic dynasty of the Banū Hūd. Thus his scientific education could be related to the well known scientific talents of some of the Banū Hūd kings.

Having mastered the Arabic language and culture, he was a pioneer in the use of the Hebrew language in various fields. He wrote on philosophy, ethics, astronomy, astrology, mathematics, and calendrial calculations. He clearly indicated that his Hebrew compositions were written for Jews living in southern France, who were unacquainted with Arabic culture and unable to read Arabic texts.

Two mathematical compositions by Abraham Bar Ḥiyya, and four astronomical ones are known.

Yesodey ha-tevuna u-migdal ha-emuna (The Foundations of Science and the Tower of the Faith) was supposed to be a scientific encyclopedia, of which only the mathematical sections survived. Presumably an adaptation from some unknown Arabic composition, it dealt with basic definitions and knowledge in arithmetic, geometry, and optics.

Ḥibbur ha-meshiḥa we ha-īshboret (The Composition on Geometrical Measures) dealt with practical geometry. This book enjoyed a very large diffusion in medieval Europe in its Latin version, the *Liber embadorum*, translated by Plato of Tivoli (1145), who was assisted by the author himself. The importance of this text for the development of practical geometry in Europe has been noted by ancient and modern scholars.

Seferṣsurat ha-areṣ we-tavnit kaddurey ha-raqi 'a (Book on the Form of the Earth and the Figure of Celestial Spheres), together with *Ḥeshbon mahalakhot ha-kokhavim* (Calculations of the Courses of the Stars) and The *Luḥot* (The Astronomical Tables), offered a basic astronomical knowledge founded on Arabic sources such as the works of al-Farghānī and al-Battānī.

Sefer ha-'Ibbur (The Book of Intercalation) dealt with calendrial calculations and aimed "to enable the Jews to observe the Holy Days on the correct dates."

Bar Ḥiyya can rightly be considered the founder of Hebrew scientific culture and language.

See also: ►al-Battānī

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Abraham Ibn Ezra

Samuel S. Kottek

Abraham Ibn Ezra was born in Toledo, Spain in 1089. In his youth, he studied all the branches of knowledge that Arabic and Jewish gifted (and well to do) youngsters could master, and was mainly known as a poet. Around 1140, he left Spain and wandered through Italy, southern France, and England. Also, legend says that in his old age he traveled to the Holy Land. During his itinerant life, Ibn Ezra met scores of scholars and wrote a number of works, of which his commentary on the Pentateuch and the Prophets in the most widely known.

He was a real polymath, who wrote on Hebrew philology (*Moznei Leshon ha-Kodesh*), translated several works on grammar from Arabic into Hebrew, and wrote on the calendar, mathematics (*Sefer ha-Mispar*, Book of the Number), and philosophy and ethics (*Yesod Mora* on the meaning of the commandments). He is considered one of the Jewish Neoplatonists, in particular regarding his description of the soul.

In his view, intellectual perfection is the only way to enjoy a relationship with the divine Providence. As a scientist, Ibn Ezra (also known by the name of Avenezra, sometimes misspelled Avenaris) is mainly known for his works on astronomy (*Sefer ha-ʿIbbur*: *Ta'amei ha-Luḥot*, Book on Intercalation) and for his treatise on mathematics mentioned above. He also composed a number of brief astrological works, most of them still unpublished. It is not known whether Ibn Ezra ever practiced medicine. He certainly showed in his biblical commentary a fair degree of knowledge in medicine and biology.

It has been said that Ibn Ezra wrote over 100 works, which seems rather exaggerated; certainly many fewer have survived. Ibn Ezra was the Paracelsian type of scholar, learning from each new experience, from each encounter with other scholars, living a simple life and despising wealth. It is particularly striking that he wrote only in Hebrew, contrary to nearly all his contemporaries in Spain who wrote in Arabic. This is mainly due to the fact that he wandered throughout Europe and North Africa, using the language that was common to all his coreligionists. He may be considered an ambassador of Spanish scholarship to the Jewish Diaspora at large. He died in 1164.

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Abū Jaʿfar al-Khāzin

JAN P. HOGENDIJK

Abū Jaʿfar Muḥammad ibn al-Ḥusay al-Khāzin was a mathematician and astronomer who lived in the early tenth century AD in Khorasān. Until recently, it was believed that there were two different mathematicians in the same period, namely Abū Jaʿfar al-Khāzin and Abū Jaʿfar Muḥammad ibn al-Ḥusayn, but in 1978 Anbouba and Sezgin showed that they are the same person.

In mathematics, Abū Jaʿfar al-Khāzin is mainly known because he was the first to realize that a cubic equation could be solved geometrically by means of conic sections. Al-Māhānī (ca. AD 850) had shown that an auxiliary problem in Archimedes' *On the Sphere and Cylinder* II: 4, which Archimedes had left unsolved, could be reduced to a cubic equation of the form $x^3 + c = ax^2$. Abū Jaʿfar knew the commentary to Archimedes' work by Eutocius of Ascalon (fifth century AD), in which Eutocius discusses a solution of the same auxiliary problem by means of conic sections. Abū Jaʿfar drew the conclusion that the equation $x^3 + c = ax^2$ could also be solved by means of conic sections. Abū Jaʿfar also studied a number of other mathematical problems. He stated that the equation $x^3 + y^3 = z^3$ did not have a solution in positive integers, but he was unable to give a correct proof. He also worked on the isoperimetric problem, and he wrote a commentary to Book X of Euclid's *Elements*.

In astronomy, Abū Jaʿfar's main work was the *Zīj alṣafāʾiḥ* (the Astronomical Handbook of Plates). A manuscript of this work has recently been discovered in

Srinagar. The work deals with a strange variant of the astrolabe. One such instrument, made in the twelfth century, was still extant in the beginning of this century in Germany, but it has since disappeared. Photographs of this instrument have been published by David King. Abū Jaᶜfar developed a homocentric solar model, in which the sun moves in a circle with the earth as its center, in such a way that its motion is uniform with respect to a point which does not coincide with the center of the earth.

See also: ►al-Māhānī

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Abū Kāmil

Jacques Sesiano

Abū Kāmil, Shujāᶜ ibn Aslam (ca. 850–ca. 930), also known as "the Egyptian Reckoner" (*al-ḥāsib al-miṣrī*) was, according to the encyclopedist Ibn Khaldūn's report on algebra in his *Muqaddima*, chronologically the second greatest algebraist after al-Khwārizmī. He was certainly one of the most influential. The peak of his activity seems to have been at the end of the ninth century.

Although at the beginning of his *Kitāb fī'l-jabr wa'l-muqābala* (Algebra) he refers to al-Khwārizmī's similar work, Abū Kāmil's purpose is radically different, for he is addressing an audience of mathematicians presumed to have a thorough knowledge of Euclid's *Elements*. His *Algebra* consists of four main parts.

a. Like his predecessor, Abū Kāmil begins by explaining how to solve the six standard equations and to deal with algebraic expressions involving an unknown and square roots. The next section (Book II) contains, as in his predecessor's work, six examples of problems and the resolutions of various questions, but the whole is notably more elaborate and geometrical illustrations or proofs are systematically appended. With Book III comes a difference, already hinted at in the introduction to the treatise: the problems now contain quadratic irrationalities, both as solutions and coefficients, and require notable proficiency in computing. Quadratic irrationalities may thus be said to enter definitely the domain of mathematics and no longer be confined to their Euclidean representation as line segments.
b. These extensions found in Book III are put to immediate use in the resolutions of problems involving polygons in which the link between their sides and the radii of a circumscribed circle is reducible to a quadratic equation – since they are all constructible by ruler and compass.
c. The subsequent set of quadratic indeterminate equations and systems is most interesting. The methods presented are similar to those of Diophantus's *Arithmetica*, but there are new cases and the problems are presented in a less particular form. Abū Kāmil surely relied on some Greek material unknown to us.
d. A set of problems which are, broadly speaking, applications of algebra to daily life are directly appended to the former. Some of these, which correspond to highly unrealistic situations, belong more to recreational mathematics. The inclusion of such problems in an algebraic textbook was to become a medieval custom, with both mathematical and didactical motives. The *Algebra* ends with the classical problem of summing the successive powers of 2, which, from the ninth century on, became attached to the 64 cells of the chessboard.

Abū Kāmil's Arabic text is preserved by a single, but excellent, manuscript. The *Algebra* was commented upon several times, in particular in Spain, and the first large mathematical book of Christendom, Johannes Hispalensis's *Liber mahameleth*, is basically a development and improvement of parts *a* and *d*. Despite the *Algebra*'s importance in Spain, no Latin translation was undertaken until the fourteenth century, when Guillelmus (presumably: de Lunis) translated half of it (up to the beginning of part *c*). This translation is better than Mordekhai Finzi's fifteenth century Hebrew one, which, however, covers the whole work. Since these translations were late, Abū Kāmil had no direct influence in the Christian West. Similar material, however, may be found in writings of Leonardo (Fibonacci) of Pisa (fl. 1220).

Abū Kāmil also wrote *Kitāb al-ṭair* (Book of the Birds), a small treatise consisting of an introduction and six problems all dealing with the purchase of different kinds of birds, of which one knows the price per unit, the total number bought and the amount spent (both taken to be 100). Since there are more unknown kinds (3–5) than equations, these linear problems are all indeterminate. Abū Kāmil undertook to determine their number of (positive integral) solutions, which he found to be, respectively, 1, 6, 96 (correct: 98), 304, 0, 2676 (correct: 2,678). Although such problems are frequently met in the medieval world, Abū Kāmil remained seemingly unparalleled in his search for all solutions in various cases.

Kitāb al-misāḥa wa’l-handasa, or *Kitāb misāḥat al-araḍīn* (On Measurement and Geometry) is an elementary treatise on calculating surfaces and volumes of common geometrical figures. Since it is meant for beginners, demonstrations and algebra are left out. Why Abū Kāmil found it necessary to write such an elementary book becomes clear when he describes some of the formulas then in use by official land surveyors in Egypt.

Finally, *Kitāb al-waṣāyābi’l-juḏūr* or *Kitāb al-waṣāyābi’l-jabr wa’l-muqābala* (Estate Sharing Using Unknowns, or Using Algebra) applies mathematics to inheritance problems. Abū Kāmil begins by explaining the requirements of the Muslim laws of inheritance and discussing the opinions of known jurists.

Bibliographic sources inform us that Abū Kāmil also wrote another treatise on algebra, and a further one on the rule of false position.

Note that two of the subjects included by al-Khwārizmī in his *Algebra* were treated by Abū Kāmil in separate works. From that time onward, algebra textbooks adopted the same form as his.

See also: ►Algebra, ►Mathematics, ►Recreational, ►Surveying, ►Algebra, ►Surveyor’s, ►Islamic number theory

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Abū ’l-Barakāt

Y. Tzvi Langermann

Abū al-Barakāt al-Baghdādī (d. 1164 or 1165) was one of the most original thinkers of the medieval period. Born a Jew in about 1080, but converted late in life to Islam, Abū ’l-Barakāt was a prominent physician and natural philosopher who achieved considerable fame during his own lifetime, as his appellation *awḥad al-zamān* (Unique of His Age) attests. His numerous insights into physics and metaphysics have been elucidated by the late Shlomo Pines in a number of brilliant studies, on which this résumé depends in large measure.

Abū ’l-Barakāt’s contributions are all contained in his *chef d’œuvre*, *al-Muʿtabar* (That Which has been Attained by Reflection). Although there may be some doctrinal discrepancies between various passages in the book, which may be due to the fact that the work is actually a collection of notes compiled over a considerable period of time, each section by itself displays a very clear and systematic exposition, surveying earlier opinions on the subject, objections to these, and possible answers to the objections (including the occasional concession that the objection is valid and necessitates a revision of the original idea), followed by Abū ’l-Barakāt’s own opinion. Abū ’l-Barakāt exhibits a remarkable ability to disentangle issues that had become densely intertwined through centuries of debate, for example the three notions of time, space, and the infinite. Particularly significant are the occasions when the author gives great, occasionally decisive, weight to “common opinion,” on the grounds that the issues at hand – the notions of time and space are the most important to fall into this group – involve a priori concepts which must be elucidated by examining how people actually perceive, rather than a posteriori academic analysis.

Some of the ideas which Abū ’l-Barakāt advances in the course of his discussions prefigure much later notions which proved to be correct: for example, the idea that a constant velocity applied to a moving body causes it to accelerate. Others, by contrast, showed themselves to be wrong: for instance, the idea that every type of body has a characteristic velocity which reaches its maximum when the resistance is zero. (In this way, Abu ’l-Barakāt answers the objection that bodies moving in a vacuum would have an infinite velocity.) All in all, the work of Abū ’l-Barakāt and its continuation by his student Fakhr al-Dīn al-Rāzī constituted a most serious challenge to the formulations of Ibn Sīnā, which then dominated physical and metaphysical thought in Near East.

All that we possess in the way of medical writings by Abū'l-Barakāt are a few prescriptions for remedies. These remain in manuscript and are as yet unstudied.

See also: ►al-Rāzī, ►Ibn Sīnā, ►Abū'l-Fidāʾ

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Abū'l-Fidāʾ

Emilia Calvo

Abū'l-Fidāʾ Īsmāʿīl ibn ʿalī ibn Maḥmūd ibn Muḥammad ibn ʿUmar ibn Shahanshāh ibn Ayyūb ʿImād al-Dīn al-Ayyūbī was a prince, historian, and geographer belonging to the Ayyūbid family. He was born in Damascus, Syria in AD 1273 and soon began his military career against the Crusaders and the Mongols. In AD 1299 he entered the service of the Sultan al-Malik al-Nāṣir and, after 12 years, he was installed as governor of Ḥamā. Two years later he received the title of al-Malik al-Ṣāliḥ. In AD 1320 he accompanied the Sultan Muḥammad on the pilgrimage to Mecca and was given the title of al-Malik al-Muʾayyad. He died at Ḥamā, Syria in AD 1331.

Abū'l-Fidāʾ is the author of some poetic productions, such as the version in verse of al-Māwardī's juridical work *al-Hāwī*. However, his celebrity is based on two works which can be considered basically compilations of earlier works which he elaborated and completed. One of them is the *Mukhtaṣar Taʾrīkh al-bashar* (A Summary on the History of Humanity) written in AD 1315 as a continuation of the *Kāmil fī-l-taʾrīkh* of Ibn al-Athīr. It was divided into two parts: the first was devoted to pre-Islamic Arabia and the second to the history of Islam until AD 1329. It was kept up to date until AD 1403 by other Arabic historians. It was translated into Western languages and became the basis for several historical syntheses by eighteenth-century Orientalists.

Abū'l-Fidāʾ's most important scientific work is *Taqwīm al-buldān* (A Sketch of the Countries) written between AD 1316 and 1321. It consists of a general geography in 28 chapters.

This book includes the problems and results of mathematical and physical geography without touching upon human geography or geographical lexicography. There is a table of the longitudes and latitudes of a number of cities, including the differing results found in the sources, setting up a comparative table for geographical coordinates. Among the sources of the book are geographers such as Ibn Hawqal and Ibn Saʿīd al-Maghribī.

This work was translated into German, Latin, and French between the sixteenth and the nineteenth centuries, making a significant contribution to the development of geography.

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Abū'l-Ṣalt

Julio Samsó

Abū'l-Ṣalt is known as Abū'l-Ṣalt al-Dānī. He was an Andalusian polymath born in Denia in 1067. In about 1096 he went to Egypt where he lived for sixteen years. An unsuccessful attempt to rescue a boat loaded with copper which had sunk in the harbor of Alexandria cost him 3 years in prison, after which he migrated to Mahdiyya (Tunis) where he died in 1134.

He wrote about pharmacology (a treatise on simple drugs, *Kitāb al-adwiya al-mufrada*, translated into Latin by Arnold of Vilanova), music, geometry, Aristotelian physics, and astronomy, and he seems to have been interested in a physical astronomy, different from the Ptolemaic mathematical astronomy which predominated in al-Andalus. His treatise on the use of the astrolabe, *Risāla fī-l-ʿamal bi-l-asṭurlāb*, written while he was in prison, probably introduced into Eastern Islam the characteristic Andalusian and Maghribi device, present in the back of Western instruments, which establishes the relation between the date of the Julian year and the solar longitude. He is also the author of a short treatise on the construction and use of the equatorium, *Ṣifat ʿamal ṣafīḥa-jāmiʿa* *tuqawwim bi-hā-jamiʿ al-kawākib al-sabʿa* (Description of the Way to Use a General Plate With Which to Calculate the Positions of the Seven Planets) which follows the techniques developed in al-Andalus by Ibn al-Samḥ (d. 1035) and Ibn al-Zarqāllu (d. 1100), although it also presents original details which show his ingenuity. He probably reintroduced this instrument in the Islamic East where it had appeared in the tenth century but was later forgotten until it was recovered by al-Kāshī (d. 1429).

See also: ►Ibn al-Zarqāllu

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Abū'l-Wafā'

Yvonne Dold-Samplonius

Abū'l-Wafā' al-Būzjānī, Muḥammad ibn Muḥammad ibn Yaḥyā ibn Ismāʿīl ibn al-'Abbās, was born in Būzjān (now in Iran) on 10 June 940. After he moved to Baghdad in 959, he wrote important works on arithmetic, trigonometry, and astronomy.

Abū'l-Wafā' provided new solutions to many problems in spherical trigonometry and computed trigonometric tables with an accuracy that had not been achieved until his time. He made astronomical observations and assisted at observations in the garden of the palace of Sharaf al-Dawla. Finally, he wrote two astronomical handbooks, the *Wāḍiḥ Zīj* and *al-Majisṭī* (*Almagest*). More information about Abū'l-Wafā''s tables must be obtained from *zījes* that have incorporated material from his works, such as the *Baghdādī Zīj*, compiled shortly before the year 1285 by Jamāl al-Dīn al-Baghdādī. A solar equation table attributed to Abū'l-Wafā' occurs in it.

Several later *zījes* incorporate Abū'l-Wafā''s mean motion parameters. Various sine and cotangent values which he gave in the extant part of *al-Majisṭī* are equal to the values found in al-Baghdādī's sine and cotangent tables. Furthermore, al-Baghdādī's table for the equation of daylight was computed by means of inverse linear interpolation in a sine table with accurate values to four sexagesimal places for every 15° of the argument, and Abū'l-Wafā' is known to have computed an accurate sine table with just that format.

In *Risāla fī iqāmat al-burhān ʻalā 'l-dā'ir min al-falak min qaws al-nahār waʻrtifā' nisf al-nahār waʻrtifā' al-waqt* (On Establishing the Proof of the [rule for finding the] Arc of Revolution from the Day Arc, the Noon Altitude, and the Altitude at the Time), Abū'l-Wafā' deals with a fundamental problem of ancient astronomy that of finding the time in terms of solar altitude. He mentions in the introduction that the formula stated by Ḥabash al-Hāsib (fl. 850) is only approximate. Abū'l-Wafā' gives three proofs of the formula. The procedure of the first two proofs deals entirely with rectilinear configurations inside the sphere, in spite of the fact that the relation being investigated concerns arcs on the surface of the sphere. This technique was characteristic of Hindu spherical astronomy, as well as that of the Greeks prior to the application of Menelaus' Theorem. The method used in the third proof consists essentially of two applications of the Transversal Theorem. Contrary to Hindu trigonometry and most Islamic astronomers, Abū'l-Wafā' was one of the few who defined the trigonometric functions with respect to the unit circle, as is the case nowadays. In *Fī ḥirāfat al-abʿād bain al-masākin* (On the Determination of the Distances Between Localities) Abū'l-Wafā' gives two rules for calculating the great circle distance between a pair of points on the earth's surface. He applies both to a worked example: given the terrestrial coordinates of Baghdad and Mecca he calculates the distance between them, a matter of some interest to Iraqi Muslims undertaking the pilgrimage. The first method employs standard medieval spherical trigonometry and can be regarded as a byproduct of a common procedure for calculating the *qibla*, the direction of Muslim prayer. It is called by al-Bīrūnī "the method of the *zījes*." The second method is less ordinary and its validity is not obvious. In addition to the tangent function, it employs the versed sine, a term Abū'l-Wafā' does not use in the treatise studied above, but which appears frequently in the literature. The origin of this second rule might stem from the so-called *analemma method*, a common and useful ancient technique for solving spherical astronomical problems. The general idea was to project or rotate elements of the given solid configuration down into a single plane, where the desired magnitude appeared in its true size. The resulting plane configuration was then solved by constructions to scale or by plane trigonometry. Aside from the trigonometry, the text is of interest as an intact example of medieval computational mathematics. Numbers are represented in Arabic alphabetical sexagesimals throughout. The results of the multiplications suggest that all operations were carried out in sexagesimal arithmetic, with none of the very common intermediate transformations into decimal integers. Trigonometric functions and their inverses are carried out to four sexagesimal places. Al-Ḥubūbī challenged Abū'l-Wafā᾿ to produce and prove a rule for calculating the area of a triangle in terms of its sides. In his *Jawāb Abī al-Wafā᾿Muḥ ibn Muḥal-Būzjānī ᶜammā sa'alahu al-Faqīh Abū ᶜAlī al-Ḥasan ibn Ḥārith al-Ḥub ūbī fī misāḥat al-muthallathāt* (Answer of Abū'l-Wafā᾿ to the Question Put to Him by the Jurist Abū ʻAlī al-Ḥasan al-Hubūbī on Measuring the Triangle), Abū'l-Wafā᾿ gives three such rules. None of these is identical with "Heron's Rule," but all are equivalent to it. The earliest work on finger reckoning that has survived is Abū'l-Wafā᾿'s *Fīmāyahtāju ilaihi l-kuttāb wa-l-ummāl min ʻilm al-ḥisāb* (On What Scribes and Officials Need from the Science of Arithmetic). As the name implies, it was written for state officials, and therefore gives an insight into tenth-century life in Islam from the administrative point of view. Three more works demonstrate Abū'l-Wafā᾿'s interest in practical mathematics: *Fīmā yahtāju ilaihi as-sāniᶜ min aᶜmāl al-handasīya* (On the Geometrical Constructions Necessary for the Craftsman), written after 990; *al-Mudkhal al-ḥifzī ilā ṣināᶜat al-arithmāṭiqī* (Introduction to Arithmetical Constructions); and *Risāla al-shamsīya fī l-fawā'id al-ḥisābīya* (On the Benefit of Arithmetic).

On What Scribes and Officials Need, written between 961 and 976, enjoyed widespread fame. The first three parts, "On Ratio," "On Multiplication and Division," and "Mensuration," are purely mathematical. The other four contain solutions of practical problems with regard to taxes, problems related to harvest, exchange of money units, conversion of payment in kind to cash, problems related to mail, weight units, and five problems concerning wells. In this compendium Abū'l-Wafā᾿ systematically sets forth the methods of calculation used by merchants, by clerks in the departments of finance, and by land surveyors in their daily work; he also introduces refinements of commonly used methods and criticizes some for being incorrect. Considering the habits of the readers for whom the textbook was written, Abū'l-Wafā᾿ completely avoids the use of numerals. Numbers are written in words, and their calculations are performed mentally. To remember the results of intermediary steps, calculators bent their finger joints in conventional ways which enabled them to indicate whole numbers from 1 to 9,999. This same device was repeated to indicate numbers from 10,000 onward. All procedures, often quite complex, are only described by words. This treatise on practical arithmetic provides the model for all the treatises on the subject from the tenth to the sixteenth centuries.

He is cited as a source or an authority, but more often can only be discerned underneath. In the *Geometrical Constructions Necessary for the Craftsman* Abū'l-Wafā᾿ discusses a host of interesting geometrical constructions and proofs. He constructs a regular pentagon, a regular octagon, and a regular decagon. The construction of the regular pentagon with a "rusty" compass is especially noteworthy. Such constructions are found in the writings of the ancient Hindus and Greeks, but Abū'l-Wafā᾿ was the first to solve a large number of problems using this compass with fixed opening.

Renaissance Europe had a great interest in these constructions. The possible practical applications (such as making decorative patterns) may have been an additional motivation for studying things like a regular (or perhaps equilateral) pentagon inscribed in a square. However, the importance of such applications should not be overestimated. In proposing his original and elegant constructions, Abū'l-Wafā᾿ simultaneously proved the inaccuracy of some practical methods used by the craftsmen.

To honor Abū'l-Wafā᾿, a crater on the moon was named after him. He died in Baghdad in 997 or 998.

See also: ►*Qibla*, ►Ḥabash al-Ḥāsib, ►Algebra, Surveyor's, ►Mathematics, Recreational and Practical

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Abū Maʿshar

Richard Lemay

Arabic sources such as the *Kitāb al-Fihrist* give the date of Abū Maʿshar al-Balkī's death as 273 of the Hegira, which is AD 886, stating that he was over 100-years old. Since he was of Persian (Afghan) origin these may well be solar years rather than the lunar years of the Muslim calendar. Therefore his age at his death could have been reckoned as "over" 100 years if counted in lunar years in Muslim fashion, or else as 100 solar years. David Pingree claimed to have found the exact date of his birth to be August 10, 787 in a natal horoscope in Abū Maʿshar's *Nativities*. The trouble with this calculation is that Abū Maʿshar himself, in *Mudhākarāt* (Recollections), lamented the fact that he did not know the exact date of his birth and had to rely therefore on a "universal" horoscope he had drawn up. The *Mudhākarāt* then supplies the basic elements of this universal horoscope. Matching these data with Pingree's, it is probably safe to consider the year 171 H/AD 787 as his birth date.

Abū Maʿshar, known in the West as Albumasar, was born in Balkhī in Khurāsān, actually Afghanistan, and seems to have lived there and acquired a reputation as an astrologer much before he came to settle in Baghdad during the reign of the Caliph al-Maʾmūn (813–833), shortly after 820. He lived in Iraq until the end of his life in 886. He must have traveled, at least up and down the Tigris, since in the *Mudhākarāt* he is shown refusing to embark on the stormy waters of the Tigris. He died in Wasit, a city situated in the Sawād, midway between Baghdad and Basra.

Abū Maʿshar's early years are clouded in confusion because of an error committed by the earliest and most important Arab bibliographer, Ibn al-Nadīm (1970), in his *Kitāb al-Fihrist*. Writing in the late tenth century, nearly a century after Abū Maʿshar's death, al-Nadīm (d. ca. AD 987) apparently confused Abū Maʿshar the astrologer from Balkh with another Abū Maʿshar, called an-Najīh, who lived in Medina but died in Baghdad AD 787, the year of Abū Maʿshar's birth.

Once settled in Baghdad, where he spent the remaining 60 years of his life, Abū Maʿshar seems to have been involved in its cultural activity, but also in its tumultuous civic life at a time when "nationalisms" in the form of the *Shuʿūbiya* (non-Arabs) were raising their aspirations to cultural parity with the dominant Arabs. Abū Maʿshar's reputation as an astrologer, his newly found friendship with al-Kindī, and the credit he gained through astrological predictions assessing the power of rulers must have opened for him the doors of the political and learned elite of Baghdad. Al-Nadīm relates an episode in which Abū Maʿshar was punished with lashes by the Caliph for a realistic prediction that the Caliph disliked. Both Abū Maʿshar and al-Kindī, using an intricate system of astral conjunctions inherited from the Sassanian tradition, attempted to anticipate the duration of the Arab rule. In his *Risāla* (Epistle) on the duration of the rule of Islam, al-Kindī tried to comfort the ruling Caliph by giving the Arab rule a minimum span of some 693 years, longer than Abū Maʿshar's prediction. In fact Abū Maʿshar gives a total of 693 years, just as al-Kindī did. Still, in combination with the parallel scheme of the two maleficent planets Saturn and Mars affecting the meaning of the conjunctions of Saturn and Jupiter, Abū Maʿshar tended to reduce the duration to some 310 or 330 years only, which would bring the end of Arab rule closer, thus encouraging the aspirations of the *shuʿūbiyya*.

The *Mudākarāt* of Abū Saʿīd further tell us that, along with other astrologers, Abū Maʿshar accompanied the army of al-Muwaffaq in its campaign against the rebellious Zanj. Astrologers were used by both sides during these civic troubles. Abū Maʿshar's credit as an astrologer served him in these circumstances, for he may have been consulted by both sides in the Rebellion. At any rate he died in the city of Wasit, south of Baghdad, a city which had seen the farthest advance of the rebellious Zanj army and had been reconquered only shortly before by al-Muwaffaq.

The *Fihrist* credits Abū Maʿshar with 36 works, to which David Pingree adds six more. The list has remained fairly the same for all later bibliographers. This holds true for the original Arabic works as well as for the numerous translations into Latin, Greek, Hebrew, and medieval Romance languages. The uncertainty is due to a number of factors. Abū Maʿshar may have produced some works in several versions or editions. He has been imitated in a number of ways by later Arab authors, some of whom displayed his name prominently at the beginning of their own work, thus complicating the task of the bibliographer. Above all there is a lack of any systematic survey of Abū Maʿshar's production. In addition to the confusion still affecting the Arabic originals, a number of Abū Maʿshar's works were translated into so many media during the Middle Ages that the task of surveying the authentic remains is enormous. This illustrates the immense popularity enjoyed by Abū Maʿshar in the West.

See also: ►Astrology

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Acoustics in Chinese Culture

Chen Cheng-Yih

A sound is perceived in terms of its pitch, loudness, and tone quality characteristics. The Chinese term for pitch is *yīn lü* or simply *lü*. Early mentions of pitch in connection to its function in ode singing, in musicology, and in the standardization of measures and weights are found in the *Yú Shū* (*The Book of Yú*). The Chinese used the terms *qīng* (clear) and *zhuó* (muddy) to describe, respectively, the high and low pitches. In remonstrating the decision of the High King Jǐng of Zhōu to have the Wǔ-Yì bell melted down and converted into the Dà-līn bell of lower pitch, minister Shan Mū Gōng stated in 522 BCE:

> The ear functions harmoniously within a certain range of high and low pitches. The determination of this pitch-range should not be left for individuals. For this reason bells constructed by our ancient kings never exceeded their corresponding size in *jūn* (unit) and weight in *dàn* (unit). This is where the specifications of measures and weights for pitches originated.

This statement, recorded in the *Guó Yǔ* (Discourses on States), reveals that the early Chinese were aware of the existence of an audible pitch range.

A description on the development of the 12 pitches preserved in bells from antiquity is provided by music master Zhōu Jiū. He says that the reason that ranges and degrees can be established for pitch is due to Shén Gǔ of antiquity, who investigated and determined the *zhōng shēng* (middle tone) as the reference. The degrees of the pitches and tuned bells are the standards observed by all officials. From the *zhōng shēng*, one first establishes three pitches, then levels them out evenly into six pitches, and finally brings them to completion in 12 pitches. This is the *dāo* of nature.

This suggests that the 12-pitch system was derived from "trichords". An early example of a trichord is provided by three jade stone-chimes unearthed from a pit of the Yin ruins (ca. thirteenth century BCE) at Anyang; they not only are capable of producing tones but also have their pitch names engraved on the stones.

Early evidence for pitch standardization mentioned in the Chinese text is provided by the common notes found among the unearthed musical instruments. The most significant archaeological evidence is provided by the pitch pipes unearthed in 1986 from a Chǔ tomb (M21) of the Warring States period located at the present Yǔtáishān in Jiāngling, Hūběi province. These pitch pipes, made of nodeless bamboo (open ends) with different lengths and diameters, are the earliest specimens currently available. Though broken, four of the pitch pipes still had readable inscriptions, providing not only the names of the pitches, but also explicit statements on assigning pitches through the usage of the character *dìng* (literally to fix or determine). From the measured frequencies of the unearthed Marquis Yǐ set-bells, one obtains for the Huáng-zhōng pitch a measured frequency of 410.1 vibs s^{-1} in the fifth century BCE.

In Chinese, the louder sound is called *dà* and the softer one *xì*. The modern Chinese term for loudness in acoustics is *yīn-liàng*. An early discussion on loudness is found in the *Guó Yu* on the arrangement of instrument in an orchestra, in which harmony and balance are considered essential.

An obvious question on loudness is its role in audibility. Lǎo Zǐ made some interesting observations which seem to have some bearing on the threshold of hearing. We have from the *Dào Dé Jīng* (Canon of the Virtue of Dào) the statement: That which is listened to but not heard is called *xī*. The term *xī*, as it is defined here, relates to the term *xī-shēng*, which Needham translates as "tenuous note".

At the time of Lǎo Zǐ, concepts such as frequency and intensity had not yet been developed. Lǎo Zǐ could not have distinguished the audibility of *xī-shēng* in relation to its frequency and intensity. But he probably was aware that most *xī-shēng* are low-pitch sounds and that their audibility depends sensitively on loudness. Thus, when he said that the loud sound contains *xī-shēng*, he was probably referring to the audibility of those *inaudible* low-pitch sounds at a louder level.

Tone quality is the perception of sound in relation to the dynamic structure of the sound. The Chinese term for tone quality is *yīn-zhì* and in classic usage simply *yīn*. The early Chinese acousticians identified tone quality with the sound-producing material and began to classify sounds in accordance with such materials. Eight distinct tone qualities known simply as *bā-yīn* (eight tones) are identified with eight such sound-producing materials.

Early mention of the "eight tones" is found in the *Yú Shū* and *Zhŏ Zhuàn*. Other than being responsible for instituting music with the two sets of six pitches, the Grand Music Masters (*Dà-Shī*) were also responsible for making sure that all music was composed in pentatonic intonations: *gōng, shāng, ju*é, *zhî*, and *yǔ*, and that all music was performed in eight tones: *jīn* (metal), *shí* (stone), *tǔ* (clay), *g*é (skin), *sī* (silk), *mù* (wood), *páo* (gourd), and *zhū* (bamboo).

Each of these sound-producing materials represents a basic tone quality. In 1936, Schaeffner commented that the *bā-yīn* was "probably the oldest extant classification of musical instruments in any civilization." Needham and Robinson compared the *bā-yīn* classification with the Greco-Roman classification of musical instruments, namely wind, stringed, and percussion instruments, and concluded that the Greco–Roman classification was more scientific. The point that needs to be emphasized here is that the *bā-yīn* classification was based on tone qualities and not on musical instruments, even though there is an intimate connection between the two. It is important to note that each complex tone has its own unique characteristic harmonic spectrum and wave form. There does not yet exist a satisfactory system for classifying tone quality. The fivefold classification of ideophones, membramophones, chordophones, electrophones, and aerophones is again a classification based on musical instruments.

In addition to the tone quality of sound due to the sound-producing materials, the ancient Chinese were also interested in the variation in tone quality coming from the configuration of musical instruments and the different ways of playing musical instruments. Twelve sounds are specified in the *Zhōu Lǐ* to identify tone qualities with the configurations of the musical instruments. According to the *Lü-Shì Chūn-Qiū* of 239 BCE, the techniques of exploiting timbre with overtones had reached a high level of art in *qín* (half-tube zither) playing. Indeed, in the playing the ancient lute (*gu qin*) with no frets and markings, each note could be played with a variety of subtleties in touch.

The Physical Nature of Sound

As described in the *Kǎo Gōng Jì* (The Artificers' Record), sound is produced by vibrations, and there is a relationship between the thickness of the vibrating walls and the pitch of the sound produced by the vibration.

In Chinese classic usage, the character *ji* means rapid (or fast) and *shū* means slow. Thus, sound produced by rapid vibration is called *yīn jí* (or *shēng jí*) and by slow vibration *yīn shū* (or *shēng shū*). Such technical terms are found in the description of acoustics of bells, stone-chimes, and drums in the *Kǎo Gōng Ji*. It is important to appreciate the relation between this terminology and the terminology for pitch. The terms *qīng* and *zhu*ó for high and low pitches represent the perceptive description of sound in relation to the rate of vibration, while the terms *yīn jí* and *yīn shū* represent the physical description of sound in relation to the rate of vibration.

An explicit statement on the direct relation between the physical and perceptive descriptions of sound is found in the *Guǎn Zǐ* (The Book of Master Guǎn), in which it is stated that the sound of rapid vibration has a high pitch.

According to the *Kǎo Gōng Jì*, Chinese bell-makers examined the audibility of a bell's sound at a distance and discovered that the audible distance of a strike tone depends on the interplay of the diameter and the length of the bell. Such an experimental investigation on the dependence of the audible distance of a bell's sound on the dimensions of the bell was a significant step toward a scientific inquiry into the physical nature of sound propagation. The early Chinese probably looked to the propagation of a disturbance in water as a mental image for the propagation of sound. This is suggested by the hydraulic terms, *qīng* (clear) and *zhuó* (muddy). Thus, the analogy between the expanding pattern of ripples on water and the propagation of sound in the air probably also began early in Chinese civilization. However, no extant record with explicit mention of this mental connection between waves in water and in air is available earlier than the work of Wáng Chōng of the first century AD.

An important physical phenomenon of sound that was discovered early in Chinese civilization is resonance. In the *Zhuāng Zǐ* (The Book of Master Zhuāng), there is a passage attributed to Lǔ Jù of Western Zhōu, in which he says that the striking of the *gōng* note of one zither causes the *gōng* note of the other zither to vibrate, and that the same is true of the *juē* note, because the notes are of the same pitch.

The resonance phenomenon of Lǔ Jù achieved wide recognition in ancient times. The principle of resonance was later summarized in the statement "*shēng-bǐ zē-yìng*." This contains two key technical terms, *bǐ* and *yìng*. The term *bǐ*, which literally means "comparison," is coined to represent "matching in pitch," a condition for resonance first pointed out by Lǚ Jù, and the term *yìng*, which literally means "respond," is coined to emphasize the sympathetic aspects of the vibrations in resonance. These technical terms became common in subsequent accounts of resonance in sound.

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Acupuncture

Yun-tao Ma et al.

Terminology

1. *Zhen Jiu* (针灸)/acupuncture/acumoxology. The term "acupuncture," meaning "using needles to pierce" (*Webster's College Dictionary*), is translated from the Chinese term *Zhen Jiu*, in which *Zhen* means "using needling to pierce" and *Jiu* refers to burning Moxa[1] on the acupoints. Moxibustion refers to the application of heat stimulation with a moxa roll or cone on the point or affected site instead of using a needle. In Chinese, the term *Zhen Jiu* is often used as one concept, so, a new term *acumoxology* has been used to translate the original meaning of *Zhen Jiu*. The term "acumoxology" will be used if the text refers to both burning moxa and needling.
2. *Jing Luo* (经络)/meridian/channel/vessels. The English words meridian, channel, or vessel have been used to translate the Chinese term *Jing Luo*. Historically the concept of *Jing Luo* was related to arterial vessels; in this text the term vessel is used for the Chinese term *Jing Luo* instead of meridian or channel.
3. Chinese classic literature. There are often different English translations for the titles of the same Chinese classics. In this article, all Chinese classics are spelt first with Chinese Pinying and then by an English translation, as, for example, *Huangdi Neijing* (Yellow Emperor's Inner Canon). If the same title appears again in the text, only the Chinese Pinyin transliteration is used.

Sociohistorical Evolution of Acumoxology

Acupuncture is an ancient healing practice which appeared in different civilizations. Documents indicate that needling treatments were found in ancient Egypt, Greece, India, Japan, and China. Nevertheless, only the Chinese have nurtured this healing practice into a systemic medical modality which consists of clinical experiences accumulated for thousands of years and the theories gradually developed to explain these experiences. All branches of Traditional Chinese Medicine (TCM), herbology, tuina,[2] and Qigong[3] have absorbed some concepts from classic acumoxology.

Chinese archeological records suggest that stone needles (*bian shi*), the earliest tools for acupuncture, were invented to treat diseases during 8000–4000 BCE of the Neolithic Age. Later, bone, bamboo, bronze, and other metals like iron, silver, and gold were used to make needles. Today most of the clinical needles are made of stainless steel. *Mai Shu* (The Book of Vessels), the earliest document of acumoxology, appeared between the fourth and third centuries BCE. The first TCM classic *Huangdi Neijing* (Yellow Emperor's Inner Canon) discussed vessel theories, clinical principles of acumoxology, needling methods, and needling tools. However, *Huangdi Neijing* is neither systemic nor rigorously structured. It is a collection of medical

[1] Moxa refers to dried, pressed leaves of Mugwort (*Artemisia vulgaris*) burned on or above the skin to stimulate an acupuncture point or serve as a counterirritant.

[2] Tuina utilizes soft tissue manipulation, acupoints, external herbal medicines, therapeutic exercise, and structural realignment methods to treat a wide variety of musculoskeletal and internal organ disorders.

[3] Qigong is a Chinese healing art using a series of gentle focused exercises for mind and body.

treatises by authors of different times possibly from the period of Warring States (475–221 BCE) to the Han Dynasty (206 BCE–AD 220). The first book specifically devoted to acumoxology was *Huang Di Ming Tang Jing* (The Yellow Emperor's Canon of Bright Hall) in the Han Dynasty. Another book, *Jiu Fang* (Prescriptions for Moxibustion), came out in the period of Three Kingdoms (AD 220–280). Thus all the basic elements – the theories, acupoint system, methods of needling and moxibustion, and treatable diseases – were organized into a system of acumoxology.

The Ministry of Health of the Tang Dynasty (AD 618–907) designated acumoxology as one of the five medical specialties and appointed medical doctors to teach and practice acumoxology in a royal institute. The government of the Song Dynasty (AD 960–1264) published an official document of acumoxology, *Tong Ren Shu Xue Zhen Jiu Tu Jing* (Standard Atlas of Acupoints on Life-Sized Bronze Human Statue for Acumoxology), in AD 1026. This document clarified the location and indications of 354 acupoints and assigned them into 14 vessels. This is the first standardization of acumoxology in history. After the Song dynasty, a notable theoretical development in acumoxology includes prescriptions of acupoints according to the time of the day and seasons (*Zi Wu Liu Zhu*) or differential diagnoses[4] (*Bian Zhen Lun Zhi*) and a variety of needling manipulation techniques. Acumoxology as a medical practice declined after the Ming Dynasty (AD 1368–1643), especially when the Chinese agricultural culture confronted the Western industrial and scientific culture ever since the middle of the nineteenth century.

After the founding of the People's Republic of China (1949), application of modern science to traditional medicine was politically advocated and financially supported by the new government. Some of the best scientists and clinicians trained in Western science were encouraged to study and modernize traditional medicine. In 1972, successful cases in acupuncture anesthesia were reported in the US[5]; this increased interest in acupuncture in both professional circles and for the public. Acupuncture became the most studied subject of all alternative medical modalities internationally. Enormous quantities of research data have been obtained from laboratories and clinics in many countries and have justified the scientific basis of acumoxology. Because of this intensive research, the trend to biomedicalize acumoxology and integrate it into mainstream medicine began in both China and the West.

Historical Development of Acumoxologic Theories

How Acupoints Were Discovered

Ancient Chinese doctors believed that a vital force, *qi*, flowed inside the vessels of the human body. They felt the quality of qi pulsation at multiple pulsing points on the body and used this to diagnose diseases. They also needled these pulsing points to treat diseases. These points became the earliest acupoints. As clinical experience accumulated, effective but nonpulsing acupoints were discovered and recorded.

The Origin of Vessel Theories

Early acumoxologic theories were formed from empirical facts. For example, ancient doctors found that needling certain pulsing loci on the dorsum of the foot and medial part of the lower leg was more effective than other points in treating pain or other symptoms of the genitals, lower abdomen, and lumbar areas. Thus they drew lines to connect the effective needling points with the parts of the body that were most affected by the needling, making a visible representation which connected all the points and related body parts together. In this example the pulsing points on the dorsum, the medial leg, the genital area, the lumbar area, and up to the tongue were connected. They believed that these symptoms were related to the imbalance of the "liver," and thus the "liver vessel" was gradually formulated. However, different doctors at different times formulated different "liver vessel" maps.

The Historical Integration of the Various Vessel Theories into a Single System

Huangdi Neijing (Yellow Emperor's Inner Canon) integrated the various channel theories into one system. However, inconsistencies in this book reveal that the authors had differing medical experience from different historical periods. In the years that followed the appearance of the *Huangdi Neijing*, acumoxology continued to evolve by incorporating more theories, and an ever-increasing number of acupoints and channels, into the existing system. When clinical realities did not fit into an existing theory, the facts were often modified to ensure the continuance of the theory. New theories coexisted with old ones. Thus classical acupuncture as we know it today is made up of theories and clinical experiences that are valuable, but they are mixed with fallacious concepts and imperfect explanations.

[4] Differential diagnosis is the determination of which one of two or more diseases or conditions a patient is suffering from, by systematically comparing and contrasting their clinical findings.

[5] American interest was triggered in 1972 by a rumor that New York Times reporter James Reston had received acupuncture anesthesia for an appendectomy while visiting China during President Nixon's historic visit. Actually, he had had standard anesthesia and received acupuncture for postoperative cramps.

Daoist Philosophy Guided both Theories and Clinical Practice

"The universe and humans are one" (*Tian Ren He Yi*) is the central thinking model of Daoism. Its *Yinyang*[6] and *Wuxing*[7] (five phases: metal, wood, water, fire, and earth) models have been applied to the human body, its anatomy, pathophysiology, and acumoxology. All 14 vessels are classified into Yin and Yang vessels and within each vessel the important acupoints below elbow and knee are ascribed to five phases such as fire point, water point, etc. When treating diseases, the nature of Yin or Yang vessels and the phases of the points are synthesized to form the prescription according to the principle of Yinyang balance.

The "Pearls" of Classic Acumoxology Theory

Since the 1960s, international scholars and scientists have conducted research, but they still cannot verify the vessel entities. Both historical documents and clinical trials clearly show that the most valuable discovery in acumoxology theory is the interrelatedness between the parts of the body surface, and between the parts of the body surface and the internal organs. These are the immortal "pearls" of classic acupuncture. The classic 14 vessels are just tentative theories used by ancient medical sages to explain this interrelatedness of human body.

The Internationalization of Acumoxology

During the Tang Dynasty (AD 618–906), Korean and Japanese students were sent to China to study medicine and other subjects. Acumoxology, massage, and herbal medicine were first taught in a Korean medical school in AD 692. In Japan, specialized faculty taught acumoxology as part of a 7-year course in the Imperial medical school established by the emperor in AD 702.

Jesuit missionaries introduced acupuncture to Europe in 1683. Acupuncture was taught in French hospitals and was practiced by some doctors in Germany, The Netherlands and England. Acupuncture therapy has remained in European countries since the eighteenth century. An American doctor, William M. Lee, learned acupuncture from a British doctor and published his paper on using acupuncture for rheumatism in 1836. Sir William Osler, in his *The Principles and Practice of Medicine* (8th ed., 1909), suggested acupuncture therapy for low back pain. Acupuncture was reintroduced into the US in 1972 from China after diplomatic normalization between the two countries.

Since the 1950s, doctors of the former Soviet Union and Eastern European countries have studied acupuncture from China and they still practice acupuncture in hospitals today.

In 1975, three international acupuncture training centers were set up to train worldwide healthcare professionals in China. The World Health Organization (WHO) has offered enormous support to spread acupuncture therapy in developing countries. In 1989, WHO approved the *Standard International Acupuncture Nomenclature* which has been used worldwide. In 1994 and 1999, WHO issued the *Standard for Clinical Acupuncture Research* and *Guidelines on Basic Training and Safety in Acupuncture*.

Medical Differences Between Acumoxology and Chinese Herbal Medicine

There is a difference between acumoxology and Chinese herbal medicine, although they have absorbed theories from each other. First, acumoxology developed its special *Jing Luo* (vessel) theories, while Chinese herbal medicine applies *Zang Xiang* (Visceral concepts) theories. Second, the same acupoints can be applied to different symptoms, while herbs, more or less, have specific therapeutic indications. Third, the method of differential diagnosis is essential in herbal medicine while it is not necessary in acumoxology.

Medical Differences Between Acupuncture and Moxibustion

Acupuncture needling inoculates minor lesions inside the soft tissues including nerve tissue. This needling-induced lesion stimulates neuroimmune response involving the cardiovascular and endocrine systems. Fresh cells will replace this needle-induced lesion within 2–5 days. Most moxibustion has the same physiological effect as needling does, but no lesion is introduced into the tissue. Traditional pus-making moxibustion (*hua nong jiu*) burns the skin and makes huge superficial lesions which produce a longer effect.

Medical Differences Between Acupuncture and Western Conventional Medicine

In general, acumoxology therapy does not target any particular cause(s) of a symptom(s) or disease(s); it just activates the self-healing potential of the built-in biological survival mechanisms to normalize the physiologic processes and let the body heal. Acumoxology

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[6] Yinyang is a Daoist symbol of the interplay of forces in the universe. In Chinese philosophy, yin and yang represent the two primal cosmic forces in the universe. Yin (moon) is the receptive, passive, cold female force. Yang (sun) is masculine, representing movement and heat. The Yinyang symbol represents the idealized balance of the forces; they demonstrate equilibrium in the universe.

[7] The theory of the five phases looks at five interrelated forces that have specific relationships to one another. Each of the elements has corresponding organs, emotions, colors, tastes, tissues, human sounds, and countless other correspondences. For example, an Earth person likes late summer, singing and sweet tastes.

treats the whole body and produces no side effects, but the efficacy is achieved within a physiologically healable limit. Western conventional medicine tries to eliminate or correct the causations of the diseases by manipulating the chemistry and biological structure of the body first. The body then recovers from the impairment of both the disease and the medical intervention. This strategy may be accompanied by some side effects.

Biomedicalization of Classic Acumoxology

The medical value of acupuncture has been recognized internationally, especially in cases in which Western medicine has been unable to cause healing, but it has been challenged for its scientific justification in both Western and Eastern countries as modern sciences predominate in every field. Since the 1960s, acupuncture has been the most researched subject of traditional folk medicine in both China and the West, from the molecular to the organismic level, using new technologies in anatomy, neuroscience and immunology laboratories and evidence-based, double blind, statistical methods in clinics. Sufficient data have verified that acumoxology shares the same biomedical basis with Western medicine, and also indicate that acupuncture can be understood, taught, and practiced in biomedical concepts. Historically acupuncture has been acculturated many times when it was adopted by different host cultures. Thus, during this new acculturation, the biomedicalization of classic acumoxology becomes both possible and necessary. In September 2004, two new biomedically oriented textbooks were published. *Acumoxology Course for International Students* was published in China and *Biomedical Acupuncture for Pain Management: An Integrative Approach* was published in the United States. The two textbooks emphasize the new developments and new trends in acumoxology while maintaining its traditional medical values and philosophy. The fact that they were published simultaneously represents the biomedicalization of acumoxology in both China and the West.

What Diseases Can Acupuncture Treat?/How Effective is Acupuncture Therapy?

Both clinical and laboratory data suggest that acupuncture and moxibustion are physiological therapies which result in self-healing, which is coordinated by the nervous system and mediated by the immune, endocrine, and cardiovascular systems. In 1979 WHO suggested a list of disorders and conditions for which acupuncture is effective, including neurological, musculoskeletal, respiratory, gastrointestinal, mouth, and eye problems. Nevertheless, WHO also made the statement that "this list was not based on controlled clinical research and cannot be considered authoritative nor does it reflect WHO's view in any way." This uncertainty can be clarified as we understand the physiological basis of acupuncture. Acupuncture does not target any specific symptoms or diseases but just normalizes physiologic processes to activate self-healing. The results of this self-healing depend on (1) the healability of the symptoms, and (2) self-healing capacity maintained by the patients. Thus, the same symptoms can be cured in some patients, or can be partially relieved in other patients but do not respond to acupuncture at all in a few patients. The information of healability may be obtained from medical examination. To estimate the self-healing capacity, readers may refer to the textbook *Biomedical Acupuncture for Pain Management: An Integrative Approach*.

Limitations of Acumoxology Therapy

As acumoxology normalizes physiological processes to activate self-healing, it works better for conditions resulting from physiological abnormalities. For example, if low back pain is caused by inflammation of soft tissues, acumoxology will cure it in most patients. If the low back pain is caused by a tumor of the spinal cord, acumoxology may provide only temporary pain relief. The former condition is an *acupuncture remedy*, while the latter is an *acupuncture-aided treatment*. In cases of acupuncture remedy, faster and more stable results can be obtained if conditions are treated at their early stage.

Questions Remaining

Today we understand acumoxology in terms of its physiological basis even better than some medical procedures used in conventional medicine, but, as in any field of science, more new questions arise after old mysteries have been clarified. There are many unanswered puzzles in acumoxology. For examples, what is the biological basis of the interrelatedness between different parts of human body as classic *Jing Luo* (Vessel) phenomena demonstrate? What symptoms or disorders are more amenable to acupuncture remedy or acupuncture-aided treatment? How are diseases related to particular acupoints? What acupoints should be selected for particular symptoms? How does needle manipulation influence the results? Clarification of these and other questions will improve clinical results of acumoxology.

See also: ►Wuxing, ►Yinyang, ►Medicine in China

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Acyuta Piṣāraṭi

K. V. Sarma

Acyuta Piṣāraṭi (ca. 1550–1621), author of over ten texts, was an astronomer from Kerala in South India. It was he who enunciated, for the first time in Indian astronomy, the planetary correction called "reduction to the ecliptic" (the band of the zodiac through which the Sun apparently moves in its yearly course), in his work *Sphuṭanirṇaya* (Determination of True Planets), composed before 1593, which was later expanded into a full-fledged tract called *Rāśigolasphuṭānīti* (True Longitude Computation of the Sphere of the Zodiac).

Acyuta was popularly known as Tṛ-k-kaṇ tiyūr Acyuta Pisāraṭi. The first term indicated his birthplace, Kundapura, and the last the sect of Kerala temple functionaries to which he belonged. He was the pupil of Jyeṣṭhadeva, author of *Yuktibhāṣā*, an elaborate treatise on mathematical and astronomical rationale. He was a protégé of Ravivarmaṇ, King of Veṭṭaṭṭunāṭu in Kerala and the teacher of the poet and grammarian Nàrāyaṇa Bhaṭṭatiri of Melputtūr. Apart from one work, entítled *Praveśaka*, which was an instructive epitome of Sanskrit grammar, all his works were on astronomy. Acyuta is also referred to as a master of medicine and poetics.

Acyuta's work *Karaṇottama* is an astronomical manual in about a hundred verses, which, in five chapters, deals with the derivation of the mean and true planets, the eclipses, gnomonical shadow, and the phenomenon of the complementary situation of the Sun and the Moon. This work and its autocommentary are significant in that they set out several computational methods for securing greater accuracy, which had been kept secret by earlier teachers and were intended to be transmitted only orally to disciples. Acyuta's *Uparāgakriyākrama* (Method of Computing Eclipses) is also significant for its containing methodologies unknown to other texts. The *Horāsāroccaya* of Acyuta, in seven chapters, is an instructive epitome of the astrological text *Jātakapaddhati* (A Course of Horoscopical Science) of Srīpati (eleventh century).

It is noteworthy that Acyuta engendered an astronomical lineage, and the trail blazed by him was continued by several lines of scholars. One such line, of which there is documentary evidence, which continued for more than 250 years, runs thus: Acyuta (1550–1621); pupil: Tṛppāṇikkara Potuvāl (sixteenth century); pupil: Nāvāyikkulattu Āzhāti (seventeenth century); pupil: Pulimukhattu Potti (1686–1758); pupil: Rāmanāśān (eighteenth century); son-pupil: Kṛṣṇadāsa (Kṛṣṇanaśān (1786–1812). Later astronomers took up the innovative trends in Acyuta's works for rationalization and elaboration through short tracts, as evidenced by nine such tracts which have been identified and added as supplements to the edition of Acyuta's *Sphuṭanirṇaya*. This points to the impact made by Acyuta in the astronomical tradition of Kerala.

See also: ►Astronomy in India, ►Śrīpati

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Agriculture: Ancient Methods

Alexia Smith

Today very few communities subsist upon hunting and gathering, with the majority of the world's population living a sedentary life dependant upon agriculture. The shift from gathering wild plants and hunting wild animals to dependence upon crop production and animal herding took place independently in different parts of the world at different times. The earliest development of agriculture is widely thought to have occurred around 12,000 years ago in the Fertile Crescent of Southwest Asia. The Fertile Crescent forms an arc leading up the Levant from the Negev Desert of Israel to southeastern Turkey, turns east along the Taurus–Zagros mountain chain, and then south between the Tigris and Euphrates rivers down to the Persian Gulf. Independent development of agriculture occurred later in South and North China, Central America, South Central Andes, the Eastern United States, sub-Saharan Africa, and perhaps Papua New Guinea.

Food Production Terminology

The ways in which societies throughout the world have organized food production varies greatly through time, and the terminology used to discuss early agriculture underscores the diversity of methods that can be used to produce or acquire food. In its widest sense, agriculture refers to the cultivation of crops and the rearing of animals. Animal husbandry refers to general animal rearing, whereas pastoralism describes a socio-economic specialization in production where animal rearing forms the primary economic endeavor of a community. The methods of production can vary widely, including nomadic pastoralism, which involves permanent migration and seasonal transhumance – where animals are moved periodically from a home base to pasture land. The term cultivation describes the preparation of land and tending of crops, which can include large- or small-scale crop production and slash-and-burn agriculture. Horticulture relates specifically to the production of fruits, vegetables, and flowers, and in preindustrialized societies was usually garden-based. Domestication is more difficult to define and there is no universally agreed upon definition. In general, however, domestication refers to the selection of desirable traits in plants and animals that leads to the genetic modification of a species, and reduces its ability to reproduce without intervention by people. Desirable traits may include reduced aggression in animals, allowing them to be controlled more easily, or ease of harvest and greater yields in plants. It is possible, therefore, to cultivate wild plants with domestication occurring only when selection processes affect natural reproduction mechanisms.

Evidence for Ancient Agriculture

Throughout the world, writing or notation systems developed well after the beginnings of agriculture, so there are no texts documenting the transition and our knowledge is based entirely on archaeological observations of plant and animal remains, changes in settlement size and patterns, storage facilities, and tools. Zooarchaeology examines ancient interaction with animals. The species, age, and sex of animal bones retrieved from archaeological sediments can be determined by reference to modern comparative skeletal material, and this information can be used to examine herding and hunting strategies. Paleoethnobotany or archaeobotany examines plant use in the past. Plant remains are preserved on archaeological sites predominantly through charring, an accidental process that renders them inert to bacterial or fungal decay; less frequently plant remains become preserved through waterlogging, desiccation, freezing, proximity to toxic metals, or indirectly by leaving an impression in ceramic vessels. Excellent preservation conditions are provided under waterlogged and desiccated conditions, although such finds are in the minority and are generally restricted to lakes and coastal margins or deserts. Charred remains are retrieved using flotation, whereby an archaeological sediment sample is placed in a large container of water and, following gentle agitation, the plant remains float to the surface where they can be collected. The remains are identified based on morphological similarity to modern reference material, and knowledge of crop and weed assemblages can be used to investigate a number of topics including crop domestication and methods of crop production, harvesting, and processing. Until recently, most paleoethnobotanical research had focused upon identifying cereal, legume, fruit, and weed seeds in the archaeological record but now, following pioneering work by Hather, increasing emphasis is being placed upon identifying tubers and investigating the role that vegetables played in the ancient diet. Such research is in its infancy, however, so the importance of horticulture in antiquity is likely underestimated.

Theories Explaining the Origins of Agriculture

A number of theories have been proposed to explain the origins of agriculture. Since farming was developed independently in different locations, the motives likely vary reflecting local social, cultural, environmental, and climatic factors. In Southwest Asia, the change occurred during a period of climatic amelioration after the Younger Dyras, a cold period marking the end of the Pleistocene and the beginning of the Holocene. Building upon work by Raphael Pumpelly, V. Gordon Childe argued in the 1930s that climatic deterioration forced people to concentrate within small oases and that these new conditions would have stimulated cultivation. His "Oasis" or "Propinquity" theory is not supported by paleoclimatic data, does not adequately explain the changes, and furthermore is viewed as too environmentally deterministic. To its credit, however, the theory stimulated much research on the origins of agriculture. In the 1960s and 1970s, Binford, Cohen, and Hassan put a number of related "Push" models forward. They argued that population growth or climatic change disrupted the food balance and provided the necessary incentive to begin cultivating crops. These models have also been criticized for being oversimplistic and monocausal as well as deterministic. Flannery expanded upon Binford's ideas and proposed a "Broad Spectrum Revolution." Citing data from Southwest Asia and Mesoamerica, Flannery argues that prior to the dependence upon agriculture, people greatly widened the range of plant and animals exploited, and developed new tool types, different methods of storage, and gained familiarity with other food resources. These changes created the necessary preadaptations for cultivation, which he argued most likely occurred in marginal areas on the fringe of production, where wild resources were less abundant.

The Broad Spectrum model is largely supported by both plant and animal data from Southwest Asia. Recent research at Ohalo II, a waterlogged site off the coast of the Sea of Galilee where preservation conditions are excellent, has underscored the importance of wild cereal collection by preagricultural groups approximately 23,000 years ago, well before the beginning of farming. Lastly, following critiques of the use of external factors and system analogies to explain change in the past, a number of social or "Pull" theories have been sought to explain the origins of agriculture. Bender and Hayden argue that domestication took place in resource-rich areas and that the ready availability of large amounts of specialty food may have led to social changes within preagricultural societies, placing greater emphasis on competitive feasting. This, in turn, would have elevated the demand for resources, acting as a precursor for cultivation and later animal herding.

The Rise and Development of Agriculture in Southwest Asia

The first domesticated crops in Southwest Asia include cereals (emmer wheat, *Triticum dicoccum* Schübl.; einkorn wheat, *T. monococcum* L.; and two-row hulled barley, *Hordeum vulgare* subsp. *distichum* (L.) Thell.), leguminous crops (lentil, *Lens culinaris* Medik.; pea, *Pisum sativum* L.; chickpea, *Cicer arietinum* L.; bitter vetch, Vicia ervilia (L.) Willd.), and flax (*Linum usitatissimum* L.), which together form the "founder crops" of Neolithic agriculture. Early farmers selected cereals with plumper, larger grains and ears that did not shatter easily, leading to greater yields and enhanced efficiency of harvesting. Transitional forms of domesticated plants and animals and their wild predecessors can be difficult to identify from the archaeological remains, but the available evidence suggests that the process took place quickly over several centuries.

Animal domesticates include sheep (*Ovis aries*), goat (*Capra hircus*), pig (*Sus scrofa*), and cattle (*Bos taurus*), each of which were ecologically and behaviorally suited to domestication due to their general diets, ability to breed in close conditions, social nature, and dominance hierarchy. Due to the selection of more docile animals, domesticated fauna tend to be smaller than their wild predecessors. The domestication of each species took place in different locations throughout Southwest Asia after communities had become sedentary and begun cultivating crops. Later a wide range of specialized pastoral practices was developed.

The adoption of agriculture in Southwest Asia was termed the "Agricultural Revolution" or the "Neolithic Revolution" by V. Gordon Childe, and it was truly revolutionary since it marked a drastic shift in the way people obtained food, placing greater emphasis on using land for production. It also involved the need to maintain and protect seed stores for the following year as well as ensure that animals were kept alive and well until they were deemed fit for slaughter. Intensive cultivation is associated with increased sedentism, which provides different opportunities for building social relationships and spacing births. Furthermore, with the accumulation of surplus crops, differential wealth could be accumulated, enabling parts of the population to be freed from farm labor. This in turn allowed for the development of institutionalized craft specialization and, some time later, the rise of urbanized state-level societies with social hierarchies, bureaucratic and administrative systems, long distance trade, monumental and public architecture, and some form of writing or record keeping.

The Construction of Cities and the Secondary Products Revolution

The first urban centers arose in Mesopotamia, the land between the Tigris and the Euphrates in modern-day Iraq around 5,500 years ago. Shortly later, urban centers developed in Egypt. Both developed along river courses and the use of irrigation to enhance crop yields is thought to have been instrumental in the rise of these city-states. Ancient irrigation canals dating between ca. 5,500 and 5,000 years ago have been located in Mesopotamia. The construction of earthen structures to control the natural flooding of the Nile banks in Egypt likely played a similar role. Concomitant with the development of cities in Mesopotamia and Egypt, an agro-economic shift took place in between these regions in the Levant, perhaps stimulated by enhanced trade with adjacent regions. The Mediterranean economy, including cultivation of cereals and legumes, viticulture and olive production, and herding of sheep and goats, together with use of animal drawn ploughs became widely established for the first time. Sherratt refers to these changes in agricultural production as the "Secondary Products Revolution," which placed greater emphasis on the use of animals for traction and for secondary products such as milk, blood, wool, and dung. Most early ploughs would have been constructed from wood, but because of their perishable nature, they do not readily preserve intact in the archaeological record. The earliest depictions of a plough, which likely postdate its invention, come from cylinder seals from Mesopotamia, dating to approximately 4,300 years ago, and terracotta figurines of yoke-bearing oxen from the Greek site of Tsoungiza dating to the Early Bronze Age. The ard, which scratches the surface of the land was developed first, with mould-board ploughs that turn soil and create furrows being developed much later. Prior to the invention of the plough, fields would have been prepared by hand, so the shift allowed larger tracts of land to be cultivated. This effect was intensified during the Iron Age, beginning around 3,200 years ago, with the manufacture of iron agricultural tools, rather than flint and bone sickles or wooden ards.

The exploitation of animals for milk and wool in Southwest Asia is reflected in animal bones that document the preferential culling of young males and the tending of a larger number of female animals to an older age. In order to release milk freely to people, lactating animals need to be separated from their young and become accustomed to being milked by hand, so initial attempts at milking were likely a perilous endeavor.

Zeder and McCorriston argue that the raising of sheep for wool fiber greatly modified the agro-economics of Southwest Asia, and led to a reduced reliance upon flax fibers; the local importance of wool as a commodity in northern Syria allowed urban centers that controlled its production to prosper. Concomitant with the rise of urban societies, the need for a recording system developed in order to log economic transactions. The invention of writing provides an additional window into agricultural production in antiquity. Clay tablets from Uruk in modern-day Iraq, dating to ca. 4,400 years ago, provide the earliest evidence of writing in the world with initial documents being used to list commodities. An extensive archive of cuneiform tablets was found at the site of Ebla in Syria, approximately 60 km south of Aleppo. These texts, dating to between 4,400 and 4,350 years ago, represent the earliest written reference to olive and grape production, although archaeological evidence of the plant remains predates the texts by almost a millennium. Since textual accounts and archaeological data provide different insights into past societies, this example demonstrates how the two records can be used to complement one another. Other cuneiform texts include the "Farmer's Instructions" from Mesopotamia dating to ca. 3,800–3,600 years ago. Civil has interpreted the text to be a Sumerian agricultural manual which outlines instructions from an old man to his son on how to prepare a field for irrigation; how and when to harrow, plough, sow seeds, inspect, harvest, thresh, and winnow the crop; maintain tools; as well as describing a desirable work ethic. It is likely that the text was used to teach scribes how to write Sumerian, since the content of the text would have been familiar to many.

Early Agriculture Outside of Southwest Asia

Following the development of agriculture in Southwest Asia, farming began to be practiced in Turkey and then Greece, followed by the rest of Europe. Models of this spread are debated, with some arguing for movements of people and other arguing for a transfer of ideas and new technology. New evidence based on plant data suggests that a complex mix of both was involved. Based on radiocarbon-dated finds of plant remains, the spread took place at an estimated rate of 1km/year, likely being adopted in fertile river valleys first.

Independent domestication of plants and animals took place in Southeast Asia approximately 8,000–7,500 years ago, with distinct modes of production evolving along the Yellow River in northern China and the Yangtze to the south. One of the most important domesticates from China is rice (*Oryza sativa* L.); rainfed lowland rice was grown initially, followed some time later by upland and deep-water rice. Due to the natural distribution of wild rice, which extends from India eastwards across China to the coast, the center of domestication was thought to lie in the southern part of China, but new finds of early domesticates in the Yangtze valley have expanded this range. Ongoing research and more extensive excavations are required until the debate regarding the location of rice domestication can be resolved fully. By approximately 7,000–5,000 years ago, rice production spanned large areas of Southeast Asia and India. Early tools found at the waterlogged site of Hemudu in China, dating to ca. 7,200 years ago, include two digging implements constructed from a water buffalo scapula (shoulder bone) attached to a wooden handle, but such finds are exceptional and as with other areas, the full range of early agricultural implements is unknown.

Further to the north, between the highlands and the plains along the Yellow River, rainfall tends to be lower and drought-tolerant species were chosen as the first domesticates. Here, broomcorn millet (*Panicum miliaceum* L.) and foxtail millet (*Setaria italica* [L.] Beauv) became important crops for Peligang communities just over 7,000 years ago. Dogs, pigs, chickens (*Gallus gallus domesticus* L.), and water buffalo (*Bubalus bubalis* L.) were the most important animal domesticates, although wild resources including various nuts, jujube dates (*Zizyphus jujuba* Mill.), and deer remained important components of the diet. It is likely that chickens were first domesticated just after 8,000 years ago in northern China.

Agriculture developed in the Americas later than in the Old World. In North America, early crops include goosefoot (*Chenopodium berlandieri* Moq.), sunflower (*Helianthus annus* L.), and marsh elder (*Iva annua* L.). Within Mesoamerica, most research has centered along the Oaxaca and Tehuacán valleys of Mexico; important domesticates include maize (*Zea mays* L.) derived from the annual grass teosinte, squash (*Cucurbita* spp.), beans (*Phaseolus vulgaris* L.), avocado (*Persea americana* Mill.), dog, turkey, and perhaps cottontail rabbit. Maize domestication is widely thought to have occurred around 7,000 years ago, but this date has recently been disputed; new radiocarbon dates of the oldest known domesticated corn cobs places them at approximately 4,600 years old. Cocoa (*Theobroma cacao* L.) also became an important domesticate in Mesoamerica. The Nuttall Codex, dating to AD 1051, depicts an early use ritual of cocoa. Further south in the Andes, llama (*Lama glama*), alpaca (*Lama *pacos*), and guinea pigs (*Cavia porcellus*) were herded. Important crops include quinoa (*Chenopodium quinoa* Willd.), and tubers such as oca (*Oxalis tuberosa* Mol.), mashua (*Tropaeolum tuberosum* Ruíz & Pav.), ullucu (*Ullucus tuberosus* Caldas.), and potatoes (*Solanum tuberosum* L.). Drawings of agricultural scenes by conquistadores in the 1500s depict the use of foot ploughs and hand hoes in the Andes.

Within Africa, agriculture first arose in the Nile Valley of Egypt, following the introduction of sheep, goat, cattle, and cereals, around 6,500 years ago from areas to the north. Independent innovation and domestication of local, indigenous species occurred between 5,000 and 3,000 years ago in a band between the Sahara and the equator, at a time when rainfall was higher than today. Important domesticates include cattle, sorghum (*Sorghum bicolor* [L.] Moench.), pearl millet (*Pennisetum glaucum* [L.] R. Br.), and much later, dating to around AD 200, African rice (*Oryza glaberrima* Steud.). African rice is still grown in parts of West Africa, although Asian varieties originally domesticated in China predominate today.

Continental Transfer of Crops

Throughout the world, the form that early agriculture took reflects, for the most part, an adoption of locally available plants and animals, with cereals such as wheat, barley, millet, and rice predominating in the Old World, and potatoes, maize, and squash predominating in the New World. There are numerous examples of people adopting non-native species throughout history, however, which demonstrates the dynamic nature of agricultural production and underscores how food production forms an integral component of social histories. The potato, for example, a native of Chile and Peru, was first introduced into Northern America and Europe during the late 1500s, after which time it became an important crop. By the 1800s, it formed the dominant staple in Ireland and the spread of potato blight resulted in the great famine that began in 1845. Tomatoes (*Lycopersicon esculentum* Mill.) were also introduced to Europe from Tropical America by Spanish conquistadors and Atlantic slave traders in the mid-1500s. Tomatoes were initially treated with suspicion due to their perceived similarity to deadly nightshade which was associated with witchcraft; they later became viewed as aphrodisiacs, rendering them the common name, "love apples." The introduction of maize, beans, cassava, and potatoes into West Africa during the Atlantic slave trade of the 1500s is particularly noteworthy. McCann provides a history of the adoption of maize throughout Africa and today it has become an important staple at the expense of indigenous crop. In Zambia and Malawi, maize contributes more than 50% of the calorific content of people's diet, greater than that in Mexico where the plant was originally domesticated, and this has resulted in a drastic narrowing of dietary breadth. Indeed, in all parts of the world, reliance upon agriculture has led to a more restricted diet than that consumed by hunting and gathering communities. Examination of paleopathology within early agricultural communities in both the Old and New worlds has shown that farming led to an initial decline in general health and nutrition.

Water Management

Through time, people have increasingly adapted their environment to grow the crops that they desire. Limits exist to the extent that the landscapes can be modified, and these limits have shifted through time as technology has evolved and as labor divisions and economic incentives have shifted. The choice of what and where to grow crops is not, therefore, always predicated upon environmental considerations, and social or economic factors can weigh more heavily. Nabatean farmers at Avdat in the Negev Desert of Israel, for example, situated their settlements at strategic locations along spice trade routes during the first century BC, and were able to grow crops in areas that received limited amounts of rainfall by using water harvesting techniques. Depending upon the timing and distribution of rainfall throughout the year, rainfed farming cannot generally be practiced in areas that receive less than 250 mm per annum. By clearing rocks from the hillsides and placing them in long lines running down slope, the thin soils were exposed to rainfall, encouraging them to slake and enhance runoff. Rainfall was then channeled down the slope into the valley bottom where walls constructed across the valley impeded the flow, minimized soil erosion, and enhanced infiltration of water into the soil allowing crops to grow successfully.

An equally ingenious method of water control was employed in South America where raised fields were used to grow potato. Raised fields have been found in dense concentrations in the Lake Titicaca area of Bolivia and Peru, and from above resemble a patchwork of fields. Raised fields were created by digging a network of ditches and placing the excess soil on top of the field to be cultivated. The fields provide optimal conditions for crop production in this area where weather conditions can be unpredictable; water can be maintained in the furrows between the fields and used for irrigation during dry spells, it can be drained away through the channels following heavy rainfall, and it also helps minimize diurnal temperature shifts, thereby reducing the risk of frost damage. There has been some interest in reintroducing this form of cultivation on a large scale today as part of the sustainable development movement, and while there are many benefits from an agronomic perspective, it is not clear how practical the construction and maintenance of raised fields would be from a social perspective because they require large investments of time. In the past they were likely constructed with corvée labor.

It is difficult to determine exactly when irrigation was first practiced because canals do not always preserve well and, additionally, preserved features can be difficult to date. Informal watering is likely as old as cultivation itself, particularly within food gardens close to the home, but more formal irrigation did not develop until much later. The earliest forms of irrigation would have employed water diversion structures such as deflection dams and gravity canals as seen in Mesopotamia; it was not until Roman times that engineering developed sufficiently to allow for water to be lifted from a river and distributed onto an adjacent field. Early examples of norias (water-powered wheels that scoop water), can be found in the more arid parts of the Roman empire including Syria, North Africa, and Spain. Horizontal wheels were also commonly used for irrigation during the Tang Dynasty (AD 618–907) in southern China, and may have been used as early as 200 BC. The Archimedean screw, invented by Archimedes during the 3rd century BC, uses a helix placed at a 45-degree angle within a tube to raise water when rotated. Despite these developments, as well as the invention of drip and sprinkler irrigation much more recently, floodwater farming continues to be a highly effective method of irrigation where topographic conditions are suitable. It was heavily utilized by the Hohokam of the Sonoran Desert in south Central Arizona, between AD 200 and 1450 to support large communities in an area of low rainfall.

Terracing

Other modifications to the environment include terracing and the cultivation of hill slopes. Due to erosion, ancient terraces are not always preserved, although examples do exist. Terraces can also be difficult to date, but based on embedded pottery finds, terracing may have been practiced in Southwest Asia during the Early Bronze Age around 5,000 years ago, perhaps being prompted by a greater demand for olive and grape commodities such as oil and wine associated with the rise of urban life in Egypt and Mesopotamia. Extensive tracts of terraced hillsides are also evident in the Peruvian highlands where numerous varieties of potatoes were grown, as well as throughout Indonesia where sophisticated methods of terrace maintenance and water use were developed and integrated into the social and religious calendar.

Soil Fertility Management

Assessing early methods of soil fertility management is more difficult since they leave fewer traces in the archaeological record and are not always documented in textual accounts. The practice of fallowing, or leaving land uncultivated for a year or more, is believed to have been an important method and it forms an integral role in slash-and-burn agriculture (swidden) that has been documented in tropical counties in Asia and Africa. In more arid areas, where slash-and-burn is not a feasible method of production, the need to maintain soil fertility was likely recognized following the first cultivation of crops, but little is known about the methods, if any, that were used. In northeastern Syria, Wilkinson observed scatters of pottery sherds surrounding large sites dating to the Bronze Age, which he interprets as non-perishable remnants of night soil or urban waste used to fertilize the fields. Since leguminous crops such as lentil, pea, and bitter vetch that fix nitrogen in the soil were important crops during the Bronze Age, it is also likely that crop rotations may have been used to maintain soil fertility, but it is difficult to assess this with any degree of certainty from archaeological evidence. It seems probable, however, that some form of crop rotation in Southwest Asia was practiced much earlier than the formalized introduction of the Norfolk four-course rotation of wheat, barley, clover, and turnips that was adopted in Europe, predominantly England, during the late 1600s and early 1700s.

More Recent Developments

Within the past century, the large-scale introduction of mechanized farming has greatly increased the efficiency of preparing land and harvesting crops. Mechanization has not been adopted uniformly throughout the world, however, and in many developing countries, animal traction is still relied upon for field preparation. The Green Revolution of the 1960s also markedly changed production following the introduction of high-yield varieties of wheat and rice throughout numerous developing countries, notably in Asia. These varieties required a strictly defined regimen of fertilizer and pesticide application for optimal growth. While many farmers enhanced yields, many of the poorer farmers whom the improved grain was intended to help were not always able to afford the prescribed chemical fertilizers and pesticides and, as a consequence, yields sometimes fell below those obtained from local varieties. While farmers have long recognized the benefits of local varieties for subsistence agriculture, the lessons from the Green Revolution prompted numerous agricultural development agencies and agricultural research stations around the world to compile seed banks to store diverse crop varieties for future generations.

The most recent, and potentially revolutionary, change in agricultural technology concerns the development of genetically modified crops. From agriculture's earliest inception, selection of species with desirable traits has led to genetic change; this selection became formalized with intentional cross breeding. The creation of genetically modified crops differs from cross breeding in that DNA is physically spliced, potentially from one species to another. Genetic modification offers enormous potential to develop crops that are able to grow productively under adverse conditions, or which contain medicines or vaccinations that can be used in remote areas without refrigeration. Such crops have not been widely accepted, however, and studies examining potential environmental, economic, and social impacts continue. It is possible to produce seed stock that will yield sterile grain that cannot be used to replant the following season. While this development protects the economic investments of the producer, it has raised enormous concerns among subsistence farmer who would not be able to use harvested crops for reseeding. The debate is likely to continue for some time.

In the eighteenth century, Reverend Thomas Malthus expressed his views regarding the balance between population growth and food production, claiming that due to the inelasticity of food supply, once population levels increased beyond the "carrying capacity" of the land, the surplus population would be eliminated either by direct starvation, or by positive checks such as misery and vice or moral restraint. Boserup counter-argued that population pressure would stimulate the creation of new methods of production that would enhance yields. The historical developments of agriculture through the ages demonstrate periodic innovation which has allowed the carrying capacity to increase. The relationship between population and carrying capacity is enormously complex and while people have continually adapted agricultural technology in order to enhance yields, as Amartya Sen has argued, social factors play an equally important role in ensuring that people are fed.

See also: ►Swidden, ►Rainwater Harvesting, ►Animal Domestication, ►Potatoes

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Agriculture in Africa

Paul Richards

According to the philosopher Hegel, Africa was the inert mass around which the history of consciousness pivoted in its journey from East to West. Even today one still encounters the view that sub-Saharan Africa is exceptionally backward in science and technology, and has no indigenous intellectual history worth the name. Judged by the conventional standards of modernity, e.g., statistics on literacy and education, Africa does indeed seem a "backward" continent; but against this we must consider the crucial part played by the African savannas in the story of human evolution; human intellectual development was shaped by challenges set by the African environment. The legacy is still perhaps apparent in the continent's exceptional linguistic diversity and an enduring facility among its peoples for coping with severe environmental challenge. Until recently, however, African indigenous knowledge of environmental resources has failed to register in conventional histories of science and technology, due in large part to the distinctive resource endowments and consequent agrarian history of large parts of the continent.

Population density, historically, has been low over much of sub-Saharan Africa, and was depressed further by the slave trade and the wars and epidemics associated with colonial conquest. This has meant an emphasis (contrary to the trend of agrarian history in Asia) on land-management strategies that efficiently deploy scarce labor, but in settings ill-suited to plough agriculture or mechanization (contrary to experience in Europe and North America). In place of labor-intensive leveling, drainage, and installation of irrigation, for example, African cultivators typically have sought to make use of diverse soil and land conditions as they find them. This requires emphasis on what might be termed "mix-and-match" approaches, e.g., maintaining different animal species in the pastoral herd, selecting a range of crop types adapted to different soil and land conditions, using different crop types in the same field (inter-cropping), or by ingenious dovetailing of a complex and varied portfolio of productive activities (hunting and gathering, shifting cultivation, tree-crop cultivation).

This emphasis on versatility above specialization has been of particular importance in those extensive tropical regions in sub-Saharan Africa blighted by insect-borne disease (notably malaria and sleeping sickness), climatic irregularities, poor soils, and lack of irrigation opportunities. Here, characteristically, human groups tend to invest heavily in the social "software" of agrarian relations rather than the "hardware" of technology and land improvement. Groups facing periodic drought may prefer to devote attention to the cooperative social relations that sustain an "optimal foraging strategy" rather than tie up large amounts of labor in costly land improvements such as irrigation systems. In an outright disaster social investments are portable, but land improvement is fixed and may have to be abandoned.

The knowledge and mental attitudes that support versatility among hazard-prone resource users do not lend themselves readily to the writing of conventional history of technology. Historians whose ideas have been formed against a background of more steadily evolving agrarian technological traditions in Europe and Asia have been at times tempted to conclude that African agriculture is deficient in technical expertise. Local knowledge tends to be regarded as makeshift and perhaps even irrational. Shifting cultivators and pastoralists, more anxious to meet the next challenge than celebrate past achievements, may have unwittingly reinforced these misperceptions. For Mende rice farmers in Sierra Leone several "traditional" techniques are colonial innovations – the local notion of tradition is simply "something that works." Sometimes, sensing potential damage to a good practical skill from wordy rationalization, African resource users may even seek to deny that they know anything useful about the topic under discussion. Outsiders end up perceiving a technological void where none exists.

Many schemes were set up during the colonial period to assist African farmers to climb across these imagined gaps in what was thought to be a fixed ladder of agro-technological progress. Colonial reformers concentrated at first on European innovations such as sickle and plough, only to be beaten back by African preferences for panicle selection in harvesting as a means to maintain the varietal distinctiveness of planting materials, or for the hand hoe as a superior means to maintain soil physical quality under difficult tropical climatic conditions. Later, it was supposed that Asia was the proper yardstick against which to measure the backwardness of African agrarian technology, and first steps were taken to transform African agriculture according to Asian experience. This culminated in efforts in the 1970s and 1980s to replicate the Asian Green Revolution in Africa, using fertilizer-responsive high-yield crop types under intensive management. Asia-to-Africa technology transfer repeatedly foundered on the issue of labor. Innovations for Asian farmers needed to be labor-absorbing, but for African farmers (not threatened, historically, to anything like the same extent by population pressure on land) labor-efficiency was often the criterion of greatest relevance.

During the colonial period in Africa a significant minority of long-serving agricultural officers came to appreciate that rural people did in fact have a considerable fund of valid practical knowledge of agriculture and the environment. This coincided with the rise of scientific ecology and related disciplines during the 1930s and 1940s; foresters, economic botanists, soil scientists, and veterinary officers were particularly active in recording African indigenous knowledge of agriculture and the environment, and in drawing parallels between these local concepts and emergent ideas in ecology and related disciplines. Perhaps the single most striking of these instances is the letter to the scientific journal *Nature* in 1936 by the Tanganyika-based soil scientist Milne, proposing the concept of the soil catena as a regularly recurring chain of soil types controlled by topography. African soils tended to be very old, and showed the influence of underlying rock types much less than in Europe. The concept of soil catena, by emphasizing topography and downplaying the role of geology, provided a much better guide to the way the soils had formed, and to how African farmers typically used their soils. Throughout the tropical zone, but especially where seasonal variations in rainfall distribution are most marked, farmers secure food supplies during the preharvest hungry season and spread their labor burdens by systematically planting up and down slopes, carefully matching different crops or crop types to the different soils within the catenary sequence. The catena rapidly became established as a basic organizing concept in tropical soil science throughout the world; Milne's letter to *Nature* makes clear its African roots by using the Sukuma terms employed by local farmers to categorize the different soils within the chain.

This is in stark contrast to earlier official thinking about land systems on the other side of the continent, in Sierra Leone. After famine in 1919, caused not by local agricultural incompetence but the loss of harvest labor resulting from the influenza that tracked colonial troops to their homes from the battlefields of Europe, the colonial governor Wilkinson sought (as he thought) to transform Sierra Leonean rice farmers from being shifting cultivators farming rain-fed up lands into permanent cultivators of irrigated valley-bottom lands along Asian lines. Moving local farmers from the tops to the bottoms of their valley slopes was for Wilkinson a shift of epochal proportions, through which the "ignorant" African would be able to catch up a 1,000 years of agrarian technological history in a matter of a few years. The official of the Madras Department of Agriculture in India employed by the Government of Sierra Leone to set things in motion requested to be sent home after nearly 2 years working with local farmers, on the grounds there was little if anything he could teach them that they did not know already, and that in any case they obtained better yields from similar resource endowments than farmers in Madras. However, the belief that there was something decisive about a shift from upland to valley-bottom farming survived into the modern period, and received a new boost from the example of the Green Revolution in the 1960s. This insistent categorical contrast on "uplands" and "wetlands" remains in stark contrast to local farmers' knowledge and practice in which seed types and labor resources are invested up and down catenary sequences, and across the upland–wetland divide, according to circumstances. Standing on the boundary between the rain-fed and water-logged soil types in their farms, Sierra Leonean peasants repudiate any gap between themselves and more technologically advanced farmers in Asia, and see instead only an opportunity for flexible adjustment to changing conditions. Recently, mathematicians have begun to provide formal tools with which to grasp the fuzzy logic that underpins this kind of cognitive flexibility, typical of African indigenous knowledge of environmental resources.

Rice farming on the western coast of West Africa is of considerable antiquity, and based on the domestication of the African species of rice (*Oryza glaberrima*). Due to contacts arising from the slave trade we have quite rich documentary sources concerning indigenous agricultural knowledge for this part of Africa at an early date, including a number of accounts from the seventeenth and eighteenth centuries specifying the way in which farmers matched planting materials to different soils, so spreading labor peaks and minimizing preharvest hunger. Today, rice farmers in the region continue to research this relationship whenever they encounter new material (e.g., accidental introductions, or new types that arise as spontaneous crosses). This knowledge of and interest in management of crop genetic resources is widespread in Africa, and is perhaps the single most important aspect of the legacy of indigenous agro-technological knowledge on the continent. Today it is threatened by social dislocation (including the effects of warfare) and agricultural modernization (including the spread of modern cultivars and labor-efficient harvesting technology).

African contributions to crop biodiversity management have been undervalued in the past, with some exceptions, because several of Africa's indigenous food crops are not widely known elsewhere (e.g., *Digitaria* millet in West Africa, *teff* in Ethiopia, and finger millet in eastern and central Africa). Vavilov recognized the Ethiopian Highlands as a major center of crop biodiversity, but a number of important crops originating in Africa are scattered more widely (e.g., African rice, white yam, sorghum, and oil palm). Greater recognition is still needed for the historical role played by Africa's farming populations in identifying, shaping, and conserving these genetic resources. In this context it is interesting to note the systematic efforts made by Thomas Jefferson in the 1790s to establish African rice in the United States. Jefferson was convinced that the hardy dryland cultivars selected and maintained by West African farmers would help reduce some of the health problems associated with rice farming in the coastal zone of South Carolina, and had a cask of upland rice imported from the coast of what is today the Republic of Guinea for distribution among inland planters in South Carolina and Georgia. Earlier, South Carolina rice planters had shown a preference for slaves from the coastal rice-growing regions of West Africa, and it is possible that the tidal-pumped wetland rice cultivation systems of the tidewater zone drew upon African technological expertise in this field. Historical examples such as these help correct the erroneous notion that the transfer of agricultural knowledge and technology between Africa and the rest of the world has been a one-way process.

During a period of aggressive modernization of African agriculture following the end of colonial rule the work of documenting and understanding African systems of resource knowledge and management, begun by ecologically oriented technologists in the colonial period, was kept alive only by a handful of enthusiasts. Special mention should be made of African pioneers such as George Benneh in Ghana and Uzo Igbozurike in Nigeria. However, interest in local knowledge systems expanded enormously in the 1980s and 1990s, after the failure of many "high-tech" schemes to promote rapid change in African agriculture. A number of agricultural and other scientists now see indigenous knowledge as a resource for orthodox science (farmer experimentation attracts particular attention). Recent studies have highlighted the specialist knowledge of Africa's women farmers, pointed to the complex ways in which indigenous technical knowledge of the environment is bound up with social relationships of production and consumption, and drawn attention to local knowledge in biodiversity conservation. The ratification of an international convention on biodiversity, adopted by the United Nations' Rio de Janiero Conference on Environment and Development in 1992, gives indigenous agricultural knowledge a new visibility, and status in international law. Questions of ownership and preservation of Africa's abundant legacy of indigenous knowledge now attract attention, though some concern has been expressed that this might serve to ossify such knowledge, and reduce its practical utility.

See also: ►Knowledge Systems: Local Knowledge, ►Colonialism and Science, ►Environment and Nature, ►Ethnobotany, ►East and West, ►Food Technology in Africa

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Agriculture of the Ancient Maya

Timothy Beach

The Maya are a diverse group of Native Americans, who speak 31 languages within the Mayan Language Family. They live in Southern Mesoamerica, in Mexico from Chiapas through Yucatan and south through Guatemala in the Peten lowlands and mountainous highlands and into Belize, Honduras, and El Salvador. Settlements started as early as 2,000 BCE along the mangrove coastal margins of the Pacific, but most settlements started after about 1200 BCE, with identifiable ceramics, and lasted through the Pre-Classic 1200 BCE to BCE 250 and the Classic Period from (BCE 250) to (BCE 850). Declines or transitions punctuated their history at the end of the Pre-Classic, perhaps in the Middle Classic, (BCE 500), the sharp decline often called the Maya "Collapse" in ninth century (BCE), and the population collapse due to the diffusion of European diseases and conquests starting in the sixteenth century. All but the last of these major transitions are regional, and the most famous is the Terminal Classic Collapse of the ninth century (BCE), which occurred in the central lowlands of Guatemala's Peten state and adjacent Belize, Honduras, and Mexico's Chiapas and southern Yucatan. Much of the writing about the Maya, including about its agriculture and environment, focuses on this Terminal Collapse and the Late Classic period (BCE 550–850) that preceded it though more and more publications are dealing with both the pre and post classic periods. The terminal classic in the central Lowlands represents an end to this intensive urban and agricultural civilization's great achievements in building, writing, art, astronomy, and agriculture, and the relatively quick return of tropical forests that enveloped the temples and terraces that had functioned for centuries.

The Maya World has two main geographic divisions: volcanic highlands and limestone lowlands. The highlands center on a series of north–south running and variably active volcanoes along the Pacific Coast side, which abut a complicated series of metamorphic and sedimentary rocks to their east. The Maya farmed these slopes and river valleys from Chiapas, Mexico into Guatemala, Honduras, and El Salvador. These uplands generally have deep and fertile soils, though rainshadow driven dryness, steep slopes, some poor soils, and seismic volcanic events have limited subsistence in different places at different times. The lowlands mainly refer to the limestone Yucatan platform ranging from Mexico, through Guatemala, to Honduras. Within this division are the karst plains of the northern Yucatan with no rivers but sinkholes, the faulted, karstic central and southern Yucatan, the more complicated geology to the south (including the granitic Maya Mountains); and the surrounding coastal zones with rivers and more coastal resources.

Climate also varies significantly across this region, from the semi-arid northwest Yucatan with about 500 mm of annual rainfall to the high elevations of the Maya Mountains that receive almost ten times more rainfall. Generally, the lowlands receive about 1,000 to 2,000 mm of rainfall and most of the region does have a distinct dry season from December to May that must be figured into every agricultural practice and adaptation in the region. These general regions all provide different potential resources and limitations for agriculture. One limitation for the whole region was recurring drought that corresponds to cultural declines especially with the Terminal Classic Collapse (Hodell et al. 2000).

Research into Maya agriculture is long and rich. The start of agriculture in the Maya World comes from the earliest evidence of maize in the floodplains of coastal Veracruz by about 7,000 BP and evidence from starch grains for root crops in nearby Panama comes about the same time (Piperno et al. 2000). This beginning of Mesoamerica's great triumvirate of staple crops – maize, bean, and squash – comes with the spread of extensive swidden or *milpa* farming and perhaps floodplain farming. This shows up in the Maya Heartland of Guatemala's Peten and nearby Belize from about 5,000 to 4,000 BP as increased charcoal and pollen from the weeds that usually accompany agriculture. Pollen from maize and manioc actually show up before 5,000 BP in Belize (Jones 1994; Pohl et al. 1996).

In the early twentieth century, scholars viewed swidden agriculture as the means for how the ancient Maya fed themselves because many had observed *milpa* farming across the region and studies showed that it provided a level of subsistence needed for the dispersed populations of a tropical forest civilization. In the 1960s, though, many scholars came to see the *milpa* as insufficient to feed the growing estimates of ancient Maya populations. Many regional surveys started showing more and more large-scale Maya sites that must have had high populations, and studies for decades had reported evidence for intensive forms of agriculture, including extensive, well-made terraces.

The agricultural staples of the Maya worlds were of course maize, beans, and squash, though there were a host of other possible and known crops like cassava, sunflower, amaranth, and many other fruits and vegetables, whether cultivated or collected. There were also sources of meat from turkeys, ducks, doves, deer, fish, and other animals, though what role they played in Maya agriculture and what proportion of Maya diets they made up is still not well known. Cacao was certainly an important commodity grown in different environments over much of the Maya Lowlands. Since we know from documents and archaeological evidence that the Maya and other Mesoamerican peoples highly prized cacao, scholars have tried to identify cacao in many possible ways: by noting the requirements of the crop, using ethnohistorical information, and looking for pollen and other fossil evidence. Tobacco, cotton, palms, and many others were nonsubsistence crops. This cornucopia of known foods has also fueled discussion of other possible staples to feed large populations and solve the riddle of Maya subsistence (Dahlin et al. 2006). Scholars have found evidence for use of many other crops like agave and many arboreal ones like ramon or breadnut (Gomez-Pompa et al. 1990).

Forms of Agriculture

We should note that we still know little about the agriculture of the ancient Maya, but many traditional and novel techniques are turning up more evidence with each field season (Beach et al. 2006b). Traditional research tools are still the backbone of research and include regional survey, sampling, mapping, and archaeological excavation. Adding to these methods have been an array of steadily improving geophysical, chemical, and biological methods. Each of these methods are whole subjects in themselves but we should not divorce a discussion of the methods from the findings, because techniques change and may make findings obsolete. For example, remote-sensing technologies have added to our breadth of knowledge, but some radar images have produced false-positive identifications for vast wetland agriculture in areas that are not even wetlands.

We can divide ancient Maya Lowlands agriculture into upland and lowland forms and outfield and infield forms. Upland agriculture occurred on well-drained and seasonally drained soils and lowland farms had to contend with seasonally or perennially high water tables. Outfields simply refer to fields at some distance from Maya sites and infields were agricultural areas within or adjacent to sites and thus more likely the focus of intensification techniques.

One type of infield in Maya societies is kitchen gardens or solares, which is still a common feature of traditional and indigenous communities. These, like similar farming systems around the world, are intensive, high input, close-to-home adaptations for growing crops. Kitchen gardens often use polycultural methods that grow as much on small areas as possible by arranging crops at different levels or canopies. Ethnohistorical studies have found that polycultural gardens produce about 11% of domestic caloric intake and few bulk staples, focusing more on dietary supplements, medicinals, ornamentals, and ritual objects. Archaeological evidence such as the size of walled areas around mounds may however, suggests greater pre-Hispanic contributions from kitchen gardens at certain periods (Beach et al. 2006b).

In uplands, milpa, or slash and burn farming, is the mainstay of nonintensive agriculture. A milpa is small farm that *milperos* slash and burn usually toward the end of dry season (from December to May). *Milperos* slash the tropical forest vegetation today with metal machetes (or more mechanized implements) but had to use stone tools in antiquity. They would slash vegetation, including girdling trees to make the vegetation dry enough to burn, and thus produce enough wood ash to enrich and prepare the seed bed for planting. They would usually plant multiple crops (e.g., corn, beans, squash, and chilies) in each milpa and indeed prepare more than one milpa every year to insure against the vicissitudes of climate (e.g., drought and hurricanes) and pests in these seasonally dry tropics. Each milpa might remain productive for 2 or 3 years and then weed competition and nutrient depletion would drive farmers along to new areas to slash and burn. Farmers might return to the old milpas after fallows of 10 or more years and restart the process. Although this is extensive agriculture, farmers might intensify this by shortening the fallow time, but this requires more labor for weeding and fertilizing (Beach et al. 2006b).

Upland agriculture occurred along slopes of varying degrees and, for any semblance of long-term sustainability, required conservation techniques to limit soil erosion in the Maya Lowlands, where the limestone soils were already thin, and in the Highlands, where slopes are much steeper and longer. We have substantial evidence that soil erosion, in lake sedimentation and buried depression soils, started early, by about 3,000 BP, in the Maya Lowlands. Rates of erosion only rise when major drivers of erosion occur and the main evidence for such drivers is the coincidence of weed and crop pollen, charcoal, and mineral sediments. These link deforestation and Maya farming together with increased runoff, caused by some combination of decreased transpiration and infiltration into soils. The increased erosion may have also coincided with another erosion driver, namely moving deforestation onto steeper slopes, where gravity can act to accelerate overland flow and all major types of water erosion. Modern evidence in this region shows that erosion rates are very high after deforestation and soils erode to bedrock surprisingly fast. Some scholars have even linked soil erosion with the Terminal Maya Collapse (Beach et al. 2006a).

Ancient Maya farmers, like early farmers everywhere, had to adjust their early pioneering experience. They had several options that all required more labor inputs: conservation techniques on slopes or management of flat or depression environments. The least laborious options would have been to farm flat areas, but there were too few flat areas that were not seasonally waterlogged around the settlement-carpeted limestone, karstic ridges of much of the central Maya Lowlands.

Upland Agriculture and Terrace Systems

In many places around the Maya Lowlands are large tracts of terraced lands. Indeed, travelers have mentioned terraces since at least the early twentieth century, and they have since identified many types of terraces that take advantage of specific slope situations. Terrace systems are intensive forms of agriculture that attempt to engineer slopes to make them sustainable. Indigenous terrace systems, starting more than 5,000 years ago, are nearly a universal human adaptation to farming on steep slopes, with several ancient terrace systems such as those in the Philippines, recognized as UNESCO World Heritage Sites. The factors that make steep slopes unsustainable are thin soils that cannot store enough water or nutrients and extremes of water: either too much destructive overland flow or too little to support crop needs during the dry season. Thus for terracing to be worth the heavy labor efforts, farmers must build up soils, minimize the impacts of overland flow, and maximize soil moisture for the growing season. Terrace systems also must return nutrients harvested in crops to maintain crop yields over time. Studies have thus attempted to find evidence for soil depletion coinciding with the Terminal Classic Collapse as well as find evidence for terrace soil maintenance from night soil, composted waste, and wetland organic matter (Turner 1974; Beach et al. 2002).

Terraces must function to slow the destructive force of overland flow, divert water away or to soils, help drain excess water, and dam up soils and potential fertility. There are surprisingly common terrace remnants left in the Peten after more than a thousand years and most tend to be engineered from limestone boulder dams, though some are earthen and some might have been vegetative hedges as well, which have left no obvious traces. The terrace dams were either single rows of large boulders or double rows of boulders with gravel, cobble, and ceramic fills. They often had gravel bases and cobble buttresses and some still testify to pre-Maya times with soils buried below the terrace dams and below soil sequences that filled in behind the dams unintentionally or by active human manipulation. Terraces occur in many slope positions: contoured around slopes, across channels, as boxes with little slope, around crests, and prominently at the base of slopes. Some landscapes have all types; others only have one. Since each has a different slope position, each creates a different microenvironment with different soil moisture conditions and aspects or orientations to the sun. In most cases a large part of the terrace system has eroded away, and, thus, our real evidence for an agricultural landscape integrated with diversion cannels is often only theoretical.

All of the terrace types are common, though box terraces are much smaller and more easily expunged by tree roots and slope wash. Some scholars have linked these systems with intensive nursery crops that could be replanted at some point in their lifecycle. Footslope terraces show up in many places because they are usually constructed of larger boulders that persist through time. These may have functioned to build up some areas above water tables in large, low elevation seasonal wetlands. Hence, we think the base of slopes that often ring depressions was an important focus of agriculture, where soil depth, fertility, and moisture could have been managed to lengthen the growing season. Likewise, upland sinkholes, called *aguadas* or *rejolladas*, could also have been a focus for agriculture because soil depths, fertility, and moisture could have been managed to lengthen growing seasons.

Some evidence exists for early terrace adoption, perhaps by 2600 BP, though most evidence of terracing coincides with the other large-scale building of the Late Classic period. Many sites in the Maya world, such as Caracol, La Milpa, the Rio Bec, Xunantunich, and the Petexbatun, had widespread terracing by the Late Classic period, though other notable sites like Copan and the Central Peten lakes region provide only meager evidence (Beach et al. 2002, 2006a, b; Beach and Dunning 1995).

Another form of upland soil management is field ridging, which looks like plowed furrows but required significantly more labor in Maya societies where beasts of burden were not available. Field ridging has been reported in many parts of Mesoamerica, but the most significant are the preserved fossil ridges in the ash covered, Maya Pompeii site of Ceren, El Salvador, which blankets a Classic Maya village from ca. BCE 650. The low ridges formed the seedbeds, and maximum air and water drainage could occur in the furrows. At Ceren, only one of eight excavated fields was in fallow, probably indicating much more intensive farming on these fertile, volcanic soils than could be possible in lowlands milpas that required years of fallow or heavy fertilizing and weeding (Beach et al. 2006a, b).

Lowland Intensive Agriculture

Lowland agriculture takes advantage of low sites where erosion is not significant, but water management is necessary to provide enough water in dry sites and enough root aeration in wet sites. These areas do not suffer from much erosion but all agricultural lands must still be fertilized for intensive long-term cropping.

One particular Maya region provides an interesting case study: the northwest Yucatan site of Chunchucmil. Here the soils are thin or nonexistent and the rainfall is spotty and low; yet this Maya site had many thousands of inhabitants around BCE 400–600, where today a few hundreds have trouble growing enough food. Milpa farming today produces only a small fraction of food requirements, but somehow high populations occupied this region ca. 1,500 years ago. Thus, either they imported food based on some other trade commodity or they used some extremely intensive systems. One line of evidence lies in the numerous polygonal wall systems around habitation mounds and surrounding empty lands. The walls only tell us that groups were trying keep predators or people out, and scholars are looking for every line of evidence about manufacturing and markets that might have functioned to provide trade goods for food from elsewhere. But these may also have been intensive kitchen gardens with traditional or special crops that were heavily fertilized with all possible wastes the site and organic matter from nearby wetlands. Modern farmers do enhance their solares this way, and we can balance subsistence for large ancient populations by maximizing infield, arboriculture, and surrounding outfield production (Dahlin et al. 2006).

Another type of agriculture that occupies the middle ground between uplands and lowlands is *bajo* or karst-depression agriculture (Dunning et al. 2002; Beach et al. 2002). This ranges from cropping that occupies the backslopes of small sinkholes of a hectare or less called *aguadas* or *rejolladas* to cropping into and around large seasonal sinks called *bajos* that are sometimes many square kilometers. Pollen of maize, cassava, and other crops in bajo sediments shows evidence of nearby agriculture, and excavation of surrounding terrace berms may show soil and water management in these "ecotonal" zones, i.e., regions that straddle two ecosystems.

Agriculture in these bajos was similar to agriculture in seasonally flooding valleys. In these environments, farmers had to manage water extremes, flooding in the wet season and insufficient soil moisture in the dry season. One globally widespread adaptation to such environments is a risky but productive technique called flood recessional agriculture. Farmers using this technique plant into the wet soils of receding floods to take advantage of plenty of soil moisture that might get a crop through the dry season. As does all farming to varying degrees, this plays the probabilities of potential drought and enough seed-corn to persist through recurrent floods. Farmers could also more actively manage soil moisture by ditching, draining, and damming.

Another option for intensive farming was manipulating perennial wetlands (Duzzader-Beach and Beach 2006). All over the Maya Lowlands perennial wetlands bear witness to a wide diversity of rectilinear features that look like cobwebs or other polygonal patterns from the air. Early on scholars suggested that these may be relicts of ancient Maya intensive wetland cultivation because the patterns look similar to the historical Mexica wetland plots or *chinampas* around the Basin of Mexico, which, like the terraces of the Aztec Realm, were highly productive systems. These *chinampas* are still very much working plots in Xochimilco on the outskirts of Mexico City, though today they are more for flowers and tourists than subsistence.

Farming wetland fields requires using plants that can grow in saturated soils or manipulating the soils and water table. Indeed, one explanation for the polygonal field patterns is that they are simply ditches to drain the fields and lower the water table below the root zone of typical crops. Thus such drained fields could function as long as there was a lower part of the landscape where water could be drained. A more elaborate model is a raised field, in which the ditches are built and the excavated soils and organic matter are used to build up and fertilize the soil plots. In both models, canals can be occasionally cleaned out and used to renew fields. In the Aztec fields, alder and willow trees were planted around the field edges to protect the sides from slumping and erosion (Armillas 1971). An even more elaborate model envisions a complex of farming and aquaculture akin to the productive but laborious Chinese rice paddy, aquaculture systems.

There are also more natural explanations for the polygonal wetland patterns. These range from human ditching in response to sea level rise and ground water rise to differential expansion patterns caused by a landscape building up from gypsum precipitating from saturated ground and surface waters. The first explanation sees wetland ditching as a Pre-Classic agricultural adaptation to wetland formation, though in the broader region other research teams saw the same patterns as evidence of Late Classic intensive cultivation with copious evidence for maize. The differential heave explanation does not discount the possibility of human modification of polygonal field patterns but argues for a landscape co-evolving from human and natural factors.

Another hypothetical use of wetlands for agriculture comes from the rock alignments of northeastern Yucatan. Perhaps these rock-aligned wetlands were used to raise algae or periphyton, which are cyanobacteria communities that have fertilizer and pesticide characteristics. Or, perhaps these were dryland plots created before sea level rise made these wetlands. In either case, Maya scholars have attempted to use every line of evidence and push the limits of science to come up with explanations for Maya subsistence. Sometimes they have pushed too far and too fast, but it was usually tin the spirit of seeking out explanations for the profound and vexing riddles of the past.

Debates about all forms of ancient agriculture underscore the difficulty of understanding ancient subsistence. We only have the lines of evidence and no historical accounts. Thus, we have vast terrace systems, walled fields, ridged fields, and numerous wetland polygons that coincide with millions of house mounds and massive buildings from especially the Late Classic. We have evidence of buried soils, elevated chemicals, fossil seeds, pollen, and other proxies of the past.

Since there are many types of intensive and extensive agriculture from around the Maya realm, many Maya scholars think the ancient Maya used heterogeneous types of farming, adapted for the different landscapes, soils, and climates of the region. Many Maya sites are on ecotones, such as at bajo edges and ridges that lie between two and more environments. Around the sites, evidence for many agricultural adaptations often occur. This makes us guess that, where possible, ancient Maya farmers tried to do with intensive systems what contemporary, traditional Maya farmers do in milpas: minimize risk by taking advantage of a diversity of sites. What is different about ancient Maya farming, however, are the many kinds of intensive agricultural systems with their extremely high labor demands.

See also: ►Ceramics, ►Swidden

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Agriculture in China

Francesca Bray

China is a vast country covering roughly the area of Europe. Because much of it is steep mountains or fragile grasslands, only about 10% of China's total area is suitable for farming (see *Online resources* for some useful maps). However, intensive patterns of land use, increasingly refined over the centuries, sustained high levels of population and production throughout much of the imperial period. The modernization of farming in the West has characteristically involved increasing the size of farms or managerial units while substituting machines or other industrial products for human labor. In China the process was reversed: farms and equipment became smaller and inputs of human skills intensified. There is a fierce debate among historians as to how this long-term trend should be interpreted. Some see it as a "technologically blocked" system, incompatible with the emergence of capitalism, in which farming families had to work ever harder for smaller returns. Others argue that the farming system of China and the rural manufactures and commercial networks that grew up around it constituted a flexible and dynamic economic system which not only generated internal prosperity, but played a key role in stimulating and shaping the emerging global economy of the modern world (see BOX). The unusual quantity of agricultural treatises and economic or policy documents that have come down to us from the imperial era help fuel and complicate this important debate as to whether "modernity" is a Western or a worldwide phenomenon. In either case, the current social and environmental critiques of contemporary "productivism" and of the problems generated by industrial agriculture suggest the value of looking more carefully at such alternative paths to development as the progressive intensification of land-use typical of Chinese agriculture.

China has several different farming regions, ranging from the chilly plains of the Northeast where the main food crops are soybeans, sorghum, spring wheat, and corn, to the lush tropical gardens of Hainan Island where the year-round growing season allows constant cropping, including two crops of rice (Bray 1984: 9–27; ►http://www.1uptravel.com/worldmaps/china39.html). Broadly speaking, however, China has two distinct farming traditions that correspond to climatic zones. North China has sparse and irregular rain that falls mostly in the summer; the winters are long and cold. The uplands of the interior are formed of thick deposits of fertile loess; over the millennia the Yellow River has eaten away at the primary loess and deposited it as silt on the alluvial plains downstream. The main constraints on agricultural productivity in the Northern region are the relatively short growing season (between five and eight months) and the lack of water. It is seldom possible to grow more than one crop a year. The typical crops are those which do well with little water: millets, wheat, sorghum, cotton, and beans.

From the Yangzi plains south, the climate is semitropical. Rainfall is much heavier and spread throughout the year. As a result much of the natural soil fertility has been leached away, but irrigated rice fields counteract this effect. They build up their own fertile microecology that allows the same field to produce two or even three harvests a year, depending on the latitude. The growing season ranges from nine months to year round. Rice is the staple, grown everywhere in the Southern zone: other important crops are winter wheat, maize, sweet potato, sugar, tea, and cotton along the Yangzi.

The distinction between a Northern and a Southern tradition has its roots in prehistoric times. The earliest Chinese farming villages date from the sixth millennium BCE, much later than those of the Fertile Crescent. Archaeologists used to consider that farming diffused throughout the Old World from that single center; the current evidence suggests however that within China itself there were at least two independent centers of plant domestication. At the 5000 BCE Neolithic site of Banpo, in the loesslands of Northwest China, the dryland crop of Setaria millet was grown (Bray 1984: 434). The village of Hemudu, built in the marshes near the mouth of the Yangzi at the same period, grew large quantities of wet rice (Bray 1984: 481). Though some archaeologists believe they have now discovered evidence of domesticated rice in sites in Central and Southern China dating back as far as 10000 BCE (An 1999), most of the early evidence for farming in China is no earlier than Banpo or Hemudu.

Land was a scarce resource from very early times. Unlike the pattern of development in the West, where capital was invested in draft animals, equipment, and machines to substitute for labor, in China the historical trend was towards increasing the productivity of land through the application of skilled labor and cheap small-scale inputs. With one or two rare exceptions, economies of scale did not apply. The roots of this relationship between land, population, and labor developed very early in China's history.

From the sixth to the fourth centuries BCE, several states battled for control of all China; the states with most men to fight and most grain to feed them emerged as victors. A fiscal policy based on peasant contributions of grain, textiles, and services became the norm. A strong state was one with a large population of skilled farmers. As a political philosopher of the third century BCE put it: "Therefore it is said: 'Where a hundred men farm and one is idle, the state will attain supremacy; where ten men farm and one is idle, the state will be strong; where half farms and half is idle, the state will be in peril.' This is why those, who govern the country well, wish the people to take to agriculture" (*Shangjun shu*, trans. Duyvendak 1928: 191). This remained the basic view of Chinese statesmen through the unification of the empire in 221 BCE right up to the end of the Maoist era. For over 2,000 years officials encouraged farming and took an active role in developing and diffusing knowledge and techniques. They fostered labor-intensive peasant farming and tried to control the accumulation of land in the hands of the rich. Successive medieval regimes confiscated land from the wealthy and redistributed it to peasants to ensure that it provided a livelihood for as many people as possible.

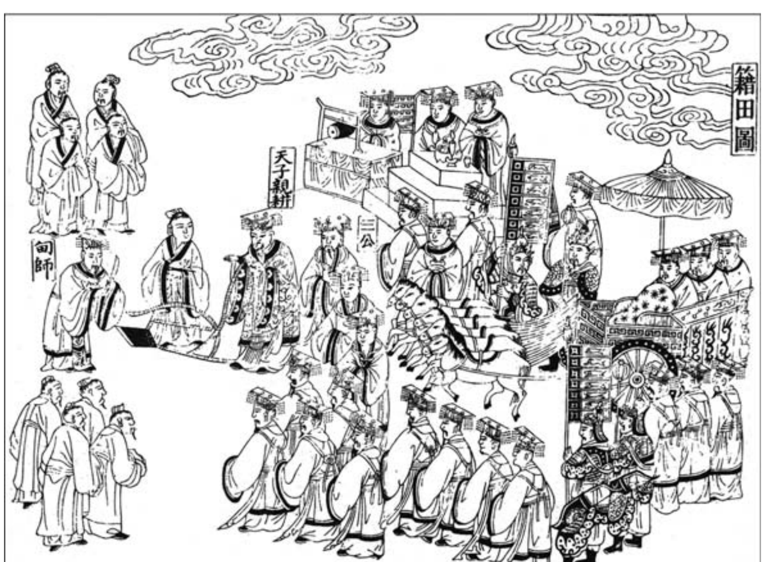
In part this intensity of land use was made possible by the particularities of Chinese farming systems. No arable land was wasted. There were few pastures in China proper. The main sources of animal protein were

Agriculture in China. Fig. 1 Water buffalo and herdboy. The sound of the herdboy's flute echoing up some distant valley was a common element in Chinese poetry, but here the agronomist Wang Zhen (see below) is illustrating the flute as one of the indispensable implements of a rice-farming household. Wang Zhen, *Nongshu*, Ming edition of 1530, 13/7a.

pigs, poultry and fish, and draft animals (oxen and mules in the North, water buffalo in the South) grazed on rough land (Fig. 1). The practice of fallowing seems to have died out as early as 2,000 years ago in parts of North China. Crop rotations alternated soil-enriching crops like beans with cereals; all human and animal waste was composted and returned to the fields. Medieval states in the North allocated approximately 6 acre of land to support a family. Land was even more intensively used in the South. By the seventeenth century, some fields in the South produced two crops of rice and another of tobacco or vegetables each year. In the early twentieth century families in the most densely populated regions lived off under a tenth of an acre of rice land.

The tax system meant that improving agriculture was a key concern in Chinese state policy from the very beginning (Wong 1997: 90), and many of the most important works on agriculture were written by members of the official elite in their capacity as civil servants (Fig. 2). Imperial compilations and works by civil servants aimed at a readership of local officials who would pass on the information to the farmers under their jurisdiction. They tended to stress practical details of husbandry, including innovations that could be introduced, and they emphasized subsistence production. Other works, written by landowners who ran their own farms, were written for fellow landowners; these works usually included discussions of labor, prices and estate management (Bray 1984: 47–80) (Fig. 3).

The earliest extant agricultural treatise belongs to the second category. It is entitled *Qimin yaoshu* (Essential Techniques for the Peasantry); the author, Jia Sixie, completed its ten volumes in around AD 535 (Bray 1984: 55–58). It describes the agriculture of the dry regions of the Yellow River plains. Perhaps its most striking features are the detailed descriptions of how careful and repeated tillage techniques (different depths of plowing, sowing with a seed-drill, harrowing and hoeing, all techniques requiring the use of several oxen or mules) were used to conserve soil moisture in a dry climate, and crop rotations were used to increase fertility. We can reconstruct much of the equipment mentioned by Jia from somewhat earlier tomb paintings, as well as archaeological discoveries of huge state iron foundries from the first century AD, that mass-produced cast iron plowshares, moldboards, and the iron shoes of seed-drills. Together with Jia's numerous citations from earlier Northern works, this evidence confirms that the *Qimin yaoshu* represented the culmination of a long Northern tradition of productive estate farming that was dependent on large acreages and heavy capital investment in equipment and draft animals. It was a form of centralized estate farming that



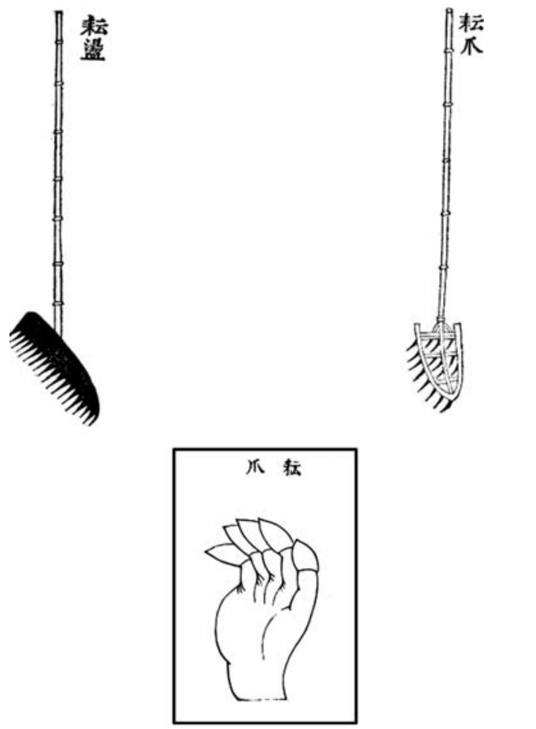
Agriculture in China. Fig. 2 Wang Zhen wrote his agricultural treatise of 1313 after service as magistrate in both Northern and Southern provinces; he hoped his work would help disseminate advanced technology and improved techniques. He begins with a section on the importance of official encouragement of farming. This included not only practical but also symbolic measures such as the New Year imperial plowing ceremony, where the emperor plowed a ceremonial furrow before the Temple of the God of the Soil in order to ensure good harvests throughout the empire. In this highly stylized rendering, an emperor of ancient times is shown holding the strut of a plow to the *left* of the picture. Wang Zhen, *Nongshu*, 7/4a–b.

Agriculture in China. Fig. 3 The harvest feast held by a landlord (shown seated right in front of his family altar) for his tenant farmers. *Bianmin tuzuan*, 1593 edition, 1/8a.

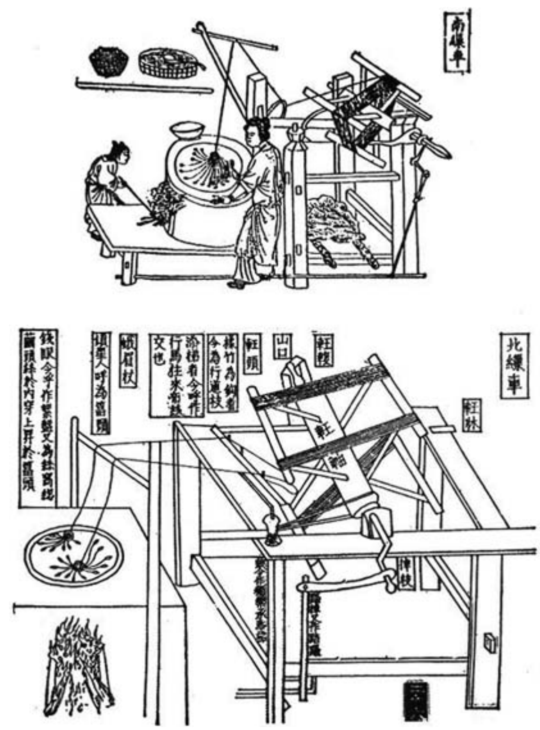
peasant farmers could not afford or compete with (Bray 1984: 587–97). The *Qimin yaoshu* was the last of the great works focused on the Northern system.

Repeated wars and invasions ravaged the Northern plains in medieval times. In the eleventh century the loss of the North to the Khitan finally established the Yangzi region as the political and economic center of Song dynasty China. The estates of the Northern aristocrats disintegrated, and as under-equipped peasant farmers did their best to scratch a living from a few acres of dry soil, the North became a backward region compared to the fruitful South. Migrants flooded into the Southern provinces from the North, and the state sought to encourage more productive agriculture by every possible means. Irrigation works were improved, seeds were handed out, information distributed, and cheap loans and tax breaks offered – the scope was similar to the Green Revolution of the 1970s, as was the impact on production (Elvin 1973; Bray 1986). One particularly fruitful venture was the introduction of quick-ripening rices from Vietnam that allowed rice farmers to double crop their fields, alternating winter wheat or barley with rice.

Several important agricultural works were published during the Song, but the landmark of the period dates from the Yuan (Mongol) dynasty. In 1313 Wang Zhen published a *Nongshu* (Treatise on Agriculture) several hundred pages long. His aim was to describe local innovations so that they could be adopted elsewhere (Bray 1984: 59–64). He included detailed woodblock illustrations of farming tools (Fig. 4), machinery (Figs. 5 and 6), irrigation equipment (Figs. 7 and 8), and various types of terraced or dyked fields that permitted the extension of farming into mountainous or marshy lands



Agriculture in China. Fig. 4 Varieties of tools for weeding rice fields depicted by Wang Zhen. On the *top left* is a simple rake. The hinged rake at the *right* was a new invention from the lower Yangzi which Wang described with great enthusiasm, hoping that it would relieve farmers of much back-breaking work going through the young rice on their hands and knees. The "weeding claws" at the bottom were made of bamboo and helped farmers grub up weeds at the roots. *Nongshu* 13/27–29.



Agriculture in China. Fig. 5 Silk-reeling machines typical of Northern China (below) and the Yangzi region (above). Rural women produced almost all the silk thread and much of the silk cloth in circulation at the time when Wang Zhen was writing, but later silk weaving moved into suburban workshops where most of the workers were men. *Nongshu* 22/26a–27b.

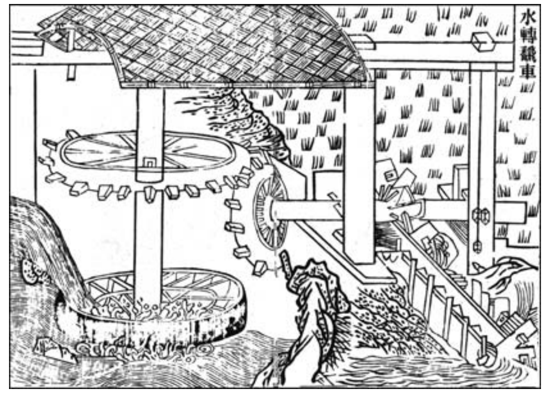
(Figs. 9 and 10). The treatise depicts a system of family farming in which poor peasants with little capital invested intensively in labor, skills, and low-cost inputs. This was the farming system that formed the basis for the commoditization and expansion of the rural economy in succeeding centuries (Bray 2000: 25–41).

Wang Zhen's *Treatise* was the paradigm for later works, including imperial compilations and the magisterial *Nongzheng quanshu* (Complete Treatise on Agricultural Administration) by the statesman Xu Guangqi, completed in 1639. Xu was a polymath and Christian convert who served for some years as Grand Secretary of China. The *Nongzheng quanshu* advocates a balance between the production of essentials (cereals for food and fiber crops for textiles) necessary for the health of the central state, and cash crops and handicrafts that would ensure a prosperous rural economy. Xu was also preoccupied with population pressure and the need to expand the arable area and improve yields; he devotes long sections of his treatise to land reclamation and improved irrigation techniques, to his own experiments with manures and commercial fertilizers such as lime and bean cake, and to crops like sweet potatoes that can be grown on poor land (Bray and Métailié 2001).

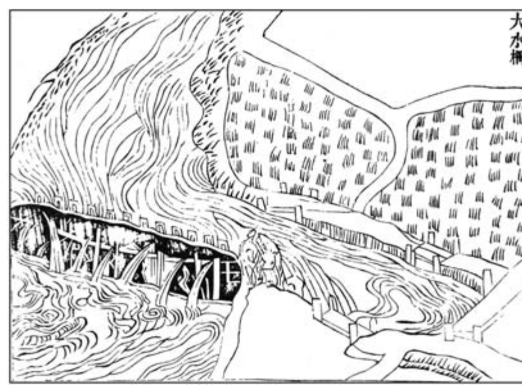
Landowners wrote a number of other works in the Southern tradition. In striking contrast to the *Qimin yaoshu*, however, the landowners themselves farmed only a few acres and rented the rest out to tenants. The main criteria for selecting a suitable tenant were his skills and experience, and his assiduity at work; capital assets were not a consideration as they would have been for a contemporaneous English capitalist landowner. The main difference between landowner and tenant lay in the ownership of land; it did not extend to differences in the scale of the farm, or in the range and size of equipment (Bray 1986: 113–119). In this highly intensive and skilled farming system there were no economies of scale, and anyone who owned more than an acre of rice land would seek a tenant to farm the

Agriculture in China. Fig. 6 Spinning wheel for making cotton yarn. When Wang Zhen was writing in the early fourteenth century, cotton was just beginning to replace other vegetable fibers as the most common everyday cloth, and Wang provides copious documentation about the techniques and equipment involved. *Nongshu* 25/6b.

Agriculture in China. Fig. 7 Chain pump operated by two men. These light, portable pumps could be made quite easily by local carpenters and they would be moved from field to field as each needed irrigating or draining. Wang Zhen, *Nongshu* 19/7a–b.

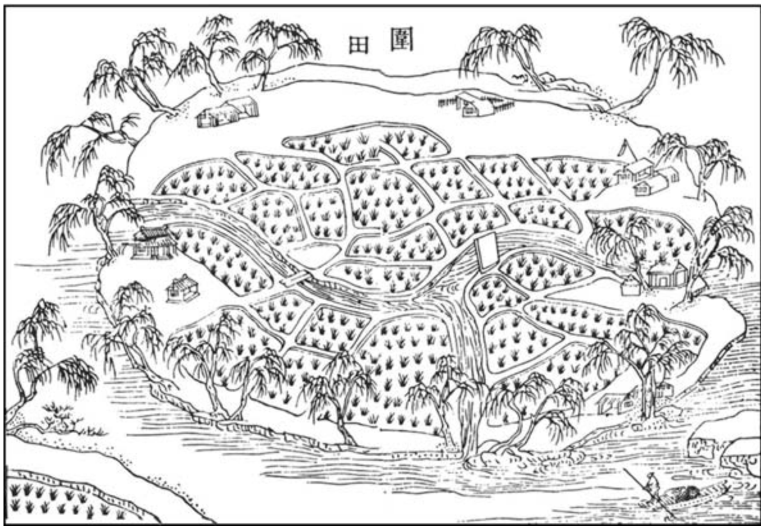


Agriculture in China. Fig. 8 Water-driven chain pump. Water mills were an essential element in medieval Chinese industry, as they were in Europe, and Wang Zhen also illustrates water mills of the kind used to power millstones, the bellows for metal foundries, and multiple trip hammers for fulling cloth or mixing clay for potteries. *Nongshu* 19/11a–b.



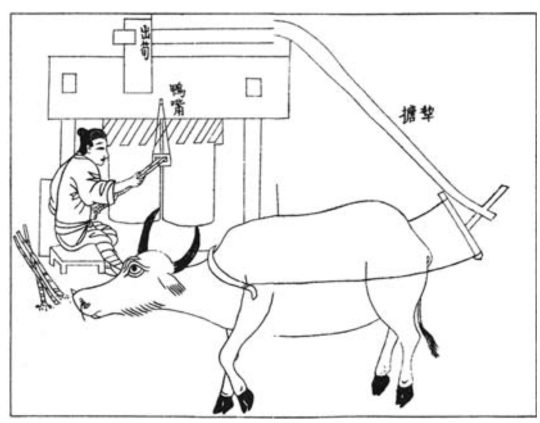
Agriculture in China. Fig. 9 A large sluice across a river, with irrigation channels leading off into padi fields. *Nongshu* 19/2a–b.

surplus. If levels of agricultural expertise were reckoned simply by the complexity of farm machinery or by levels of capital investment, then the farming methods of the eighteenth and nineteenth centuries might be reckoned a decline from those of 800 years earlier, for as average farm size diminished many peasants abandoned animal-drawn implements in favor of hand tools. However, if we look at the productivity of land, we see a different picture. Improvements in water control, in fertilizing (Fig. 11), in the spacing of plants and the breeding of varieties enabled China's peasant farmers to increase the total output of crops at a rate that kept up with population growth until about 1800 (Perkins 1969; Li 1998a, b). This intensive small-scale farming also supported a diversified rural economy of small industries and handicrafts that fed



Agriculture in China. Fig. 10 A polder (protective dyke) surrounding a block of rice fields reclaimed from swamp or the shallows of a river. Drainage channels run through the middle, and houses nestle among the willow trees planted along the high surrounding dykes. This illustration from 1742 is based on an original in Wang Zhen's *Nongshu*. *Shoushi tongkao*, 1742 edition, 14/5b.

Agriculture in China. Fig. 11 Fertilizing the rice seedlings in the nursery bed before transplanting. *Gengzhi tu*, Yongzheng imperial edition of 1742, 1/8b.



Agriculture in China. Fig. 12 Sugar mill with vertical rollers, depicted in Song Yingxing's technical treatise on crafts and industries *Tiangong kaiwu* of 1637. This type of mill had apparently come into use in the chief sugar-exporting regions of China, namely the Southeastern provinces of Fujian and Guangdong, shortly before Song wrote his book. Song describes a variety of sugars, some for internal trade and some for export to Europe. *Tiangong kaiwu*, 1637 edition, 6/2a–b.

into national and international trade networks (Rawski 1972; Gardella 1994; Daniels 1996; Marks 1998; Mazumdar 1998; Bray 2000; Pomeranz 2000) (Figs. 12 and 13).

Agriculture in China. Fig. 13 Picking cotton. A group of young women is hard at work, while a granny and a little boy, helpfully carrying a wicker basket round his neck, look on. This is from a short illustrated work written by the Provincial Governor of Zhili (the Beijing region) in order to encourage rural women to take up cotton production. Wood block print of 1808 based on the original painting of ca. 1765. *Shouyi guangxun*: 1/14b–15aBox.

The great inventions of Chinese agriculture are anonymous, the collective achievements of peasants recorded by servants of the state. Many important innovations occurred in the densely populated heartlands where pressure on land was most intense. There has been a tendency for Chinese historians past and present to assume that political and technical superiority went together, and that the Chinese taught civilization to the barbarians. However, several features crucial to Chinese high farming came not from the center but from the periphery. The technique of transplanting rice, fundamental for the development of intensive wet farming, was practiced by Thai-speaking populations in the Canton and Tonkin regions when they were conquered by China 2,000 years ago (Bray 1984: 279). Terraced fields probably spread northwards into China from Vietnam and Yunnan, reaching the Yangzi region by the fourteenth century (Bray 1984: 123–26). Tea was introduced from Tibet and Western Sichuan some time before the eighth century (Smith 1991). The techniques of cotton cultivation and processing were introduced to the Lower Yangzi from Hainan Island around the thirteenth century (Kuhn 1988).

Although there was no indigenous development of experimental agricultural science or engineering, Western agronomists found much to admire in traditional Chinese farming in the early twentieth century, particularly its careful husbandry and sustainability. Also traditional agronomic strengths such as crop breeding, have allied fruitfully with modern science. For example, Chinese geneticists used their vast range of local rice varieties to develop the first semi-dwarf high-yielding *indica* strains in the 1960s, several years before "miracle rices" were released by the International Rice Research Institute in the Philippines (Harlan 1980).

Extra: Chinese Agriculture and the "Great Debate"

Until recently comparative historians of economics or of science and technology tended to treat non-Western civilizations like China (or the Islamic world, or the Mayan empire) as *failed* or *blocked systems*. The most interesting question to ask about them was: Why did they fail to follow the European pattern of historical progress to industrialization, capitalism and modernity? Even Joseph Needham, who dramatically documented so many fundamental contributions of Chinese civilization to early science and technology, believed that China's creativity and ingenuity ground to a halt in about 1400. Needham was inclined to blame this on the mindset of the governing elite ("bureaucratic feudalism"). In 1973 Mark Elvin published a highly influential study in which he argued that the problem lay primarily with the technologies and organization of production, beginning with farming and the associated system of household manufactures. Unlike in early modern Europe, Chinese landlords and merchants saw no reason to invest in new technology in order to increase production or profits because smallholder farmers and household manufacturers, who were already highly productive, were always able to raise output a little more by increasing the family's inputs of labor. Elvin argued that by about 1400 or 1500 this system of small-scale commodity production had reached a point of technical stagnation and diminishing returns to labor, an "involutionary" system or "high-level equilibrium trap" that precluded indigenous transformation and encouraged overpopulation, impoverishment and the devastation of the environment. Only the forced confrontation with the modern Western powers in the nineteenth century offered China the opportunity to break out of this trap (Elvin 1973). In the mid-1980s Philip Huang began to elaborate on Elvin's analysis and on Chayanov's theories of peasant self-exploitation through the lens of farm management and market participation, to lay out a theory of late imperial China's "growth without development" (Huang 1985, 1990; see also Goldstone 1996).

Since the late 1990s a revisionist trend has come to prominence, stimulated by scholarship that has reconsidered the roots, nature and trajectories of the Industrial Revolution in the West. Jan de Vries' concept of "industrious revolution" suggests close parallels between early modern Europe, China and Japan. De Vries (1994) argues that between roughly 1550 and 1850 households in northwestern Europe steadily increased their working hours and allocated more of their labor to specialized production for the market. This was not "involution," however, for they freed time for this work by purchasing some goods that they had previously made for themselves. The profits they made by their sales allowed them to purchase more consumer goods. Though they sacrificed some leisure hours, this brought them higher living standards. Historians and social theorists including André Gunder Frank (1998), Bin Wong (1997, 2003) and Ken Pomeranz (2000, 2003) have argued that this was also true of much of China through the late imperial period.

A slightly different angle is taken by historians whose research suggests that sometimes increased farming output was achieved without additional labor. There were a range of improvements in farming technology that did not involve labor-saving machinery per se yet made it possible to raise farming output without increasing labor inputs (Bray 1986, Li 1998a, b, Shiba 1998). The steady expansion of inter-regional or international trading networks allowed growing numbers of rural households to specialize in commercial production while buying food and other necessities on the market (Gardella 1994, Daniels 1996, Mazumdar 1998, Marks 1998), and government policies for monitoring and regulating grain distribution and prices helped reduce the risks of such market dependence (Marks 1998, Wong 1997, Hamilton and Chang 2003). Local specialization was another factor that could raise output without necessarily leading to involution.

The revisionist historians stress that until at least 1800 China was the world's chief producer and exporter of manufactured goods. It was trading from a position of strength: from the sixteenth well into the eighteenth century, three quarters of all the silver produced in the world ended up in China (Atwell 1998, Brook 1998, Flynn et al. 1999). Not only was China a key actor in generating the economic configurations of world trade that catalyzed the rise of the modern West (Frank 1998, Arrighi et al. 2003), but life expectancy and living standards of rural households in around 1800 compared favorably with those in the most advanced regions of Western Europe at the time (Pomeranz 2003). Hamilton and Chang (2003) go so far as to claim that from as early as 1500 China should be thought of as a mass-consumption society. Moreover, many of the revisionist scholars argue, early modern China's political, social and economic institutions were not inherently incompatible with or antagonistic to industrial capitalism, nor even to today's global capitalism: the legacy of the late imperial era is clearly visible in China's national and international reflorescence today (Hamilton and Chang 2003; Arrighi et al. 2003).

The debate continues to rage, and given the patchy nature of the data both for Europe and for China it is likely to continue to seethe for some time. Often we find strong disagreements over the interpretation of the same data. In his magisterial new study of China's environmental history, for example, Elvin (2004) presents levels of deforestation in 1800 as proof that population growth and path-driven technologies had trapped China into a situation where it was probably more environmentally degraded than northwest Europe at the same time, while Pomeranz (2003) represents what he sees as roughly similar levels of deforestation in France and China around 1800 as a triumph of the Chinese political economy and its sustainable resource use.

The critical rethinking of the long-term logics of economic and technological development which we see in the revisionist scholars' work clearly owes much to the questioning of "master narratives" in postcolonial theory and critical studies of science and technology. Social and environmental critiques of productivism, together with new models of productive efficiency that emphasize decentralization, smaller scale and flexibility, provide a broader intellectual context for these new perspectives on the achievements or shortcomings of the imperial Chinese agrarian economy, as does China's meteoric rise as an economic and industrial powerhouse since the economic reforms of 1979.

See also: ►Food Technology in China

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Some Online Resources

►http://depts.washington.edu/chinaciv/ is the Web site of the *Visual Sourcebook of Chinese Civilization*, prepared by the social historian of China Patricia Buckley Ebrey, with the assistance of Joyce Chow, Lenore Hietkamp, Kevin Jensen, Robert Lin, Helen Schneider, Cyndie-Lee Wang, Kim Wishart, Cong Zhang and Lan Zhang. The project was funded by the National Endowment for the Humanities, the Freeman Foundation and the Chiang Ching-Kuo Foundation. The Web site provides useful historical timelines and geographical background, and it presents the main periods of Chinese history from the Neolithic up to the present by selecting two key themes (such as tombs, or calligraphy, or weapons) for each period. The illustrations (maps, photographs and art works) are excellent. As good background for the history of agriculture in China, under "Geography," "Land" (►http://depts.washington.edu/chinaciv/geo/land.htm) you will find a series of maps showing topography, climate, etc. If you follow through to "China proper" and then to "Outer China," among the photographs you will see images of the farming landscapes typical of China's regions, and of typical crop plants and farming techniques (plowing, transplanting rice with a machine, picking tea, herding).

Another useful online source for maps of China and its contemporary provinces, with good information about regional history, contemporary economics, climate, agriculture, cuisine, etc., is the Web site of the *South China Morning Post*, the Hong Kong English-language newspaper: ►http://china.scmp.com/map/

For brief accounts of Chinese history from its origins up to 1988, try ►http://www-chaos.umd.edu/history/toc.html

On contemporary economic issues concerning Chinese agriculture, see the UC Davis site ►http://aic.ucdavis.edu/research1/chinaeconomics.html

China Facts and Figures provides useful statistics on contemporary agriculture in its section on "Economy"; the English-language Web site for 2003 is ►http://www.china.org.cn/english/eng-shuzi2003/

The Food and Agriculture Organization (FAO) webpage on China ►http://www.fao.org/countryprofiles/index.asp?lang = en&ISO3 = CHN is an excellent source for a wide range of studies and statistics on contemporary agricultural issues in the People's Republic of China, including themes like sustainable development. It also offers a useful set of interactive maps which include maps showing elevation, slope, precipitation, length of growing period and major environmental constraints as well as more conventional maps of political boundaries, population, communications, etc.

Agriculture in India

R. K. Arora

The Harappan culture related to the earliest agricultural settlements in the Indian subcontinent is dated between 2300 and 1700 BCE. The crops of the Harappan period were chiefly of West Asian origin. They included wheat, barley, and peas. Of indigenous Indian origin were rice, tree cotton, and probably sesame. Rice first appeared in Gujarat and Bihar, not in the center of the Harappan culture in the Indus Valley. There is some rather doubtful evidence that African crops were also grown by the Harappans. There is a record of sorghum (*jowar*) from Sind and *Pennisetum* (*bajra*) from Gujarat. The earliest record of the African cereal, *Eleusine coracana* (*ragi*) is from Mysore, about 1899 BCE. The Southeast Asian crops of importance to India are sugar-cane and banana, and they both appear in the early literary record. Crops of American origin include maize, grain amaranths, and potato. The dating of the introduction of maize is uncertain, the characteristics and distribution of some forms being such as to lend support to the view that they reached India in pre-Columbian times. Crops of the Indian subcontinent have influenced the agricultural development of ancient Egyptian, Assyrian, Sumerian, and Hittite civilizations through their early spread to these regions of the Old World. The Buddhists took several Indian crops and plants to Southeast Asian countries, and there was much early exchange of plant material with Africa. The Arabs distributed crops such as cotton, jute, and rice to the Mediterranean region in the eighth to tenth centuries AD. There was also a reciprocal exchange of several New World domesticates.

Agriculture Today

India is characterized by a wide variety of climates, soils, and topographies. It is rich in biodiversity and a seat of origin and diversification for several crop plants such as rice, millets, pigeon pea, okra, eggplant, loofah, gourds, pumpkin, ginger, turmeric, citrus, banana, tamarind, coconut, and black pepper. Because India is ethnically diverse, traditional agriculture is still practiced in many places. There are about 100 million operational holdings, and the country has over 20% of the world's farming population.

India has different ecosystems such as irrigated, rain fed, lowland, upland, semideep/deep water, and wasteland. Agriculture is primarily rain fed (rain dependent); it supports 40% of the human population, 60% of cattle, and contributes 44% to the total food production. Owing to differences in latitude, altitude, variation in rainfall, temperature and edaphic diversity, great variety exists in crops and cropping patterns.

There are two important growing seasons in India: the *Kharif* or the summer season, especially important for rice; and the *Rabi* or the winter season in which major crop grown is wheat. The *Kharif* crop is primarily rain dependent, and the *Rabi* is relatively more reliant on irrigation. The *Kharif*/rainy season cropping patterns include major crops such as rice, sorghum, pearl millet, maize, groundnut, and cotton. The *Rabi*/winter season cropping patterns include important crops like wheat, barley and to some extent oats, sorghum, and gram/chickpea. Mixed cropping is also practiced, especially during the kharif season. Pulses, grain legumes, and oilseeds are grown with maize, sorghum, and pearl millet. Brassica and safflower are grown mixed with gram or even with wheat. Under subsistence farming, on small holdings, mixed cropping provides food security and is consumption oriented.

India is the major producer of a number of agricultural commodities including rice, groundnut, sugar-cane, and tea. Food grains constitute roughly two-thirds of the total agricultural output. These consist of cereals, principally rice, wheat, maize, sorghum, and minor millets. India is the second largest producer of vegetables next to China. Mango accounts for almost half of the area and over a third of production; banana is the second largest and is followed by citrus, apple, guava, pineapple, grape, and papaya. Of nonfood cash crops, the most important are oilseeds especially groundnut, short staple cotton, jute, sugar-cane, and tea.

Owing to improvements in recent years there has been widening of inter-regional disparities in agricultural production and productivity. Regions such as the north and north-west and the delta regions of peninsular India have prospered under assured irrigation, but dryland and semiarid regions have not done so well.

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Agriculture in the Islamic World

LUCIE BOLENS

The success of classical Islamic agriculture is due to the adaptation of agrarian techniques to local needs, and this adaptation itself is due to a spectacular cultural union of scientific knowledge from the past and the present, from the Near East, the Maghreb and Andalusia. A culmination more subtle than a simple accumulation of techniques, it has been an enduring ecological success, proven by the course of human history.

In the definitions which open the *Kitāb al-filāḥah* (Book of Agriculture), this function is said to be blessed by God because it has as its end the production of the sustenance of life. Agriculture consists of restoring to the earth what has been furnished by harvesting from it, by fertilizing, watering and making efforts to avoid the problems caused by excessive heat. This restoration to the soil implies a knowledge of the whole – the soils, the plants, the most suitable tools. Balance (*mizān*) is the aim, or reciprocity between what is taken from the earth and what must be given back in order to make this vital alliance with Nature endure.

The complex union of facts with the general conjunction of the Mediterranean world between the eleventh and the fifteenth centuries means that a de-positioning of history is indispensable for understanding a crisis as well as a success. No progress is linear, and it is always useful to draw inspiration from the aleatory nature of history, in order that this discipline, fundamentally cultural, may also have a practical impact.

The successional right of the four Islamic judicial schools permits "holdings" according to a customary right which is similar to the right to private property of the Romans. Royal power encouraged territorial expansion among the princes of the blood and high officials of the state.

From a historical point of view, the important thing is the fact of reciprocal information throughout the *Dār al-Islām* (the Islamic world). There emerges the impression of a coherent school and a general movement – of people, goods and ideas – from the East to the Islamic West.

The ancient tradition, prolonged and recovered from the ancients (*al-Alwālī*), integrated the ideas of fourth century scholars like Aristotle, Dioscorides, Galen and Anatolius Democritus with those of the botanists of the ninth century and contemporary scholars of geoponics, the art and science of cultivating the earth. If the mysterious *Filāḥat al-Nabaṭiyyah* (Nabataean Agriculture, by Ibn Wahshiyyah, ca. 1000) traces the origins of agriculture back to Adam, those who lived in the classical age were equally inspired by knowledge obtained from anonymous farmers who retained the memory of ancient ways. Tradition and scientific curiosity have not always been at odds with each other.

On a religious level, the earth and water, as in the Hebraic tradition, belong to no one person; they belong to God. Historical accounts of Islamic expansion distinguish between Arab lands and lands situated in the conquered countries. Under the early caliphs, Arab lands were surveyed and registered. A basic tax was established, ten *dirhams* for a *jerib* of grapes, eight *dirhams* for a *jerib* of palm trees, six on a *jerib* of sugar cane, two on barley. The *jerib*, a unit of measure, equaled 360 cubits, according to al-Mawardī. The lands of people who freely converted to Islam were subject to a deduction of a tenth, *dīme*, varying according to province and century from the eighth to the twentieth centuries. In Andalusia, the tax was one-fifth. After the Reconquista, the farmers there continued to be called *quinteros.*

Lands which were forcibly conquered were redistributed. Al-Wanshārisī, a fifteenth century Maghreb legal expert, notes numerous examples for studying classical Islamic agriculture in Andalusia and the Maghreb.

Collective lands, *jema'a*, existed in certain parts of *Dār al-Islām*, used for the movement of flocks of large and small grazing stock. Cultivated land was also divided up legally and parceled out.

"Tributary" lands were conquered lands lying outside Arabia, beginning with Syria (Sham). They were considered lands not belonging to anyone, the property of the state or the caliph. By contrast, they were left to their former owners, according to a right of use. A land tax called *kharaj* was paid to the Treasury (*bayt al-māl*) and the amount of tax was set according to the quality of the soil. From the 700s, the principle was applied in the form of a supplemental tax to Jews, Christians and Sabeans, being the *Ahl al-kitāb* (People of the Book), or *dhimmis.*

Individual land holdings were called *iqtā;* they were lands grafted to a private individual according to clauses which were more or less restrictive depending on rents. All lands which the caliph gave to his subjects so that they might transform and cultivate them were so designated. *Waqf* lands were lands granted by private individuals to mosques, hospitals, schools and other charitable institutions. They are often translated as charitable properties. They were not subject to land speculation.

All these lands, except for the *waqf* properties, could be the object of commercial transaction – sale, rent, or purchase – which had nothing to do with feudal land statutes. In the twelfth century, the Sevillian Ibn Abdūn, in his *Treaty of Ḥisbās*, encouraged personal appropriation of land as a means of stimulating economic growth.

The information which appears in the documentation needs examining. It is based on experimentation which resulted in the shattering of prior philosophical premises. Empiricism appeared to be the condition of renewing knowledge and techniques. Ibn al-ʿAwwām writes: "I affirm nothing which seems right to me without having proven it in numerous experiments". In agriculture, the results refer to the practical successes of sheaves of grain, fruits, or taxes.

The theory of climates, *al-iklim*, compares Andalusia with Iraq and makes pertinent constant reference to Nabatean agriculture.

"Indeed", writes Ibn al-ʿAwwām, "what suits our country is the result of what comes from the concordance of tradition with experimental results". The respect for ecological balance – *mizān* – between the soil, the micro-climate, and various cultivated plants guarantees the success of the harvest. The "weather" governs the results, and the seasons are stated in the "Calendar of Seville" according to their names in Syrian, Persian, Hebrew and in indigenous romance languages. More subtle than a syncretism, it was a question of a whole society.

Islamic agriculture had, at first, been Arab agriculture, since Islam first appeared in the Arabian peninsula, among the Bedouins and camel drivers. Around the big cities, agriculture was the agriculture of the oasis, a natural miracle brought about by the presence of water in a desert of sand and stones. The history of agriculture in Islamic countries, established over a long duration as Fernand Braudel has described, is made up of a fundamental unity. The first great geo-climatic regions were sub-arid dominants around the Mediterranean basin. The Ummayyad empire, then the Abbasid empire, finally integrated the sub-tropical regions with temperate ones. However, the essential originality of Islamic agriculture is still linked to the Mediterranean regions and to the fluvial valleys. The first Islamic empires and the caliphate of Andalusia owed their agriculture to the great rivers carrying water and fertilizing silt (alluvium); the Tigris, Euphrates, Nile, Guadalquivir and the Guadiana all gave both soil and waterless, sun baked lands.

Between the seventh and the thirteenth centuries, the displacement of peoples and technical skills gave rise to a migration of cultivated plants, from the East towards the West, from subtropical zones towards the Mediterranean basin, from the monsoon regions to semi-arid lands; from China towards Persia, passing through India; and from Afghanistan towards the Fertile Crescent and the Maghreb, creating in its passing the gardens of Sicily and of Andalusia. Just as the ancient Romans constructed aqueducts and waterworks to provide food on a scale for the cities and municipalities which were their centres of power, so the Islamic empire, founded on caravan cities, also wove a net across the countryside of hydraulic equipment for agricultural adaptation, for example *acequias* [an earthern channel that conveys water], *qanats* [a water management system] and *norias* [a stone grinding wheel]. In spite of the progressive climatic diversification which occurred as the area ruled by Islamic law increased, from the Sudan to the Caspian seaports, from the Straits of Gibraltar to the boundaries of the Ottoman Empire and to India, the determining character of their agricultural system remained the adaptation of irrigation to local and regional needs and the spread of plant species away from their original ecosystems.

The spread of agricultural land and the intensification of irrigation in sub-Iberian regions which tended to be hot and very humid sub-arid areas were spectacular. Legal aspects of land holding were closer to those of Rome and Byzantium than the medieval West. Individual property ownership was actively encouraged.

Technological and cultural methodologies were informed by the need for renovation while remaining empirical. Among the agrarian jobs, that of the autumn harvest is characteristic in that the human job prevails over the financial investment. The swing plough was preferred over the heavy Brabout plough of the French colonist; not exposing the deep beds of cultivated land to erosion and intense heat was the golden rule of ecology in Andalusia. In the golden Andalusian age, this protection of the Mediterranean soils was subject to laws of a scrupulously careful ecology. The *mishā*, a heavy, hand-held spade was the tool for restoring the soil. The object of such agriculture was closing the soil, not opening it.

Among agricultural systems, the biennial rotation of crops is essential for maintaining fallow fields. Biennially or by a more complex number of years, but always by an even number, the rotation of crops shows a deep understanding of the plant world. The refertilization of soil, the base of all agriculture, comes about through the joint knowledge of plants and soils, the mastery of botanical and edaphic science. In Andalusia, well before the era of the English physiocrats of the 1800s, this agriculture revolution was closely based on high level of knowledge of the life sciences and on a love of nature which was the common gift of both the Islamic and the Hebraic tradition.

Certain plants modified dietary habits, for example sorghum, a common basis of diet in Asia and Africa; rice in flooded areas; sugar cane which is used for preserving and for therapeutics; the eggplant transported by the Jews in the second diaspora; citrus fruits from China; durum wheat from Africa, a nutritional mainstay in the form of bulgur and couscous; watermelons; and banana trees, acclimated in Egypt before arriving in the Maghreb and Andalusia.

The cultivation of other plants influenced styles and types of clothing throughout the Islamic regions. There was cotton, introduced to Andalusia after the arrival of the Kurd Ziriyab in the 900s, dye plants which brought a passion for Persian and Indian colours to the puritanical Berbers, and perfume which supplied the base of a whole range of products, such as lotions, salves, and soaps, and which was manufactured from the almost limitless supplies of fragrant flowers from Turkey and Morocco.

With a deep love of nature and a relaxed way of life, classical Islamic society achieved ecological balance, a successful average economy of operation, based not on theory but on the acquired knowledge of many civilized traditions, a society which wanted to live without the spectre of famine and hunger.

Colonialism seriously upset the traditional agricultural balance in order to increase profitability for the colonizers. This has been widely written about and is proven today by global economic realities. In the 1900s, colonial settlers and city authorities (wrongly) interpreted the indigenous practice of transhumance (moving flocks of animals from one area to another) as non-ownership of land. This distortion of a multisecular custom of complement between plant and animal husbandry (for example, in the Maghreb) caused grave damage to the native economy. Colonial agriculture thus found pseudo-legal advantages in a vast redistribution of land, which brought great economic benefit to the colonial settlers who had come out from the cities and towns.

We are witness today to the slow recovery of agrarian balance in former colonies like Algeria.

See also: ►Technology in the Islamic World, ►Irrigation in the Islamic World, ►*Qanat*

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Agriculture in Japan

Mutsuyasu Ito, Kouichi Hiraizumi

Land in Japan has distinctive characteristics which make it suitable for organic produce. Because of this, agriculture has been the basis of most economic activity over the last 2,000 years. Historically, Japan was predominantly agricultural, but with the remarkably rapid growth of its economy after the Second World War, the country has been transformed into a heavily industrialized society. The Japanese have been abandoning their traditional food culture, which depends on rice plus other supplemental foods such as miscellaneous grains, vegetables, mountain plants, fish, and other sea products. They have instead been paying enormous sums of money to incorporate Western protein-rich foods from all over the world into their cuisine. In the meantime, rice consumption has decreased dramatically in the last 40 years, and the daily intake of nutritious foods such as meat, milk, and other dairy products, has increased remarkably, leading to a high demand for luxury foods. Within the Japanese agricultural sector, only rice is produced to the level of national self-sufficiency, while only 50% of the products derived from animals – themselves raised by feed concentrates which are nearly 100% imported – is supplied domestically (Table 1).

The early postwar effort to increase the production of food to meet human requirements actually led to a serious problem from around 1960, when the economy as a whole began to boom and agriculture began to decline. One of the present concerns connected with Japanese agriculture is the degradation of the rich, green nature of the country that the people had long admired as "the land of vigorous rice plants" (*Mizuho no Kuni*). At present, rice cultivation narrowly survives with the increased abandonment of agricultural fields and the deterioration of environments which the Japanese people had created over the past 2,000 years.

Geography, Climate and Resource Potential

The Japanese archipelago covers a rather wide area of sea. It includes 6,854 islands that extend from subtropical Ishigaki (24°N, 123°E) to the northernmost point of Hokkaidō at Wakkanai (46°N, 142°E). In this broad area are diverse landscapes and meteorological conditions, but most of the area has a temperate, monsoonal climate. The total land area is less than 400,000 km^2 (one-thirtieth of the territory of China),

Agriculture in Japan. Table 1 Domestic supply, importation, and domestic demand of various foodstuffs in Japan[a]

Products	(A) 2003[a]			(B) 1965			Increase of demand in 1965–2003 (A/B, %)
	Domestic production (in ton)	Imported (in ton)	Self sufficiency (%)	Domestic production (in ton)	Imported (in ton)	Self sufficiency (%)	
Rice	8,889,000	882,000	91.0	12,409,000	1,052,000	92.1	72.6
Wheat	829,000	4,973,000	14.3	1,287,000	3,468,000	27.1	122.6
Barley	197,000	2,142,000	8.4	1,233,000	470,000	72.4	137.3
Soybean	232,200	5,172,520	4.3	229,700	1,847.500	11.1	260.2
Milk	8,292,000	3,783,000	68.7	322,050	3,220,500	9.1	340.9
Beef[b]	520,000	763,000	40.5	207,774	10,813	95.1	587.0
Pork[b]	1,245,000	1,101,000	52.9	363,513	70	100.0	552.3
Broiler[c]	1,229,000	662,000	65.0	–[d]	–[d]		–[d]
Hen's egg	2,452,543	–[d]	96.0	1,423,000	–[d]		–[d]

[a]Demand and Supply Table of Agricultural Products; Ministry of Agriculture, Forestry and Fishery, Japan.

[b]In carcass weight.

[c]In fresh body weight. Hen's eggs; sold amount.

[d]No comparable data available.

and the four main islands of Hokkaidō, Honshū, Shikoku, and Kyūshū are dominated by steep mountains that reach to around 1,000 m or even more above sea level. Because of the mountainous nature of the islands, the amount of flat land suitable for cultivating crops is less than 15% of the total area of land (Table 2).

In spite of its more or less cold winter, Japan benefits from a longer warm season and yearlong, ample rainfall, both of which are indeed useful for high-yielding crop cultivation. However the condition also accelerates harmful weed generation that disturbs pure stand formation of cultivated crops. The generally warm, moist climate, which provides high organic produce – almost equivalent to that of tropical rainy forest areas – has led to forests being the dominant vegetation throughout the archipelago. The geographical features present Japanese farmers with a difficulty in scale development of their farming, forcing them to make continual attempts to improve yield potential per unit area.

Origins of Japanese Farming Based on Paddy Rice

Despite the rich potential for organic produce, the actual start of paddy rice cultivation did not occur until several thousand years after its origin in the Yangtze River basin in the nearby Asian continent. Around 2,400 years ago, when the *Jōmon* Period (ca. 10,000 BCE–ca. 400 BCE; this period was dominated by hunting and gathering with straw-rope patterned [=*Jōmon*] pottery culture) ended, the arrival of the new immigrants from the continental mainland brought techniques for cultivating rice in paddies. As the *Yayoi* Period (ca. 300 BCE–ca. 300 AD, so-called from the place in Tokyo where the new type potteries were first unearthed) started, it replaced the lifestyle based on hunting, fishing, and gathering with one based on the cultivation of rice. Because irrigation techniques had been rather primitive when rice culture was introduced, swampy areas of mountain streams and basins, where water stagnated, were primarily used for cultivating rice. However, wooden farm implements such as hoes and spades were already very popular for working with improved *japonica* rice varieties, and even some ironware was used.

Soon after the introduction of paddy rice in northern Kyūshū in the fourth or fifth century BCE, paddy rice production and its associated technology are known to have moved eastward into the Kinki district where the Yamato Court later gained supremacy over all of Japan. At least 2,000 years ago, they had arrived in the Kanto district (around modern-day Tōkyō) and subsequently moved into Tōhoku (northern Honshū). The large *Yayoi* remains of paddy fields discovered at Taruyanagi in Aomori prefecture, at the northernmost end of Honshū (42°N), demonstrate that the diffusion of rice cultivation was very rapid and took only several hundred years at most, despite the large distance and different climates between northern Kyūshū and northernmost Honshū. Through experiments, Sato (1992) has endeavored to show that domestically improved thermo-sensitive varieties, which ripened early, were probably responsible for this rapid progress of rice cultivation in cooler areas.

Agriculture in Japan. Table 2 An abstract of land size, vegetations and agricultural land use in Japan

Item	Area (km^2)	Ratio (%)
(A) Total land size of Japan	377,887	–
Hokkaidō	83,407	22.1
Honshū	231,097	61.1
Shikoku	18,795	5.0
Kyūshū	42,144	11.2
Okinawa (Ryūkyū Islands)	2,264	0.6
(B) Forests[a]	249,180	65.9
(C) Natural grasslands[b]	4,158	1.1
(D) Secondary grasslands[b]	12,852	3.4
(E) Managed grasslands[b]	5,327	1.4
(F) Arable lands[a]	47,360	12.6
Those used for paddy rice	25,920	6.9

[a]Agricultural Statistics (2003).
[b]Green Census, Japan (1983).

Agricultural Development in Ancient and Medieval Japan

The beginning of the *Yayoi* Period could be thought of as the dawn of agriculture in Japan, albeit with low productivity in poorly drained, wet rice fields. The remains of the Yoshinogari archeological site in northern Kyūshū demonstrate that the agrarian society of that time had a state-like political structure in which social stratification and classes resulted from individuals' riches or poverty. Agriculture is thought to have brought about these social arrangements.

After that, much higher technology for agriculture developed in the subsequent Kofun Period (ca. 300–700 AD; *Kofun* refers to tomb mounds prepared for rulers). The social and technological progress came with the introduction of advanced iron implements (hoes, plows, and spades led to deeper soil tillage), maintained waterways, and the orderly planting of rice, all of which resulted in higher yields and the further expansion of arable land. These developments were probably accompanied by a change from using stone knives to clip off the developed heads of genetically diverse rice population to using sickles to harvest the above-ground shoots of genetically identical crops with their heads attached.

Because of these developments, the Yamato Court was able to carry out social, economic and political reforms known as the Taika Reform of 645 AD (*Taika* is the name of the era between 645 and 650, which was first recorded in Japan) that promoted a centralized state similar to that in China at the time. In 701, the legal system, known as *Ritsuryō* (Criminal and Civil Laws) was established to govern the whole country, except for Hokkaidō (which was not yet Japanese territory). Under the *Ritsuryō* system, canal improvements, reclamation of new paddy fields, and rezoning of regular-size fields were all planned by the central government in an effort to significantly increase agricultural production. Since then, Japanese people depended greatly on rice as their main food and supplemented it with various other grains and plants. They did not raise livestock for consumption because Buddhism became the official religion in the eighth century. These characteristics of farming and cuisine that date to the period of consolidating central power in the archipelago continued over the centuries until very recently.

Although the best yields of rice in the Nara Period (710–794) were supposed to be less than 1,000 kg per hectare (one-sixth of the present yield in Japan), that figure is surprisingly high when compared to yields of wheat in England during the same period (Evans 1975). The introduction of rice was also advantageous for efficient food supply at the time because it required basically no fallowing of fields if they were regularly fertilized.

Governmental power under the Ritsuryō system, however, began to collapse in the middle of the Heian Period (794–1192) as private territories of powerful aristocrats, temples, shrines, and clans emerged as *shōen* (manors). The formation of *shōen* inspired owners to reclaim further arable land, especially from swampy areas. The farmers gradually supplied their own iron tools, which had previously been monopolized by the rulers. More precise management of water for the paddies came into existence, and agriculture appears to have become much more intense in all the rural areas. Attempts at double-cropping in paddy fields were undertaken in some areas to supplement yields in lean years. As central rule became weaker and weaker because of the social changes in the late Heian Period, officials in district branches, and the wealthy farmers, began to arm themselves, and their influential leaders formed bands of warriors known as *samurai*.

After a long struggle between samurai bands in various areas, the remaining two most powerful bands – the Genji and the Heishi – fought for national supremacy in the twelfth century. The war finished with the Genji in power and the beginning of the Kamakura Period (1192–1333) in which Japan was ruled by a samurai government. In this feudal period, a relationship developed between lords and vassals from the samurai class, in which the latter usually engaged in agriculture and managed the farmland as well as providing military service during wartime.

The establishment of manors and the intensification of agriculture in each locality resulted in a further rise of agricultural output that led to a second boom in land reclamation for paddies, and surplus agricultural products were gradually commercialized to create markets in various regions. The increasing economic strength of the lower classes, however, weakened the central power of the samurai government and drew Japan into a period of civil wars in the latter part of the Muromachi Period (the reign of second shogunate Muromachi, 1336–1573).

Unique Development of Japanese Farming During the Edo Period

Feudal lords in various regions began fighting each other in an era that has come to be known as the Sengoku Period (1467–1573; *Sengoku* refers to warring states). During this time, improving agricultural production and expanding arable land were the greatest concerns of the feudal lords (*Sengoku Daimyō*; *daimyō* originally meant “great paddy-field-owners”) because of the possibility of imminent warfare. They took control of paddy fields in their territories, even in hilly diluvial areas, by using the construction skills they had earned through their preparation for civil war. After taking over the entire country, Hideyoshi Toyotomi implemented a cadastral survey *(Kenchi)* known as *Taikō-Kenchi* (Hideyoshi was known by the title of *Taikō*) from 1582 to 1598. The survey involved measuring fields, ranking their productivity to estimate a tax base, and registering their landowners. It established the *kokudaka* (productivity, *koku* being a unit of measurement for rice) system in which the arable lands were legally graded in terms of average productivity. This brought an end to the system of direct rule by the feudal lords and determined land tenureship for small farmers.

Ieyasu Tokugawa defeated the Toyotomi family in the Battle of Sekigahara (1600) and completed the process of unifying Japan after the civil wars by establishing a new shogunate. Under the Tokugawa family, Japan in the Edo Period (1600–1867) flourished in seclusion from other countries, and each of the surviving *sengoku daimyō* was regulated by a *shōgun* (military general). Because the *daimyō* could no longer acquire more territory because of the strict Tokugawa regulations, the only way that they could expand their power was to reclaim land or to improve their fields to get better yields. This led to improved irrigation systems within the big river basins and diluvial tablelands that could not previously be well controlled, and also to improved technology for crop cultivation.

Despite the overall developments in agriculture, however, the farmers who got their own lands through *Taiko kenchi* were not allowed to move or even to choose another livelihood under the rigid feudal system. Furthermore, most of their harvested rice was collected by the *daimyō* as a tax, which left the farmers with relatively little rice and therefore, a spartan existence. The tax was usually paid in kind by harvested rice at the rate of 30% at the beginning of the period, and later it went much higher. "Don't let the farmers survive well but don't kill them either," is thought to be the principle of Tokugawa's governing policy throughout the Edo period. Under such a severe regime, and because of it, many farmers made remarkable improvements in technology for raising field crops other than rice, especially for those which were cultivated upland. The use of human manure as a fertilizer was a profound development at this time, as were the thorough use of resources and technological improvements in recycling that are informative even for today's societies.

During the Edo Period, many books called *nōsho* (writings on agriculture) were written, and some of them were even published in xylography and distributed widely. Publications to describe agricultural technology and various local varieties contributed to further technological improvements and an examination of traditional varieties. In a sense, an original agricultural science, rooted in the traditional culture of Japan, came into existence, and the most notable work in the first half of the Edo Period was the *Nōgyō Zensho* (Complete Writings on Agriculture, 1696) by the lordless samurai Yasusada Miyazaki (1623–1697) in northern Kyūshū. This was a practical textbook that was based on Miyazaki's comprehensive knowledge acquired over years, while the basic style of the book followed the famous Chinese *Nóngzhèng Quánshū* (Complete Book on the Administration of Farming, 1639) which was written by Xú Guāngqǐ late in the Ming Dynasty. Miyazaki had long regretted that the life of farmers required hard labor and low incomes because of their paucity of knowledge about the principles of agriculture, so he published information about the available scientific principles and technology that was easily put to use anywhere in the country. His book greatly influenced agriculture throughout the Edo Period, and it was reprinted repeatedly over 150 years, almost until the end of the Edo Period.

The Tokugawa shogunate built many roads which originated in Edo (present-day Tōkyō) or Ōsaka in the seventeenth century. Various sea routes for shipping were also established, so an integrated system of transportation throughout all of Japan was progressively built. Because the *daimyō* wanted to sell their rice to merchants and encouraged the cultivation of other cash crops to be marketed, transportation became very important, especially between regions. Nagatsune Ōkura (1768–1860?), one of the most famous scholars of agriculture late in the Edo Period, wrote many volumes on agriculture and particularly wrote textbooks about cash crops. He also prepared manuals on agricultural equipment, and wrote about plant protection. The books he wrote were useful, as agricultural production techniques were then thriving. The application of these techniques resulted in the prosperous cultivation of rapeseed, cotton, and other industrial crops in the Kinki district and the rise of the processing industry near Ōsaka that increased the amount of merchandise available for distribution.

Despite the remarkable growth in productivity, farming throughout the Edo Period still depended on human power. Although plowing with draft animals was practiced to some degree in and around the Kinki district, it did not spread throughout the country, partly because the traditional long-soled plows were less efficient than hoes for deep tillage in paddies to get higher yield with a higher level of fertilizer use. Hence, labor-intensive cultivation continued to dominate and relied on specialized hoes and spades. In his *nōsho* (An Investigation of Usefulness of Various Agricultural Tools), Nagatsune Ōkura precisely illustrated a diverse range of hoes modified for various purposes or soil conditions.

Another example of prosperous development of farming was found in sericulture, the process of raising silkworms and producing silk yarn from their cocoons, in the late Edo Period. Instances include thermal management of silkworm development and crossbreeding of various productive strains. These later contributed to the further development of sericulture and silk spinning industries in the following Meiji Period.

Modernization in Agriculture After the Collapse of the Tokugawa Shogunate

In the second half of the nineteenth century, under the pressure of Western powers, Japan opened itself to international relations. The Tokugawa regime lost its ability to govern effectively, and the feudal system finally came to an end in 1868. The new government under the restored emperor began to modernize Japan along contemporary Western lines. As Japan had no particular source of revenue except for agriculture at that time, and since 80% of the population belonged to the agrarian class, the collection of land taxes was of great concern to the new government. Introducing Western agricultural technology (*Taisei nógaku*) was therefore an urgent project for the government, which wanted to increase the wealth and military strength of the country in order to catch up with the European powers and the United States in a short amount of time.

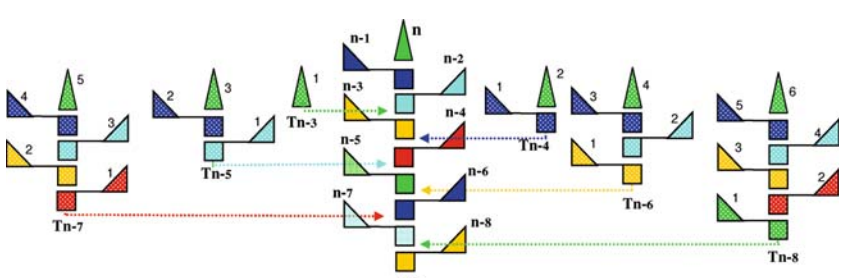
However, the Westernization of Japanese agriculture at the very outset was not as successful as it was with industrialization. British scientists who specialized in agriculture, and who were among the first foreign experts to be invited into the country, did not do well at solving problems facing Japanese agriculture. They simply tried to bring their own style of agriculture without any modification and did not consider the different state of affairs that existed between Japan and their homelands. However, a few European scientists used a different approach to developing Japanese agriculture by evaluating traditional technology and knowledge. For instance, excellent researchers such as Max Fesca from Germany made a huge effort at scientifically analyzing traditional Japanese techniques of cultivation, applying Western technology to suit the needs of Japanese agriculture and developing new technology for practical cultivation. So-called *rōnō* (*rōnō* refers to farmers with outstanding farming knowledge), who had fully mastered the knowledge and skills of traditional agriculture, also played an active part in the modernization of traditional agricultural technology and its extension throughout the country in the late nineteenth century.

In the early twentieth century, Japan had nearly completed establishing a public system of education and scientific research based on Western models. As centralized power became stronger through and after the First World War, research at institutes and universities contributed to the remarkable increase in agricultural production from 1920 to 1940. Studies on the genome of wheat strains by Hitoshi Kihara, the autumn deterioration of paddy soils by Matsusaburō Shioiri, and the selection of the famous Nōrin No. 10 wheat variety (*Nōrin* is the abbreviation for the Ministry of Agriculture and Forestry) by Gonjirō Inatsuka, were all world-renown accomplishments prior to the Second World War.

Through repeated crossing with various native varieties from Mexico, the Nōrin No. 10 later obtained high yielding dwarf varieties, which increased wheat production in developing countries dramatically through the "Green Revolution". Also pursued was the concept of "synchronism in tillering and tiller development in rice, wheat, and barley crops" established by Tsukuda Katayama, which led to precise technology for monitoring the growth and improving the yield of grain crops (Fig. 1). In Western countries, "phyllochron" (leaf appearance interval) studies have been initiated in the last 30 years to take precise control of the growth of improved wheat and other crops. In fact, Katayama and his students had completed the principle of phyllochronic development of grain crops more than 50 years ago; the original studies, written mostly in Japanese, were hardly read by Western researchers. The abovementioned scientific achievements principally contributed to much higher productivity, which had remained unchanged in traditional, labor-intensive agriculture in Japan.

The Dramatic Transformation After the Second World War

Warfare throughout the 1930s to 1945 in the Far East came to an end with the unconditional surrender of the Japanese Empire. This defeat gave the Japanese people an opportunity to replace an autocratic system with a representative democracy akin to those in Western Europe. A thorough land reform was undertaken under the auspices of the occupying powers, mainly the United States, and among its achievements were the abolition of the parasitic landlordism (*jinushisei*) and



Agriculture in Japan. Fig. 1 A schematic illustration of Katayama's Concept on tillering regularity in rice, wheat and barley plants – the synchronism in tillering and tiller development. Mother shoot (MS), which forms her leaves in constant interval in any order, generally bears her daughter tillers regularly in parallel with successive leaf formation of MS, so that the new tiller appearance at the age of "*n*"th leaf emergence of MS usually becomes apparent at the leaf axil of *n*–3 and the tiller develops further with homologous leaf formation, resulting in successive increase in leaf number in lower daughter tillers. Thus the grain crop plant is an integrated unit of synchronously appeared tillers in various orders and synchronously developed leaves on synchronized tillers while showing different appearance. In the figure, (Δ) indicates the top elongating leaf on any time. (⊾) denotes the expanded mature leaf attached to any node (□) of MS or daughter tillers. Arrow is the position of the leaf axil with which successive daughter tiller is subtended. Daughter tillers are numbered acropetally with the codes as…Tn-5, Tn-4, and Tn-3, being subtended by… "*n*–5"th, "*n*–4"th, and "*n*–3"th leaves of MS, respectively. Number noted by each leaf of daughter tiller indicates the leaf position as counted from the initial foliage leaf of each tiller. Leaves with the same color denote the synchronous emergence (and analogy in size) on different tillers. The Katayama's Concept shown above had been very useful tool for developing the intensive technology in rice plant cultivation in Japan during the Postwar period.

the creation of independent farmers, mainly from the ranks of the previous tenant farmers. The newly created independent farmers struggled to improve their yields of rice, even though their small, scattered landholdings put them at a severe disadvantage.

Among the early postwar developments was the almost entirely Japanese original machine called the *kōunki*, a cultivator which reduced the amount of hard work required from farmers and stimulated agricultural growth in the first decade after the war (Fig. 2a). Remarkable progress was also made in the technical development of farming materials such as pesticides, insecticides, herbicides, plastic films used for soil mulching and simplified greenhouses, all useful for small-scaled, intensive agriculture in Japan. Advances in efficient fertilization, such as top-dressing at the ear-formation stage proposed by Shingo Mitsui, led to stable, high rice yields as well. When the farmers achieved an abundant harvest of 12 million tons of rice in 1955, the government declared that the country was in "no postwar situation any longer!"

From 1955 to 1973, when an international oil crisis interrupted its progress, Japan experienced rapid economic growth. The labor force for this growth was supplied principally by a rural-to-urban migration so that the number of agricultural workers fell from 15 million (38% of the entire work force) in 1955 to 6.7 million (13%) in 1975. This transfer of labor from agriculture to manufacturing originally comprised younger sons and brothers of independent farmers, but later, other members of households began to take on part-time work outside agriculture and, by 1965, the ratio of farmers with side jobs exceeded 40%.

In 1961, the Basic Agricultural Law (*Nōgyō Kihonhō*) was enacted, after a massive outflow of people from the countryside had become apparent, and aimed to make farmers economically self-reliant with incomes about the same as those for urban laborers. Administering the law concentrated on improving the productivity and efficiency of labor in agriculture through mechanization; the government did in fact succeed in improving agricultural labor productivity.

Thus, rapid economic growth after the Second World War improved the standard of living for farmers – much more quickly than had been the case in Western Europe – and they have been relieved of a lot of heavy

Agriculture in Japan. Fig. 2 Characteristic improvement of small-sized machines that facilitate labor intensive cultivation in rice-growing paddy fields in Japan. (a) *Kōunki*, the innovative cultivator that was intensively developed and iteratively refined during the postwar period in order to improve labor efficiency in small-sized fields covered with heavy and wet soils. The improved machines achieved the easier and quicker farming practices in labor intensive agriculture, relieving farmers who had previously been forced to work very hard using manpower alone. (A scene showing students from Hokkaido University, 1976. Photo taken by Michiaki Ito, Niigata University. Used with his kind permission) (b) An early type of rice transplanter machine under development. The crawling machine was being used to research labor efficiency in a paddy field in Hokkaido University (1968). A series of extensive projects for the innovative development of rice transplanters was made in late 1960s in order to lighten the heavy labor burden that required almost 100 persons/hectare/day for transplanting rice seedlings by hand. (Photo taken by Michiaki Ito, Niigata University. Used with his kind permission.) (c) Improved rice transplanter in action in the paddy rice fields of a part-time farmer that owns 3 or 4 hectares of land. Those part-time farmers normally complete routine tasks in 3 or 4 days during holidays in May. (d) A rice combine harvester in action to harvest the yield of a well ripened rice crop, being easily operated by an aged farmer (Niigata, September 2004). Rice harvesting, which was once one of the most labor-intensive farming activities, is now usually completed by low numbers of people – around one person/hectare/day or less.

labor by such machines as four-wheeled tractors, rice transplanters (Fig. 2b,c), and rice harvesters (Fig. 2d) (the last two being Japanese originals) as well as various unique farming tools useful for Japanese intensive agriculture. However, the changes also created a serious inconsistency for the existence of traditional agriculture. The population of farmers decreased dramatically to about 6% of the Japanese total in the past half century, and most of them are living as part-time farmers dependent to a large extent on other industries. In the meantime, Japan has been simply exhorting the agricultural sector "to be efficient economically", hence its output of such crops as wheat, barley, soybeans, and buckwheat gets beaten in international competition. Rice cultivation now narrowly survives but is dependent on being located in optimal environments as well as the official policy of protection. The current, apparently irreversible trend foreshadows the increasing abandonment of agricultural land usage, further alienation of seminatural environments and the inevitable decline of Japan's agricultural practices and traditions which had been developed over almost two millennia.

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Agriculture in the Pacific

William C. Clarke

The environments where traditional agriculture was practiced in the Pacific Islands ranged from frost-prone but gardened mountain slopes at 8,500 ft (2,600 m) in Papua New Guinea to tiny atoll islets lying scarcely above the reach of the waves in the always warm equatorial ocean. Heavy downpours almost everyday keep some places in the Pacific Islands permanently humid; short wet seasons followed by long dry spells characterize the rainfall in other places. Still others with almost no rainfall are true deserts. Some single islands contain this whole range – the big island of Hawaii, with its high, massive volcanoes and its sharply contrasting windward and leeward coasts, is a notable example of such climatic variety. A comparable dissimilarity exists in Pacific Island soils, with some young volcanic soils being highly fertile, whereas on atoll islets the only natural soil material may be rough coral rubble, which is alkaline, has a very low water-holding capacity, contains little organic matter, and is unable to supply plants adequately with many of the nutrients required for vigorous growth.

Traditional Pacific Island agriculturalists met this wide range of often challenging conditions with an even wider range of agronomic techniques and crops, which enabled food production on all but the most barren islets or at the highest elevations of the larger volcanic and continental islands. This universe of agroecosystems included elaborate terracing and irrigation to grow the water-loving taro, massive drainage works to grow less water-tolerant crops such as sweet potatoes, mulching and composting to enrich the soil and to slow water loss, planting crops in built-up mounds of soil to encourage cold-air drainage and so lessen frost damage, planting in excavated pits to reach the water table on dry atoll islets, and (in systems of shifting cultivation) the use of forest or woodland fallow – planted in some places, spontaneously natural in others – to restore fertility to soils after they had been gardened.

The Origin and Evolution of Pacific Island Agriculture

When, from the sixteenth century onwards, European explorers began to encounter the sophisticated Pacific Island agriculture then practiced, it was not surprising that some of them believed they had sailed to a Garden of Eden, where breadfruit trees and coconut palms provided food without work, and where only a little labor was needed to make irrigated terraces of taro bear heavy harvests of starch-rich corms or tilled beds of sweet potatoes produce many baskets full of nutritious tubers. Initially, Europeans saw this productive agriculture as though it were some sort of a divine gift given to the Pacific Islanders, who had been favored with gardens and orchards that yielded unchangingly through time and that remained continuously in harmony with local environments. It is now clear on the basis of the extensive research into Pacific prehistory carried out only over the past few decades that such a view is far from accurate.

Pacific Island agriculture has never been static. It has been evolving constantly from its beginnings, as migration led people to new environments where there were previously unknown wild plant species, as the agriculture itself changed the environment, as the need for food expanded with growing island populations, as new crop plants were introduced, or as the agriculturalists experimented and introduced productive innovations. The Pacific Island agriculture first seen by Europeans was only an instant snapshot of a long and very dynamic history.

Twenty-five years ago it would have been asserted confidently by many scholars that Pacific Island agriculture had originated in southeast Asia and that Pacific Island cultivated plants had been domesticated in that same hearth. All that the ancestors of Pacific Islanders had done was to carry the Asian techniques and crops with them as they dispersed to the farther oceanic islands. It was recognized that the sweet potato and a few other less important crops did not fit this scenario, having been shown to have originated in the American tropics. However, the presence of these exceptions was explained away by various, often fanciful, theories of migration or simply as the result of introductions by Portuguese or Spanish voyagers during the fifteenth and sixteenth centuries – though recent archeological research in the Cook Islands (central eastern Polynesia) shows the sweet potato to have been present there by about AD 1000.

We know now that although some plants of Southeast Asian origin and domestication were transferred without significant change far into the Pacific (some species of yam, for instance), there is also evidence in support of early indigenous domestication and development of agriculture in the Pacific, specifically in western Melanesia (Solomon Islands and the island of New Guinea). The length of occupation there (at least 40,000 years in New Guinea) is more than sufficient for the experimentation necessary for independent domestication. And chromosomal and paleobotanical studies now indicate that plants that may have been domesticated in this region include sago, one type of *Colocasia* taro, one kind of banana, sugar cane, *Canarium* (a nut-bearing tree), *Saccharum edule* (a relative of sugar cane with an edible inflorescence), *kava* (the ritual and social drink still important in many parts of the Pacific Islands), and a variety of other plants, including several fruit trees. This attention to trees and the creation of orchards is a characteristic of food production all across the Pacific and was probably carried by itinerant colonist-cultivators from its place of origin in western Melanesia to Polynesia and Micronesia.

Further, especially strong evidence for the early development of agriculture to the east of southeast Asia comes from an archeological study in the Papua New Guinean highlands at a place called Kuk. A great deal has been written about Kuk, and the evidence has been interpreted in various and changing ways, but there is general agreement that Kuk demonstrates a long history of agricultural development, beginning about 9,000 years ago and involving, among much else, an ever-growing complexity of drainage works and water control in a large swamp, changes over time in cropping combinations from mixed gardens to taro monoculture to sweet potato dominance, responses to deforestation and land degradation brought about by shifting cultivation on the surrounding slopes, and the development of planted or encouraged tree fallows. Kuk, as well as evidence from prehistory elsewhere in the Pacific, shows that a dynamic agronomic and botanical science has long existed in the Pacific, in terms both of basic understanding and applied techniques. The origins of agriculture in the Pacific can now be said to have a time depth comparable to that of better known sites in southwestern Asia and tropical America.

No less mistaken than the view that traditional agriculture has been static in the Pacific Islands is the view that it has always been in harmony with its environment. Rather, as in the history of any dynamic agriculture, there have been episodes of deforestation, serious soil erosion, land degradation, and crop failure. Pacific Islanders did what all peoples, especially pioneers, do: in their efforts to make a living, they actively manipulated, modified, and, at times, degraded the ecosystems in which they lived, producing environmental changes that in turn required ecological adaptations and social adjustments. Considering the whole landscape, the most widespread of the human-induced changes in the prehistoric Pacific has been deforestation, with the cleared forests replaced by grasslands that required cultivation techniques different from those associated with forest-fallowed gardens. In many places, fire-maintained fern grass savannas underlain by infertile, eroded, or truncated soils came into existence or were extended by agricultural activities. This distinctive plant – soil complex is known as *toafa* in several Polynesian islands and as *talasiga* in Fiji. These dramatic landscape changes resulting from pioneering clearance for agriculture did not, however, bring unmitigated environmental degradation. Rather, in many places, they resulted in what has been termed "landscape enhancement," whereby the eroded soil transported down the slopes filled in the lower valleys and created swampy zones that were ideal sites for what came to be sustained yield, intensive cultivation of wetland taro. Other responses included the development of dryland cultivation techniques to cope with the changed agricultural environment, irrigated terracing, and an elaborated use of trees.

Traditional Agriculture in the Pacific Islands

The wide range of agricultural systems and techniques devised by Pacific peoples over millennia can be considered as ways of solving the agronomic problems presented by the great variety of island environments. For instance, in forested areas of low population density, soil fertility was maintained by simple no-tillage shifting cultivation wherein natural forest fallow rehabilitated the soil after gardening. Where forest was diminished, leguminous or other nitrogen-fixing trees (such as *Casuarina* spp.) were encouraged or planted. In grasslands a variety of mulching and composting techniques were developed. On atolls where soil was poor or absent and rainfall often low, Islanders created an ingeniously productive and sustainable agricultural environment for the giant swamp taro (*Cyrtosperma chamissonis*) by excavating a pit to reach the water table ("the freshwater lens") below the coral rubble and building up fertile soil in the pit by composting leaves of breadfruit and several other wild or semidomesticated trees as well as seaweed, pumice, and other materials.

The management of wet and dry conditions by irrigation and drainage was widespread and ranged from very simple ponds and small ditches to elaborate, kilometer-long, stone-lined channels and extensive hillside terracing. Irrigation and drainage were not necessarily spatially exclusive in that the ditches that drained water away from sweet potato beds were used to provide a moist growing site for taro and other water-loving crops. Water control may also have been used to control insect pests. As population densities increased or as political control expanded enabling greater labor mobilization, some systems of wet cultivation of taro in Polynesia became very intensive, productive of yields as high as from 30 to 60 metric tons per hectare.

The agricultural tool kit of the traditional Pacific was simple, mostly derived from unprocessed natural materials: wood, plant fiber, stone, shell, and bone. Wooden spades were elaborated in places where tillage and swamp cultivation was common. Wooden hoes were made here and there but were rare. The paramount agricultural tool was the digging stick. Used for loosening soil, digging roots and corms, making holes for planting and house posts, or as poles for carrying burdens, digging sticks ranged in size from heavy, two-meter, two-man tools used cooperatively to turn grassland or swampland sod to the light sticks used by girls to open shallow holes in soft forest soil. They remain widely in use today, and modern technology has yet to find a better tool for planting taro.

Before being replaced by steel tools, stone adzes and axes were effective in opening vast areas of forest and were far more sophisticated than they might seem at first glance. For instance, the cutting edges of stone axes might be facetted and asymmetrical to make resharpening more effective and to prevent the blade sticking in the tree during felling. Wooden spades and the way they were handled had similarly subtle attributes.

Organization of agricultural labor varied across the Pacific, with, for example, men doing the clearing but women most of the gardening in Melanesia, whereas in Tonga and Samoa in Polynesia men carried out all the agricultural tasks. Traditional Pacific livestock comprised the pig and chicken. Pigs were of great importance ritually and socially in many places and were a way to "bank" the food produced in tuberous starchy vegetables, which did not store well. During the periods when pigs were being accumulated for ceremonial feasts, considerable land and agricultural labor would be devoted to producing their food.

Like all traditional agriculturalists, Pacific Islanders possessed an enormous store of knowledge about both the domesticated and the wild plants and animals in their environment. This indigenous knowledge was organized by means of complex folk taxonomies that provided a framework for pleasurable intellectual activity as well as serving practical purposes. Similarly, aesthetics was a part of Pacific Island science of agriculture and land use management. Pacific people in traditional landscapes enjoyed the arrangement of productive diversity all around. Medicine here, perfume there, fiber in the hibiscus stem, fruit, timber, edible leaves, and so forth. There is a strong aesthetic pleasure in these observations of utilitarian diversity. As Malinowski (1935) wrote about the Trobriand gardens he made famous in Papua New Guinea:

> The gardens are, in a way, a work of art. Exactly as a native will take an artist's delight in constructing a canoe or a house, perfect in shape, decoration and finish, and the whole community will glory in such an achievement, exactly thus will he go about the laying out and developing of his garden. He and his kinsmen and his fellow-villagers as well, will be proud of his labours… During all the

successive stages of the work, visits are exchanged and mutual admiration and appreciation of the aesthetic qualities of the gardens are a constant feature of village life.

In the Pacific, as elsewhere, the complexity of traditional agriculture has undergone a simplification in modern times. Polycultural gardens of subsistence crops have been replaced by monocultural stands of commercial crops such as coconuts, ginger, coffee, and citrus. Intensive systems of irrigated taro or dryland yam cultivation have fallen out of use, often replaced by the less demanding cassava (manioc). On the other hand, with the current interest in locally based sustainable development, there is a growing concern to revive some of the indigenous traditional systems that served Pacific Islanders well in their past.

See also: ►Agroforestry in the Pacific

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Agriculture in South and Central America

Karl H. Schwerin

Conquest of South and Central America by the Spanish and Portuguese in the sixteenth century was rapidly followed by the introduction of Old World crops. These included both those familiar to European farmers, such as wheat, barley, oats, and many temperate vegetables and fruits catering to European food tastes, as well as tropical crops from Africa and Asia, such as bananas and plantains, sugar cane, and rice. At the same time many American crops were carried to the Old World – the most important being maize, potatoes, manioc, beans, and squash.

From the time of conquest to the present, agriculture in this region has been dichotomized between small-scale subsistence farming and large-scale monocrop operations producing for profit. Their development is summarized here.

Some native agricultural methods continued, such as swidden agriculture in temperate and tropical forested regions, field cultivation with the foot plow in the Andes, and intensive *chinampa* agriculture in central Mexico. Other techniques such as terracing declined, or as with raised fields, disappeared altogether. The small

Agriculture in South and Central America. Fig. 1 Cachama. Bananas and manioc in a morichal field, Cachama, Venezuela. Drained field in a moriche swamp, Karinya Indians. 1962. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 2 Mamo. Bananas, sugar cane, manioc in a morichal field, Yavito, Rio Yabo. Typical drained field in Yavito, in a moriche swamp. Karinya Indians. February 1962. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 3 Mamo. Fruit trees in patio 1967, Mamo, Venezuela. House garden. Karinya Indians. July 1967. Photo by Karl H. Schwerin.

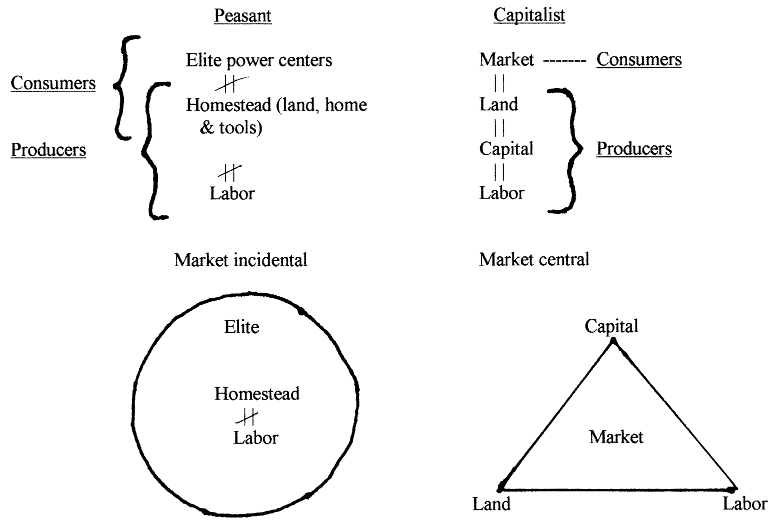
farmers incorporated some European crops as staples – wheat in Mexico (principally among mestizo farmers), barley in the Andes, onions, cabbage or collards almost everywhere. Bananas and plantains spread rapidly throughout the tropics. Agricultural technology continued much as before contact, perhaps because it was appropriate to traditional agriculture which, though small-scale, was highly productive.

Although early colonial institutions such as the *encomienda, corregimiento*, and *repartimiento* were designed to exploit native labor and mineral resources, they also produced surplus foodstuffs to support the European population, mining, and colonial administration. As native populations declined, large land holdings were granted to Spanish and Portuguese immigrants. Some were cultivated dilatorily, but others were transformed into plantation enterprises producing sugar, tobacco, cacao, indigo, or cochineal (a red dye obtained from the crushed dried bodies of female cochineal insects, used to color food and drinks and to dye fabrics) (also cattle, sheep, and horses) which soon supported a lucrative trade with the home country. Most plantations were dependent on slave labor. Sugar, consumed raw or distilled into *aguardiente* or rum, became the principal economic enterprise in Brazil and the Caribbean, and was particularly dependent on slave labor.

By the eighteenth century mining became concentrated in a few rich areas. Agriculture acquired more importance in the colonial economy. Land grants were increasingly cultivated to supply colonial needs for food grains and raw materials such as cotton. The *hacienda* became the vehicle for accomplishing this production. Labor was secured through mechanisms such as debt peonage and was administered in such a way that it was almost impossible for the individual laborer to break free.

After independence early in the nineteenth century, slavery was gradually abolished throughout the Americas. The hacienda, however, continued as a major system of ensuring agricultural labor. It only began to disappear with the Mexican Revolution of 1910. Though much less important today, it continues to operate in some Andean countries and in parts of Brazil.

The nineteenth century was marked by widespread expansion of agricultural capitalism in the form of plantation systems producing a wide variety of crops for industrial and consumer markets in Europe and North America. These included *henequen* (fiber obtained from the leaves of the henequen agave plant, used in making rope, twine, and coarse fabric) from the Yucatan, bananas in Central America, and sugar in the Caribbean and Brazil. Coffee, one of the most profitable crops, was widely introduced, from Mexico



Agriculture in South and Central America. Fig. 4 The peasant economy versus the capitalist economy.

Agriculture in South and Central America. Fig. 5 Maize field. Mexico, Tenancingo, Tlaxcala, Mexico. Typical peasant maize field. June 1957. Photo by Karl H. Schwerin.

to Brazil. In Mexico and parts of Central America, small farmers produced it; in Costa Rica and Colombia medium sized farmers were the rule; elsewhere large coffee *fincas* predominated. Particularly in the latter case, land was intensively exploited, without efforts at conservation or improvement, leading to rapid deterioration in soil quality and declining production. Where land was abundant, the response was to clear virgin land and plant new coffee groves. Uruguay and Argentina became major world producers of wheat, owing to the rich Pampean soil. In both Brazil and the pampas, immigrant labor was employed to clear the land, in exchange for temporary usufruct of part of the cleared area. Evicted after a time in favor of the landowner, some immigrants acquired their own (usually smaller) farms, but most withdrew to the cities, leaving only the larger *fincas* and *estancias* as significant agricultural producers.

Several different systems of agricultural exploitation can be identified in this region today. Yet agriculture has declined in importance in national economies throughout the century, dropping precipitously since 1980. Only in Central America, Mexico and Brazil is 15–30% of the work force still farming, in most countries only 10% is still employed in agriculture, which represents less than 10% of the GDP for the region.

The persistent dichotomy between large, extensively cultivated holdings (*latifundio*) and small, intensively cultivated properties (*minifundios*) survives today. Though these are sometimes geographically separated, they frequently occur interspersed with each other interacting as a symbiotic whole. This dichotomy is also

A

Agriculture in South and Central America. Fig. 6 Mamo. Maize field. Maize field and shelters of Francisco Vasquez, Isla La Isabel, Venezuela. Karinya Indians. February 1962. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 7 Forest and maize fields, Michoacan, Mexico. August 1962. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 8 Mamo, maize field on Isla La Isabel, Venezuela. Karinya Indians. February 1962. Photo by Karl H. Schwerin.

at the root of many economic and social problems. Although precise data on distribution of agricultural landholdings have not been reported since the 1970s, the extreme bimodal distribution has probably not changed significantly. In El Salvador, Guatemala, and Peru more than 90% of agricultural landholdings were under 10 ha, yet represented only about 30% of the area. In contrast, 26% of the area in Guatemala and 61% of the area in Peru were larger than 1,000 ha, yet represented less than 0.5% of the holdings.

Some small-scale specialized farming techniques survive in scattered locales, such as localized irrigation systems, *chinampas* in the Valley of Mexico, drained fields among the Karinya in eastern Venezuela (Figs. 1 and 2), or terraces and lazy beds in Mesoamerica and the Andes. Traditional methods of agriculture generally promote ecological stability both because environmental disturbance is minimal and because the agroecosystem is stable. Unfortunately, development, modernization, and institutional pressures from the larger society often lead to abandonment of these techniques, in spite of their suitability to local conditions and often exceptional productivity. Thus most irrigation has been modernized and commercialized and relies on pumping, reservoirs, and lined canals. Yet there are efforts in some places to reintroduce ancient agricultural techniques, like ridged fields in the Titicaca Basin, which have proven superior to current practices. Many traditional practices should be preserved in order to exploit their productive advantages, utilize marginal microenvironments, maintain crop diversity, and minimize production risks.

Swidden agriculture or shifting cultivation is still widely used in forested regions. It may support as many

Agriculture in South and Central America. Fig. 9 Tenancingo. Harvesting beans. Tenancingo, Tlaxcala, Mexico. Don Eleuterio Guzman pulling up bean plants in a maize field. July 1957. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 10 Tenancingo. Don Eleuterio Guzman harvesting beans in a maize field. Tenancingo, Tlaxcala, Mexico. July 1957. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 11 Mamo. Threshing beans. Ramón Antonio Vásquez threshing out beans by beating them with a pole. Isla La Isabel, Venezuela. Karinya Indians. March 1962. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 12 Manioc field, Kuri, Rio Platano, Honduras. Miskito Indians. January 1981. Photo by Karl H. Schwerin.

as 50 million people. It is relatively productive and successfully integrated into the ecological regime of the tropical forest, yet requires less labor than many other methods. It is a technology that does not require capital investment or energy subsidies. When associated with sparse populations its environmental impact is minimal, perhaps even beneficial by stimulating renewed forest growth. When intensified to the point that the forest can no longer replace itself, swidden may produce widespread environmental degradation. Rapid population growth throughout Latin America has spurred migration in search of farmland in lowland tropical forests from the Peten and the Caribbean coast to the Amazon basin. Resulting widespread deforestation has had serious ecological repercussions.

A

Agriculture in South and Central America.
Fig. 13 Cachama. Teresa Tamanaico pulling, up (harvesting) manioc tubers. Cachama, Venezuela. Karinya Indians. July 1962. Photo by Karl H. Schwerin.

Agriculture in South and Central America.
Fig. 14 Cachama. Teresa Tamanaico stripping manioc tubers from uprooted plants. Cachama, Venezuela. Karinya Indians. July 1962. Photo by Karl H. Schwerin.

One agriculture technique, the house garden, is nearly ubiquitous among small farmers, even in towns and cities. Their species diversity is high, providing

Agriculture in South and Central America.
Fig. 15 Cachama. Teresa, Luis and Delia Tamanaico, loading manioc tubers into a basket to be carried home, for processing. Cachama, Venezuela. Karinya Indians. July 1962. Photo by Karl H. Schwerin.

Agriculture in South and Central America.
Fig. 16 Tenancingo. *Maguey* (*Agave* sp.) Tenancingo, Tlaxcala, Mexico. Nearly mature maguey plants planted along edge of field. July 1957. Photo by Karl H. Schwerin.

Agriculture in South and Central America.
Fig. 17 Tenancingo. Collecting *agua miel.* Tenancingo, Tlaxcala, Mexico. Mature maguey plant (Agave sp.) with heart carved out to create a cavity for collecting the sap or agua miel–subsequently fermented to produce pulque. July 1957. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 18 San Pedro. Hacienda peons. Hacienda San Pedro, Cañar, Ecuador. 1970. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 19 San Pedro. Team of oxen. Hacienda San Pedro, Cañar, Ecuador, José Narvaez loading plow on yoke to carry to field. 1970. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 20 San Pedro. Plowing field with oxen 1. Hacienda San Pedro, Cañar, Ecuador, 1970. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 21 San Pedro. Plowing field with oxen 2. Hacienda San Pedro, Cañar, Ecuador, 1970. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 22 Wheat harvest 1. Hacienda El Colegio, Cañar, Ecuador. Mayordomo Augusto Urgiles oversees the cutting of wheat. October 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 23 Wheat harvest 2. Hacienda El Colegio, Cañar, Ecuador October 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 24 Wheat harvest 3. Hacienda El Colegio, Cañar, Ecuador, October 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 25 San Pedro. Threshing barley with horses. Hacienda San Pedro, Cañar, Ecuador. Joaquin Fajardo, Cayetano Tenesaca, Corazon Murudumbay and Juan Jose Tacuri threshing barley September 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 26 Planting potatoes. Hacienda El Colegio, Cañar, Ecuador. September 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 27 San Pedro. José Narvaez planting *ocas.* Hacienda San Pedro, Cañar. Ecuador. September 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 28 San Pedro. José Narvaez planting *ocas.* Hacienda San Pedro, Cañar, Ecuador. September 1969. Photo by Karl H. Schwerin.

supplementary food, condiments, herbs, medicinal remedies, fuel, fertilizer, and ornamental plants (Fig. 3).

Peasant farmers conduct most small-scale agriculture. A true peasant owns or controls his land, runs his own operation and makes his own decisions independently. The primary production objective is for subsistence and survival. Peasants do not think in capitalist terms, but instead are oriented around the homestead (land, home, tools), which cannot be converted or exchanged for other means of production (see Fig. 4). Because cash is

Agriculture in South and Central America. Fig. 29 Peons harvesting *mellocos* (*Ullucus tuberosus*). Hacienda El Colegio, Cañar, Ecuador. September 1969. Photo by Karl H. Schwerin.

limited, the peasant cannot afford to take risks; he often resists trying new crops and techniques; technology remains traditional (paleotechnic).

The strength of peasant farming is its heterogeneity and diversity. Planting a variety of crops, in several locales, under varying conditions, minimizes risk. The most important crops are starchy staples – grains or root crops – and legumes; perhaps supplemented by a high value cash crop – tomatoes, coffee, or narcotics (Figs. 5–17).

Large holdings can be roughly divided into haciendas, estancias, plantations, and agroindustrial enterprises. Hacienda organization represents a unique adaptation to abundant land and scarce capital. Labor to work the estate is attracted by offering small subsistence plots to local smallholders or landless laborers (most commonly known as *peons*). Traditionally little or no

CHARACTERISTICS OF THE PLANTATION

Distinguishing Characteristics of the Plantation

1. Sharp separation of classes
2. Capitalistic enterprise
3. Monocrop specialization
4. Continuous commercial production

(2–4:) Hacienda lacks these, tends toward self-sufficiency

plantation - A capitalistic type of agricultural organization in which a considerable number of laborers are employed under unified direction and control in the production of a staple crop for sale to an external market. (Sidney Mintz)

Contrasts Between the Hacienda and the Plantation

Hacienda	Plantation
abundant land	pervasive control of the land
scarce capital	abundant capital
pervasive control of labor	scarce labor, often mobile
tries to avoid wages	relatively high wages
ownership by family or traditional institution (church, government)	ownership by company or corporation
personalistic & paternalistic	universalistic & impersonal
economically inefficient	economically efficient
paleotechnic	neotechnic, often highly mechanized
produces for domestic market	produces for external market
participates in regional and national power structure	participates in international power structure

Agriculture in South and Central America. Fig. 30 The hacienda and the plantation.

Agriculture in South and Central America. Fig. 31 Field of pyrethrum (*Chrysanthemum* spp.). Highland Ecuador. June 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 32 San Pedro. Laborers from Chimborazo Province hoeing pyrethrum 1. Hacienda/Plantation San Pedro, Cañar, Ecuador February 1970. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 33 San Pedro. Laborers from Chimborazo Province hoeing pyrethrum 2. Manuela Transito Balente and Transito Illapa Hacienda/Plantation San Pedro, Cañar, Ecuador February 1970. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 34 San Pedro. Floreras (peon women) picking pyrethrum. Hacienda/ Plantation San Pedro, Cañar, Ecuador October 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 35 San Pedro. Olga Jachero picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969. Photo by Karl H. Schwerin.

wages exchanged hands; today real wages may actually be paid, although they are often seriously in arrears because capital remains scarce. For the same reason haciendas try to be self-sufficient in terms of basic needs. They also tend to be inefficient, relying on antiquated technology and cultivating only a small area of the best land, leaving the rest uncultivated or in the hands of the workers. Yet their production of staple cereals and tubers, or milk, meat, and wool may contribute significantly to national economies. Hacienda property may be viewed more as a basis for prestige or a hedge against inflation than as an income producer. For this reason, as well as scarce capital, haciendas also tend to resist innovation. Most surviving haciendas are found in highland areas of the Andes and Mesoamerica,

Agriculture in South and Central America. Fig. 36 San Pedro. Olga Jachero picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 37 San Pedro. Lucrecia Alvaros picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador October 1969. Photo by Karl H. Schwerin.

Agriculture in South and Central America. Fig. 38 San Pedro. Peon women picking pyrethrum. Hacienda/Plantation San Pedro, Cañar, Ecuador. August 1969. Photo by Karl H. Schwerin.

though they have also been the object of land reform from Mexico to Bolivia, Peru and Ecuador (Figs. 18–29).

Estancias are large holdings devoted to livestock production found mostly in the Southern Cone and northern Mexico, although in recent years cattle production has expanded rapidly in the Amazon lowlands and Central America to feed the North American demand for hamburger and processed meats.

The modern plantation contrasts with the traditional hacienda in that it is fully and efficiently operated with large amounts of capital (see Fig. 30). The plantation generally concentrates on monocrop specialization with the aim of continuous commercial production, usually for export. Although their proportion of total agricultural production has been declining, plantation crops such as sugar, coffee, bananas, pineapples, oil palm, cotton, tobacco, maize, and wheat continue to be the major source of foreign exchange for several countries (Figs. 31–38).

Large farms in central Chile, Northern Mexico, and Central America have also adopted this mode, producing fruits and vegetables for the winter market in North America. Production and marketing of feed products (maize, sorghum and millets, soybeans) and oilseeds (safflower, soybeans, cottonseed) have become important in Brazil, Argentina, Colombia, Guatemala, El Salvador, and Mexico. Commercial farming is almost always profitable, but profits increase exponentially with the size of the operation. They generally practise monocropping with chemical additives such as fertilizers and pesticides. Since larger commercial farmers participate in the international economy, they can survive bad years by falling back on economic institutions (loans, savings, insurance) to carry them through.

The North American Free Trade Agreement (NAFTA) has had serious repercussions in Mexico. Imports of agricultural products produced cheaply by large US and Canadian agribusinesses has undercut the production of small and medium sized farmers in Mexico, forcing many to abandon the land, often moving to the cities in search of alternative employment.

Agriculture in South and Central America. Table 1 Most important crops for domestic consumption in Latin America

Maize	59,817
Manioc	29,633
Rice	23,217
Wheat	22,452
Potatoes	16,997
Dry beans	5,117
Sweet potato	1,796
Barley	1,646

From *Statistical Abstract of Latin America*. v. 38, 2002. Data for 1999 (in thousand metric tons).

Agriculture in South and Central America. Table 2 Export and industrial crops for Latin America showing principal exporting countries, 1999

	In thousand metric tons	Export value (millions of US dollars)
Cotton (Brazil, Argentina, Paraguay)	1,164	261
Sugar cane	539,308	4,457
Coffee	3,693	7,912
Bananas	22,279,000	2,816
Maize (Argentina, Paraguay)	13,183	832
Soybeans (Argentina, Brazil, Paraguay)	5,141	2,481
Wheat (Argentina)	14,500	999

From *Statistical Abstract of Latin America*. v. 38, 2002 and *International Trade Statistics Yearbook*, 2001.

Social consequences of these developments are that the peasantry is losing control over its productive processes and is being transformed into a rural proletarian underclass that is being exploited as the primary labor force. These factors have deeply transformed production relations within the agricultural sector, resulting in the modern agroindustrial complex. As a result of increasing commercialization of agriculture, the production of cash crops for export and industrial use has expanded at the expense of the production of basic food crops, leading to significant imports in many countries of basic foodstuffs (Tables 1 and 2).

Efforts at agricultural modernization vacillate between large, capital intensive projects and smaller "appropriate" technology, designed especially for small farmers. However, the bias is toward large-scale projects that are highly visible and politically profitable, but which are often viable only for the short term. In any case they are rarely beneficial to the small farmer.

See also: ►Potato, ►Swidden, ►Food Technology in Latin America

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Agroforestry in Africa

Arnold Pacey

Agroforestry is not a new idea; it is merely a new word used by scientists to describe ancient land use practices operated by farmers in many parts of the world. Other names stressing different aspects of the same technique include forest farming, forest interculture, layered gardening, and multistorey farming. The latter word has been used in West Africa to refer to a system where crops are produced from the same area of land at several levels or storeys, ranging from tops of trees (oil palms, for example), to ground crops beneath the trees, and to root crops below ground (yams, cocoyams, cassava).

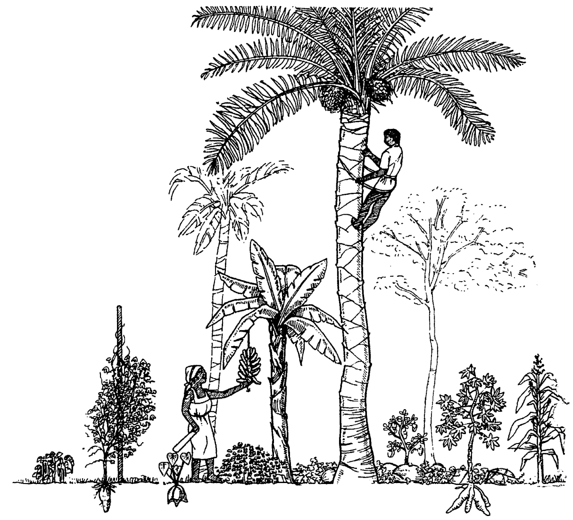
Rediscovery of such farming methods during the last third of the twentieth century was linked to a realization that imported western techniques in tropical Africa had often led to soil erosion and loss of fertility. Cleared fields planted with single crops in the western manner left the soil acutely vulnerable to damage by heavy seasonal rainfall. By contrast, trees gave protection against erosion during rainstorms, while their leaf litter helped maintain soil fertility.

During the 1980s and 1990s, professionals working on this topic, notably at the International Council for Research on Agroforestry (ICRAF) in Nairobi, came to see agroforestry as a holistic approach to land use, using combinations of trees and shrubs with crops, pastures, or animals. What this means in practice depends on climate and environment, for there are different traditions of agroforestry in semiarid tropical regions, in rainforest areas, and in more temperate zones.

In the West African Sahel, traditional customs of retaining and using sparse tree cover in coordination with livestock raising and cropping tended to moderate the effects of high temperatures and low rainfall and to conserve plant nutrients while making possible a diversity of products, not all of which would suffer when droughts led to crop failure. Whilst many tree and shrub species were involved, one tree in particular, *Acacia albida*, was of such value in the western Sahel that it was often regarded as sacred, and there were severe punishments for its unauthorized felling. Because it is a leguminous, nitrogen-fixing species, yields of millet and sorghum sometimes increased greatly when grown in fields which had a scatter of trees of this type. Its leaves and seed pods were a nutritious fodder for livestock. Materials were obtained from it for the preparation of medicines, and its timber was useful in building.

Another species of importance, particularly in Sudan, was *Acacia senegal*, which produced gum arabic, and was grown in conjunction with millet and other crops in a 20-year rotation. With the disruption of this and other cropping systems, sometimes in favor of more "modern" methods, the productivity of the land, and the number of people it could support, was greatly reduced.

In rainforest areas, the retention of tree cover on land where crops are grown is even more important. Oil palm is particularly valuable in West Africa as a tree yielding a valuable crop yet also offering protection of the soil against erosion, and banana may be grown in the same context (Fig. 1). Crops grown at ground level under these trees traditionally include a great variety of beans, squashes, and leafy vegetables, with cereals in more open, sunnier glades.



Agroforestry in Africa. Fig. 1 A form of agroforestry in West Africa sometimes known as multistorey farming. The upper storeys are represented by oil-palm and banana crops. Below that is the cereal crop, maize (corn). Nearer ground level are beans and melons, whilst in the "basement" are the main root crops. Left to right the latter are yams, cocoyams and cassava. This somewhat compressed view does not reflect realistic spacing, in which maize would be in open glades and more shade-tolerant species under trees. Illustration by Hazel Cotterell based on sketches by Arnold Pacey. Reproduced from *Technology in World Civilization*, by Arnold Pacey, MIT Press 1990, p. 200.

Many early innovations in agroforestry arose when crops were introduced into new areas. Thus over the last 1,500 years, African agroforestry has incorporated bananas and the Asian yam from Indonesia, then later, cassava and other crops from the Americas. Recently, though, agroforestry has been researched and repackaged by scientists, then taught to farmers by extension workers as if it were something new, with its origins in traditional practice heavily disguised.

One example of an innovation that arose from scientists' observing traditional practices is "alley cropping". This is said to have arisen when an Indonesian scientist working in Nigeria saw farmers planting a tree species on fallow land to speed the regeneration of the soil. He was led to experiment with trees that could be cut back prior to planting a corn crop, but which would grow up again quickly after the crop was harvested. The Alley Farming Network for Tropical Africa (AFNETA) was set up in 1989 to promote sustainable cropping systems based on alley farming and other ideas drawn from agroforestry practice, and in the 1990s it was developing and disseminating such farming methods in 20 African countries.

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Agroforestry: Agri-Silviculture

Harold Olofson

Agri-silviculture is the intercropping of timber and fuelwood species and/or fruit and other useful trees with vegetables and other crops in a common space, at the same time. It may characterize a harmonic swidden (see Agroforestry: Harmonic Swiddens) where fallow periods are sped on their way toward full fertility and a forest architecture by the purposive planting and protection of leguminous and fruit trees in the cropping period or afterwards. Or it may be found in permanent farms. In the first case, we can refer to such swiddens as accelerated swiddens, to be distinguished as a term from the Food and Agriculture Organization's "accelerated fallow" to refer to swidden fallows which, because of population pressure, must be planted to food crops before they have recovered full fertility. In agri-silviculture, the sylvan component of the field is cultivated through practices like weeding and thinning. Agri-silviculture is an example of Alternative Forest-like Structures (AFS) because of the presence of arboreal species which provide some values of the forest. It is also a simultaneous polyculture. Indigenous examples follow.

Within swiddens themselves we frequently find that swiddenists are making efforts to encourage reforestation at a very early stage by interplanting forest trees and tree crops. These are then simultaneously harmonic, polycultural swiddens, as well as examples of agri-silviculture. Agri-silviculture is one type of indigenous agroforestry that seems identical with some of the ideas which modern agroforestry has adopted. From various anthropological sources on the Lingnan Yao of Kwangtung Province, China, which were written in the first third of this century, a summary of their agri-silviculture has been constructed.

> The first year after burning, a swidden is used mainly for mountain rice and maize; the second year for sweet potatoes; and the third year for taro. Simultaneously with the first planting, seedlings of various economically important trees are put in the ground. At the end of three years, these are large enough to discourage further growth of weeds and grasses. The swidden is thereafter fallowed for 18 or 19 years until the trees are large enough to be cut for timber (Lebar et al. 1964: 82–83).

They go on to say that cedar and bamboo are also planted in the swidden. The Lingnan Yao apparently have had a symbiotic relationship with the Han Chinese. The Yao are skilled neither in timber extraction nor in woodwork. In exchange for allowing the Chinese to take most of the timber and other forest products, the Yao receive rice, paper, cloth, salt, guns, and the skilled carpentry of the Chinese. Thus while the Yao grow the timber, the Chinese cut it and transform it into useful shapes (Lebar et al. 1964: 82–83). A search should be made for indigenous agroforestry models among other South China cultural minorities.

Acceleration appears to begin with selective weeding in the swidden so that forest tree seedlings that have established themselves can survive. In his description of the Tsembaga Maring, Rappaport noted that one is chided for stepping on what is called "the mother of the forest" – tree seedlings that are appearing in the swidden but not recognized by the visitor (Rappaport 1971: 122).

For the Siane of New Guinea, Salisbury provides this description of the importance of *Casuarina*:

> Casuarina trees [*Casuarina equisetifolia*] provide wood for fencing, fuel, and house building, and their growth as a secondary tree cover is facilitated by the weeding of garden sites. This prevents the growth of kunai-grass, which would crowd out young casuarina roots. If the casuarinas are given a chance to establish themselves, their shade often prevents the spread of the sun-loving *kunai*. The growth of casuarinas is deliberately encouraged, and gardens are often made when a boy is born, with the explicit expectation that this will provide a crop of timber for the boy at the time of marriage, and so enable him to build a house and

> fence a garden for his wife. Occasionally, too, casuarina seedlings are deliberately planted in areas which no windblown seeds could reach. This happened, for example, in 1941 when Antomona clan of Emenyo tribe returned to their devastated village site, where all trees had been ring-barked following their rout and expulsion in a war. Thus casuarina trees may be considered "cultivated" plants (Salisbury 1962: 43).

Thus it was considered enough to completely conquer an enemy by ring-barking all of the casuarinas in his territory. This would mean that the vanquished would have to retreat up to the high mossy forests to make their swiddens, while their forest areas lower down might run the risk of grassy invasion, since ghost-fear would prevent these areas from being immediately assimilated into enemy territory (Salisbury 1962: 48).

These accounts reveal that traditional swiddenists are frequently capable of long-term future orientation when it comes to forest regeneration, but primarily in the context of viewing the trees that are so protected and preserved as being useful to people.

Given the right economic conditions, this propensity to accelerate swiddens can evolve into a completely stable form of horticulture with the establishment of orchards. This has been described for the Cuyunon of Palawan Island, Philippines. Many of them have made this transition since the 1930s as a response to the flourishing nearby market and port of Puerto Princesa. As an ethnographer describes it,

> Orchards are usually established as an adjunct to swiddening. A farmer systematically intercrops his newly-planted swidden with tree crops and then controls regeneration of herbaceous secondary growth until the tree crops are established (Eder 1981: 95).

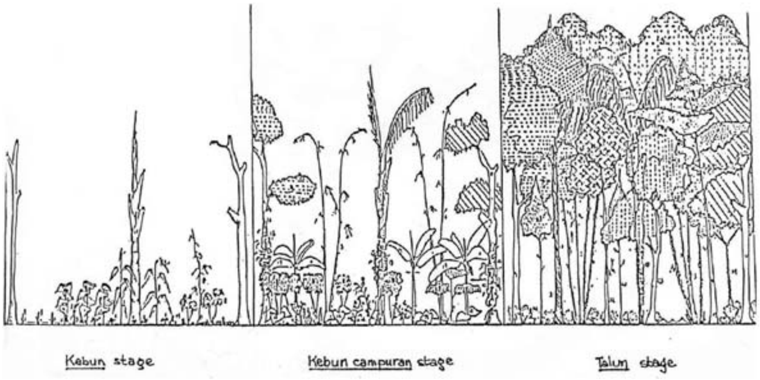
The land used for tree crops, which are mostly fruit of many different species, is in this example taken right out of the swidden cycle.

Cairns (ca. 1995) discovered that the nitrogen-fixing (even though nonleguminous) *Alnus nepalensis* (an alder) enables the Angami Naga shifting cultivators of the Himalayan foothills in northeast India to accelerate their swiddens without causing ecological damage. Oral histories collected from village elders revealed that this has been going on for 500 years, ever since alders invaded the originally opened fields and always seemed to enhance the growth of crops planted near them. The Angami came to protect individual alders (which coppice prolifically and thus are good renewable sources of firewood) and their seedlings, and through the centuries actively to plant them in their fields. This intensification of their agroforestry was probably a response to the fact that the fields had to be clustered near the village due to the hostility of neighboring communities of head-takers. Swiddenists had to be able to retreat quickly to their walled villages.

Over two years of cropping, the alders are pollarded for firewood twice, at the reopening of the fallow and again twelve months later. This is to allow sunlight to reach the staple crops of upland rice and pearl millet, and others. The alders are then left to grow and dominate the tree canopy in the next fallow period of two years. During that fallow, the trees' "extensive roots draw nutrients from a large soil area and return them to the surface in high volumes of nutrient-rich litterfall" (Cairns 1995: 7). As a result, Cairns maintains, the Angami Naga do not remember ever having suffered from this rapid succession of fallow and cropping periods. It is made possible by the presence of the alders, and "without the need of outside technologies, investment capital, or excessive labor inputs." This system is a model for how to stabilize shifting cultivation.

The Huastec Indians of Veracruz State, Mexico, manage stands of forest trees named by them *tel'om* (Alcorn 1981: 409–410). These are particularly closely managed in communities sited near markets. This can be done by adding shade-loving coffee trees into the forest, in places where some forest trees have been cut down to allow space for them. Those trees and vines which are particularly useful for construction are spared. In the shade of the coffee trees, cassava and chili peppers are planted. Furthermore, a species of valued medicinal palm, mango, and citrus trees may be added. The *tel'om* includes both primary and secondary species, as well as useful species introduced from other plant communities. The managed forest is used by women and children for food gathering and play, and streams running through it are sites for bathing and laundering. Within a range of humanly managed plant associations moving from crop field to natural forest, the *tel'om* approaches the forest in structure, but Huastec culture has turned it into a multiple use artifact which can persist for many years as a stable ecosystem. Having originated as an enriched fallow, it need never be opened again for swidden.

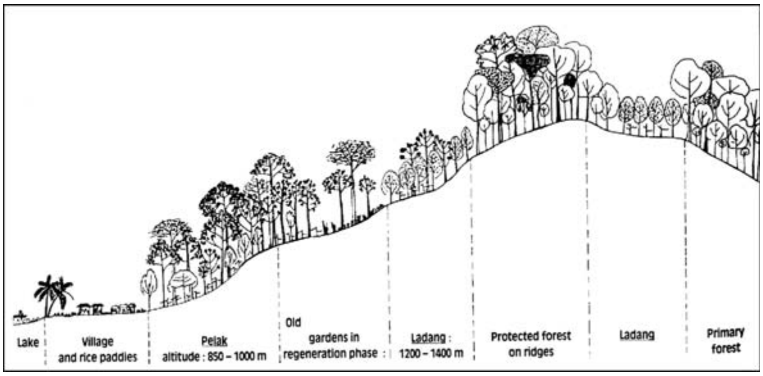
Closely related to the *tel'om* conceptually are the "village-agroforests" of the Sundanese in West Java, Indonesia. Named *talun-kebun*, these cover up to 50% of a village's cultivated land (Christanty 1982, Michon et al. 1983, see Figs. 1 and 2). Thus they are not to be confused with mixed dooryard gardens, which these farmers also have, for they are found further away from the residences. Architecturally imitative of the tropical forest ecosystem in their structure and bio-diversity, Michon et al. (1983: 118, 120) say that they "should be described in the same way as natural forest ecosystems" as well as "in terms of an agricultural lay-out." As in the *tel'om* of the Huastec, the Sundanese *talun-kebun* preserves wild vines, bananas, and trees. Annuals and



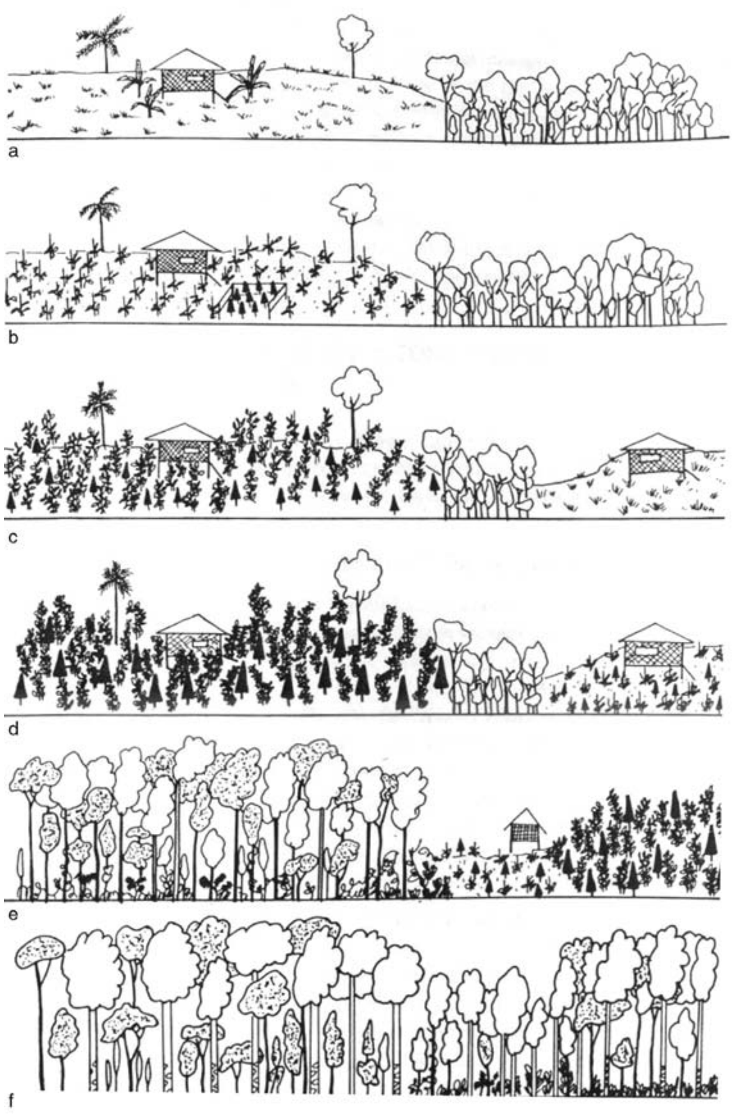
Agroforestry: Agri-Silviculture. Fig. 1 Successional stages in the *talun-kebun* agroforest of the Sundanese, West Java. (From Christanty 1982, 20).

Agroforestry: Agri-Silviculture. Fig. 2 Partial profile of a *talun-kebun* agroforest of the Sundanese, West Java. (From Michon et al. 1983, 126 ff).

perennials are mixed with wild and domesticated plants and livestock (chickens, sheep, and goats) as well. Crop species can reach up to 250 in number. This richness prevents the spread of plant pests and diseases and "represents an invaluable gene pool on an island [Java] where original forests have about disappeared" (Michon et al. 1983: 118–119). Like the *tel'om*, the *talun-kebun* evolved out of the fallowing phases of an older shifting cultivation, no doubt in response to increased population pressure.



Agroforestry: Agri-Silviculture. Fig. 3 Schematic diagram of land use in Semarang village, at the edge of Kerinci Seblat National Park, Sumatra, Indonesia (*ladang* = swidden). (From Aumeeruddy 1994, 22).



Agroforestry: Agri-Silviculture. Fig. 4 From rice field to coffee plantation to damar (*Shorea javanica*) agroforest in Krui, Sumatra. (From Michon et al. 2000, 184).

Agroforestry: Agri-Silviculture. Fig. 5 Profile of an agroforest showing an association of timber, legume, and cinnamon tree crops, Jujun, Kerinci, Sumatra. (From Aumeeruddy 1994, 28–29).

Much study has been done recently of indigenous agroforestry in Sumatra, Indonesia that has been able to restore biodiversity to the forest by incorporating cash tree crops into village forest gardens (Aumeeruddy 1994; Michon et al. 2000; see Figs. 3, 4, and 5).

In the agri-silvicultural form of accelerated swidden, crops may sometimes support the trees. This can occur if some of the crops are nitrogen fixing. But more importantly, food crops that are interplanted with tree seedlings have the function of giving the farmer quick returns, which he may require before he is willing to go into the venture of a long-term investment in the form of trees interplanted with his crops.

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Agroforestry: Field-and-Grove Systems

Harold Olofson

This is the most interesting, complex, and varied form of indigenous agroforestry. The fields can be either harmonic or disharmonic swiddens, accelerated swiddens (agrisilviculture or agroforestry rotations), irrigated or nonirrigated permanent fields, or combinations of these. But they are interspersed with groves of trees that may vary along a range from predominantly wild forest species that are consciously conserved to groves largely composed of domesticated tree species planted by people. These two components may alternate or be scattered in a highly productive mosaic across the landscape of a village, district, or watershed. There may also be a tendency over a long period for some fields to become groves, and some groves to become fields, with both components thus slowly migrating across the landscape, producing in effect a very long-term agroforestry rotation. I was able to find four different types of field-and-grove systems in the literature available to me.

The Field-and-Forest

In some countries having temperate climates, these have been a feature of indigenous agroforestry. In England, patches of trees are known as copses when they are composed of species that can be managed by coppicing (cutting back trees regularly to encourage more growth). Larger woodlots and forests have been preserved for centuries as a source of game, deadwood for fuel, honey, and visual pleasure (see Rackham 1985). But in more definite examples of the "field-and-forest," forest resources may be more consciously pulled into the support of agriculture than they usually are in swiddening systems, where the forest tends to take on the passive role of a growing fertilizer reserve. The forest becomes more markedly a component of an agroecosystem.

In many areas of Japan, it is the custom to maintain a forest adjacent to wet-rice fields so that litter from the forest floor can be annually incorporated into the pondfield soils. This may in some measure account for the traditional high productivity of Japanese rice farmers. But the groves are subject to premature aging as a result of the fact that they are not allowed to reabsorb their own litter as food (Kira 1976: 36–7).

Some fascinating examples of field-and-forest relationships are described by Wilken (1977) for Mesoamerica. As in Japan, in western Guatemala and Mexico he observed the "transfer of the forest floor to the fields." Leaf litter is scattered onto the fields and turned into the soil to improve its structure and moisture retention. The litter may first be placed on the stable floor, where it picks up nitrogen content from the urine of livestock. Also, forest materials may be transported to the field to provide protective micro-climates, in the form of mulches to reduce radiation and evaporation from the soil and absorb the impact of raindrops, or actual shelters in the form of leaves and branches to perform similar functions and to allow cash crops to become gradually attuned to the open field. Wilken uses the term "forest structure mimicry" to describe the protective uses of litter and also the custom of letting leguminous trees or pines to simply invade the fields, leading to an eventual replacement of the field by a grove.

Wilken, like Kira, points out that the practice of forest litter removal may have deleterious effects on the forest. However, one could easily imagine long-term experiments to determine the best system of leaf-litter removal management so that no section of the forest floor is harvested year after year, thereby at least prolonging the life of the grove.

The Field-and-Sacred Grove

A second variant of the field-and-grove type of indigenous agroforestry is found primarily among shifting cultivators who maintain forests, which they believe are inhabited by spirits or deities. These are thought of as fiercely defending their homes by visiting illness on human intruders. An excellent example is found in the Philippines among the Tagbanuwa on the island of Palawan, described by Fox (1982: 163–76; for India see Gadgil and Vartak 1976). When a Tagbanuwa selects a site in the forest for making a swidden, it must be first determined by a religious practitioner (the shaman) whether there are malevolent spirits (*panya'ɨn*) who claim the place. He or she enters the forest alone, makes an offering, and perhaps experiences a trance or dream in which an answer is received from the spirits. If the results are negative, the area becomes untouchable, and swiddens cannot be opened in it for the lifetimes of the shaman and the shaman's spouse. Another way of testing a potential site is described by Katherine Warner.

> …A potential site was further tested for the presence of a *panya'ɨn* by sticking a piece of bamboo into the ground. The next day when the bamboo was pulled out, if there was dirt sticking inside it, it was said that it was a *panya'ɨn*'s area and that sickness would come if it was planted. Interestingly, the test that showed the presence of the forest spirit on another level gave information on the texture and suitability of the soil. If the soil is hard and stays in the bamboo, it is not quite ready to be planted, whereas if it is soft and fine textured it will fall out, indicating not only the absence of *panya'ɨn* but also the suitability of the soil for planting (Warner 1981: 20).

The result in Tagbanuwa country has been a patchwork effect of swiddens, fallows, secondary growth, bamboo groves, useful grasses, and sacred groves, which has led to a harmonic and productive system that allowed the Tagbanuwa to live in what for swiddenists are quite large villages without depleting the nearby land. The numerous ecotones (well-defined boundaries typical of closed communities) also have insured the abundance of wildlife and game. But unlike the systems described by Wilken, forest material cannot be moved to the field, as sickness and death might follow the breaking of the taboo against trespass. However, the groves provide seed, which can reach the centers of swiddens easily since the Tagbanuwa do not arrange their swiddens in clusters. With the death of the shaman or the migration of his village, his taboo would be forgotten, and a later shaman might come in and determine the former sacred patch to be safe for swiddening. The long-term effect of this again was an agroforestry rotation between fertile sacred groves and cultivated areas.

In field-and-sacred grove systems, forest resources are not used consciously in support of agriculture. But the existence of the grove is preserved so that it can be truly available to play eventually its integral role in shifting cultivation along with all forest vegetation as the "beginning and end" of the swidden cycle, as Warner has expressed it in a nice way (1981: 27).

Apel (1996) describes the complex forest management of the villages of the Dai minority people in Yunnan Province, China. The bulk of their forests are "amenity forests," which provide an aesthetic setting for each village, an expression of a value rare in tropical Asia. Watershed forests are "used forests," recognized as providing construction timber and an adequate supply of water for each village and its rice pondfields. "Forests without special functions" are another kind. All types of forest have high species diversity. About 5% of forests are considered sacred. There are three kinds of these. "Sacred natural woodlands" are wild and have been considered sacred since animist, pre-Buddhist times and are situated on hilltops adjacent to villages. Hunting, tree felling, and collecting are all forbidden there. "Sacred groves," purposively planted near Buddhist temples, are biodiverse, providing sanctuary for rare plants, and yield fruits for Buddhist monks. "Forest cemeteries" must be kept separate from the village at an elevation well below it. Conceptually distinct from all of these are individual "sacred trees," especially the strangling fig (*Ficus altissima*) with its many striking features, which can be planted in sacred Buddhist groves, found wild on hilltops as the homes of spirits and sites of sacrifice to them, or scattered throughout the "used forest." In the latter case, there is a taboo against felling the *Ficus* for use, and they serve a positive ecological function in assuring that frugivores (birds and mammals) have a food supply available to see them through periods of wider food scarcity, thanks to the characteristic of figs to bear fruit at different times. Apel claims that the taboo against cutting down the strangling fig thus prevents local degradation of the forest through overexploitation.

McWilliam (2001) has gathered significant evidence to say that probably all communities on the Island of Timor historically recognized, and many still do recognize, within the districts belonging to them, sacred (*lulic*) forests or groves, existing within government forest land, which they protect against shifting cultivation. Today, much of Timor's forest has been denuded of vegetation, and sacred groves remain as relicts of the wider forest. Depending on the traditions of the varied cultures concerned, sacred groves may have been preserved as the "mythic origin places of local clan groups" and sites of religious sacrifice to those founding ancestors (McWilliam 2001: 97). McWilliam makes a case for East Timor government support of these "forest custodial communities" as entry points for "negotiated reforestation activities," the responsibility for which can be shared between Timorese government and villages. The basis for this survival of sacred groves, he contends, is a tradition of "rural land management and protection" which "provides a powerful source of moral authority and ecological knowledge" that could lead to sustainable conservation programs. This bold suggestion could be true for places other than Timor, as well.

The Field-and-Woodlot: The Ifugao Pinugo

The most striking example of a field-and-grove system is that of the Ifugao of the Cordillera Central mountain range in northern Luzon, Philippines. This system, which may be 1,000-years old, has been described by Harold Conklin (1980; for a review article on this see Olofson 1980). The Ifugao are best known for their wet-rice terraces and irrigation technology on steep terrain. But few know that their woodlots, or *pinugo* as they call them, among pondfields, or at higher elevations, are almost as interesting. Sweet potato swiddens, too, are found at high elevations of a watershed. The most instructive aspect of the Ifugao woodlot is that it is made out of grassland (and secondary forest) through an intermediate swidden stage. To the Ifugao, making a swidden is the logical first step in reforestation. In the swidden stage, the land being used is not owned by the one making the swidden; he only has the right to use its products. But when a family member decides to grow a woodlot on this swidden, it becomes recognized by all families in the watershed that it is now owned, as a piece of land, by that individual, and its boundaries will be clearly demarcated for all to see.

The Ifugao woodlot is itself an agrisilvicultural system. The only kind of economic plant not grown appears to be vegetables and tubers, if Conklin in his account has mentioned everything. But there are plantings of trees for firewood and for the provision of building materials, utensils, furniture, tools, and religious figurines; fruit trees and grove crops such as betel nut; bamboos and rattans; and medicinal plants. According to Conklin, the species diversity exceeds that of the natural forest. The woodlot is weeded, pruned, and thinned as it grows. It has in fact grown out of an accelerated swidden. And, it might be added, that as a woodlot is harvested and ages, it reaches a later stage in its cultural successional sere.

Oftentimes, the Ifugao cluster their swiddens together, perhaps to defend them better from wild pigs by digging trenches on the edges of the cluster. When the swiddens are converted into woodlots, the cluster is more ecologically sound as a forested expanse than would be a single cluster alone.

Besides supplying the Ifugao with numerous products, which make woodlots second only to pondfields in economic value, the woodlots are overtly recognized by the Ifugao as supportive of the terraces, though not by the use of tree litter as fertilizer (this comes from the floor of the public forest). They are well aware, rather, of the fact that they aid crucially in conserving the water needed in irrigation, and in preventing soil erosion and land slippage. Conklin found that even children could talk about this. In addition, when the woodlot becomes aged and completely harvested it can be reconverted to swidden, at which time its soil should be particularly fertile for sweet potato.

The Field-and-Mixed Home Garden

Of some importance as indigenous agroforestry are field-and-grove systems in which the grove component is the mixed tropical "dooryard," "kitchen," or "home" garden. The dooryard garden represents a distinct agricultural enterprise with its own integrity and often with crucial connections to the farm component. Such gardens are similar to harmonic, polycultural swiddens, except that more important in them are fruit trees, which provide a protective canopy under which other plants are grown, and that perhaps as a result of the need for closed nutrient cycling as in forests, have become permanent. Stuart Schlegel (1979) in his description of the home gardens of the Tiruray of Mindanao finds that they are in fact a terminal stage in swidden. They would thus in Tiruray be an equivalent to the Ifugao woodlot, which also develops out of swidden, except that the Ifugao woodlot may be some distance from the house.

Home gardens are of great significance on the world's most densely populated island, Java, where they are called *pekarangan*. First of all, this is due to their ability to protect the soil through forest mimicry. Among the first to note this was the geographer Karl Pelzer (1945: 43–47) drawing on the work of Ochse and Terra in Indonesia. Then, according to an economic anthropologist, who was also including *talun-kebun* (village-agroforests) in her statistics,

> [For Java] … garden land … makes up anywhere from 15–75% of the cultivable land area, may provide more than 20% of household income, and more than 40% of a household's caloric requirements (Stoler 1978: 86–87).

Another interesting statistic comes from Terra (1966), who found that once well established and continuously producing throughout the year, the home garden grove in Java requires only 5-man days of labor per year for its upkeep. Finally, Indonesian ecologists, noting that dooryard gardens in some overfarmed areas of Central Java "look like green oases in a desert of eroded hills," have characterized them as the last line of defense against ecosystem degradation (Soemarwoto et al. 1976: 194). These same observers go on to suggest that they could be expanded spatially to become *talun-kebun* and begin a rehabilitation of these same uplands. In this last regard, Central Javanese home gardens are fulfilling the same function as has been reported for sacred groves in western India (Gadgil and Vartak 1976) by representing the last patches of forest-like cover in the landscape.

Pelzer believed that mixed home gardens were not well developed in the Philippines. But recent work by Sommers (1978) has shown that they are rather widespread there, and the problem remains of diffusing them further to the many households where they are yet nonexistent or underdeveloped.

From descriptions such as Stoler's, it is clear that Javanese home gardens are an alternative forest structure (AFS).

> They often lack the orderly appearance of other forms of cultivation. They seem a haphazard array of scattered trees, untended plants, crawling vines, and decaying vegetation. In fact the lack of orderly rows and clean swept vegetation is precisely what allows *pekarangan* to produce its own natural fertilizers, and remain erosion-free even in critical watershed areas of poor land use. The multileveled "disorder" functions in part to prevent unnecessary organic waste found under other systems of cultivation (Stoler 1978: 88–9).

She goes on to mention timber trees as one of their products.

By viewing home gardens as part of a field-and-grove system, we throw them into a wider context. The ways in which they are related to the staple field, livestock, and other gardens are probably many and varied, but not covered systematically in the literature in any one place. One thing that stands out from putting together scattered references on the dooryard garden, especially in the context of shifting cultivation combined with stable residences, is its role as an experimental site for new varieties of vegetables and even staples borrowed from neighboring people or visitors. If these do well in the dooryard, they may be grown on a wider scale and even tried out in the main field. For example, among the wet-rice growing Bontok in northern Luzon, Philippines, where sweet potato grown in swiddens is calorically more important than rice grown in mountain terraces, new varieties of sweet potato are planted first in the *doran,* which is found around the house. This area acts as a reserve for all kinds of cuttings, and also has fruit trees, green vegetables, and other root crops. From the *doran*, the cuttings may be transplanted to swiddens or fed to pigs (Yen 1974: 92, 95, 96).

This brings us to the connection between home gardens and livestock. Among the Ikalahan of northern Luzon, papaya, chayote, and sweet potato vines from the dooryard go into the special pig's cauldron in the kitchen where cooked food is prepared for them daily (Olofson 1984). The Ikalahan pig, however, is allowed to roam freely to hunt for mast on the forest floor during the day, so it cannot contribute collectible manure for the maintenance of the dooryard plants. Among the Bontok, however, pigs are kept near or under the house and their manure can be collected and added to compost which goes into rice fields and which helps to account for the high productivity of Bontok wet rice without capital inputs (Sajise and Omengan 1981).

In the entry on harmonic swiddens, we noted that a number of South American Amazonian Indian groups have experimented with swiddens of much-less-than-expected species diversity, swiddens often polyvarietal in nature, to perhaps find other ways of providing some of the values of the tropical rainforest to the cropped field. Among the Siona–Secoya, one of these groups, Vickers (1983) found that home gardens had sparse and discontinuous canopies; they are also not the best examples of the AFS. However, it is important to note that Lathrap earlier (1977: 729–736) had much to say about highly diverse mixed-home gardens among people like the Shipibo and Desana and found that they may have been very significant in the evolution of agriculture among South American Indians. It is worth quoting from him at a little length.

> The house garden functioned as an experimental plot. New species of plants brought in from the forest or received through contact with other ethnic groups would be introduced into the house garden in a conscious effort to evaluate their potential as useful cultigens. The composition of the house garden was dynamic; …the potential of [new] species was constantly being investigated…. I would argue that the important food crops of Amazonia were ennobled in the context of these experimental plots…. Under the artificial growing conditions and a degree of artificial selection, they were genetically modified so as to become the supremely efficient food producers of the tropical forest system at the time of the contact period (Lathrap 1977: 733).

See also: ►Swidden, ►Forestry in Japan, ►Environment and Nature: Buddhism, ►Environment and Nature in Thailand

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Agroforestry: Field-and-Interstitial Support Trees

Harold Olofson

In this type of agroforestry, trees in groves or rows are separated spatially from crops, but are in a common field with them. The trees may be planted in arrangements interstitial (with small openings or gaps) to crop fields, for example, as field borders, or along the contours of a slope. In a variation, the trees and crops may be rotated in a field. In this agroforestry rotation, the trees interplanted in a mixture with crops may be cut back (coppiced) to allow crops to grow in the sun, and in a later phase allowed to take over and dominate the field for a period when their products are needed. This last essentially entails a rotation or alternation – or "separation" – of trees and crops through time. In all variations, the trees support the crops, as well as yield products of their own.

Spatially Interstitial Trees

There are many examples of trees that are spatially interstitial:

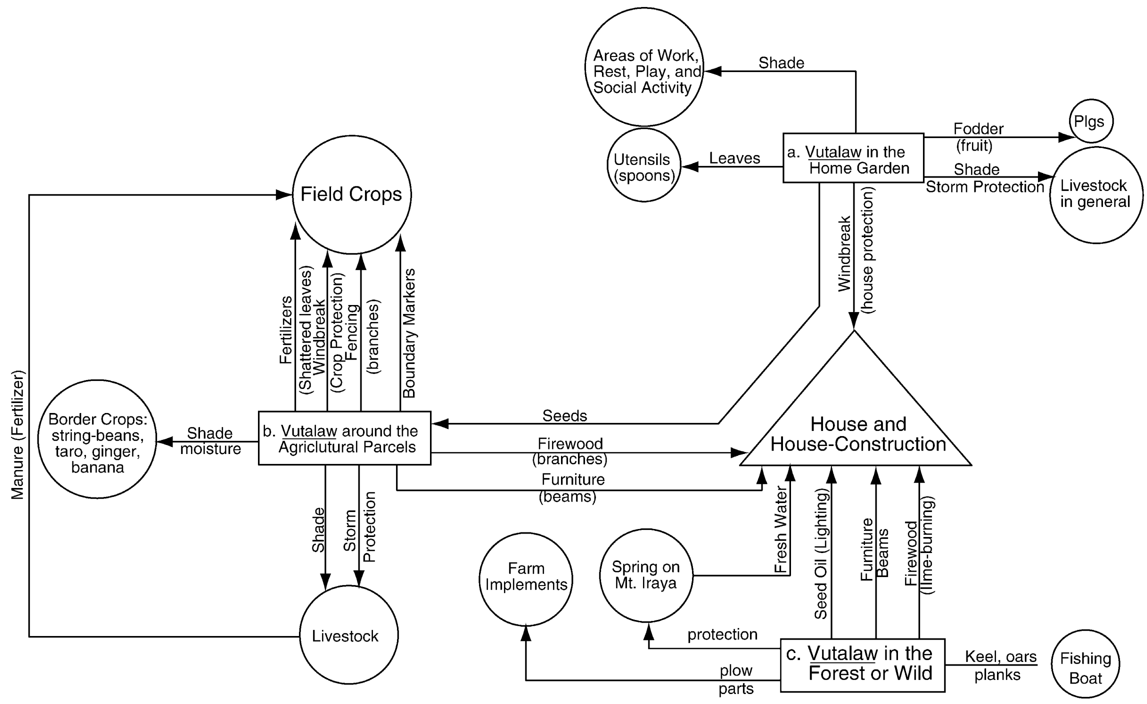
1. The planting of Osage orange in the American Great Plains as a hedge to protect fields from animals and then, as they grew, as a windbreak (Smith and Perino 1981);
2. The growing of ipil–ipil for fertilizer or firewood on rice bunds in Pangasinan, Philippines (interview data);
3. A living fencerow of *Cestrum nocturnum*, guava, and forest trees to prevent the passage of pigs from a pigsty into a swiddening area among the Ikalahan of northern Luzon, Philippines (personal observation);
4. The use of ipil–ipil in contoured rows to prevent erosion on steep corn farms in Cebu (National Academy of Sciences 1977: 72–3);
5. The planting of teak on fallow boundaries by the Yoruba of Nigeria to claim ownership of the fallow (John Wyatt-Smith, personal communication), and thus probably prevent premature cropping by others; and
6. The planting in Batanes, Philippines of palo maria (*Calophyllum inophyllum*) as living fencerows on parcel borders to mark boundaries, provide shade for cattle, windbreaks for crop protection in a typhoon-battered region, firewood, fencing material, and moist soil for plantings of ginger and beans (Rede-Blolong and Olofson 1997: 110–2; see Fig. 1).

Of special interest is the use of trees to reclaim soil to fixate sand dunes, thus adding to the total arable land. A good example is the construction of living fencerows in seasonal floodplains by the Indians of Sonora, Mexico. These are arranged in such a way that they are able to capture arable soil from seasonally torrential watercourses that would otherwise erode away the area in which the fencerows have been planted. The trees are planted so as to impede the flow of water, allowing soil particles in the water to sink to the bottom of the stream (Nabhan and Sheridan 1977). While this type of agroforestry involves the use of residual, leftover, or boundary spaces, such trees can be of the utmost importance; they can be used to reverse the deleterious forces of nature.

Interstitial arrangements involving livestock occur where spatially interstitial trees provide fodder. A case in point occurs in Jalajala, Rizal, Philippines, where native ipil–ipil growing between (and within) upland parcels is collected and brought down to sites situated on a level lakeside plain in order to stall- or force-feed milch cows (Olofson 1985: 322).

Temporally Interstitial Trees, or the Agroforestry Rotation

An interesting system that falls into this rubric has been described for the Atoni language speakers in the province of Amarasi in southwestern Timor. The system is a relatively recent innovation, but originated within and has been strongly supported by traditional institutions. It is a many-faceted response to famines caused by slash-and-burn on poor soils in a climate with a 9-month dry season, and to the spread of *Lantana camara*, which was interfering with the attempt to develop a livestock industry in the resulting savannahs, because it is poisonous to cattle:



Agroforestry: Field-and-Interstitial Support Trees. Fig. 1 The participation of the *vutalaw* (*Calophyllum inophyllum*) in the Ivatan agroecosystem. From Rede-Blolong and Olofson (1997: 115). By permission of *Philippine Quarterly of Culture & Society*. Thanks to Fr. Herman van Engelen for his help in constructing this illustration.

> With the systematic use of [*Leucaena leucocephala*], which had been known in Timor for centuries as a fallow plant, a significant agroecological change took place in Amarasi. An *adat* regulation pronounced in 1932 by the local ruler (*raja*) in accordance with his council obliged every farmer in Amarasi to plant rows of this leguminous plant with at least 3-m spacings along the contour lines on his shifting plot before abandoning it. This was intended to reduce erosion, to encourage new plant growth, and to improve soil fertility by making use of the nitrogen-fixing properties of this legume. In order to put the necessary pressure behind these regulations, each farmer was threatened with a heavy fine for failing to comply (Metzner 1981: 96).

In 1948 the government officially adopted this custom law as its own, and by 1951 *Lantana* had been significantly reduced by the ipil–ipil (*lamtoro* in Atoni), so that land-use zoning, also originating in *adat* decisions taken by the raja in 1938, could be most efficiently implemented to aid in the separation of farming and grazing areas (Metzner 1981: 96–8).

It can be assumed that the ipil–ipil was planted late into the swidden because of its rapid growth, so that a succession of food crops and ipil–ipil took place, rather than a mixture, in the initial phase. In one area this use of ipil–ipil led to a situation where the farmers could make a labor-saving innovation that eventually resulted in almost permanent cultivation.

> Once the *lamtoro* poles and leaves are cut they are not burnt but left on the field as mulch. Into this mulch layer maize and other crops are planted. Weeding is limited to cutting off the fresh shoots growing from the roots of the legume left in the ground. Similarly the cut-off shoots remain on the field as mulch. Since the soil is neither hoed nor turned the thin layer of topsoil is hardly disturbed. According to the farmers…even after seven years of continuous cultivation yields were not lower than those expected from newly cleared *lamtoro* plots (Metzner 1981: 100).

In this system, the growth of the trees and crops alternate over time in the same space. In most swiddens, the forest stage of the swidden cycle primarily functions as a source of fertilizer to be released by the next burning, of shade to eliminate weeds, and of seed for reforestation of fallow areas. Here the fast growth of the ipil–ipil as well as the soil enrichment caused by nitrogen fixation adds significantly to these functions, making the next cultivation of the plot possible much sooner as well as extending the cropping period. This last, in turn, makes it possible to delay fallow and to allow adjacent ipil–ipil fallows to grow more. For this reason, agroforestry rotations of temporally interstitial trees that nourish the soil could be called forms of accelerated swidden.

It is important to note here that while the tree component is kept "submerged" or cut back during the cropping phase, so that we cannot speak of a mix of growing trees and crops, this example is still one of a simultaneous polyculture. The underground portions of the ipil–ipil still play a positive role in generating nitrogen and holding the soil.

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Agroforestry: Harmonic Swiddens

Harold Olofson

Forest swiddens are clearings made in a forest by shifting cultivators, to be planted to crops. They are generally of two types, depending on the cultural traditions of the cultivators: harmonic and disharmonic.

Harmonic swiddens are found among many indigenous cultivators, and are essentially a form of agroforestry. In fact, when they are designed and managed in such a way as to enable rapid recovery of the forest after a brief period of use during which their soil fertility is depleted, they are good models for modern agroforestry. As integral agroforestry paralleling Conklin's (Conklin 1961) famous classification of types of shifting cultivation, they are embedded in cultures into which members of a society are born, as part of their plan for survival. Making harmonic swiddens is learned as part of growing up in indigenous societies where they are integral to the tradition of cultivation. One of the effects of harmonic swiddens which is often "in the awareness" of their practitioners is to accelerate the recovery of the forest structure which was eliminated in the process of making a swidden in the forest, once they have to leave the swidden. This is done by paralleling or imitating in the swidden that forest structure which they have felled, or one which exists nearby. They attempt to harmonize the structure of the swidden with the nature of the environmental context in which they live. Such swiddens can be called Alternative Forest Structures (AFS). The AFS can have up to five characteristics that aid in identifying it as forest alternatives. The first three were clearly described by the anthropologist Geertz (Geertz 1963; Harris 1971).

1. There is a high diversity index of plant species in the swidden, as in the natural forest. In contrast to monoculture, which specializes in one species only, there are many species and varieties planted in the field. Thus, a swidden is a simultaneous polyculture (coined by Kass 1976: 6), but a complex, not a simple one. This term covers patterns involved in mixed cropping, intercropping, interculture, interplanting and relay-planting. Also in contrast to monoculture, there are relatively few representatives of any species.
2. The vegetation is stratified into soil-protecting canopy layers, two or four in number, but usually less than in a tropical forest climax.
3. As in the natural forest ecosystem, the tight cycling of nutrients within the bounded agroecosystem is quite rapid. As has been said for the tropical forest, the AFS cannibalizes itself by quickly reabsorbing its own litter into its root systems. While this is widely believed to be true for some of the AFS described below, there is a need to confirm this through detailed agroecological studies.
4. Oldeman nicely analyzes the fourth analogy. According to him, especially in older forests, "the death of forest patches is a perfectly natural mechanism which constitutes the motor of all vegetational dynamism" (Oldeman 1981: 79). Numerous accidents through time, such as earthquake, exposure to storm winds, or the formation of goblet-shaped clearings or *chablis* by the falling of single, large, old trees cause the forest to take on the appearance of a mosaic of points on a successional sere. As Rambo (Rambo 1981: 36) has put it, man may purposefully and systematically manipulate the forest – through an eco-catastrosphe of felling and burning – to deflect the natural succession on a site back to more open conditions and thus cause a patch to enter a succession which he himself designs. Geertz called

this "putting the forest through its paces." Thus, like patches in the forest many AFS will be located on some point along a sere. Oldeman points out how it requires a good deal of art and science to preserve with some stability the analogical relationships between the cultivation cycle and the natural cycle, and to replace the wild species by domesticated ones that fill the "same functional and structural niche as their wild precedents" (Oldeman 1981: 81). Like the forest, swiddens also have phases in their histories.

5. The overall effect is one of resonance between the AFS and the surrounding natural forest. The structure of the forest is imitated, planting materials may actually be brought in from the forest, and forest wildlife may flourish at the ecotone (boundary) with the AFS. In these ways, the AFS may act to reinforce the forest ecosystem.

Disharmonic swiddens may have evolved from harmonic ones, with the farmer learning to specialize to the point of monoculture or near-monoculture, with one species such as sweet potato, upland rice, or corn dominating in the field. In this process, the swidden loses its stratified canopies and there is a dangerous reduction of plant cover in the clearing during the cropping stage. Or, disharmonic swiddens may be cleared by land-hungry, lowland migrants to the hills or forests who may be people who have little knowledge of indigenous practices, who did not grow up in cultures traditionally skilled in forest farming.

Disharmonic swiddens have no resonance with the surrounding forest other than attracting wildlife; they bring on the threat of soil erosion through heavy rainfull impacting on the bare soil, grassy intrusion, and a decrease of nutritional diversity in the family diet. The harmonic swidden is much more capable than the disharmonic of regenerating into natural forest during the fallow period.

Swiddens can be found on a continuum of incipient to advanced indigenous agroforestries. In the first, trees may not be a major component of the swiddens, but species of fruit trees are usually present. These incipient agroforestries may be seen as evolutionary precursors to indigenous agroforestries which put more stress on trees, usually always to support the crops. Swiddens of this nature have been reported widely for traditional peoples. For the T'boli of Mindanao, Rice has made this observation:

> Usually there are three or more different crops on a given piece of land at all times and as each crop ripens and is harvested its place is taken by another. A well-developed system of inherited agricultural knowledge governs which seeds are to be planted together and in which months they can be planted for most effectiveness. This… tends to maintain the soil fertility longer since at least one legume is usually in the soil to stimulate nitrogen fixation. Second, the land is covered more continuously and heavily, and erosion and weed control are thus more effective… (Rice 1981: 77).

For the Tsembaga Maring of New Guinea, one anthropologist has described the forest-like structure of their swiddens.

> In the garden as in the forest, species are not segregated by rows or sections but are intricately intermingled, so that as they mature the garden becomes stratified and the plants make maximum use of surface area and of variations in vertical dimensions. For example, taro and sweet potato tubers mature just below the surface; the cassava root lies deeper and yams are the deepest of all. A mat of sweet potato leaves covers the soil at ground level. The taro leaves project above this mat; the hibiscus, sugarcane and [*Setaria palmaefolia*] stand higher still, and the fronds of the banana spread out above the rest. This intermingling does more than make the best use of a fixed volume. It also discourages plant-specific insect pests, it allows advantage to be taken of slight variations in garden habitats, it is protective of the thin tropical soil and it achieves a high photosynthetic efficiency (Rappaport 1971: 121–2).

The Tiruray of Mindanao have been described as having another kind of what I call resonance between the forest and the cultivated areas. This involves a virtual exchange of planting materials between the two sites. Four bamboo species, the fruit tree *Averrhoa carambola*, narra, and *Gendarussa vulgaris* are taken from the forest and planted in swiddens, gardens, at the edge of watercourses, or right at the forest boundary, while the candlenut (*Aleurites moluccana*) is planted directly in the forest (Schlegel 1979: 171–9, 194–205).

In harmonic swiddens, trees support the domesticated plants grown in the clearing by first bringing about more fertile soil conditions and then by being sacrificed through burning for fertilizer. It is difficult to see, however, how nutrients from the clearing do much in their turn to make the forest prosper. Perhaps on the edges of swiddens, where some slash or crop residues may be thrown from the swidden into the forest, or where rainwater is eroded down from the swidden, nutrients may re-enter the nutrient cycle of a small section of forest. On the field itself, only crop residues remain to act as a source of nutrients for the returning forest. It may be that young trees are able to make incredibly efficient use of such small amounts of nutrients, for on soils in which domesticated plants no longer flourish, secondary growth will oftentimes thrive.

The Lacandon Maya of Chiapas, Mexico plant numerous varieties of fast-growing root and tree crops prior to the planting of corn in their *milpas* (swiddens); these prevent soil erosion and nutrient leaching in the newly cleared field. During the rains, many other species of tubers, trees, cereals and vegetables are planted. Of great interest is the observation that the Lacandones have learned to plant several of these crops only when certain "indicator" species in the primary forest begin to flower. For each planted species, the corresponding flowering forest species is called the "foot" of that crop. "Such a system coordinates the agricultural cycle with current environmental conditions, rather than with a fixed calendar that makes no provisions for annual variations in temperature and precipitation" (Nations and Nigh 1980: 9–11, see Table 1). Thus the Lacandones tune in to what ecologists would call the forest's information flow. This could also be described as the dispersion of crop cycles through time.

There is also, among the Lacandones, dispersion of plants in space through their swiddens. This prevents large clusters of single species and so emulates the high species diversity index of the forest, ensuring that the swidden "becomes a living mass of food-producing plants which occupy the entire cleared area both above and below the soil." These dispersions in space and time enable the plants to escape their herbivorous predators, and make possible a sustained yield of food throughout the year (Nations and Nigh 1980: 11).

The Lacandones have evolved a swidden system wherein a swidden is only cultivated for short periods, and few weedings are done. This allows secondary species to establish themselves quickly on sites that are abandoned, so that re-opening of that space to cultivation can take place after only two or three years of fallowing, since forest growth will have been enough to provide sufficient ash fertilizer after burning. Not only that, but wild species are encouraged, and a variety of other useful plants are deliberately seeded into the *acahual* (fallow) to accelerate the reappearance of the forest (Nations and Nigh 1980: 15).

The Lacandones recognize the forest as the principle factor in regulating itself. The strategy is thus to "farm" in the forest… not to replace the forest in order to farm (Nations and Nigh 1980: 20).

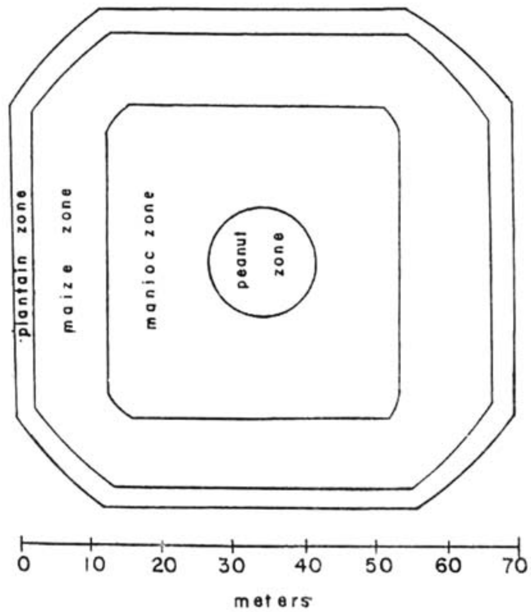
All of the above is not to imply that all shifting cultivators have harmonic swiddens, as defined previously. Newcomers to forest farming do not have the required knowledge for managing forest-friendly swiddens. But traditional, integrated swiddenists also may not have swiddens that are Alternative Forest-Like Structures. Anthropological research prior to 1983 among Amazonian Indian groups living near the Equator in South America found a number of tribes without them, interspersed among those who do. In 1983, the journal *Human Ecology* published a symposium of papers on these groups, wherein the authors attempted "appropriate descriptions" of them, which were summarized by Beckerman (Beckerman 1983a). The research found, instead of harmonic features, monocropping, planting of different monocrops in concentric circles around the swidden (in one culture, the family house was always cited in the center of the swidden), and polyvarieties of the staple cultigen (usually many varieties of cassava [manioc] mixed together). In the symposium, attempts were made to explain how these arrangements were able to perform some of the functions of the Alternative Forest-Like Structure. For example, the different varieties of cassava planted in Jivaroan gardens have a "variation of branching pattern, leaf shape, and growth period …promoting effective vertical and lateral exploitation of available light, warmth, and moisture" (Boster 1983: 62) that would be much the same as that achieved by the mixture of distinct species. Beckman notes that the simultaneous monocrops planted in an annular fashion among the Bari (Beckerman 1983b) and the Candoshi (Stocks 1983, see Fig. 1) are done so that the tallest plants are in the outer ring and the shortest in the center ring, creating a downward gradient of crop elevations from the edge to the center – a "funnel-like" effect in the garden. Stocks suggested that this arrangement reduces the shading of a shorter crop by a taller one; protects interior crops from pests by placing crops that are valued less by people but which taste best to pests on the outer rim, thus preventing satisfied pests from continuing on into the center; nourishes the crops on the edge better by placing them next to the forest; and/or disperses crops across a range of "micro-edaphic variation". Beckerman suggested that these and other hypotheses needed agronomic field testing before they could be accepted.

Another possibility springs to mind. In the evolution of agriculture there must have been people who initiated the practice of planting whole fields to one or a few favored staples. The first experimental monocultural fields could have been forest swiddens. Could these Amazonian Indian groups have been among the first to move in this direction? Their heavy reliance on the cassava as their staple food could have supplied a motive. The Amazonian swiddens discussed above may well represent a frozen stage in that transition, a stage continuing on today in those societies.

Swiddens of the South American rain forest which are Alternative Forest-Like Structures happened to be among the earliest studied, particularly by geographers, for example those of the Yanomamo people found in the Upper Orinoco of Venezuela (Harris 1971). Treacy (Treacy 1982) has also written of them among the Bora in southern Colombia. He makes the following very

Agroforestry: Harmonic Swiddens. Table 1 "Foot" indicator plants: Wild forest species whose flowering provides information flow to the Lacandon Maya. From Nations and Nigh 1980, p. 12.

Crop				Indicator Species		
Month	Region	English	Latin	English	Latin	Lacandon
January	South	corn	Zea mays	barbasco	Paullina pinnata	mäsh ak'
February	North	watermelon	Citrullus vulgaris	corkwood	Heliocarpus donnell-smithii	halo
	North	corn	Zea mays	corkwood	Heliocarpus donnell-smithii	halo
March	–	–	–	–	–	–
April-early	South	corn	Zea mays	"white rope" vine	unidentified	säk su'um
April-late	North & South	corn	Zea mays	?	Bucida buceras	pok te'
May-late	North & South	corn	Zea mays	mahogany	Swietenia macrophylla	punah
June-early	North & South	corn	Zea mays	mahogany	Swietenia macrophylla	punah
	North	rice	Oryza sativa	mahogany	Swietenia macrophylla	punah
	North	peanuts	Arachis hypogaea	mahogany	Swietenia macrophylla	punah
July	–	–	–	–	–	–
August	North	tobacco	Nicotiana tabacum	black bache	Guatteria anomala	ek'bache
	North	black climbing beans	Phaseolus vulgaris	black bache	Guatteria anomala	ek'bache
September-late	North	sweet potato	Ipomoea batatas	?	Nectandra sp.	ek'onté
October	North	tobacco	Nicotiana tabacum	wild tamarind	Dialum guianese	wäch
	South	jícama	Pachyrrhizus erosus	water vine	Vitis tillifolia	yuhi
	South	corn	Zea mays	?	unidentified	k'uwan
November-early	South	corn	Zea mays	?	unidentified	piskinin
November-late	North	corn	Zea mays	barbasco	Paullina pinnata	mäsh ak'
December-late	North	corn	Zea mays	corkwood	Heliocarpus donnell-smithii	halo



Agroforestry: Harmonic Swiddens. Fig. 1 Idealized plan view of ring-planting in a Candoshi swidden. From Stocks 1983, p. 77. (Permission pending).

nice point for them: "...the notion that shifting cultivation fields are 'abandoned' with fallowing needs reassessment" because fruit trees, planted in the Bora swidden, continue to grow for a long period of time after final crop harvesting and the ground around them is regularly weeded to prevent competition with fast-growing secondary forest species (Treacy 1982: 16).

See also: ►Swidden

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Agroforestry: Special Systems

Harold Olofson

Certain indigenous agroforestry systems do not fit easily into a Western-science classification of such systems because, anomalously, they do not have as major components either a field of agricultural food crops or grazing livestock. Instead they involve, on the one hand, specific conserved species of forest vegetation, or sizeable conserved sections of forest, and on the other, such animal food sources as fish or bees in the place of domesticated animals or plants (although other agricultural or even agroforestry types may be found elsewhere in the village or district under consideration). Bee culture, however, is considered a branch of agriculture in some places (Commonwealth Agricultural Bureaux 1980). Existing forest species are simply maintained as a support for either aquaculture or apiculture. These systems are not well known.

Aqua-Silviculture

The evidence for an indigenous aqua-silviculture, or combination of aquatic resources with managed forest vegetation, is thin. One possibility is a system described by Joly (1981) for a mixed Hispanic and Indian group living along rivers in upland Panama. These people train a species of riverine fish (*Brycon chagrensis*) to feed on the leaves of *Piper auritum* placed as bait in a system of stockades in family-owned pools during periods of low water. The fish absorbs the pleasant flavor of the leaves and the stockades facilitate the trapping of the fish.

It is somewhat questionable whether the plant *P. auritum* can be included in a discussion of silviculture, which pertains primarily to trees. Although Joly's discussion is unclear, it seems that this herb is not a part of the gallery forest found adjacent to the pools. It is apparently gathered from secondary forest vegetation growing away from the river and brought to the feeder devices. It is, however, at the very least a conserved forest resource, for when clearings are made for swidden, "clumps" of the plants are left untouched. If it requires shade, then other forest trees are involved in its conservation.

The Uanano Indians in the Uaupes River Basin in the Brazilian Amazon rainforest provide another example of indigenous aqua-silviculture. They take care to preserve particularly the forests along major rivers, by prohibiting the practice of shifting cultivation on the river margins. They know that if they interfere with those trees, they will harm the rivers' fish populations, their major source of protein.

A Western science explanation can be made for what the Uanano perceive in doing this. The rivers in the Uaupes Basin are all blackwater rivers, full of tannins produced by the rainforest plant species as a protection against herbivores. Rains wash these tannins from the litter on the forest floor into the drainage system, where they prevent the growth of microflora which fish feed upon. These rivers generally have low levels of nutrients and primary phytoplankton. But during rainy seasons of high water in the rivers, the fish are able to swim into the forest with the rising river waters and feed on the vegetable matter (leaves, fruits, flowers, seeds, and microflora) and small animals (insects and their larvae, arachnids, crustaceans, and worms) that they can find there as "floating and decomposed matter and mud." Observing this, the Uanano are "acutely aware" that preservation of the forest will save for them the fish as well (Chernela 1982).

Another example of aqua-silviculture has been noticed in a lakeside community in the Philippines, where the finally branching tree *Streblus asper* is maintained in farmers' parcels. Branches are cut and submerged in the lake water for a time necessary to capture shrimp which come to shelter among them (H. Olofson, fieldnotes, Jalajala, Rizal, Philippines).

Api-Silviculture

When forest resources in the form of nectar-producing flowering trees and other plants are consciously conserved in order to support domestic beekeeping and honey production, we have what could be called an indigenous api-silviculture. Essential to the recognition that api-silviculture exists is the knowledge that a beekeeping people can name flowering forest species important in honey production and also conserve them by, for example, not cutting them for swidden.

The protection of nectar-producing forest trees occurs among the swiddening Iraya of northern Mindoro Island, Philippines. Another aspect of their traditional conservation is the restriction of honey collection to the waxing period of the moon, thus forcing bees to swarm and to build up new hives with honey in the waning of the moon. Such customs may be stimulated by the fact that the Iraya look upon honey as a shamanic medicine (Revel-Macdonald 1971). But the Iraya are "honey hunters," not beekeepers, having to look for such new hives by observing the flight directions of bees after those bees partake of river water. (The term "honey gatherers" would be most properly reserved for those people who know of permanent hive sites, such as those located on known cliff faces, to which they can return year after year.)

It would seem logical that if honey-hunters protect relevant trees, so also there must be examples of indigenous beekeepers who do. A good description of ritualized domestic beekeeping among the Yucatecan Maya is given in Weaver and Weaver (1981) but only the plant *Gymnopodium antigonoides* is mentioned as a recognized nectar source; they do not say whether it is protected. However, Chemas and Rico-Gray (1991) say that the Yucatecan Maya are able to identify 12 species of wild trees and weeds that are good sources of nectar foraged by bees to produce honey. They can rank these in terms of quantity, odor, flavor, color, and viscosity of the honey produced, as well as the quality of their pollen and nectar. They have a good knowledge of the flowering phenology of these trees, and know how very dry and very rainy seasons, very humid and very cool years, affect the honey produced by bees. They find that the management of honey and pollen-producing vegetation need be only minimal. In their area, forest cutting has led to the forest being composed of mainly young trees. But this may have done little damage to the annual honey production cycle, since bees prefer to visit younger successional stages of forest growth anyway, as well as roadside plants.

The conservation of interstitial trees or of bee pasture useful to bees would be essential to growing populations who combine farming and beekeeping, since otherwise the nectar sources would give way to the spread of crop land (see Editorial 1981).

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Agroforestry: Systems with Animals and Grasses

Harold Olofson

Silvipasture

Silvipasture is an agroecosystem which involves a necessarily precise combination of forest trees, livestock, and selected grasses.

It is difficult to locate references on indigenous communities which have achieved the combination of forest-grazing consciously involving silviculture. For example, one would not expect to find this among pastoralists, who have in the course of cultural evolution branched off from a way of agricultural life involving both domesticated animals and plants to concentrate on domestic animals alone – full-time pastoralists are not usually planters. They are known to graze their animals among forest trees, and to use those trees for shade for their livestock, but it is difficult to find reference to their actually having planted those trees. This type of agroforestry appears to be a very recent conception.

If they can be accepted as a people who are now, in this day, "indigenous" to their homeland, some nth-generation Caucasian New Zealanders are a good example of temperate-climate silvipastoralists (Stover 1979). Silvipasture, interestingly enough, was discovered almost accidentally and simultaneously by imaginative, private farmers and private company employees in the 1960s, not by scientific research. Observations of their schemes led to serious consideration of silvipasture in the Forestry Development Conferences of that country in the 60s and 70s and silvipasture was then realized as a way of reversing the historical depletion of timber resources caused by clearing land for cattle and sheep. As a response to increased timber prices, and to the lowering prices for meat and wool,

> Farmers … have come to see trees not only as shelters for livestock both winter and summer and as sources of fuel and locally needed posts, but as another potential cash crop, albeit, a slow-growing one, that might share growing space with grass (Stover 1979: 441).

The New Zealanders' view of the role of livestock is reminiscent of the rationale for the food crops in accelerated swidden or food-tree crop interplantings. In the latter, the crops provided the short-term returns necessary to stimulate the willingness to plant and wait for trees on the same space, as among the Ifugao in Northern Luzon, Philippines. In New Zealand, the farmers see that the animals provide income to cover interest costs during the period before the trees can be harvested. Silvipasture in New Zealand involves allowing livestock into well-established forest, once the potential relationships are well understood; planting trees into well-established pasture; or sowing grass among tree-seedlings on run-down land.

Agri-Silvipasture

A remarkable indigenous system involving the mix of three components – livestock, trees, and a staple crop, is found among the Fur of Sudan. This permanent system is made possible by the unique characteristics of the savannah tree *Acacia albida* (Radwanski and Wickens 1967). Unlike almost all other trees, this legume sheds its leaves at the start of the rainy season, and plots of millet or sorghum placed directly under the trees quickly benefit from the rapidly decaying leaves, at a time when sunlight is able to reach the crop through the tree canopy. In the dry season, the trees are in leaf, providing shade for the plots below, and keeping down the temperature of the soil which is able to retain more water than otherwise. During this fallow period, livestock may be allowed to graze and rest in the shade under the trees, especially when a storm blows down the nutritious fruits of the acacia. The livestock in turn fertilize the area. They are also fed with the leaves and fruits of the tree especially collected by the Fur as fodder. And the combination of animal manure and *Acacia albida* leaves makes nitrogen plentifully available under the trees.

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Agroforestry in the Pacific Islands

William C. Clarke

The planting of trees together with the cultivation of annual crops, a combination now generally termed agroforestry, has been strongly promoted in recent years as a way to prevent land degradation and to increase total production of food and useful products from a unit of land. Throughout the Third World, development agencies and government departments of agriculture and forestry have been advocating agroforestry as a way to harmonize forests with farming, or as a way to make up, at least partially, for the destruction of natural forests and their replacement by pasture or by fields of annual crops. In the Pacific these modern, aid-funded attempts to promote agroforestry are ironic, for they take place in a region where agroforestry systems were developed thousands of years ago and where hundreds of species of trees are still used in a be wildering variety of ways.

At least a few trees even have a place in the popular imagination about the Pacific Islands. If asked what particularly characterizes the landscape of the islands, most people would think of a line of coconut palms overhanging a beach beside a coral-reef lagoon. They might also envision the stately and strikingly beautiful breadfruit tree, whose yield of starchy fruit so enchanted Captain Cook and his companions on the first European visit to Tahiti and subsequently led to Captain Bligh's famous voyage to Tahiti in H. M. S. *Bounty* to collect breadfruit cultivars for the West Indies. These conceptions of coconut palms and breadfruit trees in Pacific landscapes are accurate enough, but they only begin to suggest the full significance of trees, both domesticated and wild, in the lives of traditional Pacific peoples.

Recent chromosomal and paleo-botanical studies in the Melanesian islands of the western Pacific reveal that the domestication of plants extends back in time there for thousands of years, thus demonstrating that agriculture evolved endogenously in the Pacific region, rather than being solely or mainly the result of a direct transfer from southeast Asia, as had been believed previously. Plants that may have been domesticated in western Melanesia include – aside from important short-term crops such as *Colocasia* taro and sugar cane – a remarkable number of trees or shrubs. This early emphasis on arboriculture – the cultivation of trees and shrubs – was eventually transported all across the Pacific by the voyaging colonist cultivators, to be incorporated into production systems everywhere and to beget the typical tree-filled environs of human settlements in Polynesia and Micronesia.

Archaeological evidence for a well-developed arboriculture at least 3,500 years ago comes from the Mussau Islands, which are now part of the country of Papua New Guinea. Tree species already in use then included: coconut, two or three species of *Pandanus*, *Inocarpus fagifer* (the "Tahitian chestnut," which remains one of the most important Oceanic arboricultural species), *Canarium indicum* (a nutritionally substantial "almond"-producing tree in Melanesia), *Spondias dulcis* (the vi-apple, now of very wide distribution in the tropical Pacific), and other useful trees such as *Pometia* (which provides edible fruit, medicine, and other products), *Pangium* (seeds edible after treatment to remove the poisonous component), *Terminalia* (edible "beach almond," useful timber), *Burckella* (edible fruit), and *Calophyllum* (timber favored for many uses, sticky sap used for caulking canoes). There is also evidence for the early domestication in the Pacific of several species of sago palm (used in some places to produce starch for food, elsewhere its leaves used as long-lasting house thatching), one kind of banana, and kava (a sprawling shrubby plant, the pounded stems and roots of which are used to make the ritual-social drink long important in many parts of the Pacific).

Over 400 species of trees or tree-like plants have been identified as having widespread or localized economic, cultural, and ecological importance in the Pacific Islands. The adoption of these many kinds of trees for human purposes is the cumulative result of a selection process that occurred over thousands of years and that involved both the domestication of previously unknown species encountered when Pacific voyagers landed on uninhabited islands as well as the deliberate transport from island to island of plants already known to be useful. The trees and their products served Pacific peoples in a great variety of ways. For instance, ecologically, trees provided, among other services, shade, erosion control, wind protection, beach stabilization, soil improvement, and frost protection (at high elevations in New Guinea). Cultural and economic uses included, among many others, house timber, firewood, tools, weapons, fishing equipment, abrasives (for example, the "sandpaper" leaves of some fig species), gums and oils, fiber, beverages (for example, the fluid from coconuts, immensely important for drinking on dry atoll islets), caulking, stimulants, medicines, and love potions and perfumes. Many Pacific trees are also of great importance nutritionally. For example, in various places people depend heavily on one or a combination of staple foods from coconut, breadfruit, bananas, sago palm, or several species of *Pandanus.* Many other species provide supplementary and snack foods. Although many tree foods are energy-rich in carbohydrates or vegetable fats or both, it is in other nutritional essentials that they often excel, compared with the starchy root-crop staples. Several fruits are excellent sources of provitamin A; others provide B-complex vitamins or are rich in vitamin C. Most seeds and green leaves from trees (which are widely eaten) are good sources of plant protein and various micronutrients. Spices and sauces derived from tree products can also be of great nutritional and culinary significance. An oily sauce made from the huge red fruit of a *Pandanus* species in highland New Guinea provides a rich, nutritious condiment for many otherwise bland foods. Or coconut milk or cream (squeezed from the coconut flesh) is widely used in cooking in coastal areas, and in places is aged or fermented with sea water and other flavorings to make a tasty sauce that enhances local cuisines.

The multipurpose nature of many Pacific trees in providing a diversity of different products or services to people is well exemplified by the breadfruit. Its straight trunk is valued for canoe hulls; the inner bark is used to make bark cloth in some areas; the tree's thick, milky sap is used for caulking canoes, as adhesive for bark cloth, and as chewing gum; its large leaves are used as plates and for wrapping food for cooking in earth ovens; the dried inflorescence is burnt as a mosquito repellant; and the fruit is eaten cooked as a staple or important supplementary food in most areas of Polynesia and Micronesia and as a supplementary food in Melanesia, where seed-bearing varieties are often more important than the seedless varieties used as a staple food in Polynesia.

Like most trees, the breadfruit's production of fruit is seasonal, so that people dependent on it for food can expect periods of food shortage recurrently each year. Pacific-Island peoples developed two solutions to this problem. First, high intraspecies diversity had been developed in breadfruit (and most other domesticated crops) by centuries of observation, selection, and transportation of promising varieties from place to place. As only one example of the prolific number of named cultivars that might have been accumulated within a single species, the volcanic island of Pohnpei in Micronesia is reported to have 150 named varieties of breadfruit. Generally, each of the many cultivars followed its own distinct calendar, so that production of breadfruit on atolls and high islands of Polynesia and Micronesia (or, to give another example, the yield of *Pandanus* fruits in highland New Guinea) is staggered over a much longer period than would be available from a single cultivar or individual tree. The second way in which the availability of food from breadfruit was extended over the year was by the pit fermentation of the fruit so that it could be stored. Unlike grains, there were few Pacific-Island indigenous foods except yams (*Dioscorea* spp.) that if unprocessed last long in storage once harvested. Because harvested breadfruit lasts only a few days, a way had to be found whereby the seasonal surpluses could be accumulated for later use. The method developed was pit storage. After the ripe fruit was peeled and cored, it was preserved by a process of semianaerobic fermentation, involving intense acidification, which reduces the fruit to a sour paste that lasted in storage for decades. The pits, which served both as fermentation chamber and storage area, were dug in clay soil to prevent water seeping in and then lined with stones, woven mats, and a variety of leaves to keep soil from mixing with the breadfruit paste. Modern food analysis shows that the fermented product contains more carbohydrate, fat, protein, calcium, iron, and B vitamins than the fresh fruit. The pits of breadfruit paste also provided a reserve food supply after tropical cyclones, or hurricanes, devastated gardens and orchards or during times of warfare. Packages of the baked fermented paste wrapped in leaves also provided a portable, long-lasting food for sea voyages.

Although trees had a great significance in people's lives almost everywhere in the traditional Pacific, the hundreds of species utilized were combined in a great variety of unique agroforestry systems, each distinct to particular locales spread over hundreds of islands, each with a unique environment and each occupied by a distinct group of Pacific peoples, with their own particular history and set of agricultural techniques. In forested areas of low population density where shifting cultivation was practiced, a mixture of certain trees might be planted in old gardens, creating orchards that produced food, fiber, and other products for decades while also serving as a kind of fallow for the gardened soil, which eventually would be reused. The spontaneous secondary forest in such areas came to be everywhere dotted with valuable trees, remnants of past orchards and gardens. Elsewhere, in drier, more heavily populated areas where complex irrigation channels had been built to bring water to permanent plots of taro, there might also be permanent and highly diverse tree gardens surrounding the irrigated plots and shading the villages. On atolls, with their severe environmental constraints, a particularly intensive form of agroforestry had been developed to support the often high population densities. Spread through a matrix of planted coconut palms, which were particularly common and immensely useful on atolls, were a variety of other domesticated trees including species of *Pandanus*, breadfruit, and a native fig. As in much of the Pacific, what might look like an untouched natural forest to an uninformed eye was in reality a managed agroforest in which almost every tree was known and owned by an individual or a family and served at least one valuable purpose if not several. Unfortunately, a variety of present-day socio-economic factors and changes are leading to a decline of traditional agroforestry in the Pacific region.

A

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Aida Yasuaki

JOCHI SHIGERU

Aida Yasuaki, also called Aida Ammei, was born in Yamagata, Japan on February 10, 1747 (March 20, in the present calendar). Aida studied mathematics under Okazaki Yasuyuki, a mathematician of the *Nakanishi-ryu* school, from the time he was 15 years old until he reached the level of the *Tianyuanshu* technique (Chinese Algebra system).

Then he went to Edo (now Tokyo), in September 1769 and became a son-in-law of SUZUKI Seizaemon, a Samurai of the Shogun. Aida changed his name to SUZUKI Hikosuke and worked as a *Fushin' yaku*, a civil engineer. Here he came to know KAMIYA Teirei, a student of FUJITA Sadasuke (1734–1807). Fujita was a mathematician of the *Seki-ryu* school who wrote the *Seiyo Sampo* (Exact Mathematics, 1781) which was one of the best mathematical textbooks of that time.

Aida decided to become a mathematician, retired from his work, changed his name back to Aida Yasuaki, and asked Fujita if he could teach mathematics. Fujita did not accept Aida's offer because he was concerned about mistakes in Aida's *Sangaku*. (*Sangaku* is a picture board with mathematical drawings, mostly of geographical problems. They were hung on the walls of shrines and temples for praying for mathematical progress.) Aida grew angry with Fujita and wrote the *Kaisei Sampō* (Counter-argument with Seiyo Sampo, 1785).

He then founded the *Saijō-ryū* school, and both schools disputed mathematics with each other for about 20 years. This encouraged Japanese mathematics to progress to a high level. Aida published eight books, nearly 2,000 chapters of manuscript. He taught mathematics to WATANABE Hajime (1767–1839), SAITO Naonaka (1773–1844), ICHINOSE Korenaga (fl. 1819), and KANDO Seii (nineteenth century).

Aida died at Edo (Tokyo) on October 26, 1817 (December 4 in the present calendar).

The strong point of the *Saijo-ryu* school was in systematic algebraic symbols. Aida created the original symbol for "equal," which was the first use of equal in Eastern Asia. He wrote the *Sampo Tensei-ho Shinan* (Mathematical Instruction of "Tensei-ho" (or the Tenzanjutsu technic in the Seki-ryu school)), which is one of the most systematic books describing the Japanese algebraic system.

Aida's mathematical method was similar to SEKI Kowa's. Aida studied the characteristics of irrational numbers. First, Aida computed the approximate value of irrational numbers by a sort of "Horner's method" (Horner 1819); then he computed the value of the continued fractions. An example of the root 2 is as follows:

Approximate value	Continued fraction
$\sqrt{2} \approx 1.4142$	1, 2, 2, 2, 2, 2, 1…
$\sqrt{2} \approx 1.414213$	1, 2, 2, 2, 2, 2, 2, 2, 1…
$\sqrt{2} \approx 1.41421356$	1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, …

Aida then calculated the continued fractional value of prime numbers smaller than 100. He also used the inductive method.

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Aida's works are discussed in vol. 4 of Fujiwara Matsusaburo 1956. One of the more complete works is Hirayama and Matsuoka 1966. Most of his works are kept at the Yamagata University Library ►http://www.lib.yamagata-u.ac.jp/rarebooks/sakuma_1-1280.html#anchor1150321.

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Ajima Naonobu

SHIGERU JOCHI

Ajima Naonobu (1739–1796), also called Ajima Chokuen, was born at Edo (now Tokyo) in 1732. Ajima's father was eighty *Pyo*[1] and a samurai warrior of Lord Shinjo,[2] in Dewa (now Yamagata prefecture). Ajima studied mathematics first under IRIE Masataka, a mathematician of the *Nakanishi-ryu* school, then under YAMAJI Nushizumi (also called Yamaji Shuji 1704–1772), who was the third president of the *Seki-ryu* school and an astronomer at *Bakufu Temmongata* (Shogun'sAstronomical Observatory). Then Ajima became an accountant of Lord Shinjo, at the rank of 100 *Koku*.

Yamaji made the *Horeki* (*Kojutsu*) *Reki* calendar (Calendar Made in Horeki Era 1754), which was used from 1755 to 1797; however, this calendar was not very accurate. In order to make a new luni-solar calendar, in 1762 he started to observe the sky with FUJITA Sadasuke (1734–1807), his assistant. When Fujita was appointed *Sangaku Shihan* (Professor of Mathematics) of Lord Arima (1714–1783) in 1768, he retired from the Shogun's Observatory. After that, Ajima helped Yamaji to observe the sky and taught astronomy at Yamaji's astronomical school. are Ajima wrote four astronomical manuscripts: *Jujireki Bimmo* (Introduction of the "Works and Days Calendar"), *Anshi Seiyo-reki Koso* (Professor Ajima's Studies for Western Calendars), *Ajima Sensei Bimmo no Jutsu* (Methods of Professor Ajima's "Bimmo") and *Koshoku Mokyu Zokkai* (Introductions of Eclipses (of the Sun and Moon)). These manuscripts were probably students' notes of Ajima's lectures.

The Lunar crater of "Naonobu" (4.6S 57.8E) commemorated him and was named in 1976.

Ajima's works for pure mathematics were studies for logarithms, computing the values of spheres, and series. Ajima and other Japanese mathematicians studied Western mathematics indirectly, that is to say, through Chinese books such as the *Shuli Jingyun* (Mei Juecheng (1681–1763), 1723, China). Ajima studied logarithms from this book, and then made a table of logarithms whose values are from 0.9 to 10^{-12}, 108 items. When Ajima used this table and these formulae:

$$\log = \log X + \log Y \quad \text{and} \quad \log 0 = 1,$$

he could compute all logarithmic numbers up to 12 decimal places.

Ajima expanded Japanese mathematicians' traditional method *Tetsu-jutsu*, which uses a sort of inductive method. (*Tetsu-jutsu* was created by TAKEBE Katahiro (1664–1739), second president of the *Seki-ryu* school.) Ajima computed the value of a sphere. In this case, he solved a sort of integral equation using *Tetsu-jutsu* twice.

Ajima also wrote the *Sansha San'en Jutsu* (Methods of Three Diagonals and Three Circles).

After Yamaji died, Ajima became the fourth president of the *Seki-ryu* school (or fifth, because Fujita was sometimes counted as the fourth). Ajima died in Tokyo, April 5, 1798 (May 20, 1798, current calendar).

Ajima Naonobu. Fig. 1 Ajima Naonobu's grave.

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[1] *Pyo* was an annual salary of 60 kg of rice, and 80 *pyo* was the same salary as a landlord of an 80-person village, or *Koku* would earn.
[2] Lord Shinjo belonged to the Tozawa family.

Al-Battānī

Julio Samsó

Abū ʿAbd Allāh Muḥammad ibn Jābir ibn Sinān al-Raqqī al-Ḥarrānī al-Ṣābiʾ was an extremely important Islamic astronomer of the ninth to tenth centuries. He was probably born in Ḥarrān before 858, and had Sabian ancestors. He lived most of his life in Raqqa (Syria) where he made most of his observations, but there is also evidence that he visited Baghdad and Antioch.

Apart from a few astrological tracts which have not been studied so far, he compiled (after 901) his *al-Zīj* (astronomical handbook with tables) also called *al-Zīj al-Ṣābi'* (Sabian *Zīj*), a work which marks the stage of full assimilation of Ptolemaic astronomy in Islam. This process had produced its first results ca. 830 with the *zījes* which were the consequence of the program of observations undertaken in Baghdad and Damascus under the patronage of Caliph al-Maʾmūn. Al-Battānī's *zīj* contains a set of instructions for the use of the numerical tables which have an essentially practical character. We do not find in them careful descriptions of the Ptolemaic models implied in the tables, and the author makes surprising simplifications, such as not describing Ptolemy's model for Mercury or not mentioning the equant point around which the mean motion of the center of the epicycle takes place. Nevertheless he describes, sometimes very carefully, the observations he made in Raqqa between 887 and 918, which allowed him to establish new and more precise mean motion parameters, a new eccentricity (0;2,4,45°) for the Sun and Venus, the longitude of the apogee (82;17°) of these two celestial bodies, a very accurate determination of the obliquity of the ecliptic (23;35°) (the band of the zodiac through which the Sun apparently moves in its yearly course), measurements of the apparent diameters of the Sun and the Moon, and their variation in a solar year and anomalistic month, respectively. These new parameters show a clear improvement over those of Ptolemy and led al-Battānī to establish some important corrections on Ptolemaic theory such as the mobility of the solar apogee, the fact that the obliquity of the ecliptic is not a fixed value, and the possibility of solar annular eclipses.

Apart from the *Almagest* and the *Planetary Hypotheses* (used by Battānī to determine the geocentric distances of the planets), Theon's *Handy Tables* constitute a major Ptolemaic influence in the *zīj*: the planetary equation tables (with the obvious exception of those for the equation of the center of Venus), for example, derive from Theon, and al-Battānī's work constitutes one of the important instruments for the diffusion of the *Handy Tables* during the Middle Ages. The *zīj* was translated twice into Latin (by Robert of Ketton and Plato of Tivoli) in the twelfth century, as well as into Spanish (thirteenth century) under the patronage of Alfonso X. It influenced strongly the Latin version of the *Alfonsine Tables*, was known in Jewish circles through the summary made in Hebrew by Abraham bar Ḥiyya (d. ca. 1136), and was quoted by European astronomers until the seventeenth century. Al-Battānī died in 929.

See also: ►al-Maʾmūn, ►Abraham bar Ḥiyya, ►*Zīj*, ►*Almagest*

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Al-Bīrūnī

Abdul Latif Samian

Abū Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī was born on Thursday, 3rd of Dhū al-Hijjah, 362 H (4th September AD 973) at Madīnah Khwārizm. His exact birthplace is still a matter of controversy. It is conjectured that he was born in the outskirts (*bīrūn*) of Kath, at al-Jurjāniyah, Khwārizm or at a place called Bīrūn, as implied by his nickname al-Bīrūnī. The only clue given by al-Bīrūnī was that he was born in a city in Khwārizm. The name Abū Rayḥān was given to him because of his love for sweet fragrance. Al-Bīrūnī died on 443 H (AD 1051).

He knew Persian but preferred Arabic, because the latter was more suitable for academic pursuit. Most of his numerous books and compendia were written in Arabic. He received some of his early education under the tutelage of the astromathematician Abū Naṣr Manṣur b. ‘Alī b. Īrāq al-Jilāni (d. ca. 427 H) and ᶜAbd Al-Samad b. ᶜAbdal Samad from Khwārizm. This is in addition to his formal elementary religious education at the *madrasah*, an institution where Islamic sciences are studied.

Al-Bīrūnī’s first patron was the Sāmānid Sultan Abū Ṣālih Manṣūr II, who reigned in Bukhara until the city was invaded by the Ghaznavid Sultan Maḥmūd in 389 H (AD 999). Later al-Bīrūnī went to Jurjān to the court of Abu’l Haṣṣan Qābūs b. Washmjīr Shams al-Ma’ālī (r. AD 998–1012), under whose patronage he wrote *al-Āthār al-bāqiya min al-qurūn al-khāliya* (Chronology) which was completed in 390 H (AD 1000). Al-Bīrūnī found the Sultan indiscriminate and harsh. His next sojourn was in Khwārizm and Jurjāniyah, in the service of the Sāmānid Prince Abu’l Abbas al-Ma’mūn ibn Muḥammad II. Under his partonage, al-Bīrūnī received great respect. It was during this period that al-Bīrūnī met the physician ‘Abu Sahl ᶜIsa b. Yaḥaya al-Jurjāni. His *Taḥdīd nihāyāt al-amākin li taṣḥih masāfāt al-masākin* (Determination of the Coordinates of Cities) was completed in AD 1025.

His *Kitāb fī taḥqīq ma li’l-Hind* (Book on India) was finally published in 421 H (AD 1030). The Ghaznavid Sultan Maḥmūd invaded and conquered the city in 407 H (AD 1017). Al-Bīrūnī’s other book, *Kitāb al-tafhīm li-awā’il sināᶜat al-ṭānjīm* (The Book of Instruction in the Art of Astrology), which was dedicated to Rayḥānah, daughter of al-Ḥassan, was written in Ghaznah, AD 1029. Al-Bīrūnī’s *magnum opus*, *al-Qānūn al-Masᶜūdī fī al-hay’ah wa’l-tanjīm* (Canon Masudicus), an astronomical encyclopedia comprising 11 treatises divided into 143 chapters, was completed at a later date, in 427 H (AD 1035) and was dedicated to the son of Maḥmūd, Masᶜūd. Apart from emphasizing the importance of astronomy, he gave accurate latitudes and longitudes and also geodetic measurements. His *Kitāb al-jamāhir fī maᶜrifat al-jawāhir* (Mineralogy) was completed less than a decade later (about 435 H/AD 1043) and was dedicated to the Ghaznavid Prince Sultan Shihāb al-Dīn Abu’l Fatḥ Mawdūd b. Masūd, Sultan Maḥmūd’s grandson. His *Kitāb al-ṣaydanah fi’l-ṭibb* (Materia Medica or Pharmacology) was written toward the very end of his life.

Al-Bīrūnī lived during a period of intense scientific activity. Among his contemporaries were Ibn al-Haytham (AD 975–1039) and Abu ᶜAli al-Husayn ibn ᶜAbd Allāh ibn Sīnā (370 H/AD 980–428 H/AD 1027). Others include Abū Nasr Mansūr ibn ᶜAli ibn Irāq who was one of al-Bīrūnī’s patrons, Abū al-Hassān ᶜAli ibn Sāid ᶜAbd ar-Raḥmān ibn Aḥmād ibn Yūnus who was an astronomer of distinction (d. AD 1009), and Abū Sahl ᶜIsa ibn Yaḥya al-Masīhi al-Jurjāni (d. AD 1000) who was a close associate of al-Bīrūnī’s and wrote 12 books under his name.

Al-Bīrūnī was a philosopher–scientist, but science prevailed over philosophy and he appeared not to have identified himself with any school of philosophy. It was reported that he started doing astronomical observation as early as 18-years old.

In addition to his *Kitāb al-tafhīm* (Astrology) and his *Kitāb fī ifrād al-maqāl fī amr al-ẓilāl* (The Exhaustive Treatise on Shadows) we can also find remarks which reflect his conception of nature in his other works. As an example, the introduction to his *Kitāb al-jamāhir fī maᶜrifat al-jawāhir* consists of 15 *tarwīhāh* (philosophical reflections) which give his view on the attitude of man toward nature. It is more than a book on pearls and precious stones.

According to al-Bīrūnī, God creates nature from nothing (*creatio ex-nihilo*). Concerning his views on the relationship between man and nature, in his introduction to *Taḥdīd nihāyat al-amākin* (The Determination of the Coordinates of Cities), al-Bīrūnī explicitly refers to the *Qurʾānic* verse, “And contemplate the wonders of the creation in the Heavens and the Earth,” “Our Lord: Not for naught hast Thou created (all) this” (Ch. 3: 191). Moreover, al-Bīrūnī contends, “This noble verse contains the totality of what I have explained…” In other words, this particular *āyāt*, out of all the other *Qurʾānic* verses, is of paramount importance to his scholarly life.

The element of transcendence is evident in al-Bīrūnī’s outlook on nature. One of his major postulates is that God creates nature; al-Bīrūnī envisages from the very beginning the affinity between natural phenomena and their metaphysical causes. God creates nature through the *Qurʾānic* injunction of *kun fayakun* (Ch. 17: 163). Nature and her phenomena are nothing but the manifestation of God’s initial creative act that is verbal. But God’s creative act is also continuous. God always intervenes. It is different from the Cartesian worldview where God stops to intervene after the initial act of creation.

The laws of nature (*sunnat ‘Allah*), which are the laws of God and which to al-Bīrūnī warrant examination, are possible because of the appearance of permanency in them. The affinity between nature, the created, and God who is the Creator points also to the element of the sacredness of nature. The study of nature through contemplation and action ought to be done within the parameters of religion, which to al-Bīrūnī is Islam. Therefore there is an esoteric and exoteric utility to religion in studying nature. In addition to the esoteric utility of studying nature, al-Bīrūnī emphasizes the exoteric aspect too. Again, in *Kitāb Ṭāḥḍīḍ* (The Determination of the Coordinates), he states, “The Jews also need a direction, because they turn in their prayers to the Temple in Jerusalem… The Christian need the (direction of) true East because their elders…prescribed to them that they should turn to Paradise in their prayers."

Prayer (*ṣālat*) is one of the fundamental principles of Islam. It is well known that Muslims offer their prayers facing the *qibla* in Mecca. The problem for Muslims all over the world is to ensure that they are facing the correct direction in their prayers. This is an example of what can be viewed as the exoteric aspect which al-Bīrūnī attempted to solve.

Another example is determining the time for prayer. Al-Bīrūnī devoted a whole chapter in his *Kitāb fī ifrād al-maqāl fī amr al-zilāl* (The Exhaustive Treatise on Shadows) to this problem. Studying nature should not be for the sake of studying nature; there must be a greater purpose sanctioned by religion, and in this case it is to solve the problem faced by Muslims in offering their prayers.

Al-Bīrūnī places truth as one of the noble aims of contemplating nature. "I must assay all aspects of this statement, because I do not refuse to accept the truth from any source, wherever I can find it" (*Taḥdīd*). Studying nature is akin to an investigation to find out the truth. The external world can provide truth. Thus al-Bīrūnī maintains, "There is a great difference between an investigator of truth [who studies nature] and a follower of tradition." God says: "Are those equal, those who know and those who do not know" (*Taḥdīd*).

Al-Bīrūnī never uses the word "science" in the sense that the word is understood today – that knowledge which is exact, objective, verifiable, deductive, and systematic. The closest term that he ever used is the Arabic word *ᶜilm*, which also means knowledge. *Al-ᶜilm* in the language of the *Qurʾān* and Sunnah (traditions of the Prophet) implies knowledge which makes man conscious of God, of His attributes, of the eternals, of the next world, and of the return to Him.

Science, to al-Bīrūnī, is a problem-solving activity. Scientists seek solutions to problems. Solving problems, which to al-Bīrūnī is analogous to "untying knots," (*Kitāb fī ifrād al-maqāl*), is the main activity of scientists. That science is a problem-solving activity and a scientific problem is a problem circumscribed by the Holy *Qurʾān* and Sunnah which needs to be solved in order for a Muslim to improve his *taqwa* (God consciousness) can be discerned by examining, in particular, the Introductions of his major books. We can see in these cases that this concept of religion is fundamental in shaping his attitude toward science as a problem-solving activity. His *India*, for example, was written "as a help to those who want to discuss religious questions with them, as a repertory of information to those who want to associate with them."

In another work, *Taḥdīd nihāyat al-amākin* (The Determination of the Coordinates), he clearly states another aspect of a scientific problem. "Geography is very essential for a Muslim for knowing the right direction of *qibla*." Finding the direction of the *qibla* is an example of a scientific problem which is circumscribed by the *Qurʾān* and Sunnah.

The evaluation of the problems tackled, except in the *Taḥdīd*, is not given post hoc or ad hoc. It is not the case that al-Bīrūnī solved scientific problems before thinking of their necessity, their worthiness for the *society*, viz., their legitimacy from the *Qurʾānic* and Sunnah point of view. Concerning geography and astronomy, he states: "…For whoever determines the longitude and latitude of this country with precision will thereby enable him to find out…times which are needed…for fasting." Realizing the comprehensiveness of Islam as a complete way of life, he adds, "…the usefulness here exceeds specific religious matters and extends to worldly affairs." Clearly, there is a sacred orientation in scientific problems. Scientists *qua* scientists should solve problems in a manner which brings them closer to God that can "yield His satisfaction (*riḍā*)."

In yet another book, *The Exhaustive Treatise on Shadows*, we can see very clearly his orientation toward scientific problems. In studying shadows, not only did he analyze shadows of this world, but also shadows in the Hereafter. He investigated in detail their differences, similarities, and the nature of their existence. He differentiated between shadows in Heaven and shadows in Hell. Thus al-Bīrūnī showed that there is a "revealed perspective" on scientific problems which the scientist should take into account. The scientist should always be mindful of the connection that the problems have to this world and to the Hereafter. The science of astronomy, for example, has its origin from the prophet Idrīs. These are examples of scientific problems in the Holy *Qurʾān* and Sunnah that from al-Bīrūnī's point of view merit investigation.

There is an element of transcendence in seeking scientific solution. Al-Bīrūnī is always conscious of God while solving problems. He strives to be among those who "…remember Allah, standing, sitting and reclining and consider the creation of the heavens and the earth, (and say): O Lord; Thou created not this in vain." Examples are abundant in his writings where he invokes God's help. In *India*, he beseeches God to "help him to a proper insight into the nature of that which is false and idle, that he may sift it so as to distinguish the chaff from the wheat."

Generally speaking, within the schema of contemplation, al-Bīrūnī solves problems mathematically. He considers himself a mathematician more than anything else. In *al-Qānūn al-Masūdī*, he says: "…I belong to a branch of mathematics (*riyāḍhi*),… and have been known by it and may intention never exceeded it…"

There are two complementary aspects of his problem solving: one is the "external" and the other is the "internal." The "external" aspect involves more of the external senses as opposed to the "internal" aspect. The "internal" aspect heavily involves the processes of mathematical abstraction by the internal senses.

Man has to look for information, for evidence, in nature. This is an external aspect of his problem solving. "Human reason needs data and no human being can be an exception from the need of phenomena in which the mind functions" (*Kitāb al-Taḥdīd*). Al-Bīrūnī's statement urging his readers to observe and collect data about observables shed some light on his approach to mathematical inquiry: that the process of mathematization, from the external aspect that is, should have empirical import. There are two parts related to his external aspect of this problem solving (as an act of contemplation) that warrant elaboration. First is al-Bīrūnī's view on the manner in which one arrives at a theory and second in his perspective on theory choice.

Al-Bīrūnī attaches great importance to intense observation and putting exhaustive effort into procuring, comparing, analyzing, and synthesizing data (which includes both oral and written reports) in arriving at a theory. In fact in his *Kitāb fī ifrād al maqāl* (The Exhaustive Treatise on Shadows), he cautions people against "ignoramuses" who do not spare much effort but simply "attribute to God's wisdom all that they do not know of the physical sciences." The physical world is out there to be studied in order for us to internalize the greatness of God. Observation is essential to all scientific endeavors, including medicine. Al-Bīrūnī says, in the *Kitāb fī ifrād*, "through the frequency of observations he will gain in resource, both intellectual and intuitive."

To begin with, one has to define his object of study. In the case of geology, he needs to focus his observation on "the rocks and vestiges of the past." Observation involves seeing. Unlike Aristotle, who believed that vision was made possible by emitting rays from the eyes, al-Bīrūnī believed that rays were emitted to the eyes by the object themselves. Images are then formed in the eyes. There is no objective observation. Seeing is an experience. It is a not physical state. A retinal reaction is a photochemical excitation, a physical state. Scientists—and not their eyes—see. Al-Bīrūnī admits the possibility of the observation made by his contemporary, the astronomer Abū Saᶜid of Sistan, even though al-Bīrūnī preferred the geocentric theory. Unlike al-Bīrūnī, the latter was a proponent of the heliocentric (the sun is the center of the universe) theory. Al-Bīrūnī saw the sun rising but Abū Saᶜid saw the horizons of the earth changing in the East at dawn.

Al-Bīrūnī underscored the importance of observation not only in studying geology, but also in mineralogy. One should have keen eyesight, more so than others. Without good eyesight, it would be difficult for them to observe the minute differences and similarities in metals and precious stones.

It is through sight that mathematicians can observe nature and contemplate. Observation, which is an integral part of al-Bīrūnī's problem solving, is not only for the sake of accumulating information. Observation is done within the schema of contemplation. For example, in his *Kitāb ifrād al-maqāl* (The Exhaustive Treatise on Shadows), he quotes a *Qurʾānic* verse (Ch. 77: 31) and states: "If one meditates on the verse, he will find two of the attributes of the shadow in the masculine form…" In his *Kitāb al-jamāhir* (Mineralogy), he says: "Sight connects what we see to the signs of Divine Wisdom in creatures and demonstrates the existence of the Creator from his creation."

Sight and hearing are two of the most important sense perceptions for gathering data for scientific inquiry insofar as observation is concerned. Both are integrated "in the heart, which is the seat of intelligence."

Reports are equally important as observation. The scientist gathers his data from documented reports. Reports are written in several languages. Al-Bīrūnī's preference for Arabic is not without a strong reason. Through etymological examination of the names of things, the scientist can be more informed about them. For example, there is the word *falāk* in his explanation about celestial motion. He writes in *Kitāb al-tafhīm* (Astrology), "The celestial sphere…is called *falāk* on account of its circular movement, like that of a whirl of a spindle…"

It is interesting to note that in so far as history of science is concerned, al-Bīrūnī preferred written tradition to immediate observation and he recommended *comparing* reports. Al-Bīrūnī lamented his predecessors who did not scrutinize their data.

After focusing on the problem, al-Bīrūnī collects data which are then compared and analyzed or synthesized, mainly through experiment or verbal verification (questioning the transmitters) or both, depending upon the field of study. In al-Bīrūnī's pattern of problem solving, the stage of theorizing comes only after one has exhausted all reasonable efforts in procuring data and in comparing the results of previous or contemporary researches. It is only after he is satisfied with the amount of information relevant to the problem that he goes "from the known to the unknown, from the near distant to the far" – to wit, the inductive and deductive process.

Examples are abundant throughout his works which demonstrate this exhaustive effort. In his study of astronomy, after procuring data, he examines solutions offered by others. His study entitled "A Number of Topics Dealing with Shadows" is a case in point. In it he discusses methods for computing the length of daylight at any time of the year used by Brahmagupta, Vijayanandin, and Yaᶜqūb ibn Tāriq besides three other methods of Babylonian and Persian origin.

In the fourth chapter of *al-Qānūn al-Masᶜūdī* (Canon Masudicus), he compared results obtained by Ptolemy and one Yaᶜqūb al-Sehri and thereafter made the trenchant remark, "Both the methods give results correct to the second order but Ptolemy understood what he did, whilst Yaᶜqūb did not known what he was doing." In mineralogy, there were extensive etymological considerations in his analysis of minerals. He revised the findings of others. He did the same in his studies of medicine in his *Kitāb al-ṣaydanah* (Materia Medica or Pharmacology).

In his analysis of societies such as in *Kitāb fī taḥqīq ma li'l Hind* and *al-Āthār al-bāqiya* (India and Chronology), in subtopics where experiments could not be conducted, where most of the data is not in the form of direct observation but through oral and written reports, he examines witnesses to remove distortions in addition to comparing reports to ensure that they are as correct and accurate as possible. His emphasis is on the comparative method. In his *al-Āthār al-bāqiya*, he writes on most, if not all, of the festivals of various creeds and religions found in the regions of the Caliphate. In *Kitāb fī taḥqīq* he compares the beliefs and lifestyles of the Hindus with Buddhists, Manicheans, and Zoroastrians to what others wrote about them. Similarly in his study of the circumference of the earth, al-Bīrūnī examines the previous results obtained by astronomers under the patronage of Ma'mūn al-Rashid (AD 813–833), the Abbāsid Caliph. He discovers that they reached different results. Dissatisfied, he conducted experiments in the area of Ghazz, Turks, and Jurjān.

In the external aspect of al-Bīrūnī's pattern of scientific problem solving, the problem of theory choice from his view occurs when there are several possible theories (as viable solutions) to a specific problem. In particular, the problem arises when al-Bīrūnī compares possible explanations in order to find a good one. Al-Bīrūnī does have some criteria which determine his choice and these criteria help him in formulating a good theory. What is more interesting is that these criteria reflect his scientific acumen and his conception of God (as the "perfect scientist").

An important criterion to al-Bīrūnī is accuracy. That accuracy dictates the choice of one theory instead of another is partly because accuracy is less equivocal compared to other characteristics such as simplicity or fruitfulness. The predictive and explanatory power of theories depends on their accuracies. Al-Bīrūnī knew that accuracy is almost synonymous with exactness which certainly involves measurements. The finer the measurement, the higher the degrees of accuracy. Al-Bīrūnī's treatment on measurements, on inventing measuring instruments such as the *Yamīni* ring, the *Ustuwani* which he used "to measure the height of heavenly bodies, their apogees, time, depth of well or rivers and heights of walls, towers and hills..." His expertise with *al-dahj*, *sarqālah al-ma'*, *Sirāj al-Khādim*, and *naqshah*, and a particular machine that found the exact prayer times which he constructed for the mosque in Ghaznah, points to the importance of accuracy to him. More important than that, the striving for accuracy on the part of the scientist reflects al-Bīrūnī's understanding that perfect scientific knowledge belongs to no other but God because it is only He that measures perfectly.

In addition to accuracy, another criterion is novelty. Al-Bīrūnī believed that a good theory should be able to disclose new relationships of previously unnoted phenomena. A theory should help the mathematician to discover "new" aspects of God's creation, increasing his awareness of God as *al-Khāliq*, the Creator who creates everything unceasingly. An example to illustrate this is al-Bīrūnī's study of the variation in the length of the year related to the motion of the apogee where he gives the theorem "that the apogee and the perigee are the points at which the apparent velocity reaches its extreme values."

However the most important criterion is truth. Truth to al-Bīrūnī is more than a regulative principle; it is *the* regulative principle. The notion of truth is central to his conception of problem solving. We can find that truth permeates at all stages in his pattern of problem solving outlined above. Al-Bīrūnī did not view truth as an illusive notion which, construed as such, is irrelevant to science. After focusing on a particular problem, he begins his inquiry in *al-Āthār al-bāqiya* (Chronology) by asking God to "help [him in] perceiving and realising the Truth, and facilitate its pursuit and lighten its courses..." In collecting as much relevant information as possible to the problem, he states in *Taḥdīd* (The Determination of the Coordinates): "I do not scorn to accept truth from whatever source I can find it." He even reminded himself in *India* to "speak the truth, even if it were against yourselves." In *Chronology*, al-Bīrūnī perceives truth as that which is "enjoined by the holy scriptures on mankind [and] possesses its own intrinsic beauty just like justice..."

Al-Bīrūnī's notion of truth is not equivalent to the popular conceptions of truth. It cannot be construed as correspondence theory of truth favored by realists. Neither can it be categorized under the coherence theory nor the pragmatic theory of truth per se. These are the reductive approaches to truth. Truth, to al-Bīrūnī, must be seen from the perspective of the *Holy Qurʾān dan Sunnah* since the *Qurʾān* is revealed as a "guidance" (*huda*). Therefore it is interesting to note that whenever a theory which is a result of his rigorous approach is not consistent with a new discovery of an "irregularity" of nature, it points not so much to its falsity but more so to Divine Wisdom.

In light of the importance of contemplation to al-Bīrūnī, it needs to be emphasized that although al-Bīrūnī construes science as an activity of problem solving, the scientist himself is not obsessed with the problems. Rather he is obsessed with the relationship between himself and God. It is God that is central in this problem-solving activity. Therefore solving scientific problems is only a consequence of his consciousness and conception of God.

To recapitulate, nature to al-Bīrūnī is the handiwork of God. The activity of deciphering nature, of solving scientific problems, can be an act of *ʿibādah*, a "sacred" act which can raise the status of the scientist in the eyes of God. Scientific activity to al-Bīrūnī is an activity bounded by the parameter of religion. In his quest to gain understanding of nature, he believed that one should be conscious of Divine Wisdom, which is manifested in nature and all its intricacies. It is both a theoretical and practical activity of solving problems. As a very prolific and multidimensional scholar, al-Bīrūnī did serious work in almost all branches of science in his time and his 146 treatises range from 10 to 700 pages each.

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Al-Bīrūnī and Geography

Akhtar H. Siddiqi

The geographical knowledge of the Muslims, in part derived from the Greeks and others, and contemporaneously developed and advanced by themselves, had reached a very high level of development by the tenth century. It is in this development that the work of al-Bīrūnī is significant. Al-Bīrūnī presented a critical summary of the total geographical knowledge up to his own time. He made some remarkable theoretical advances in general, physical, and human geography. Al-Bīrūnī did not confine himself to a simple description of the subject matter with which he was concerned. He compared it with relevant materials and evidence, and evaluated it critically, offering alternative solutions.

George Sarton identifies al-Bīrūnī as one of the great leaders of this period because of his relative freedom from prejudice and his intellectual curiosity. Although his interests ranged from mathematics, astronomy, physics and the history of science to moral philosophy, comparative religion and civilization, al-Bīrūnī became interested in geography at a young age. He is considered to be the greatest geographer of his time.

In the area of physical geography, he discussed physical laws in analyzing meteorology and climatology. He wrote of the process of streams development and landscape evolution. He introduced geomorphological enquiry to elucidate a history of landscape. He developed the mathematical side of geography, making geodetic measurements and determining with remarkable precision the coordinates of a number of places. Some of his noteworthy contributions to geography include: a theory of landform building processes (erosion, transportation, and deposition), proofs that light travels faster than sound, explanations of the force of gravity, determination of the sun's declination and zenithal movement, and discussion of whether the Earth rotates on its axis. He described various concepts of the limits for which he seems to have had recourse to contemporary sources not available to earlier geographers. He made original contributions to the regional geography of India.

In the study of physical phenomena, including landforms, weather, and geology, al-Bīrūnī adopted the methods of the physical sciences and drew conclusions with scientific precision. Al-Bīrūnī developed a schema for physical geography: (a) terrestrial conditions, describing the shape and size of the Earth; (b) cosmic concepts, dealing with the measurement of the circumference of the Earth and the establishment of the exact location of places; and (c) classification of natural phenomena either in accordance with their nature or with their position in time and space. He studied phenomena in time (chronological science) and also tried to study them in space. In his view, geography was an empirical science.

Based on available knowledge concerning the surface of the Earth, he deduced and described the shape and forms of land surface. Al-Bīrūnī examined questions concerning the Earth's shape, size, and movement.

He explained running water as the most effective agent by which the surface of the land is sculpted. He further asserted that as the rivers of the plains of India approached the sea they gradually lost their velocity and their power of transportation, while the deposition process along their beds increased proportionately. Al-Bīrūnī considered the changes in the course of a river a universal phenomenon. He also recognized the influence of the sun upon the tide and suggested that heavenly bodies exert a gravitational effect on the tides.

Al-Bīrūnī recognized that the heat of the atmosphere and the Earth's surface is derived from the sun through the transfer of energy by rays, and that it varies with the length of time that the Earth is exposed to the rays. He recognized the wind's force and velocity and argued that the wind, in all its phases, is determined by certain causes.

Al-Bīrūnī noticed the peculiarities of the Indian monsoon, observed the time of its breaking, and described its westward and northward movements and the unequal distribution of rain in different areas of India.

Finally, he added that the habitable world does not reach the north on account of the cold, except in certain places where it penetrates into the north in the shape, as it were, of tongues and bays. In the south it reaches as far as the coast of the ocean, which in the east and west is connected with what he calls the comprehending ocean (*India*, Vol. I, p. 196).

In short, al-Bīrūnī recognized geography as an empirical science, and he dealt with the terrestrial globe as a whole. He stressed its nature and properties. He also tried to investigate the causes of global phenomena and described them as they existed.

See also: ▶Geography in India, ▶Maps and Mapmaking in India

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Al-Biṭrūjī

Julio Samsó

Al-Biṭrūjī (fl. 1185–1192) was an Andalusian astronomer whose complete name seems to be Abū Isḥāq (ibn?) al-Biṭrūjī, Nūr al-Dīn. Nothing is known about his biography apart from the fact that his name probably derives from the region of Los Pedroches, near Cordoba, and that he was a disciple of the philosopher Ibn Ṭufayl (ca. 1110–1185). The latter was already dead when al-Biṭrūjī wrote his only known work, the *Kitāb fī-l-hayʾa* (Book on Cosmology), which seems to have been read by the anonymous author of a book on tides dated in 1192. On the other hand, al-Biṭrūjī's treatise was translated into Latin by Michael Scott in Toledo in 1217.

Al-Biṭrūjī was a member of the Andalusian school of Aristotelian philosophers composed of Ibn Bājja (1070?–1138), the aforementioned Ibn Ṭufayl, Ibn Rushd (Averroes, 1126–1198), and Mūsā ibn Maymūn (Maimonides, 1135–1204). All these authors criticized Ptolemaic astronomy due to its mathematical character which did not agree with Aristotelian physics. Al-Biṭrūjī was, however, the only one who made a serious, although unsuccessful, attempt to create an astronomical system which could have a physical reality. In it he uses homocentric spheres in the Eudoxan tradition which he combines with materials derived from the Toledan astronomer Ibn al-Zarqāllu (Azarquiel, d. 1100). It is interesting to remark that al-Biṭrūjī's dynamics are not exclusively Aristotelian but also use Neoplatonic concepts such as the impetus theory which he seems to have been the first to introduce into Western Islam. Al-Biṭrūjī's system was soon known in Western Europe and became very popular among Scholastic philosophers of the thirteenth century, who considered it a serious alternative to Ptolemy.

See also: ►*Hayʾa*, ►al-Zarqāllu

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Alchemy in China

Fabrizio Pregadio

In China, as elsewhere, alchemy is a science based on cosmological doctrines, aiming to afford (a) an understanding of the principles governing the formation and functioning of the cosmos, and (b) the transcendence of those very principles. These two facets are complementary and ultimately equivalent: the alchemist rises through the hierarchy of the constituents of being by "exhausting" (*jin* or *liao*, two words also denoting "thorough knowledge") the nature and properties of each previous stage. He thus overcomes the limits of individuality, and ascends to higher states of being; he becomes, in Chinese terms, a *zhenren* or Authentic Man.

While historical and literary sources (including poetry) provide many important details, the bulk of the Chinese alchemical sources is found in the *Daozang* (Daoist Canon), the largest collection of Daoist texts. One fifth of its approximately 1,500 texts are closely related to the various alchemical traditions that developed until the fifteenth century, when the extant Canon was compiled and printed. Later texts are included in the *Daozang jiyao* (Essentials of the Daoist Canon) and other minor collections. Modern study of the alchemical literature began in the present century, after the Canon was reprinted and made widely available in 1926. Among the most important contributions in Western languages are those of Needham (1978), Sivin (1968, 1976, 1980, 1990), Ho (1985), Baldrian-Hussein (1984), and Robinet (1989).

Though the underlying doctrines remained unchanged, Chinese alchemy went through a complex and not yet entirely understood development along its 20 centuries of documented history. The two main traditions are conventionally known as *waidan* or "external alchemy" and *neidan* or "internal alchemy." The former, which arose earlier, is based on the preparation of elixirs through the manipulation of natural substances. Its texts consist of recipes, along with descriptions of ingredients, ritual rules, and passages concerned with the cosmological associations of minerals and metals, instruments, and operation. Internal alchemy developed as an independent discipline around the middle or the late Tang period (618–906). It borrows a substantial part of its vocabulary from its earlier counterpart, but aims to produce an elixir – equated with transcendental knowledge – within the alchemist's person.

At the basis of both traditions are traditional doctrines of metaphysics and cosmology. Chinese alchemy has always been closely related to the teachings that find their classical expression in the early "philosophical" texts of Daoism, especially the *Daode jing* and the *Zhuangzi*. The cosmos as we know it is conceived of as the final stage in a series of spontaneous transmutations stemming from original nonbeing. This process entails the apparent separation of primeval Unity into the two complementary principles, *yin* and *yang*. Once the cosmogonic process is completed, the cosmos is perceived as subject to the laws of cosmology, *wuxing*, the Five Agents or Phases. The alchemist's task is to retrace this process backward. Alchemy, whether "external" or "internal," provides him with a support, leading him to the point when, as some texts put it, "Heaven spontaneously reveals its secrets." Its practice must be performed under the close supervision of a master, who provides the oral instructions (*koujue*) necessary to an understanding of the processes that the adept performs with minerals and metals, or undergoes within himself.

In order to transcend space and time – the two main features of the cosmos as it is ordinarily perceived – the alchemist should take extreme care of their correspondences to the work he performs. Space is delimited and protected by talismans (*fu*), and the laboratory (*danwu* or "chamber of the elixirs"), and instruments are properly oriented. According to some texts, heating must conform to minutely defined time cycles. This system, known as "fire times" (*huohou*) and sometimes described in painstaking detail, allows an adept to perform in a relatively short time the same work that Nature would achieve in thousands of years – in other words, to accelerate the rhythms of Nature. Bringing time to its end, or tracing it back to its beginning, is equivalent: in either case time is transcended, and the alchemist gains access to the eternal, constant present that precedes (or follows, though both terms become inadequate) the time of cosmogony and cosmology. The same is true with space: its center, where the alchemist places himself and his work, is a point devoid of dimension. From this point without space and time he is able to move at will along the axis that connects the higher and lower levels of being ("Heaven," *tian* and the "Abyss," *yuan*).

Among a variety of procedures that the sources describe in an often allusive way, and in a language rich in metaphors and secret names, two stand out for their recurrence and importance. The first is based on lead (*yin*) and mercury (*yang*). In external alchemy the two substances are refined and joined in a compound whose properties are likened to the condition of primal Unity. In internal alchemy, lead becomes a cover name for the knowledge of the Dao (pure yang, *chunyang*) with which each being is fundamentally endowed, but which is obscured (i.e., transmuted into yin) in the conditioned state. Mercury, on the other hand, represents the individual mind. The second most important method, which is proper to external alchemy, is centered on cinnabar (yang). The mercury contained therein (representing as such the Yin principle contained within the yang) is extracted and newly added to sulfur (yang). This process, typically performed nine times, finally yields an elixir embodying the luminous qualities of pure yang. This yang is not the complementary opposite of yin, but, again, represents the one before its apparent separation into the two complementary principles.

The final object of both disciplines is represented as the preparation of an elixir commonly defined as *huandan* (lit., elixir of return). This expression, recurring in the whole literature, originally denotes an elixir obtained by bringing the ingredients back to their original condition through repeated cyclical operations – an operation comparable to the process that the adept performs within himself with the support of the alchemical practice. The word *dan* (elixir) also denotes cinnabar, suggesting that the process begins and ends on two corresponding points along an ascensional spiral. This synonymy also shows the centrality of cinnabar in external alchemy, where this substance plays a role comparable to that of gold in the corresponding Western traditions. This role is taken by lead in internal alchemy. Both lead and gold, in their turn, are denoted by the word *jin*. The value of gold, and the word "gold" itself, is therefore mainly symbolic in China: the elixir, whether external or internal, and whatever its ingredients, is often defined as "gold," and Golden Elixir (*jindan*) is a name of the alchemical arts.

The extant *waidan* sources suggest that the two main methods outlined above acquired progressive importance in the history of the discipline. In the *Huangdi jiuding shendan jing* (Book of the Nine Elixirs) and other texts dating from the first centuries AD, cinnabar is never the main ingredient of an elixir, and the lead–mercury compound – sometimes replaced by refined lead alone – is only used as a layer in the crucible together with other ingredients. In these methods, the substances undergo cycles of refining in a hermetically sealed crucible. This process consists of a backward reenactment of cosmogony that brings the ingredients to a state of *prima materia*. The elixir can be finally transmuted into alchemical gold projecting on it a minute quantity of the native metal. Important details on the early phase of Chinese alchemy are also found in portions of the *Baopu zi neipian*, written around AD 320 by Ge Hong. Its descriptions of processes that can be compared with extant sources are, however, often abridged and sometimes inaccurate.

During the Tang dynasty, the *waidan* tradition reached one of its peaks with Chen Shaowei (beginning of the eighth century), whose work describes the preparation of an elixir obtained by the refining of cinnabar. Each cycle yields a "gold" that can be ingested, or used as an ingredient in the next cycle. In the second part of the process, the final product of the first part is used as an ingredient of a *huandan*. Among the representative texts of this period are several collections of recipes, one of the most important of which was compiled by Sun Simo. The first half of the Tang dynasty also marked the climax of contacts between China and the Arabic world. These exchanges may be at the origin of the medieval word *alchymia*, one of whose suggested etymologies is from middle Chinese *kiem-yak* (the approximate pronunciation of the modern *jinye* or "Golden Liquor") with the addition of the Arabic prefix *al-*.

While the Tang period is sometimes defined as the golden age of external alchemy, it also marked the stage of transition to internal alchemy. This shift, sometimes taken to be only due to the multiplication of cases of elixir poisoning, or to the influence of Buddhism, requires further study to be properly evaluated. The very incidence and relevance of cases of accidental poisoning (which claimed their toll even among Emperors) suggest that external alchemy had lost, at least to some extent and in some contexts, its soteriological character, and that its practices had become known outside the legitimate transmission. Some masters may, therefore, have transmitted their doctrine modifying the supports used for the practice. In internal alchemy, the adept's person itself performs the role which natural substances and instruments play in external alchemy. In doing so, this discipline avails itself – in ways and degrees that vary, and which require further study to be correctly understood – of traditional Chinese doctrines based on the analogies between macrocosm and microcosm, of earlier native contemplative and meditative disciplines, and of practices of Buddhist origin (apparently of Tantric character, through the possible medium of the Tiantai school).

Among the forerunners of internal alchemy is the Shangqing (Supreme Purity) tradition of Daoism, as practiced for example by Tao Hongjing. Based on revelations of the late fourth century, this school attributed particular importance to meditation, but also included the compounding of elixirs among its practices. (Shangqing represents in fact the first example of close relations between alchemy and an established movement of "religious" Daoism.) The relevant sources exhibit the earliest traces of the interiorization of alchemy. Among the texts used in this school is the *Huangting jing* (Book of the Yellow Court), a meditation manual often quoted in *neidan* texts.

In Song and Yuan times, the history of *neidan* identifies itself with that of the lines of transmission known as Southern Lineage (*nanzong*) and Northern Lineage (*beizong*). The respective initiators were Zhang Boduan (eleventh century) and Wang Zhe (1112–1170). Both schools placed emphasis on the cultivation of *xing* and *ming*, which constitute two central notions of internal alchemy. *Xing* refers to one's original nature, whose properties, transcending individuality, are identical to those of pure being and, even beyond, nonbeing. *Ming* denotes the "imprint," as it is, that each individual entity receives upon being generated, and which may or may not be actualized in life (the word also means "destiny" or "life," but neither translation covers all the implications in a *neidan* context). The Northern and Southern lineages, and subtraditions within them, were distinguished by the relative emphasis given to either element. The textual foundation of both lineages was provided by the *Zhouyi cantong qi* of Wei Boyang, and the *Wuzhen pian* (Awakening to Reality), a work in poetry by Zhang Boduan.

During the Ming and Qing dynasties the *neidan* tradition is known to have divided into several schools, but their history and doctrines are still barely appreciated. One of the last greatest known masters of this discipline was Liu Yiming (eighteenth century), who, in his works, propounded an entirely spiritual interpretation of the scriptural sources of his tradition.

See also: ►*Huangdi jiuding shendan jing*, ►Ge Hong, ►*Yinyang*, ►Five Phases (Wuxing), ►Sun Simo, ►Wei Boyang

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Alchemy in Islam

Karin Ryding

Arabic alchemical writing and documentation emerges in approximately the second half of the eighth century (750–800 AD), a period that witnessed substantial growth in intellectual activity and methodological refinement for all the known sciences. With the rapid expansion of the Islamic empire, knowledge from civilizations such as the Greek, Persian and Indian was melded and shared by means of the new lingua franca, Arabic. The unifying force of the Arabic language enabled scholars of diverse ethnic and disciplinary origins to exchange ideas, to transmit those ideas to their students, and to develop conceptual frameworks for exploring and expanding knowledge of the natural world. The Arabic term *al-kīmyāʾ* appears morphologically to be non-Arabic in origin, most likely a borrowing from Syriac *kīmīyā*, which may derive from Greek *khemeia*, or *khymia*, prefixed with the definite article *al-* in Arabic (Ullman 1965: 110; Wild 1965: 4). This word has survived as the term for the entire pre-modern tradition of proto-chemistry. Nonetheless, this era within the Arabic/Islamic cultural tradition remains little explored and poorly understood within mainstream history of science.

Arabic alchemical writings show influences of Egyptian, Greek, Sabaean, Syriac, Persian, and Indian cultures. Hermetic and gnostic influences are abundant, as many Arabic alchemical texts combine description and analysis of naturally occurring substances and chemical experiments with firm admonitions to adepts on the need for purity of heart, behavior and intent in order for transformation to occur.[1] The texts evidence not only cultural syncretism, but also interweave practices for psycho-spiritual transcendence with procedures to transform natural substances. The distinctive discourse of Arabic alchemical texts is variable in style. Sometimes it is descriptive, didactic, and straightforward, other times complex, highly abstract, mystical, and profoundly arcane.

That alchemy was well established as a branch of scientific study is attested by the fact that two 10th-century Arabic encyclopedia authors, al-Nadīm and al-Khwārizmī, each have extensive chapters on alchemy. Both chapters are available in English translation (Dodge 1970; Ryding 1994). Al-Nadīm focuses on the history, personalities, and scholarly works of the alchemists, whereas al-Khwārizmī concentrates on the instruments, substances and procedures involved in alchemical operations.

The earliest Arab contributor to alchemical science is reputed to have been the Umayyad prince Khālid ibn Yazīd ibn Muʿāwiya ibn Abī Sufyān (ca. 665–704) (Nadīm 1970, chapter on alchemy). Tradition says that he was instructed in alchemy by a Christian monk named Morienus/Marianus. A Latin manuscript entitled the *Booklet of Morienus Romanus, of old the Hermit of Jerusalem, on the Transfiguration of the Metals and the Whole of the Ancient Philosophers' Occult Arts,* appeared in Paris in 1559 with the notation that the original translation from the Arabic was dated 1182. Stavenhagen (1974) has details on the manuscript as well as the English translation. Documentation of al-Khālid's alchemical interests is sketchy; no works of his on the topic have been discovered, and some scholars consider al-Khālid's reputation for alchemical scholarship unjustified (e.g., Ruska 1924).

The central figure in Arabic alchemy is the semilegendary Jābir ibn Hayyān, who is said to have lived in Mesopotamia during the second half of the eighth century and died around 810–815 AD (Holmyard 1923: 47). Nadīm gives Jābir's full name as (Abū Mūsā ʿĀmī) Abū ʿAbdallāh Jābir ibn Ḥayyān ibn ʿAbdallāh al-Kūfī, known as al-Ṣūfī (Nadīm 1988: 420). Elsewhere his name is given as Abū Mūsā, and he is variously described as Tūsī, Tartūsī or Tarsūsī, Harranian and from Khorasān (Holmyard 1923: 47). Major Arab biographers (including Nadīm, Qifṭī, and al-Kutubī) consider him a genuine historical personage (Qiftī 1903: 160–1; Al-Kutubī 1973). Sarton considers him "the most famous alchemist of Islam," calling the era 750–800, the Age of Jābir ibn Ḥayyān" (Sarton 1927: 521).

There has been debate as to the extent of Jābir's authorship of what is referred to as the Jābirian corpus, with Kraus, Mieli, Ruska, and Plessner asserting that these works are largely attributable to an early Ismaʿīlī sect in the late tenth century (Kraus 1986, also Plessner and Kraus 1968; Plessner 1980), whereas Holmyard, Stapleton, and more recently, Corbin and Lory, give substantially more credence to the authorship of the historical Jābir.[2] The Jābirian manuscript matrix may include later accretions

[1] See Affifi (1949), Plessner (1954), and Corbin (1964: 179–183) on hermeticism in Arabic sciences. For more on the Arabic *corpus hermeticum* see Klein-Franke (1973). On Islamic gnosis see Corbin (1975), and for Egyptian hermeticism in particular, see Fowden (1996).

[2] See especially Corbin (1986: 68–69), where he discusses the work of Paul Kraus, "notre regretté collègue" who, he states, "fût entraîné sur sa lancée à un certain extrémisme." (our sorely-missed colleague, who was drawn by his impulsiveness to a certain degree of extremism.) He goes on to state that "il se trouve que depuis trente ans la théorie traditionnelle a trouvé de vigoureux défenseurs, dont les recherches ont sérieusement ébranlé la thèse extrémiste de Paul Kraus." (For 30 years the traditional theory has found vigorous defenders whose research has seriously weakened the extremist thesis of Paul Kraus.) See also Holmyard (1923), Corbin (1964: 184ff); Lory's introduction to Corbin (1986: 20ff); Stapleton (1936), and Sezgin (1971: 132–269). Cf. Hachmi (1961), Macuch (1982), Mahmūd (1975), and Burnett (1992).

from commentators and imitators, with a core of authentic older writings.

Whether or not the original Jābir is the source of all the manuscripts attributed to him in Arabic, and whether or not any of those writings constitute the source of the contributions of the European Geber has not yet been established, since the extant Arabic manuscripts have not been compared thoroughly or systematically with those in Latin of the European Geber. On this topic, see Holmyard's introduction to Russell (1678, 1928), esp. pp. xvii–xxi and on the European Geber see Newman's extensive 1991 analysis.

As Manfred Ullman states (1965: 112),

> Arabic alchemy holds a key position in the development of chemical thinking as a whole. However, in glaring contrast to its importance, it has been regrettably neglected by research until now. Most of what historians of science have written on the Arabic alchemists is second-hand, based on obsolescent literature and disfigured by gross errors. A vast and fertile field lies here open to research; access to it, however, is not easy.

Ullman (1965: 113) cites three components of the theoretical foundations of Arabic alchemy (1) The quicksilver–sulfur method for synthesizing gold, calculating the true proportions of quicksilver and sulfur in gold and endeavoring to reproduce those proportions; (2) The doctrine of "the relations of quantities" (used especially in the Jābirian texts). This took the form of speculation on the concept of balance, especially the "balance of letters", a form of phonosymbolism wherein the letters of the Arabic alphabet are attributed certain weights (in dirhams) and qualities (dryness, moisture, heat, cold) that correspond proportionately to the contents of minerals and metals as they occur in the names of those metals (Kraus 1986: vol. 2, 223–236). Thus the name of a particular metal such as lead (*usrub*) reflects exactly the essence of that metal; (3) Formulating the elixir (*al-ʾ iksīr*) that, when added to base metals, has the power to transform them into gold or silver, or to grant everlasting life.

Other major contributors to the vast alchemical literature of Islam include Abū Bakr Muhammad ibn Zakariyā al-Rāzi (Rhazes) (ca. 864–925 or 935), whose work in alchemy "takes a new, more empirical and naturalistic approach than that of the Greeks of Djabir" (Goodman 2001), Muhammad Ibn Umayl (ca. 900–960), and Aydamīr ibn Alī al-Jildakī (fourteenth century). Translations of all these texts, starting with Jābir, are sorely needed.

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Al-Damīrī

Emilia Calvo

Al-Damīrī Muḥammad ibn Mūsa ibn ʿĪsā was born in Cairo, Egypt in AD 1341. Although he began work as a tailor, he soon decided to study with the leading teachers of the time such as Bahāʾ al-Dīn al-Subkī, Jamāl al-Dīn al-Asnāwī, Ibn ʿAqīl, and others. He became a professional theologian and taught in different centers such as al-Azhar University, achieving a great recognition for his preaching and his ascetic life. A very religious man, he made the pilgrimage to Mecca six times between AD 1361 and 1367 and died in Cairo in AD 1405.

The majority of al-Damīrī's works are conventional commentaries and epitomes of earlier works such as the one on al-Nawawī's *Minhāj* (a manual of Islamic law). He also wrote sermons and treatises on canon law. Most of these works seem to be lost. His most famous work is *Hayāt al-ḥayawān* (Life of the Animals), a zoological dictionary which contains information on the animals mentioned in the *Quʾrān* and in the Arabic literature. It includes not only the zoological aspects, but also everything related to the animals mentioned.

The work contains 1,069 articles describing a lesser number of animals because the same animal is occasionally described twice using two different names. The animals are described in alphabetical order and usually contain seven sections (1) grammatical and lexicographical peculiarities of the name, (2) a description of the animal according to the leading authorities, (3) Muslim traditions in which the animal is mentioned, (4) juridico-theological considerations regarding the animal, (5) proverbs about the animal, (6) the medicinal properties of the products derived from the animal, and (7) rules for the interpretation of dreams in which the animal appears.

There are three versions of this work: the large (*al-kubrā*), the medium (*al-wusṭā*), and the small (*al-ṣugrā*) and it has been republished several times and translated into Persian and Turkish.

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Al-Farghānī

Ahmed Bouzid

Al-Farghānī, Abu-l-ʿAbbas Aḥmad ibn Muḥammad ibn Kathīr was born in Farghana, Transoxania and died in Egypt, ca. 850. He was a famous astronomer during the time of the ʿAbbasid caliph al-Maʾmūn and a contemporary of al-Khwārizmī, al-Marwarudhī, al-Jawharī, and Yaḥya ibn Abi-Manṣūr. He was well known in the Latin Middle Ages under the name of Alfraganus, thanks principally to his widely read book, *Compilatio astronomica* (also called *Liber 30 differentiarum*, Book of the 30 Chapters), which is a summary of Ptolemy's *Almagest*. The work still survives in Arabic under the following titles: *Jawāmiʿ ʿilm al-nujūm wa'l-ḥarakāt al-samāwiyya*, *Uṣūl ʿilm al-nujūm*, *ʿllal al-aflāk*, and *Kitāb al-fuṣūl al-thalāthīn*. The *Jawāmiʿ* (sometimes translated as *Elements*) provided the medieval reader with a rather comprehensive account of Ptolemy's astronomy through a well-organized, accessible, and nonmathematical presentation. The work was translated into Latin at least twice in the twelfth century: by John of Spain (John of Seville) in 1135, and by Gerard of Cremona before 1175. The *Jawāmiʿ* was also translated into Hebrew during the thirteenth century by Jacob Anatoli. Copies of this translation exist today in Berlin, Munich, Vienna, and Oxford, among other places. In 1590, drawing from Anatoli's translation, Jacob Christmann published the third Latin version of the book in Frankfurt-am-Main. A later Latin translation of the text, along with al-Farghānī's original Arabic, was published in 1669 by Jacob Golius. Widely circulated in the West during the Middle Ages, the *Jawāmiʿ* was frequently referenced by medieval writers, and it is generally accredited today for having contributed considerably to the propagation of knowledge on the Ptolemaic system. In addition to the *Jawāmiʿ*, al-Farghānī wrote on the astrolabe. A number of his manuscripts on the subject survive under the following titles: *Fīṣanʿ at al-asṭurlāb*, *al-Kāmil fi'l-asṭurlāb*, and *Kitāb ʿamal al-asṭurlāb*.

See also: ►Astrolabe, ►*Almagest*

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Al-Fazārī

Boris Rosenfeld

Abū Isḥāq Ibrāhīm ibn Ḥabīb ibn Sulaymān ibn Samura ibn Jundab al-Fazārī (d. ca. 777) was a Muslim astronomer and the first Muslim constructor of astrolabes. He was the author of many scientific works whose manuscripts are not extant, but the Arabic historians Abū'l-Faraj Muḥammad ibn Nadīm al-Warrāq al-Baghdādī (d. 993) in his *Kitāb al-fihrist al-ʿulūm* (Bibliography of Sciences) and Jamāl al-Dīn ʿAlī ibn al-Qifṭī (1173–1248) in his *Taʾrīkh al-ḥukamā* (History of Sages) mention one mathematical and five astronomical works by al-Fazārī:

1. *Kitāb fī tasṭīh al-kura* (Book on the Projection of a Sphere onto a Plane)
2. *al-Zīj ʿalā sinī al-ʿarab* (Astronomical Tables According to Arabic Years)
3. *Kitāb al-ʿamal bi'l-asṭurlāb al-musaṭṭaḥ* (Book on the Use of the Plane Astrolabe)
4. *Kitāb al-ʿamal bi'l-as ṭurlābāt dhawāt al-ḥalaq* (Book on the Use of Astrolabes with Rings)
5. *Kitāb al-miqyās li'l-zawāl* (Book on the Gnomon for the Noon)
6. *Qaṣīda fī ʿilm al-nujūm* (Poem on the Science of Stars)

His son Muḥammad translated an astronomical work *Brāhma-sphuṭasiddhānta* by the sixth century Indian astronomer and mathematician Brahmagupta from Sanskrit into Arabic. The Arabic name of this work, *Sindhind*, came from the word *siddhānta*, astronomical texts, and the Arabic name for India, *Hind*. The extant fragments of *Sindhind* have been translated into English by David Pingree.

See also: ►Astrolabe, ►Brahmagupta

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Alfonso X

Julio Samsó

Alfonso X, King of Castile (1252–1284) and a patron of literature and learning, made an important effort to recover Arabic and, very especially, Andalusian astronomical materials by translating them first into Spanish and later into Latin. His collaborators were one Muslim convert into Christianity, eight Christians (of whom four were Spaniards and another four Italians) and a very important group of five Jews. Alfonso failed in his attempt to integrate in his team a Muslim scientist of the importance of Muḥammad al-Riqūṭī but his interest for us here lies in the fact that his translations preserve Andalusian astronomical works which would have been lost otherwise. This is the case, for example, of the *Libro de las Cruzes* (Book of Crosses), a late Latin astrological handbook translated into Arabic in the early ninth century and revised, in the eleventh century, by a certain ᶜUbayd Allāh. Other works which are only known through his translations are the *Lapidario* (a book on the magical applications of stones) written by the otherwise unknown Abolays, the two books on the construction of equatoria written by Ibn al-Samḥ (d. 1035) and Ibn al-Zarqāllu (d 1100), ᶜĀlīibn Khalaf's book on the use of the plate for all latitudes (*Lámina Universal*, Toledo, eleventh century) and Ibn al-Zarqāllu's treatise on the construction of the armillary sphere. Other works which are, apparently, originals contributed to the European diffusion of Arabic astronomical ideas: the famous *Alfonsine Tables*, extremely popular between the fourteenth and the sixteenth centuries, were strongly influenced by the *Tables* of al-Battānī and marked a turning point in the development of late Medieval European astronomy.

See also: ►Ibn al-Zarqāllu

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Algebra, Surveyors'

Jens Høyrup

Around 1930, a mathematical technique very close to later second-degree algebra was discovered in Babylonian cuneiform tablets, most of them dating from the early second and a few from the late first millennium BCE (the "Old Babylonian" and "Seleucid" periods, respectively). Although the texts did not say so in any way, it was supposed that the technique was purely arithmetical, and that its "lengths," "widths," and "areas" were metaphors designating numerical unknowns and their products. The geometry of Euclid's *Elements* II was then believed to represent a Greek geometrical reinterpretation of the arithmetical results of the Babylonians, necessitated by the discovery of irrationality.

A more sophisticated analysis of the Old Babylonian texts shows that the arithmetical interpretation does not hold water. For instance, the texts distinguish sharply between two different concepts that had been understood as one and the same "addition"; two different "subtractions"; two different "halves"; and no less than four different "multiplications." Instead, a nonmetaphorical interpretation as "naïve cut-and-paste geometry" imposes itself. A problem where the sum of the area and the side of a square is said to be 3/4 is solved as in the illustration given later: The square itself represents the area. From one of its sides a "projection" 1 is drawn, which together with the unknown side contains a rectangle with an area equal to the side – the total area of the square itself and this rectangle is thus 3/4. This projection is bisected, and the outer half is moved so that the two halves together contain a square of area equal to

$$\frac{1}{2}\cdot\frac{1}{2}=\frac{1}{4}.$$

This small square completes the gnomon into which the original area 3/4 is transformed as a larger square of area

$$\frac{3}{4}+\frac{1}{4}=1.$$

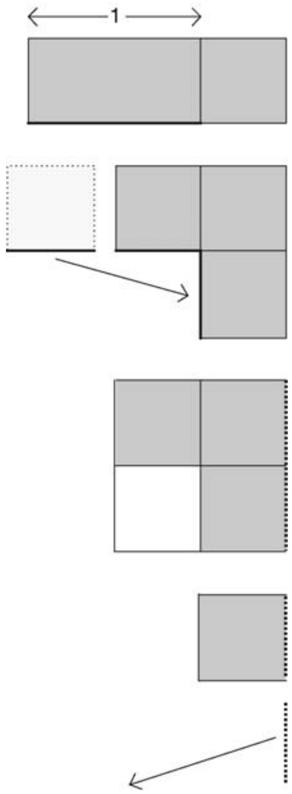
The side of this completed square will then be $\sqrt{1}=1$. "Tearing out" that rectangular length 1/2, which was moved around leaves

$$1-\frac{1}{2}=\frac{1}{2}$$

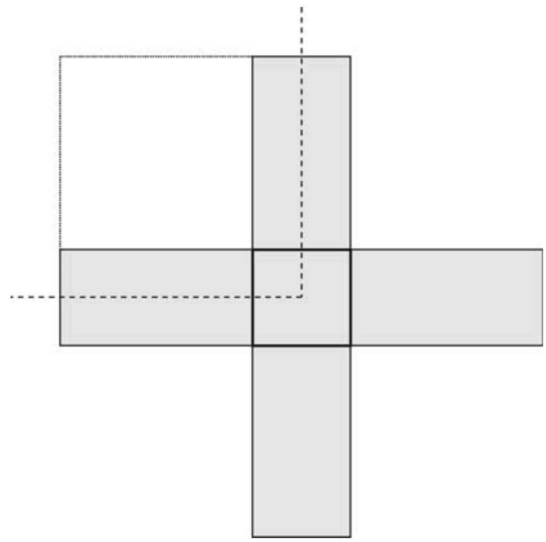
for the side.

With this technique, the Babylonian scribe school teachers solved problems of much higher complexity than the present one – in non-normalized problems (e.g., if 2/3 of the area plus 1/3 of the side equals 1/3) a change of scale is introduced, but apart from that everything goes by cutting and pasting – the approach is always "naïve" (as opposed to "critical") in the sense that everything can be *seen* immediately to be true. No explicit argument proves that, for example, the two halves of the bisected rectangle really contain a square when arranged as in Fig. 1.

A few texts, apart from using the terms for "lengths," "widths," and "areas" of fields, hint in other ways at surveying practice. An important example is this



Algebra, Surveyors'. Fig. 1 The sum of the area and the side of a square equals 3/4.



Algebra, Surveyors'. Fig. 2 The four fronts and the area. The dotted lines show the solution: one-fourth of the total area is taken and completed as a square.

problem: "Concerning a field: I have added the four fronts (sides) and the field (the area)." The formulation is unique in mentioning the sides before the area, and so is the solution, which refers to a configuration where a rectangle with length 1 is glued to each side of the field (Fig. 2).

Certain treatises from the Islamic Middle Ages reveal a close connection to this cut-and-paste tradition. The best known is al- Khwārizmī's *Algebra* (*Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa'l muqābalah* – The Book of Summary Concerning Calculating, restoration, and Equation) from the early ninth century AD. The algebraic technique itself is arithmetical and at most obliquely if at all connected to the Babylonian tradition. However, in order to prove the correctness of his algorithms – first the one for "square and ten roots equal 39" – al-Khwārizmī makes use precisely of the diagrams of the figures shown, the second with completion in all four corners instead of quadrisection.

Less widely discussed is a *Book on Mensuration*, written by an otherwise unidentified Abū Bakr. The text is known from a meticulous Latin translation made in the twelfth century by Gerard of Cremona, and contains in its first half a large number of problems similar to those known from the Babylonian texts, both in mathematical substance and method and in the very characteristic grammatical format. However, the differences that are also present and systematic reveal that the Babylonian scribe school "algebra" is not the source. Instead, both the scribe school and Abū Bakr appear to have drawn on a surveyors' tradition, which had been present at least in Central Iraq, and probably in a wider region, from the early second millennium BCE onward.

This tradition nurtured and transmitted a stock of recreational problems with appurtenant techniques for their solution. Those that can be determined with some certainty were of the same quasialgebraic nature as the Babylonian problems cited earlier.

If we designate by Q a square area and by s its side, by A a rectangular area and by l, w, and d its sides and the diagonal, we may be fairly sure (from what is common to the scribe school and Abū Bakr together with other medieval sources) that the following problems were present (Greek letters stand for given numbers, which cannot be safely determined because the Babylonian and the Medieval tradition give different values – question marks indicate doubtful presence):

$$s + Q = 110; \qquad Q - s = 90,$$
$$4s - Q = \alpha(??); \qquad A + (l \pm w) = \alpha, \qquad l \pm w = \beta,$$
$$4s + Q = 140; \qquad Q - 4s = 60(?),$$
$$A = \alpha, l \pm w = \beta; \qquad A = \alpha, d = \beta.$$

For two squares Q_1 and Q_2, one of which was probably thought of as located concentrically within the other, the four problems $Q_1 + Q_2 = \alpha$, $s_1 \pm s_2 = \beta$ and $Q_1 - Q_2 = \alpha, s_1 \pm s_2 = \beta$ were dealt with. All problems are of the second degree (although $Q_1 - Q_2 = \alpha$, $s_1 \pm s_2 = \beta$ reduce trivially to the first degree, since $Q_1 - Q_2$ is easily seen in a diagram to equal $[s_1 + s_2] \times [s_1 - s_2]$).

Since Abū Bakr's treatise contains the problem $d - s = 4$, we may guess that the subscientific tradition solved this problem by equating the diagonal of the 10×10 square with 14. Abū Bakr gives the exact solution $s = 4 + \sqrt{32}$, whereas the Babylonians (who always worked backward from known solutions in their "algebra") eliminated this "unscientific" problem in the same process as they transformed the restricted stock of surveyors' riddles into a genuine, systematic discipline and into something that can legitimately be regarded as an *algebra.*

The Seleucid cuneiform "algebra" texts have traditionally been understood as faithful continuations of the Old Babylonian tradition. Close scrutiny of the texts shows even this to be a half truth. Indeed, the Old Babylonian mathematical tradition lost its higher, algebraic level when the scribe school system collapsed around 1600 BCE, and only the directly applicable level survived in an environment whose professional pride was based on other aspects of its practice. The surveyors' tradition, however, survived, and appears to have supplied the material for an algebraic revival in the later first millennium at the level of scholar scribes. In the meantime, the surveyors had developed more sophisticated methods – e.g., calculating the heights of triangles and using this for area determination instead of restricting themselves to practically right triangles laid out in the terrain. The most important Seleucid algebraic text also reads as a catalog of new problems and methods for the treatment of rectangles, some of them quite refined (e.g., determining the sides from $l + d$ and $w + d$ or from A and $l + w + d$).

The surveyors' tradition influenced not only Late Babylonian scribal mathematics and Medieval Islamic mensuration but also ancient Greek geometry and arithmetic. What is reflected in *Elements* II is, indeed, not Babylonian "algebra" in general but very precisely *that part of Old Babylonian algebra which it shared with the surveyors' tradition* – whence one may conclude that the real inspiration was *not* Old Babylonian scribal mathematics – long since forgotten – but the still living stock of surveyors' riddles. Proposition l, it turns out, justifies the geometrical addition of rectangles which have one side in common, whereas propositions 2 and 3 concern the special cases where sides are subtracted from or added to square areas. Propositions 4 and 7 are used, e.g., in two different but equivalent solutions to the problem of finding the sides of a rectangle from the area and the diagonal. Proposition 6 explains the solution of all problems $Q \pm \alpha s = \beta$ (including "the four sides and the area") and $A = \alpha$, $l - w = \beta$, while proposition 5 has a similar relation to rectangular problems $A = \alpha$, $l + w = \beta$ and to $\alpha s - Q = \beta$. Proposition 8, which is used nowhere else in the *Elements*, is associated with the concentric inscription of one square into another, and propositions 9 and 10 are connected to the solution of the problems $Q_1 + Q_2 = \alpha$, $s_1 \pm s_2 = \beta$.

What the Greek text does is not merely repeat the traditional solutions – in fact, it presents us with theorems, not with problems to be solved. But the theorems are *critiques* of the traditional "naïve" procedures, showing that what is immediately "seen" is indeed correct and can be proved within the axiomatic framework. The proofs fall into two parts, the first of which establishes the equality of areas and that the quadrangles which are believed to be squares are indeed so. Then on firm ground, the second part goes through the traditional cut-and-paste procedure.

Propositions 11–13 are connected to matters found in Abū Bakr's treatise, and the textual evidence suggests that at least propositions 12 and 13 (the generalized Pythagorean theorem) were originally developed independently of the Greek theoreticians, as part of the "new" stage of the surveyors' geometry. Propositions 1–10, on the other hand, are completely untouched by the innovations. This critique thus seems to go back to a moment when the "new" development had not yet taken place, or not yet reached the ears of Greek geometers (we may point to the late fifth century BCE, the epoch of Hippocrates of Chios and of Theodoros).

Book I of Diophantos' *Arithmetic*, which also contains undressed versions of favorite arithmetical recreational problems, embraces a few problems of the second degree – as it turns out, arithmeticized versions of $A = \alpha$, $l \pm w = \beta$ and $Q_1 + Q_2 = \alpha$ $s_1 \pm s_2 = \beta$ (all four belonging to the original surveyors' stock). As can be seen from certain passages in Plato, Diophantos' work builds at least in its terminology upon a tradition reaching back to Greek calculators of the fifth century BCE or earlier. The present simple problems can be assumed to belong to the early ingredients of this tradition, which then agrees with the chronological conclusions that could be drawn from *Elements* II.

A single Greco-Egyptian papyrus (probably second century AD) shows that the "new" diagonal-centered group of surveyors' problems circulated among the mathematical practitioners of the Greco-Roman orbit at this later moment, without being adopted into the corpus of scientific mathematics. In China, on the other hand, they appear to turn up in the *Jiuzhang suanshu* (Nine Chapters on Arithmetic) (one of them in a dress which with high probability points back to Babylonia and thus shows the Chinese problems to be borrowed). In the later Chinese tradition, however, this interest disappears again.

"Naïve" geometry is also to be found in the Indian *Śulbasūtra* geometry (mid-first millennium BCE), and a few commentaries to later Indian algebraic works might suggest a fundament in something similar to our surveyors' tradition. The evidence, however, is too shaky to allow any conclusion, except in the case of the ninth century Jaina mathematician Mahāvīra, whose *Gaṇita-sāra-saṅgraha* contains indubitable borrowings from it, and even treats material stemming from the Bronce Age phase, the preseleucid Late Babylonian phase and the Seleucid phase in separate sections of its geometry chapter. Apart from that and from its role for the emergence of Babylonian "algebra" and for that of Greek metric geometry as found in *Elements* II, the only literate mathematical culture where the anonymous surveyors gained real influence is thus that of medieval Islam. Its reflection in al- Khwārizmī was already mentioned, to which it may be added that al-Khwārizmī's borrowed geometric proofs were taken over by numerous algebraic authors until the mid-sixteenth century – one step in Cardano's solution of the third-degree equation makes use of a three-dimensional generalization of this diagram, another of the solution of the rectangle problem $A = \alpha$, $l + w = \beta$. Within the mensuration tradition, the twelfth-century Abraham bar Ḥiyya (Savasorda) betrays familiarity with the surveyors' quasialgebraic riddles, in a version which shows him to be independent of Abū Bakr); so does Jean de Murs' fourteenth century *De arte mensurandi*.

As the technique was taken over by scientific mathematicians, the reason to uphold a distinct naïve-geometric tradition disappeared. Abū Bakr had already solved many of the problems in two ways, first by naïve geometry and then by *al-jabr* – the originally sub-scientific discipline committed to writing and made famous by al- Khwārizmī. Abraham bar Ḥiyya, for his part, refers to *Elements* II in his solutions. Nonetheless, the riddles themselves continued to be attractive. They are important in Leonardo Fibonacci's *Pratica geometrie* (1220), which draws on Abraham bar Ḥiyya, on Gerard of Cremona's translation of Abū Bakr, and on at least one other work belonging to the tradition. And they turn up again in Luca Pacioli's *Summa de arithmetica geometria Proportioni: et proportionalita* (1494), which still asks for the side when "the four sides and the area" equals 140, with the same anomalous order of the members as in the Bronze Age. The last shimmering of the tradition is in Pedro Nunez' *Libro de Algebra en Arithmetica y Geometria* (1567), after which every trace disappears, together with the knowledge that such a tradition had ever existed.

From the beginning some 4000 years ago, the surveyors' riddles were algebraic in the sense that the solutions follow steps that correspond to those of a modern solution by means of symbolic algebra. They were also algebraic in the sense that their method was *analytic:* the unknown side of the square is treated as if it were known, and submitted to such operations that at the end it is isolated and thus known – precisely as a modern x.

However, the surveyors' technique lacked two essential characteristics of modern equation-algebra (characteristics which, by the way, modern equation-algebra shares with the Old Babylonian scribe school "algebra"). First, it was no general method for finding unknown quantities; the measurable lines and areas which it manipulated were never used as representatives of something else. It was, and remained until it was taken over and reshaped by the written traditions, a collection of sophisticated riddles with no practical purpose beyond itself. Second, it always dealt with the entities which are naturally present in the geometrical configurations of which it spoke: *the* area, *the* side or *the four* sides, etc. It is never, as we may find it even in those of the Old Babylonian scribal texts which otherwise come closest to the background tradition, "one half of the length and one third of the width" of a rectangle. This is also the reason that its problems are – with one very late and thus dubious exception – always normalized, and a supplementary reason that it did not develop into an all-purpose algebra. We may therefore, legitimately, speak of a surveyors' "algebra" – but not of a surveyors' algebra without quotes.

See also: ►Mathematics, Recreational, ►al-Khwārizmī, ►Abraham bar Ḥiyya, ►Surveying

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Algebra in China

LAM LAY YONG

Arithmetic and geometry are the two oldest branches of mathematics. Algebra has its beginnings from both of them when attempts were made to generalize operations and relationships. Initially, such ideas were expressed in words; in the course of time, they were represented by some form of notation. The symbols facilitated the methods which in turn generated new concepts and methods. For instance, we are now able to solve with ease any arithmetical problem involving what we call a pair of linear equations in two unknowns through the use of the notational equations $ax + by = c$ and $dx + ey = f$. Around AD 825, Muḥammad ibn Mūsā al-Khwārizmī wrote a book expressing equations in words. In order to arrive at a solution, the two sides of an equation were manipulated through two main operations which he called *al-jabr* and *al-muqābala* – the name "algebra" was derived from the first word.

In ancient China, arithmetic developed through the use of the rod numeral system. Arithmetic was fully developed – not only were the methods of addition, subtraction, multiplication, and division known, but also the manipulations of the common fraction and the decimal fraction were commonplace, and methods such as those involving proportion and the Rule of Three were widely used. This article will describe very briefly how the mathematicians were able to generalize arithmetical operations and relationships which resulted in general methods of solution. The period covered will be from antiquity to the beginning of the fourteenth century. Traditional mathematics in China was at its height during the thirteenth and early fourteenth centuries; this was a time in Western Europe when the importance of the new arithmetic that evolved from the Hindu–Arabic numeral system was just beginning to be realized.

It might seem strange and improbable that the ancient Chinese were able to find general methods of solving equations since they did not compute through a written system but through the use of rods. However, the rod numeral system was extremely sophisticated and flexible, and the positions where the numerals were placed usually represented certain mathematical concepts. For example, let us consider a set of linear equations in three unknowns which we now write in the following manner:

$$a_1x + b_1y + c_1z = d_1,$$
$$a_2x + b_2y + c_2z = d_2,$$
$$a_3x + b_3y + c_3z = d_3.$$

The ancient Chinese would notate such a mathematical concept by placing the numerical values of the *a*s, *b*s, *c*s, and *d*s in rod numerals in the following matrix form:

$$\begin{matrix} a_3 & a_2 & a_1 \\ b_3 & b_2 & b_1 \\ c_3 & c_2 & c_1 \\ d_3 & d_2 & d_1 \end{matrix}$$

The positions occupied by the rod numerals were important – the positions in the first row represented the first unknown, and those in the second and third rows represented the second and third unknowns, respectively.

The aim of the method was to obtain a group of zeros forming a triangle in the top left diagonal half of the matrix through a process of elimination with two columns at a time. Thus the elimination process would result in zeros for the positions which were occupied by a_3, a_2, and b_3 of the above matrix. After this was attained, the third unknown was derived from the third column from the right. This result would be able to derive the second unknown from the second column, and the solutions would in turn derive the first unknown from the remaining column.

The method is called *fang cheng* and can be found in the eighth chapter of *Jiu zhang suan shu* (Nine Chapters on the Mathematical Art). The whole chapter is devoted to the solutions of such equations which include a problem involving five equations in five unknowns and another involving five equations in six unknowns.

The matrix notation was derived through an evolution of a fundamental tradition that used positions occupied by rod numerals to represent concepts or things. Besides the placement of numerals involving the common fraction, problems related to proportion were solved by similar operations. The ancient Chinese were familiar with what is now called the Rule of False Position which, for them, originated from the solution of the concept of a pair of linear equations in two unknowns. The method is called *ying bu zu* and is the precursor of the *fang cheng* method.

The procedure for finding the square root of a number was derived from the geometrical division of a square into smaller areas. This was then arithmetized through the placement of rod numerals to become a general method. The offshoot of this method was the solution of what we call a quadratic equation of the form $x^2 + bx = c$, where b and c are positive. The ninth chapter of *Jiu zhang suan shu* has a problem involving an equation of this form. Besides the method of finding the square root, the book also gives the method of finding the cube root of a number. Knowledge of this method led to the solution of a cubic equation of the form $x^3 + ax^2 + bx = c$, where a, b, and c are positive.

The seventh-century work *Jigu suanjing* (Continuation of Ancient Mathematics) by Wang Xiaotong has problems involving such equations.

The struggle to solve other types of quadratic equations besides the one mentioned above was depicted by the thirteenth-century mathematician Yang Hui, who quoted from the works of Liu Yi of the eleventh century – Liu Yi's works are now no longer extant. Though the concepts of the different types of quadratic equations were initially derived from a variety of geometrical considerations, the arithmetization of their operations through rod numerals revealed certain patterns and similarities which enabled the emergence of a general method of solution.

In his explanation of the development of the polynomial equation and its solution, Yang Hui quoted another eleventh-century mathematician, Jia Xian. He pointed out that Jia Xian was familiar with the triangular array of numbers now known as the *Pascal triangle* and was the first to realize its close relationship with the procedure of root extraction. From here, Jia Xian laid the foundation for a ladder or algorithmic method of finding the root of a number of any degree. This eventually provided the breakthrough to finding a solution of any numerical polynomial equation.

It was Qin Jiushao's detailed and systematic methods of explaining the problems in his book, *Shushu jiuzhang* (Mathematical Treatise in Nine Sections), that established beyond doubt the competence of the Chinese mathematicians to solve numerical equations of higher degree. Among the problems in the book, there are three that are involved with equations of the fourth degree and one of the tenth degree. These equations are of the following form:

$$-x^4 + 763200x^2 - 40642560000 = 0,$$
$$-x^4 + 15245x^2 - 6262506.25 = 0,$$
$$-x^4 + 1534464x^2 - 526727577600 = 0,$$
$$x^{10} + 15x^8 + 72x^6 - 864x^4 - 11664x^2 - 34992 = 0.$$

Yang Hui, Li Ye, and Zhu Shijie were the other thirteenth-century mathematicians who were also familiar with the algorithm method of solving a polynomial equation of any degree. This method is now generally accepted as similar to that put forward by Horner in 1819.

The Chinese were able to express the complex concept of a polynomial equation through the placement of rod numerals on the counting board. This notational representation was called *tian yuan shu* (Technique of the Celestial Element) in which an equation was formulated in terms of the unknown called *yuan*. An equation of the form

$$a_0x^n + a_1x^{n-1} + \cdots + a_{n-1}x + a_n = 0$$

was represented in rod numerals in a vertical line as follows:

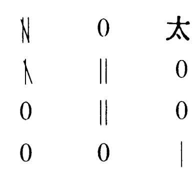
$$\begin{array}{l} a_n \\ a_{n-1} \\ \vdots \\ a_1 \\ a_0 \end{array}$$

The positions occupied by the rod numerals had meanings – the first row signified that the rod numeral was a constant and the other rows in the downward direction signified that the numerals were the coefficients of the unknown in increasing power.

From here, Zhu Shijie in his *Siyuan yujian* (Precious Mirror of the Four Elements), written in 1303, proceeded to express polynomial equations in two, three, and four unknowns with rod numerals. For instance, the equation in two unknowns

$$(-x-2)y^2 + (2x^2 + 2x)y + x^3 = 0$$

is expressed as follows:



The slanting rod indicates that the numeral is negative. In the first column from the right, the character *tai* indicates the constant of the equation, which in the above case is zero. This column, which is similar to the notation of a polynomial in one unknown, represents $0 + 0x + 0x^2 + x^3$. The second column represents $0y + 2xy + 2x^2y + 0x^3y$, and the last column represents $-2y^2 - xy^2 + 0x^2y^2 + 0x^3y^2$.

Zhu Shijie gave examples to show how a set of simultaneous polynomial equations of varying degrees up to four unknowns could be reduced to an equation in one unknown, and thereby finding the solution. For example, he illustrated how the set of equations of the form

$$-2y + x + z = 0,$$
$$-xy^2 + 4y - x^2 + 2x + xz + 4z = 0,$$
$$y^2 + x^2 - z^2 = 0,$$
$$2y + 2x - u = 0$$

was reduced to the following single equation in one unknown:

$$4u^2 - 7u - 686 = 0.$$

In *Siyuan yujian*, Zhu Shijie excelled in another area in algebra: he gave correct formulae for the sums of higher order equal difference series. They are of two types which may be described in the following manner. First type:

$$
\begin{aligned}
&1+2+3+4+\cdots+n=\tfrac{1}{2!}n(n+1),\\
&1+3+6+10+\cdots+\tfrac{1}{2!}n(n+1)\\
&\quad=\tfrac{1}{3!}n(n+1)(n+2),\\
&1+4+10+20+\cdots+\tfrac{1}{3!}n(n+1)(n+2)\\
&\quad=\tfrac{1}{4!}n(n+1)(n+2)(n+3),\\
&1+5+15+35+\cdots+\tfrac{1}{4!}n(n+1)(n+2)(n+3)\\
&\quad=\tfrac{1}{5!}n(n+1)(n+2)(n+3)(n+4),\\
&1+6+21+56+\cdots\\
&\quad+\tfrac{1}{5!}n(n+1)(n+2)(n+3)(n+4)\\
&\quad=\tfrac{1}{6!}n(n+1)(n+2)(n+3)(n+4)(n+5).
\end{aligned}
$$

Second type:

$$
\begin{aligned}
&1\cdot 1+2\cdot 2+3\cdot 3+\cdots+n\cdot n=\tfrac{1}{3!}n(n+1)(2n+1),\\
&1\cdot 1+2\cdot 3+3\cdot 6+\cdots+n\cdot\tfrac{1}{2!}n(n+1)\\
&\quad=\tfrac{1}{4!}n(n+1)(n+2)(3n+1),\\
&1\cdot 1+2\cdot 4+3\cdot 10+\cdots+n\cdot\tfrac{1}{3!}n(n+1)(n+2)\\
&\quad=\tfrac{1}{5!}n(n+1)(n+2)(n+3)(4n+1).
\end{aligned}
$$

It was Shen Guo (1032–1095) who initiated the study of this type of series and he was followed by Yang Hui and Zhu Shijie – their basic technique was related to the piling of stacks.

The foundation of algebra, as we know it today, and its impetus for growth arose from the successful development of arithmetic based on the Hindu–Arabic numeral system. In the earlier civilizations, there were various beginnings of algebra which also depicted the struggle to find expressions for arithmetical operations and geometrical relationships. The development of algebra in China has proved to be unique and significant with its growth being maintained continuously until the Ming dynasty (1368–1644).

The essential ingredient that fostered the growth of algebra in traditional China was the rod numeral system. What was extraordinary about it was its notation: the position of each digit of a numeral represented the place value of that digit, such as units, tens, hundreds, and so forth. This notation of a number freed the mind of unnecessary work and enabled arithmetic to be developed to the fullest. The same kind of thinking in the use of the positions of rod numerals to represent concepts or things made possible the subsequent evolution of algebra.

Though the Chinese used rods to develop algebra, the results obtained manifested numerous similarities with our early algebra. In the solution of a set of simultaneous linear equations, the ancient Chinese invented the matrix notation and the *fang cheng* method of elimination. About 1,500 years later, Seki Kowa and Leibniz initiated the study of determinants – Seki Kowa knew of the *fang cheng* method.

In searching for a general solution of a polynomial equation, Jia Xian drew attention to a triangular array of numbers which we now call Pascal's triangle. The method that the Chinese used to solve the polynomial equation was rediscovered by Horner half a century later. The concise notation of expressing the concept of a polynomial equation led Zhu Shijie to invent a notation to express a set of polynomial equations up to four unknowns. He gave examples to show how to solve them. In eighteenth-century Europe, it was Étienne Bezout who initiated the study of solving a pair of polynomial equations in two unknowns. Zhu Shijie's formulae for the series of higher order equal difference series also showed that he was a few centuries ahead of his counterparts in Europe.

It is ironical that the use of rods, which enabled the expansion and sustenance of algebra in China for over one and a half millennia, was also the reason for its decline. The rods were used not only for the development of mathematics but also for computation. By the Song dynasty (960–1279), a faster-paced society could not tolerate the time required for manipulating the rods. The demand for quicker computation led to the invention of the abacus. However, the abacus was only suitable for swift calculations and had neither the potential to foster the growth of mathematics nor the capacity to allow for the conceptual retention of what had already been developed in mathematics. The replacement of the rods by the abacus signaled the demise of traditional mathematics.

Since ancient times, the Chinese mathematicians had been using a base ten place value numeral concept in the rod numerals, and so it would not have been difficult for them to adopt this concept in a written form. If they had made such an adoption during the switch to calculation with the abacus, there would have been a smooth transference of mathematical concepts from the rod medium to the written medium. However, such an adoption was only made when western mathematics entered China beginning with the arrival of Matteo Ricci in 1582. The consolation from this erroneous turn of events was that during the sixteenth and seventh centuries many Chinese were still knowledgeable in traditional mathematics, and they helped greatly to lighten what would have been a tremendous upheaval in the change to the new mathematics.

See also: ►Computation: Chinese Counting Rods, ►Liu Hui and the Jiuzhang suanshu, ►Wang Xiaotong, ►Yang Hui, ►Jia Xian, ►Qin Jinshao, ►Li Ye, ►Zhu Shijie, ►Seki Kowa, ►Abacus, ►al-Khwārizmī

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Algebra in India: *Bījagaṇita*

Takao Hayashi

Bījagaṇita, which literally means "mathematics (*gaṇita*) by means of seeds (*bīja*)," is the name of one of the two main fields of medieval Indian mathematics, the other being *pāṭīgaṇita* or "mathematics by means of algorithms." *Bījagaṇita* is so-called because it employs algebraic equations (*samīkaraṇa*) which are compared to seeds (*bīja*) of plants since they have the potentiality to generate solutions to mathematical problems. *Bījagaṇita* deals with unknown numbers expressed by symbols. It is therefore also called *avyaktagaṇita* or "mathematics of invisible (or unknown) [numbers]." Algebraic analyses are also employed for generating algorithms for many types of mathematical problems, and the algorithms obtained are included in a book of *pāṭī*. *Bījagaṇita* therefore also means "mathematics as a seed [that generates *pāṭī* (algorithms)]."

Extant works in *bījagaṇita* include chapter 18 (*kuṭṭaka* only) of Āryabhaṭa's *Mahāsiddhānta* (ca. AD 950 or 1500), chapter 14 (*avyaktagaṇita*) of Śrīpati's *Siddhāntaśekhara* (ca. AD 1050), Bhāskara's *Bījagaṇita* (AD 1150), Nārāyaṇa's *Bījagaṇitāvataṃsa* (before AD 1356, incomplete), and Jñānarāja's *Bījādhyāya* (ca. AD 1500). Śrīdhara's work (ca. D 750), from which Bhāskara quotes a verse for the solution of quadratic equations, is lost. Chapter 18 (*kuṭṭaka*) of Brahmagupta's *Brāhmasphuṭasiddhānta* (AD 628) has many topics in common with later works of *bījagaṇita*, but the arrangement of its contents is not so systematic as that of the later works, and an unusual stress is placed on *kuṭṭaka* as the title of the chapter suggests. *Kuṭṭaka* (lit. pulverizer) is a solution to the linear indeterminate equation: $y = (ax + c)/b$.

The symbols used for unknown numbers in *bījagaṇita* are the initial letters (syllables) of the word *yāvattāvat* (as much as) and of the color names such as *kālaka* (black), *nīlaka* (blue), *pīta* (yellow), etc. The use of the color names may be related to Āryabhaṭa's *gulikā* (see below). Powers of an unknown number are expressed by combination of the initials of the words *varga* (square), *ghana* (cube), and *ghāta* (product). A coefficient is placed next (right) to the symbol(s) to be affected by it, and the two sides of an equation are placed one below the other. A dot (or a small circle) is placed above negative numbers. Thus, for example, our equation, $5x^5 - 4x^4 + 3x^3 - 2x^2 + x = x^2 + 1$, would be expressed as:

yāvaghaghā 5 *yāvava* $\dot{4}$ *yāgha* 3 *yāva* $\dot{2}$ *yā* 1 *rū* 0,

yāvaghaghā 0 *yāvava* 0 *yāgha* 0 *yāva* 1 *yā* 0 *rū* 1,

where *rū* is an abbreviation of *rūpa* meaning an integer or an absolute term. The product of two (or more) different unknowns is indicated by the initial letter of the word *bhāvita* (produced): e.g., *yākābhā* 3 for $3xy$.

These tools for algebra had been fully developed by the twelfth century, when Bhāskara wrote a book entitled *Bījagaṇita* (AD 1150), the main topics of which are "four seeds" (*bījacatuṣṭaya*), namely (1) *ekavarṇasamīkaraṇa* or equations with one color (i.e., in one unknown), (2) *madhyamāharaṇa* or elimination of the middle term (solution of quadratic equations), (3) *anekavarṇasamīkaraṇa* or equations with more than one color, and (4) *bhāvitakasamīkaraṇa* or equations with "the product" (i.e., of the type $ax + by + c = dxy$).

At least part of this algebraic notation was known to Brahmagupta. He uses the words *avyakta* (invisible) and *varṇa* (color) for denoting unknown numbers, when he gives his rules concerning the same four seeds as Bhāskara's, in chapter 18 (*kuṭṭaka*) of his *Brāhmasphuṭasiddhānta*. The details of Brahmagupta's algebraic notation are, however, not known to us.

Bhāskara, a contemporary of Brahmagupta, did know the word *yāvattāvat* meaning an unknown number, but it is not certain if he used it in equations, because he expresses the equation, $7x + 7 = 2x + 12$, without the symbol *yā* as:

7	7
2	12

in his commentary (LAD 629) on the *Āryabhaṭīiya*. In the same work he refers to four seeds which are said to generate "mathematics of practical problems" (*vyavahāragaṇita*) having eightfold of names beginning with "mixture," but what kinds of seeds he mentioned by the names *yāvattāvat*, *vargāvarga* (square?), *ghanāghana* (cube?), and *viṣama* (odd), are not exactly known. Similar terms (*yāvattāvat*, *varga*, *ghana*, and *vargavarga*) occur in a list of ten mathematical topics given in a Jaina canon, *Sthānāṅga* (Sūtra 747), which is ascascribed to the third century BCE.

Āryabhaṭa used the term *gulikā* (a bead) for an unknown number when he gave his rule for linear equations of the type $ax + b = cx + d$ in his *Āryabhaṭīya* (AD 499). All the equations to which he gave solutions (including *kuṭṭaka*) are linear, although his rules for the interest and for the period of an arithmetical progression presuppose the solution of quadratic equations.

Brahmagupta gave many theorems for *vargaprakṛti* (lit. square nature), i.e., the indeterminate equation of the second degree: $Px^2 + t = y^2$, but it is Jayadeva (the eleventh century or before) that gave a complete solution for the case $t = 1$ (the so-called Pell's equation).

Bījagaṇita reached its culmination in the twelfth century, when Bhāskara gave solutions to various types of equations of higher degrees by means of *kuṭṭaka* and *vargaprakṛti*. After him significant developments in the field of *bījagaṇita* are not known.

See also: ►Arithmetic in India: *Pāṭīgaṇita*, ►Āryabhaṭa, ►Śrīpati, ►Bhāskara, ►Nārāyaṇa, ►Brahmagupta, ►Śrīdhara, ►Jayadeva

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Algebra in Islamic Mathematics

MAT ROFA BIN ISMAIL (*with the collaboration of* OSMAN BAKAR AND KAMEL ARIFIN MOHD ATAN)

The word *algebra* is derived from the Arabic *al-jabr*, a term used by its founder, Muḥammad ibn Mūsā al-Khwārizmī, in the title of his book written in the ninth century, *al-Jabr waʾl-muqābalah* (The Science of Equations and Balancing). Algebra is also known as "the science of solving the unknowns in equations."

The simplest equation with one unknown is of the form $ax = b$, with a and b as constants x here is called *al-jadhr* of the equation. Al-Khwārizmī enumerated six standard second-degree equations in his *al-Jabr wa'l-muqābalah*:

$$ax^2 = bx, \quad ax^2 = b, \quad ax = b,$$

$$ax^2 + bx = c, \quad ax^2 + c = bx, \quad ax = bx + c.$$

Also, he provided solutions to these equations using algebraic and geometrical justifications.

The main aim of al-Khwārizmī's algebra was to provide the Muslim community with the necessary arithmetical knowledge essential in their daily calculation needs, such as in matters pertaining to heritage and legacy, transaction, sharing and partnership, loss and profit, irrigation and land-acreage, and geometrical problems. Al-Khwārizmī devoted about half of his *al-Jabr wa ʻl-muqābalah* to such problems.

Abū Kāmil Shujāʿ ibn Aslam of Egypt (AD 850–930) gave his treatise on algebra the name *al-Jabr wa ʻl-muqābalah*, the same title as al-Khwārizmī's. This treatise gives commentaries on al-Khwārizmī's six standard quadratic equations using Euclid's lemmas in geometry to justify the existence of two roots for a general quadratic equation. In the twelfth century, Abū'l-Fath ʿUmar bin al-Khayyām listed 39 standard cubic equations in his *Risāla fi'l-barāhīn ʿalā masā'il al-jabr wa ʻl muqābalah*, and solved them by intersecting suitable conic-sections (circle or semicircle, parabola, hyperbola, and ellipse) using Apollonius's theory of conics. The solutions to the equations were represented by intersections of the curves, but he failed to identify the exact numerical solutions. Many attempts had been made toward finding the geometrical solutions of cubic equations before ʿUmar al-Khayyām mentioned them in his book, such as those by al-Māhāni and Abu'l-Jūd.

Also in the twelfth century, Sharaf-al-Dīn al-Ṭūsī examined the cubic equation species classified by ʿUmar al-Khayyām and provided their solutions through a systematic study of the minimum and maximum values of their associated functions. He gave the number of real solutions of a cubic equation in terms of its coefficients.

In the third portion of his *Kitāb fi ʻl-al-jabr wa'l-muqābalah*, Abū Kāmil discussed indeterminate problems (*mu ʻādalah siālah*) of the second degree. Some of these were of Greek origin and could be found in the *Ṣinā ʻah al-jabr* by Diophantus, the translation of *Arithmetica* by Qusṭā ibn Lūqā. The problems were then cited by Leonardo Fibonacci in his book *Liber abaci*. Abū Kāmil concentrated on enumerating the possible solutions of simultaneous equations in his *Ṭarāʾif al-Ḥisāb*. They were based on the problem of determining the number of birds that could be purchased with 100 dirhams. Somebody is to buy 100 fowls, given that, for example, a rooster costs five units, a hen 3, and chicks are sold three for one unit. Problems of this type gave rise to a system of equations of the form:

$$x + y + z + u + v = 100 = ax + bx + cz + du + ev.$$

In the case of $a = 2,\ b = 1/2,\ c = 1/3,\ d = 1/4,\ e = 1$, Abū Kāmil gave 2,696 possible integer solutions. The analysis marks the birth of a field in algebra which is known today as linear algebra.

Extraction of square and cubic roots became an important subject of discussion in arithmetic and algebra books, or *Ḥisāb al-Hindī* based on Indian Mathematics during the heyday of the Muslim mathematicians. The rule for the extraction of roots was then based on binomial expansion of the form $(a + b)^n$. Al-Ṭūsī listed the coefficients in the expansion of $(a + l)^n - a^n$ for some n, in his *Jawāmiʿ* and arranged them in a triangular form which he called *manāzil al-ʿadad*. This triangular arrangement came to be known in the West as Pascal's triangle, after Blaise Pascal, the famous French mathematician who published his *Traité du triangle arithmétique* in 1665. Such an arrangement was also drawn up by al-Karajī in one of his books. This was further mentioned by Samuʿīl (or Samauʿal) ibn ʿAbbas, also called al-Maghribī (eleventh century), in his *al-Bāhir fi ʻl-jabr*. ʿUmar al-Khayyām did write a book on the extraction of cubic and fourth roots, but the book is assumed to be lost. The extraction of the fifth root was carried out by al-Kāshī in the fifteenth century in his *Miftāḥ al-Ḥisāb*. He gave a numerical example of extracting the fifth root of 44,240,899.506,197 (order of trillions).

In the expansion of an algebraic term raised to a certain power, the concept of the negative number is extremely important. Muslim mathematicians made a substantial contribution to the development of this concept. Abū'l-Wafā al-Būzjānī in his *Ma Yaḥtaj ilayh al-kuttāb wa ʻl-ʿummāl min ʿilm al-ḥisāb* considered debts as negative numbers. For example, the calculation for 35 + (−20) = 15 was written as 35 + *dain* 20 = 15 − (*dain* = debt). Abū Kāmil, as a commentator on the *al-Jabr wa ʻl-muqabalah* of al-Khwārizmī, explained the application of positive and negative signs for the purpose of expanding the multiplication $(a \pm b)(c \pm d)$. This resulted in his rules:

$$(+)(+) = + = (-)(-), \quad (+)(-) = (-)(+) = -.$$

These rules are embodied in his famous work *Kitāb al-jabr wa ʻl-muqābalah*. Al-Karajī showed clearer examples illustrating operations with negative quantities in his al-Fakhrī. These rules are implicitly used throughout the book:

$$a - (-b) = a + b, \quad (-a) + b = -(a - b),$$
$$(-a) - (-b) = -(a - b), \quad (-a) - b = -(a + b).$$

Samuīl and Ibn al-Bannāʾ al-Marrākushi then made some finer rules about calculations involving negative numbers in their works, *al-Bāhir fi ʻl-jabr and Kitāb al-jabr wa ʻl-muqābalah*, respectively.

The art of proving became an important part of mathematical science. The direct and proof by contradiction methods are two important tools in proving mathematical statements. In some cases, however, they fail to work, especially in proving formulae containing integral terms. In this case, the method of *istiqrāʾ*, or proof by induction, is an appropriate one to use. Al-Karajī wrote an article by that name to explain this method. Samuīl and Ibn al-Haytham used it to prove some formulae on infinite series. A good example of the employment of proof by contradiction was given by

Abū Jaᶜfar al-Khāzin to establish some properties of right-angled triangles. These can be found in the treatise *Risālah fi ʻl-muthallathāt al-qāᶜimat al-zawāyā* or in the *Tadhkirat al-aḥbāb fī bayān al-tuḥābb* of Kamāl al-Dīn al-Fārisī. The contradiction method based on the logical property "if (statement *a* is true) then it implies (statement *b* is true)" is equivalent to "if (statement *b* is not true) then (statement *a* is not true)." The converse, however, is not always true. This type of reasoning is characteristic of discussions in *manṭiq* or logic.

To explain the method of *istiqrāʾ*, Samuᶜīl proved the case $n = k$ through the assumption that the case $n = k - 1$ is true. For example, to prove $a^3b^3 = (ab)^3$, Samuᶜīl started with the assumption of $a^2b^2 = (ab)^2$ (which had been proved before), then multiplied both sides by (ab) to obtain $(ab)(a^2b^2) = (ab)(ab)^2 = (ab)^3$. Using the proposition mentioned earlier, i.e., $(ab)(cd) = (ac)(bd)$, he obtained $(ab)(a^2b^2) = a^3b^3$. Although in this demonstration, Samuᶜīl used particular numbers instead of a general *k*, he successfully showed the method of *istiqrāʾ* correctly as we understand it today. Some writers, however, continue to attribute the method to Pascal or Bernoulli in the seventeenth century (Yadegari 1978).

The inherent idea in the use of logarithm is to expedite the multiplication process by converting it into an addition one. This is done by employing the rules of exponent. Abūʾl-Ḥasan al-Nasawī wrote a book on the idea in Persian which was later translated into Arabic with the title *al-Muqniᶜ fi ʻl-Ḥisāb al-Hindi*. Ibn Yūnus (eleventh century), a well-known Egyptian astronomer, discovered the role of the trigonometric relation

$$\cos(a)\cos(b) = \frac{1}{2}[\cos(a+b) + \cos(a-b)]$$

in transforming the process of multiplication into addition. For example, suppose one wishes to obtain the product of 35.84 and 54.46. Since cos(69°) = 0.3584 and cos(57°) = 0.5446, then (35.84)(54.46) = 1951.5 by using this identity. This formula had been proven earlier by Abū'l-Wafā al-Būzjānī (d. 998) in his commentary on the *al-Majesṭi* (*Almagest*) of Ptolemy.

The expression of a fraction in the decimal form, based on an extant manuscript, goes back to *Kitāb al-fuṣūl fī al-Ḥisāb al-Hindī* of Abu'l-Ḥasan Aḥmad al-Uqlīdisī. It was written in the year 341H (AD 952). Uqlīdisī operated on the number 19 by consecutive halvings. First, he obtained (using his symbol) 9′5 then 4′75, 2′375, 1′11875, and finally 0′59375 (some commas indicating separations of hierarchy were dropped in the manuscript). Subsequently, Samuᶜīl al-Maghribī gave a clearer idea of the notion of decimal fractions in his *al-Qiwāmi fi ʻl-Ḥisāb al-Hindī.* This book was written in the year AD 1172. The quotient of 210 by 13 was expressed as follows:

Integer	Parts of 10	Parts of 100	Parts of 1,000	Parts of 10,000	Parts of 100,000
16	1	5	3	8	4

The square root of 10 is expressed as 3.16227, a clear definition of a decimal fraction, as the number 16,227 is considered part of 1,000,000, with 3 as a whole number. More precisely, 3.16227 means:

$$3 + \frac{1}{10} + \frac{6}{100} + \frac{2}{1,000} + \frac{7}{100,000}.$$

Jamshīd al-Kāshī (fourteenth century) expressed the decimal fraction in both al-Khwārizmī's and the astronomers' system in the article "*al-Risāla al-muḥīṭīyyah.*" He gave the value of 2π as 6.2831853071795865 (in al-Khwārizmī's decimal system) or as 6–6, 16, 59, 28, 1, 34, 51, 46, 15, 50 (in the astronomers' sexagesimal system).

The method of writing numbers as decimal fractions later appeared in the West in Stevin's *de Theinde* or its French version, *La Disma*, in 1585. To indicate the integral and fractional portions of the number, Stevin employed a stroke to separate the two. He is considered the founder of the decimal fraction by some writers in the West.

Nicomachus in his *al-Madkhal ilā ᶜilm al-ᶜadad* (an Arabic translation of *Introduction*) gave the four first perfect numbers: 6, 28, 469, and 8,128. Ismail al-Māridīnī (twelfth century) added some others to the list of perfect numbers: 6, 28, 496, 8128, 1130816, (2096128), 33550336, 8589869056, 137438691328, (35184367894528). Actually, the two numbers in brackets are not perfect. This mistake is due to the difficulty in determining the primality of a number.

One can observe from al-Māridīnī's list that it is hard to find an odd perfect number. The numbers seem to be even, and the first digit (remember that Arabs write from the right) of a perfect number obtained by the formula is always 6 or 8. Indeed, the perfect numbers described by the formula $(2^{n-1} - 1)2^n$ are always even, since they are the product of even and odd numbers. However, many think that odd perfect numbers do exist. Euler, centuries later (1849), in his paper in *Tractus de numererum doctrina*, described a necessary condition for the existence of an odd perfect number, but it was not a sufficient condition.

Other types of numbers that became the subject of scrutiny of Muslim mathematicians are the deficient and abundant numbers. The mathematicians supplied some criteria to identify these numbers:

- Every odd number less that 945 is deficient.

- Every even-times-even number has factors less than itself.
- The first abundant number is 12, and the first odd one in this class is 945.
- If $2^n S$ is a perfect number, then $2^{n+1} S$ is an abundant number, and $2^{n-1} S$ is a deficient number.

Kamāl al-Dīn al-Fārisī (d. 1320) in his treatise, *Tadhkirah al-aḥbāb fi bayān al-tuḥābb* supplied the rule to find pairs of amicable numbers (*al-a'dād al-mutaḥābbah*) in a systematic way. Thābit ibn Qurra (836–901) developed the theory of amicable numbers and provided a technique to find such pairs in his *Risālah fi'l-a'dād al-mutaḥābah*. Al-Fārisī reached the same conclusions through somewhat different paths. He based his new technique on the systematic knowledge of the divisors of a composite number and their sum. A pair of amicable numbers is defined as a pair of numbers (a, b) with the properties that the sum of all possible proper divisors of a is equal to b and the sum of all possible proper divisors of b is equal to a.

Ibn Ṭāhir al-Baghdādī defined a new variety of numbers known as equivalent numbers or numbers of equal weight (*mutaʾadilan*) in his *al-Takmila fi'l-Ḥisāb*. According to him:

> If we have a given number and wish to find two numbers, the parts of which make up this number, we reduce it by one and split the result into two prime numbers, then two others, and so on, as many times as we can. The product of each pair is a number equivalent to the given number. Thus if we are given 57, we split 56 into (3.53), (13,43), etc. The products of 53 by 3 and 4 by 13 are numbers such that the sum of the parts of each is 57 (Saidan 1977).

Equivalent numbers had not been studied by al-Baghdādī's contemporaries, nor by mathematicians for a few generations after him, until the time of Muḥammad Bāqir al-Yazdī (seventeenth century). Al-Yazdī, in his *ʿUyūn al-Ḥisāb*, considered such numbers and chose evenly even numbers to be decomposed as al-Baghdādī had done. In this way it was convenient for him to establish some properties of equivalent numbers, such as: if p and q are prime numbers, then p and q are of equal weight. It was felt that numbers of this kind needed more attention and to be examined further as they exhibited interesting unique behaviors.

The problem of finding the sides (x, y, z) of a right-angle triangle was studied and addressed by many Muslim mathematicians, including Samuʿīl (twelfth century) and Abū Jaʿfar al-Khāzin (tenth century). Al-Khwārizmī considered some basic problems related to a right-angled triangle. These problems became the source of his algebraic problems in his *Kitāb a-jabr wa 'l-muqābala*. Samuʿīl in his *al-Bāhir fi 'l-Ḥisāb* showed that any triple of the form

$$\left(a, \frac{(a^2 - b^2)}{2b}, \frac{(a^2 + b^2)}{2b}\right)$$

with a, b, c being appropriate positive integers, would describe right-angled triangles. Earlier, al-Khāzin had considered such problems in his *Risālah fī al-muthallathāt alqā 'imat al-zawāyā al-munṭaqat al-adḷāʿ*. He showed that it was not possible that any triple (x, y, z), with x and y being odd (or evenly even) could be the sides of a right-angled triangle with z as an integer. Al-Khāzin then used the results to study the problems of the form $x^m + y^n = z^p$ with m, n, and p some small positive integers. He left out some cases, however, such as $m = n = p$ 3 or 4, for such problems have no solutions. Problems of these types were examined centuries later by de Fermat (1736).

The problem of splitting a cube into three other cubes, i.e., to find the solution of the equation with three unknowns, $x^3 + y^3 + z^3 = n^3$, was discussed by Ibn Ṭāhir al-Baghdādī (tenth century) in *Takmila fi 'l-Ḥisāb*. He gave the answer as

$$(x, y, z) = \left(\frac{n}{2}, \frac{2n}{3}, \frac{5n}{6}\right).$$

This problem then reappeared in the works of Barbareta (1910).

See also: ►al-Khwārizmī, ►Abū Kāmil Shujāʿ ibn Aslam, ►ʿUmar al-Khayyām, ►Sharaf al-Dīn al-Ṭūsī, ►Qusṭā ibn Lūqā, ►Samuīl ibn Abbas (al-Maghribī), ►Abu'l Wafā, ►al-Karajī, ►Ibn al-Bannāʾ, ►Ibn Yūnus, ►al-Uqlīdisī, ►al-Kāshī, ►Thābit ibn Qurra, ►Sexagesimal System

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Algebra in the Malay World: A Case Study of Islamic Mathematics

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The Malay World comprises countries which are now known as Malaysia, Indonesia, Brunei, Singapore, Thailand, Philippines, and Kampuchea. This part of the world is also known as *Nusantara* or *Pascabima*. Ptolemy, the Egyptian geographer, visited the Malay world in the second century AD and called it "Golden Chersonese" (*Semenanjung Emas* in Malay – a beautiful golden peninsula) for its beauty and greenness. Indian travelers once referred to it as *Sunarvabumi*, which can be translated in the same way. The significance of this area in ancient history as a meeting place for sea travelers between east and west is due to its strategic location between India and China.

The region went through its own history under many religious influences such as Hinduism, Buddhism, and Islam. It is recorded that Islam came to this region in the very early period of the Umayyad caliphate when a Srivijayan king embraced Islam during the reign of Caliph Umar ibn al-Aziz (AD 717–720). Since then, Islam gradually became an important religion in the region. Religious matters, such as compulsory charity (*zakat*), inheritance problems (*farā'iḍ*), and crescent sighting to mark a new month in the lunar calendar needed knowledge of systematic mathematical calculation. For these purposes, the works of al-Khwārizmī, Ibn al-Bannā', al-Turtūsī, Ibn al-Hā'im, Ulugh Beg and Ibn al-Yāsamīn in algebra, mathematics and astronomy were frequently cited by the Malay scholars.

Text books in algebra and arithmetic, such as *Khulasah al-Ḥisab* (A Concise Treatise on Mathematics) by al-'Amili, *Talqīḥ al-afkār* (Combining Ideas) and *al-Urjūyah al-Yāsaminiyyah* (The Poem of al-Yasamin) by Ibn al-Yāsamin, *Tuḥfah al-a'dād li dhawī al-rushd wa al-rashād* (A Special Arithmetic for the Wise and the Rightly Guided) by Ibn Hamzah al-Maghribi, *Kashf al-asrār* (Unveiling of Secrets) by al-Qalsaldi, *Talkhīṣ al-ḥisab* (Purification of Mathematics/Understanding Mathematics?) by Ibn al-Bannā' al-Marrakushi, and *Murshid al-ṭālib ila asna al-mutalib* (Student's Guide to Excellence in the Pursuit of Knowledge) by Ibn al-Ha'im, were among frequent quoted references by Malay writers (see Zain 2001).

The beginning of the history of Islamic mathematics can be traced to the late eighth century. Among the earliest Muslim mathematicians was al-Khwārizmī (780–850 AD) who introduced a new system of numbering which greatly simplified the Roman one which had been widely used previously. The decimal system (*a'shariyyah*) provided simplification in carrying out basic arithmetical operations. In the Islamic tradition of knowledge, religious scholars who were experts in the field of theology were also conversant with and masters of other areas of knowledge. These included astronomy, medicine, the arts, logic, and rhetoric. Among those who fall into this category are al-Kindī (born 796 AD), al-Battānī (858–929), Ibn al-Haytham (965–1038), al-Bīrūnī (973–1048), and Ibn Sīnā (eleventh century). By the fourteenth century Islamic civilization was already very rich in its mathematical knowledge. Scholars moved to other fields besides basic mathematics.

The treatise by Ibn al Bannā', entitled *Raf'u al-ḥijāb 'an A'māl al-Ḥisāb* (Unveil the Cover in the Arts of Mathematics) or *Khulasah al-ḥisab* by al-'Āmili, discussed the subject of basic arithmetic and algebra. For example, the discussion of permutations and combinations in the book of Ibn al-Bannā' (fourteenth century) marks the first advance made by Islamic mathematics since the time of al-Khwārizmī. Islamic scholars continued to be active and productive in the field of mathematics until the seventeenth century, when their involvement waned due to backlash in the political arena during that period and subsequent to it. Until that time many outstanding treatises were produced and became references not only by contemporaneous scholars, but also by mathematicians in the subsequent centuries. They played an outstanding role in shaping and providing directions for the future development of mathematics in the world. Muslim works were brought into Europe by early scholars by translating Arabic treatises into Latin. Leonardo Fibonacci was among the pioneers in this pursuit. Centers of learning set up in places such as Cordova, Toledo, and other places in Spain became the focal point of convergence for western scholars to study Islamic mathematics.

Islamic mathematics came into the Malay world through the efforts of Malay religious scholars who had gone to the Middle East to study Islamic theology. They mastered the mathematics of the day in its original form and in an integrated manner with branches of theology. Whatever was learnt in the Middle East was brought back and disseminated to students in traditional schools. Among the works collected and brought back were books on a variety of branches of mathematics which had been their references during their study, especially in Mecca, Medina, and the University of Al-Azhar. Some of the scholars became writers and produced mathematical works based on their learning experience. Many of the written works were in the form of leaflets, short notes, and letters, written in Malay using the Arabic script. These works came down to us through the descendants of these scholars. Though only a few manuscripts survived, they give us a glimpse of the serious efforts and quality of work of the early Malay scholars in mathematics.

The documentation of Islamic mathematics in the Malay World has to date not been completed. The earliest known record of a treatise in logic by a Malay writer, entitled *'Ilm al-Manṭiq* (The Art of Logic), is dated 1593. However our search for such treatises in mathematics written in the region mainly concentrated on surviving documents that are dated later than the eighteenth century.

The records tell us about the existence of a number of Malay mathematicians for the period between the nineteenth and mid-twentieth century. They were mathematicians who were also scholars in religious studies. Our early survey (Ismail 1995) showed that they originated mainly from Fatani/Patani (in southern Thailand), Sumatera Indonesia, and Kelantan Malaysia. Some were also of Riau and Kampuchean origin. They were highly respected by the Malay community then and now because of their knowledge in religion as well as in other scholarly areas. Syeikh Daud al-Fatani (b. 1720 AD), for example, was regarded as one of the great Malay scholars during that period. So were Syeikh Abdul Kadir al-Fatani (b. 1817 AD), Syeikh Muhammad Nur al-Fatani (b. 1873), Faqih Wan Musa al-Fatani (second half of nineteenth century), and Syeikh Wan Ahmad Mohamad Zain al-Fatani (1856–1908). Another Malay scholar was Ahmad bin Abdul Latif al-Khatib al-Minangkabawi from Sumatra, Indonesia. He is regarded as the greatest Malay mathematician of the nineteenth century. Syeikh Tahir Jalaluddin (1867–1957), also of Sumatran origin, who later settled down in peninsular Malaysia, was regarded as a fine Malay astronomer towards the end of the nineteenth century. So was 'Umar Nuruddin al-Kelantani.

Mathematical works by Ahmad bin Abdul Latif al-Khatib al-Minangkabawi entitled *'Alam al-Ḥussāb* (The Banner for Mathematicians) (1892) and *Rauḍat al-Ḥussāb* (The Garden for Mathematicians) (1890) became the models for others to follow in the Malay world then. *'Alam al-Ḥussāb* was a Malay version of the Arabic *Rauḍat al-Ḥussāb*. Al-Khatib was the first Malay *imam* (prayer leader), *khatib* (Friday prayer's speaker) and religious teacher in Masjid al-Haram Mecca, appointed by The Holy Land's authority. Many of his students came from the Malay region. In these two books were mathematical topics of the period found in the Muslim world, which included number theory, algebra, geometry, trigonometry, approximation theory, and discussions on daily problems especially those arising from Islamic practices (*fiqh*) and the like. The contents of these works reflected the discussions and debates that took place in the period that began in ninth century and ended in the seventeenth, especially on the works of Muhammad bin Musa al-Khwārizmī produced during the late eighth and early ninth centuries. Also included were those by Abu Kamil Shuja' al-Aslam (tenth century), Abu Bakar al-Karaji (eleventh century), Ibn Yasamin (twelfth century), Ibn al-Bannā' (fourteenth century), Ibn Hamzah al-Maghribi (sixteenth century), and Baha'uddin al-'Amili (seventeenth century).

Umar Nurudin's work on the distribution of properties left behind by deceased members of the family was entitled *Pelajaran Membahagi Pesaka* (Lessons in Distribution of Inheritance) (early nineteenth century). His other works include *Syams al-Fathiyyah fi A'amāl al Juyūb* (The Guiding Light to Success in the Art of Trigonometry) or *al-Jaibiyyah* (The Art of the (Trigonometrical) Sine) (1925), *Rubu' al-Mujayyab* (The Quadrant of the (Astronomical) Sine) (date unknown), and *Miftāḥ al-Ta'alīm* (The Key to Teaching and Learning) (1924). In the early twentieth century a scholar by the name of Muhamad Nur al-Ibrahimi, from Sumatra Indonesia, wrote a treatise on logic called *'Ilm Mantiq* (The Art of Logic) (1931). Sheikh Muhammad Nur Ibrahim of Kelantan wrote a book *Bantuan Ketika Bagi Orang yang Membahagi Pusaka* (A People's Guide to Inheritance Problems) (1936). Earlier, in 1932 he published a book entitled

Pilihan Mastika pada Menerangkan Qiblat dan Ketika (Selected Gems in the Calculation of the Qibla Direction and (Prayer) Times), on the exact Qibla location in Mecca. Syeikh Tahir Jalaluddin, of Sumatran origin, wrote a book on the mathematical method of determining Muslim prayer times, entitled *Pati Kiraan pada Menentukan Waktu yang Lima dengan Logaritma* (The Essence of Calculations Related to the Five Prayer Times Using Logarithms) in 1938. He also authored two other books on astronomy and wealth distribution. His book on astronomy, *Risā'il fi'l-Falak* (Treatises on Astronomy), contained an article by Abdul Rahman Kelantan bin Muhamad al-Battul which was dated 1826. In our view, this may be the oldest extant treatise on astronomy ever found in the Malay language.

An arithmetic text written by Abd Qadir ibn 'Ali al-Sakhawi, known as *Matn al-Sakhawiyyah* (The Shortened Version of Sakhawi), was rewritten by Sheikh Wan Ahmad bin Muhammad Zain of Patani with some significant commentaries and footnotes towards the end of the nineteenth century. This book was a standard text in arithmetic and algebra among new students in Islamic schools. The commentator mentioned the book by Ibn al-Ha'im as one of the references in his commentary.

The philosophy of learning mathematics in the Malay Islamic world is closely linked to the concept of the relationship between Allah, The Supreme Being and man, his servant. A Muslim is always conscious of this relationship and of the fact that whatever he has at his disposal must be directed to the expression of his enslavement to Allah. Hence in the pursuit of knowledge he is always aware of his role and the roles of knowledge in glorifying the Supreme Being and the confines of his activities in this pursuit. Islam places high priority on the importance of learning. It is a religion whose understanding relies greatly on the grasp and the depth of one's knowledge of the physical and nonphysical world. Hence the learning of mathematics became necessary in a Muslim's life, as this subject is a tool in enhancing one's understanding of the world. If one is aware that the world is a creation of Allah, one's understanding of the greatness and infinite wisdom of Allah will be further heightened by grasping the mathematics principles that describe Allah's creations. Also the knowledge he has mastered will make him better able to contribute to the development of his society, which is also consonant with the teachings of the religion. Hence the positions of scholars and intellectuals rank high in an Islamic environment.

Among the daily activities in a Muslim society is the conducting of business transactions. Bartering, weighing, and using other means were characteristic activities in Muslim markets. All of these are closely connected to the ability to compute based on agreed principles. In his book *'Alam al-Ḥussāb*, al-Khatib gave examples of the units of measures which were in use during that time. These include *sen*, *ringgit*, and *rupiah* as currency units, *pikul*, *kati*, *saga*, *kundi*, and *bungkal* as weights measures, *hasta* and *depa* for length units and *cupak*, and *gantang* for volume. Further discussions on the topic of measures according to al-Khatib can be found in his book in Arabic entitled *Sulh al-Jama'atain* (Conciliation of the Two Parties). Quizzes were also included in al-Khatib's books. They ranged from topics on multiplication and division to determinations of square roots based on real life problems. Among the topics covered in this book are *permulaan ḥisāb* (elementary arithmetic), *haqiqah bilangan* (on counting principles), *hitungan sahih* (on the integers), *kumpulan* (addition), *kurangan* (subtraction), *pukulan* (multiplication), *jenis–jenis pukulan* (types of multiplication), *bahagian* (division), *nisbah a-muttaṣilah ḥisābiyah* (arithmetic progression), *al-muttaṣilah handasiyah* (geometric progression), *kaifiat mengetahui yang majhul* (systems of equations), *tabādul* (permutations), *kaifiat bilangan kali–kali mungkin* (combinations), *amal dua yang tersalah* (approximations method; golden rule), *al-jabr wa al-muqabbalah* or *amal dengan bertemper dan berkebetulan* (the term in Malay for the *algebra* of al-Khwārizmī and solutions to quadratic equations), *misāḥah* (plane geometry), and *al-mizan* (modular congruence). Most of the topics covered by this book are taught in modern day Malaysia. An interesting feature of this book, which was also admitted by the author, was the striking similarity between its content and that of the book *Khulāṣah al-ḥisāb* written by al-'Amili (seventeenth century) which was one of the many links in the chain of Islamic mathematical tradition which had begun from the time of al-Khwārizmī. Al-Khatib's approach in the teaching of mathematics was almost exclusively influenced by the traditional methods of teaching from the scholars of the early Muslim period which clung to the descriptive way of solving problems. Although symbolism was already introduced in the Islamic world as early as at the time of al-Khwārizmī and further popularized by Abu Kamil, al-Maghribi and later by al-Qalsaldi in Spain (fifteenth century) Malay Muslim mathematicians were not responsive to the idea of adopting the symbolism approach (Ismail 2004). Descriptive representation of mathematical problems is the special feature of the curriculum in mathematics education outlined above, as demonstrated by the content of the book *'Alam al-Ḥussāb fi 'Ilm al-ḥisāb* by al-Khatib, a representative of works written in the Malay language in the nineteenth century.

The motivating factors in the teaching of mathematics in the Islamic system of education in the Malay archipelago are tied to the need to comprehend the basic teachings of the religion and efficient implementation of the administrative procedures as outlined by regulations stipulated by Islamic jurisprudence (*fiqh*) that governs everyday activities in the life of a Muslim. This was the dominant factor in the determination of mathematics education in the Islamic school curriculum prior to the introduction of the secular school system brought by the British in the late nineteenth century.

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Al-Ḥajjāj

GREGG DE YOUNG

Al-Ḥajjāj ibn Yūsuf ibn Maṭar was one of the earliest translators of Greek mathematical and astronomical texts into Arabic. Few details of his life are known. According to a report of the biobibliographer, Ibn al-Nadīm, he prepared an Arabic version of Euclid's *Elements* under the sponsorship of the ʻAbbāsid caliph, Hārūn al-Rashīd (170–193 AH/AD 786–809). Later, under caliph al-Ma'mūn (198–218 AH/AD 813–833), he prepared a second (and improved) version. There are some hints that the mathematician, Thābit ibn Qurra (died 288 AH/AD 901), may have helped to revise the latter version.

Neither version is extant. Quotations from what purports to be the second version serve as the basis for a commentary by al-Nayrīzī (d. early fifth century AH/AD tenth century). These quotations seem, however, to have been edited by the commentator on the basis of the later translation of Isḥāq ibn Ḥunayn (215–298 AH/AD 830–910). There appear to be other traces of the transmission of al-Ḥajjāj in commentaries by Aḥmed al-Karābīsī and in the epitome of the Euclidean *Elements* in Ibn Sīnā's *Kitāb al-Shifā'* (The Cure [of Ignorance]). Probably this transmission tradition also served as the basis for the Latin translation of Adelard of Bath and the nearly contemporaneous Latin version of Hermann of Carinthia.

Al-Ḥajjāj is also credited with production of an Arabic version of Ptolemy's *Almagest*, perhaps by way of a Syriac intermediary. The relation of this transmission to that of Isḥāq ibn Ḥunayn has not yet been fully established. In this case, both traditions are extant, allowing a more careful scrutiny of philological characteristics and translation techniques. Attempts to apply what we learn from a study of the *Almagest* transmissions to Euclid remain incomplete.

See also: ►al-Ma'mūn, ►Thābit ibn Qurra, ►al-Nayrīzī, ►*Almagest*

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Al-Hamdānī

CHRISTOPHER TOLL

Abū Muḥammad al-Ḥasan ibn Aḥmad ibn Yaʿqūb al-Hamdānī, with the honorific name Lisān al-Yaman ("The Tongue, i.e., the Mouthpiece of the Yaman"), was born into a turbulent time in a turbulent world and was not called to make his time and world less turbulent. He did create not only turbulence, but also a scholarly monument which has remained the pride of his Yamanite compatriots and an enduring contribution to the culture of mankind.

Background and Life

When al-Hamdānī was born, in Ṣanʿāʾ, perhaps on Ṣafar 19th, 280 AH (May 10th, 893 AD), the Muslim expansion had created a wide common market and an equally wide uncommonly cultured world, both without frontiers. The common market and the peace of the caliphate had given rise to huge fortunes which had financed numerous cultural and scholarly activities inspired by the new religion Islam, carried by its versatile language, Arabic, on a foundation laid by Hellenistic culture. Members of different religions, Muslims, Christians, and Jews, with different languages, Arabic, Greek, Aramaic and Persian, had collaborated in transforming the Hellenistic heritage into the Islamic culture of Arabic language. It was possible to travel in search of profit, *faḍl Allāh*, or of knowledge, from the River Indus in the East to Spain in the West without being hindered by frontiers, customs, wars, language difficulties, or different currencies.

Knowledge and profit supported each other. New technology, new industries, new goods and new money were spread; palaces, universities and schools were built. Gardens were made for the study of plants; books were written and manuscripts were collected, copied and translated and libraries founded. Scholars and artists met in the houses of patrons, and in spite of intense discussions there reigned a liberal atmosphere. Never in the Middle Ages had there been such a width and liberty in research and teaching.

Nevertheless, there were sectarian conflicts, e.g. with the Khārijites and Shīʿites, which had dynastic and political aspects, and there were nationalistic conflicts, e.g. with the Shuʿūbīya, a movement of mainly Persians who opposed Arab supremacy. There were nationalistic conflicts also among the Arabs themselves when South and North Arabians brought their rivalry as far as Spain. And there were local conflicts where the control of the central power was weak, as in the Yaman, so that local chiefs were able to oust the representative of the caliph. Al-Hamdānī was one of the most energetic champions of South Arabian nationalism, and yet his nationalism prompted him to scholarly and literary works of high value while it also rendered him open to persecution and maybe, as has been said, brought him a premature death in prison.

As his name shows, al-Hamdānī was a descendant of the powerful tribe Hamdān which had already played an important role in the Yaman to the north of Ṣanʿāʾ in pre-Islamic time. He was born in Ṣanʿāʾ, in the neighbourhood in which his family had lived for four generations. He was surnamed Ibn al-Ḥāʾik, after an ancestor who was a famous poet, and al-Hamdānī was to take up this family tradition.

A few decades before al-Hamdānī's birth the head of a local dynasty from Shibām, Yuʿfir b. ʿAbdarraḥmān al-Ḥiwālī, defeated the governor of the ʿAbbāsid caliphate and later transferred his power to his son Muḥammad who in his turn relinquished it to his son Ibrāhīm. When al-Hamdānī was born, Yuʿfir had recently ordered his grandson Ibrāhīm to murder his father which led to a revolution and the destruction of the silver mine in al-Jawf. In this revolution Ibrāhīmʾs house was plundered and he himself murdered, and the ʿAbbāsid governor reinstated the power of the caliph. But when al-Hamdānī was a small child the governor was called back to Baghdad and his Turkish soldiers were left to ravage Ṣanʿāʾ. The first Zaydī *imām*, al-Hādī ilā l-Ḥaqq, was called in to restore order. The following years witnessed repeated battles between al-Hādī and the Yuʾfirids. When a Fāṭimid *dāʿī* entered the scene, however, the Yuʿfirids under Asʿad b. Ibrāhīm and al-Hādī became allied.

These events did not leave al-Hamdānī unaffected: his own tribe Bakīl of Hamdān won a victory over the Fāṭimid army, and he was imprisoned by Asʿad's nephew, because he was opposed to the foreign element among the followers of the Yuʿfirid's ally. Al-Hamdānī's satirical verses gave rise to a revolt against al-Hādī's son an-Nāṣir, which culminated in the battle of Katafā and the death of an-Nāṣir and his brother Ḥasan. Al-Hamdānī escaped from prison to Hamdān's *sayyid* in Rayda and praised the leaders of the revolt in poems. It is thus doubtful that he died in prison in Ṣanʿāʾ in 334/946 as had been said by Ṣāʿid b. Ṣāʿid al-Andalusī on the authority of the Andalusian caliph al-Mustanṣir; others maintain that he did not die until about 350.

The Geographer

As a scholar, al-Hamdānī had an excellent education and did much travelling. One result of his travels is his geography of Arabia, particularly South Arabia, *Ṣifat jazīrat al-ʿarab*, the only systematic monograph of the Arabian Peninsula from the Middle Ages, which has been preserved in its entirety.

The first part of the work is a general geographical–astronomical introduction which follows Ptolemy. In this introduction al-Hamdānī showed his knowledge of Greek learning (he also quoted Hermes Trismegistos and Dioscorides). He was also familiar with the Indian astronomical work *Sindhind* and its Arabian translator al-Fazārī, as well as Ṣanʿāʾ's own astronomers.

The next part is a work on the physical, political and economical geography of the Arabian Peninsula. Starting with the Yaman, al-Hamdānī describes the different parts of Arabia with their mountains, valleys and wādīs, their vegetation and animal life, their tribes, habitations, villages, towns and castles, the number of inhabitants, the ownership and cultivation and irrigation of land, the pilgrim's roads and the dominions of sultans and governors. One of the themes is meteorology, as has repeatedly been observed, a theme that recurs in al-Hamdānī's medical work *Kitāb al-Quwā* (see below), as he mentions himself in his *Kitāb al-Jawharatayn* (see below).

The geographical description is interspersed with historical, genealogical, ethnographical and psychological notes, and he quotes Islamic and pre-Islamic poetry. In one of the concluding chapters, Hamdānī deals with weather conditions, food, prices, domestic animals and deposits of precious stones.

The Poet

Also as a poet and a collector of poetry al-Hamdānī shows his national and political fervour. His *Qaṣīda aḍ-Ḍāmigha fī faḍl al-Qaḥṭān* is an answer to Kumayt b. Zayd al-Asadī's satirical attack on the South Arabian tribes two hundred years earlier. To this poem – of its 590 verses rhyming *in -i/una* 476 are preserved – al-Hamdānī is said to have written a detailed commentary in a big volume. Another poem, *Qaṣīdat al-Jār*, deals with politics contemporary with the author, blaming the Yu ʻfirid ruler for having put him in prison. *Al-Iklīl* also contains many specimens of South Arabic poetry, including al-Hamdānī's own. His Diwān, with the commentary of Ibn Khālawayh, is said to have comprised six volumes, but has not come down to us.

The Philologist

As a philologist, al-Hamdānī is interested in words for things, e.g., in his *Ṣifa* it is the names of the flowers rather than the flowers themselves which are the object of his interest. In his *K. al-Jawharatayn* he discusses different words for gold and silver and for gold and silver coins and their sides and parts with their etymologies. In this context he explains the South Arabian mīmation and the formation of words of four radicals with *-m* as the fourth radical as originating in the *mā l-ibhāmīya*. In his *Ṣifa* he treats the spoken language of 113 different parts of the Arab peninsula and whether their language is correct or not or even ununderstandable. The best Arabic is spoken by, i.a., the Hamdān and by the nomads in the Ḥijāz and Najd as far as Syria, whereas in ʻAdan the common people not only speak bad but are even stupid, and the Mahra are as foreigners, impossible to understand (actually, the South Arabic Mahrī dialect is also today not understood by those speaking a North Arabic dialect). Al-Hamdānī also illustrates his verdicts by examples, e.g. when he says that the Sarw Ḥimyar say *ya bna m- ʻamm* instead of *ya bna l- ʻamm* and *sima*' instead of *isma* '- also other tribes have a definite article with *-m* instead of *-l*. Some tribes are said to speak Ḥimyarite. Al-Hamdānī gives in *al-Iklīl* some further examples to illustrate the Ḥ imyarite language and even some text samples.

Quotations from book 9 of *al-Iklīl* in a later work (the commentary on Nashwān's Ḥimyaritic *qaṣīda*) show that al-Hamdānī had a certain knowledge of the South Arabic script, which he reproduces in a table in book 8 with the (North) Arabic equivalents, but that he did not understand the inscriptions.

Al-Hamdānī's own language, by the way, does not seem quite to have followed the rules of the classical grammar. Al-Qifṭi tells us that *lamma dakhala l-Ḥusayn b. Khālawayh al-Hamadhānī an-Naḥwī ilā l-Yaman wa' -aqāma bi-hā bi-Dhamār, jama'a diwān shi ʻrihi* (*ya ʻni shi ʻr al-Hamdānī*) *wa- ʻarrabahu wa-a ʻrabahu* ("When Ḥ. b. Kh. al-H. the Grammarian came to Dh., he collected his (sc. al-Hamdānī's) poetry and made it into correct and clear Arabic"). And at least his *Kitāb al-Jawharatayn* shows in fact deviations from the classical norm and traces of the author's spoken language.

The *Faqīh*

Al-Hamdānī was also interested in law. In a work that has not been preserved but has been mentioned by al-Qifṭī, *Kitāb al-Ya ʻsūb*, he is said to have written about the legal rules concerning hunting. The legal chapter in the *Kitāb al-Jawharatayn* has been omitted in the manuscript with the exception of the title, *bāb ḥukūmat al- ʻiyār wa-fiqhihi wa-mā' ashbahahu*. Only short comments on gold and silver in the Hadith, on the prohibition of interest and of two purchases in one or the selling of gold for gold and silver for silver, and on the question of whether it is allowed to change God's creation are found in other chapters of the *Kitāb al-Jawharatayn*. The idea that gold as God's creation should be worked as it is without being refined is refuted by al-Hamdānī who compares it with wheat and sugar-cane which are also of God's creation but are worked and used in different ways.

The Historian

Al-Hamdānī's geography is supplemented by his historical work, *al-Iklīl*. This work was written in 332/944 while its author was living as the guest of Sayyid Hamdān, Abū Jaʿfar ad-Dahhāk, in the castle of Tayfum in Rayda. It consisted of ten books: books 1, 2 and 10 deal with the beginning of genealogy and present genealogies of South Arabian tribes, and book 8 describes the old castles of pre-Islamic South Arabia. These books are extant today. Of those not preserved, book 3 is said to deal with the merits of the South Arabian tribes, books 4–6 with the history of South Arabia before Islam, book 7 contained a critique of false traditions, and book 9 South Arabian inscriptions. Al-Hamdānī's sources were Abū Naṣr Muḥammad b. ʿAbdallāh b. Saʿīd al-Yahar al-Ḥanbaṣī, the learned lord of the castle Ḥanbaṣ, the archives (*sijill*) of the Banū Khawlān in Ṣaʿda and oral popular tradition and written information from different sides, e.g. from the legendary ʿUbayd b. Sharya al-Jurhumī, the collector of legends

Wahb b. Munabbih and the famous genealogist Hishām b. Muḥammad al-Kalbī. *Al-Iklīl* (The Crown) is quoted in al-Bakrī's *Muᶜjam ma staᶜjam*. Another historical work of al-Hamdānī, *Kitāb al-Ayyām*, to which he refers in his *Ṣifa*, has not been recovered. That so many of al-Hamdānī's historical writings were lost is, according to al-Qifṭī, because members of tribes not favourably mentioned had destroyed all the copies they could find.

The Philosopher

The two works, *Ṣifat Jazīrat al-ᶜArab* and *al-Iklīl* have made al-Hamdānī known as a geographer and a historian. But that he was also said to be one of only two famous Arab philosophers – the other was al-Kindī – is difficult to understand. Al-Kindī is well known as a famous philosopher, but why al-Hamdānī? After two other works by al-Hamdānī have become known, however, it is easier to understand the appreciation of the philosopher al-Hamdānī. As a philosopher, al-Hamdānī was interested, in his book on gold and silver, *Kitāb al-Jawharatayn al-ᶜatīqatayn* (see below), in the generation and corruption of matter, in the transmutation of one element into another and in the influence of the heavenly bodies upon the earth. He was a follower of the Greek philosophers, and he quotes the works of Aristotle concerning the generation of heat. But in his astronomical work *Sarāᶜir al-ḥikma* (see below) he opposes Aristotle, maintaining that each part of the celestial sphere is connected with a corresponding part of the earth.

The celestial sphere is divided according to the signs of the Zodiac, and this division also governs that of the seasons. In his *Kitāb al-Jawharatayn* al-Hamdānī gives a survey of the seasons with the qualities (warm, cold, dry and moist), elements (fire, water, earth and air) and cardinal humours (blood, phlegm, black and yellow bile) belonging to each season, and he also tells us which substances are related to which planet or sign of the Zodiac: lead, e.g. belongs to Saturn and to Capricorn. The influence of the planets on their substances varies according to their positions and the season of the year. The influence occurs also according to similarity: fire can influence only what already contains fire.

When al-Hamdānī compares the earth as round and globular and situated in the middle of the likewise round and globular sphere with the centre in the circle, he is repeating a comparison already to be found in a quotation by Archimedes from Aristarchos. Also in his historical work, ancient conceptions of the world as being eternal or created are said to be discussed. Some influence from the theory of atoms seems to be found in expressions such as *ijtimāᶜ* for having a three-dimensional body, properly signifying the fusion of atoms into a body, and the repeated use of the word *ajzāᶜ*, particles, atoms.

The Aristotelian theory of the generation of substances from the four elements under the influence of the heavenly bodies forms the basis of alchemy. The theory is that the different matters consist of a mixture of the four elements. According to their purity and proportions and the influence of the planets the metals arise in the earth. Of the metals, gold is the most pure, containing the elements in ideal proportions. Thus it ought to be possible to imitate the processes of nature by artificial means, removing the impurities and restoring the ideal proportions and thereby to obtain gold.

The alchemists used sulphur, being hot and dry, and mercury, being cold and moist, as representing the elements. It appeared, however, that no mixing of sulphur and mercury results in gold. The alchemists then presumed ideal forms of sulphur and mercury, not existing in the natural world. In order to accelerate the transformation which happens very slowly in nature, they used an elixir, having the same effect as yeast, and to produce this elixir the alchemists used a lot of methods, such as distillation and sublimation, boiling and calcination, amalgamation, etc. by means of crucibles, retorts and distilling-apparatuses, thus laying the foundations of chemistry. Later alchemists made this procedure into a ritual with an allegorical meaning, and a secret art.

The Muslim scholars had different opinions about alchemy. The great physician al-Rāzi (d. 313 or 323 H) tried to transmute metals, and he classified the matters he used according to their natures and properties. The great scientists al-Bīrūnī and Ibn Sīna (both fifth century H) believed in the generation of matter and in the sulphur–mercury theory, but they were opposed to alchemy because they were of the opinion that art was not able to imitate nature.

The Astronomer

In Greek and Islamic tradition you cannot separate the philosopher, the scientist and the doctor, and the views which I have mentioned are closely related to astronomy and astrology, chemistry and medicine, subjects on which al-Hamdānī was also productive.

Al-Hamdānī is also said to have compiled astronomical tables, *az-Zīj* – he mentions *Tanbīh az-Zīj* – and a book on horoscopes and the projection of rays (*Kitāb at-Ṭāliᶜ wal-maṭāriᵓ*. In a medicinal work, *al-Quwā*, which is lost, he showed the influence of the planets upon the temperature of the earth. It is also said that pieces on astronomy and physics are scattered through his historical work.

Of his astronomical work, *Sarā 'ir al-ḥikma fi ‘ilm an-nujūm*, al-Qifṭī says, quoting Ṣā‘id al-Andalusī, that its aim is *at-ta‘rīf bi-jumal hay 'at al-aflāk wa-maqādīr ḥarakāt al-kawākib wa-tabyīn ‘ilm aḥkām an-nujūm wa-stifa' ḍurūbihi* "the definition of the total form of the celestial bodys, the extent of the movements of the stars, the exposition of astronomy, and the exhaustive treatment of its kinds". It is also quoted by Abū Marwānal-Istijī, according to Ṣā 'id one of the best astrologers in al-Andalus. However, only the tenth chapter of this work has been recovered in two manuscripts in al-Yaman. In this work several Greek scholars are cited – Dorotheos of Sidon, Ptolemy, Valens, Hipparchos and the mythical Hermes Trismegistos – as also the Indian astronomical work Sindhind as well as its Arabic translator al-Fazārī and Persian astronomical works but also Islamic scholars, such as Māshā'allāh, Abū Ma 'shar, Abū Muḥammad b. Nawbakht, Sulaymān b. 'Iṣma.

The Economist

We have seen that al-Hamdānī's historical and geographical works were intended to be complementary to each other. In the same way his book on gold and silver, *Kitāb al-Jawharatayn al-ʿatīqatayn min aṣ-ṣafrāʾ wal-bayḍāʾ*, belonged to a trilogy on South Arabic economy, the parts of which were also complementary. Part 1 dealt with agriculture, part 2 with camel breeding and part 3 with gold and silver, i.e. the three kinds of property: landed property, cattle and precious metals. Only the part dealing with gold and silver has been preserved. Here gold and silver are mentioned as a form of investment, and its advantages in this respect are praised, above all that it is easy to take along.

The Metallurgist

In the *Kitāb al-Jawharatayn* the *Qurʾān* and the *Tradition* are quoted but so are popular traditions. An abundance of Persian expressions for substances and tools show that al-Hamdānī also had inherited an Iranian tradition with which he had personal contact. He says that Persian tribes, which had immigrated into al-Yaman already before Islam, were working the mines in South Arabia. They were called *furs al-maʿdin* and enjoyed a good position and property in Ṣanʿāʾ.

Al-Hamdānī also learnt about metallurgy and minting from specialists among his compatriots. The art of forging is very old in al-Yaman. It perhaps has its origin in the connections of al-Yaman with India – the Indian steel and the Indian swords made from it are often mentioned in Arabic poetry and by al-Hamdānī. The art of forging swords and armours is traced back by tradition to the Tubbaʿ, the kings of Ḥimyar, and the swords of al-Yaman are famous in Arabic poetry. Another important source of his knowledge was the master of the mints in Ṣanʿāʾ and Ṣaʿda and his sons, one of whom was to succeed him in the office.

Al-Hamdānī's *Kitāb al-Jawharatayn* is the oldest and most comprehensive of the four Arabic works on gold, silver and minting known to us (the other three are *Kashf al-asrār* by Ibn Baʿra, a manual of the Egyptian mint of the seventh century H, *ad-Dawḥa al-mushtabika fī ḍawābiṭ dār as-sikka* by ʿAlī b. Yūsuf al-Ḥakīm, a manual of the mint in Fās of the eighth century H, and a manual of the mint in Marrākush from the 990s H). It abounds in technical and chemical information which extends from the extraction of ore from the mines to the minting of coins. It also contains valuable information about gold and silver mines in Arabia, Africa and Iran. It also mentions the use of gold and silver for gilding and silvering and for ornaments and of gold leaf for decorating pages of the *Qurʾān*. It describes glass and methods of counterfeiting. Also the use of other metals such as iron and mercury and the sickness caused by some substances and their use are dealt with. The main subject of the book is, however, the fabrication of coins.

The fabrication of coins can be divided into three stages: the fabrication of the dies, the fabrication of the flans and the stamping of the flans. According to al-Hamdānī the die was made from hardened steel, its surface filed and the inscription engraved with an iron stylus. The die was pegged and holed in order to hold its two halves in a fixed position and to achieve a fixed relationship between the coin's obverse and reverse.

The flans were made after the gold and silver had been purified. The impurities in the gold ore were separated from the gold by means of sulphur, and the gold left in the separated impurities was collected by amalgamation with mercury. Silver was also extracted by amalgamation and otherwise purified by heating while supplying air at the same time, so that the lead in the silver ore combined with the oxygen in the air and was separated as lead oxide. Al-Hamdānī describes three methods to fabricate the flans. One was lamination: the cutting of flans from moulded bars. A second method consisted of casting the flans in moulds of clay. The third method consisted of pouring molten silver or gold into water. Thus small round pieces of metal were obtained which were hammered flat and used as flans, in spite of their different size.

The Physician

Al-Qiftī calls al-Hamdānī *aṭ-ṭabīb* (physician), and one of his books, *al-Quwā*, is said to be a medical work, but we do not know its content. That al-Hamdānī was interested in medicine is, however, clear also from *Kitāb al-Jawharatayn*, which contains some medical information. The pain of burns is mitigated by means of gold. Rash is treated with water containing gold. Chips of gold and silver are ingredients in important remedies. The oculists use dross of gold and silver. Silver slag removes the stink of the sweating of the axillae and is used in salves to close wounds. Verdigris, made from copper and wine vinegar, is used in many remedies and in colours. Antimony heals wounds and stops haemorrhage from the cerebral membranes, and mixed with fat it is used for burns. Mercury is used against colic but can also increase colic, causing constipation and death.

There are also some general remarks on the influence of compound drugs on the body and the difference between medicine for internal and external application. Some of the information is borrowed from Dioscorides' materia medica.

Al-Hamdānī also mentions damages caused by different substances. The mercury vapour produced by gilding and amalgamating causes hemiplegia and convulsions. Since mercury is moist and cold the remedy ought to be something warm, such as wine. The fumes of lead, which evaporate when silver is purified, affect the brain, and the vapours of the substances used for purifying the gold dry out the nose and saliva, cause cutaneous fissures and affect the brain. Therefore, a wall is put between the furnace and the workers, or the workers cover their noses – early examples of safety precautions for workers. Fumes from lead and copper injure the teeth, weaken the bladder and cause a pain in the waist. The fume from the manure used when silver amalgam is heated causes headaches, and other fumes from the furnace give rise to jaundice, disturbed vision, attacks of sickness, abdominal pains, and headaches.

The Man

Intellectually, al-Hamdānī was a man of independent thought. We have seen that he did not simply reproduce the learning of others. As a geographer he relied mainly on his own observations, travelling extensively over the country he was going to describe. He had his own opinion about the colour of the skin of the peoples in the tropical countries, which was contrary to that of Ptolemy. He had his own division of the world with more climata than the usual seven. He contrasted the opinion of the Greeks concerning the extension of the inhabited world with that of the Indians and the Chinese and exposed in detail the differences between the Greek, Indians and Arabs concerning latitude and longitude. He also contrasted two theories concerning the seasons, their qualities and the cause of these qualities.

Morally, al-Hamdānī was a man of courage and strong passions. Although a Muslim, he dared to attack the tribe of the Prophet, and his strong stand for the Yaman can also be seen in the absence of descriptions of Makka and al-Madīna from his *Ṣifa*. He was not afraid of taking part in the political turmoil of his days, and prison did not frighten him and did not break him down. Nothing in his writings, however, gives the impression that he was but a pious Muslim, well versed in the *Qurʾān* and the *Hadīth*.

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Al-Hāshimī

F. Jamil Ragep

ʿAlī ibn Sulaymān al-Hāshimī flourished some time in the second half of the ninth century, probably somewhere in the central lands of Islam. Virtually nothing is known about him other than the fact that he wrote a rather uncritical work on *zījes* (astronomical handbooks) that nevertheless preserves a great deal of otherwise unknown or little known information. This book, *Kitāb fi ʿilal al-zījāt* (Explanation of Zījes), was written at a time before Ptolemaic astronomy had become the dominant astronomical tradition in Eastern Islam. As such, it contains considerable material about the Indian and Persian astronomical traditions, at least insofar as they were received and preserved during this early period of Islamic science.

Hāshimī mentions some sixteen *zījes*, of which two are Greek (Ptolemy's *Almagest* and Theon's *Canon*, which is based upon it); seven are Indian or derived mainly from Indian sources (the *Arjabhar*, the *Zīj al-Arkand*, the *Zīj al-Jāmiʿ*, the *Zīj al-Hazūr*, the *Zīj al-Sindhind* of al-Fazārī [eighth century] as well as a second *zīj* by him, and the *Zīj* of Yaʿqub ibn Ṭariq [eighth century]); two are Persian but mainly Indian in inspiration (the *Zīj al-Shāh* of Khusro Anūshirwān and the *Zīj al-Shāh* of Yazdigird III); and five are from the ninth century and use material from these three traditions in varying degrees (the *Zīj al-Sindhind* of al-Khwārizmī, the *Zīj al-Mumtaḥan* of Yaḥyā ibn abī Manṣūr, the first Arabic *zīj* that was principally Ptolemaic, two *zījes* of Ḥabash, one mainly Indian, the other mainly Ptolemaic, and the *Zīj al-Hazārāt* of Abū Maʿshar).

Besides its importance as a historical resource, Hāshimī's work provides some valuable clues about the state of Islamic science during this early period. It is clear that the impressive number of astronomical works floating about made a work explaining them desirable, giving evidence for the vitality of science during this period. The influx of "foreign" knowledge had its detractors, though, and Hāshimī felt compelled, in a passing comment, to affirm that the cycles of Indian astronomy were not from their prophets, whatever might be claimed; nor were they for the purpose of "soothsaying", something he knows would be unIslamic. Rather he asserts that they are mathematically derivable and as such safe, an interesting and not atypical way of handling religious opposition to astronomy in Islam.

This makes the subsequent history of Islamic astronomy all the more remarkable. Indian astronomy with its cycles and computational tradition, but lacking a full-blown cosmology would, at first glance, seem to be a much more congenial tradition for Islam, which had its own religious cosmology and metaphysics. In fact Hāshimī implies as much in introducing the *Sindhind*; he also reports that Shāh Anūshirwān (sixth century) preferred Indian to Ptolemaic astronomy. So the subsequent predominance and triumph in Islam of Ptolemaic astronomy, based ultimately on Aristotelian physical principles and cosmology, was a remarkable occurrence indeed.

See also: ►al-Khwārizmī, ►Yaḥyā ibn abī Manṣūr, ►Abū Maʿshar, ►*Almagest*, ►*Zīj*

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Al-Idrīsī

Sayyid Maqbul Ahmad

Abū ʿAbd Allāh Muḥammad ibn Muḥammad ibn ʿAbd Allāh ibn Idrīs, known as al-Sharīf al-Idrīsī, was one of the great Arab geographers of medieval Islam. He was born in Ceuta (Morocco) in AH 493/AD 1100 and died there in AH 560/AD 1166. Al-Idrīsī belonged to a ruling family, the Alavī Idrīsīs, who were claimants to the caliphate and had ruled in the region around Ceuta from AD 789 to 985. His ancestors were the nobles of Malaga, Spain who, unable to maintain their authority there, migrated to Ceuta in the eleventh century. Al-Idrīsī was educated in Cordoba and began traveling at a very early age. At the age of 16, he visited Asia Minor and then traveled in southern France, England, Spain, and Morocco.

This was a period of the growing power of the Normans in Europe and the Mediterranean region. It is said that Roger II (1097–1154), the Norman ruler, invited al-Idrīsī to come and stay with him in Palermo (Sicily), saying he would be safe from Muslim kings who were trying to murder him. Al-Idrīsī accepted the king's invitation and went to Palermo sometime in AD 1138 and stayed there until after the death of Roger in AD 1154. Then he returned to Ceuta.

Sicily at this time was an important center, where Arab-Islamic and Western European cultures intermingled. Roger himself was very interested in the promotion of arts and sciences, and we learn from al-Idrīsī that he was also interested in geography and astronomy. Roger gave al-Idrīsī an important task, probably from political motives, which was to construct a world map. Roger was still engaged in expanding his empire in North Africa, and thought al-Idrīsī would be a suitable person for this task. Although he was well traveled in North Africa and Europe, al-Idrīsī was not a geographer in the true sense of the word at this stage. But he began constructing the map under the patronage and supervision of Roger. Finding that the courtiers at his palace did not possess sufficient knowledge of the geography of the world, Roger sent envoys to different regions to collect fresh data. After the information was acquired, al-Idrīsī utilized only such data on which there was unanimity; the rest was discarded. He also used the Arabic geographical works which were available to him, such as the Arabic version of Claudius Ptolemy's (ca. AD 90–186) *Geography* (Arabic *Jughrāfiya*), *Kitāb Ṣūrat al-Arḍ* (Book on Routes and Kingdoms) by Ibn Hawqal, *Al-Masālik wa'l Mamālik* by Ibn Khurdādhbih (AH 232/AD 846), and the lost work of al-Jayhānī entitled *Kitāb al-Masālik wa'l Mamālik*. Thus it seems that al-Idrīsī had a vast amount of geographical material on the known world at his disposal.

He worked on the map for 15 years, basing it primarily on Ptolemy's map, with some modifications. When it was completed, Roger asked him to have it carved on a round silver disc, which al-Idrīsī did with great skill with the help of artisans. The silver map had all the physical features and names of places drawn on it. Roger was so pleased with al-Idrīsī's performance that he asked him to write a book on world geography. He produced the voluminous compendium *Nuzhat al-Muṣṭāq fi ikhtirāq al-ʾAfāq*, the full Arabic text of which has now been published as *Opus Geographicum* under the auspices of the Italian Institute of the Middle and Far East in Rome and the Institute of Oriental Studies at Naples University. Although the silver map has not survived, the original world map has. The *Nuzhat* is supposed to be a description of this world map. Al-Idrīsī divided the known world into seven climes (*iqlīm*) running parallel to the equator up to 64°N latitude and divided each of the climes into ten longitudinal sections. Thus there are 70 odd sectional maps, and the arrangement of the book follows the 70 divisions. In many cases, there is more information in the book than is depicted on the maps. Al-Idrīsī's world map is the most detailed and largest map drawn by any Muslim cartographer. His book is indeed a mine of information on physical, topographical, human, cultural, and political geography. From the world map and the book, one can see that his knowledge of Europe, North Africa, and West and Central Asia was much deeper and more correct and extensive than it was of South Asia or the Far East.

Al-Idrīsī had a mathematical basis for his map, but he did not provide latitudes or longitudes as al-Maghribī did, who followed the pattern of al-Idrīsī. As he tried to include all the information at his disposal, some distortions were bound to take place, especially in the northern and southern regions. For example, the shapes and positions of the islands in the Indian Ocean were distorted. Even with these errors, his book is an encyclopedia of geographical knowledge of medieval times, and was an important geographical textbook for a long time.

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Al-Jawharī

Sonja Brentjes

Probably of Iranian origin, al-ʿAbbās Ibn Saʿīd al-Jawharī was one of the court astronomers/astrologers of Caliph al-Maʾmūn (r. 813–833) in charge of the construction of astronomical instruments. He participated in astronomical observations carried out in Baghdad in 829–830 and in Damascus in 832–833. He is said to have composed an astronomical handbook (*Zīj*), which is lost, except for indirect references (Sezgin 1973). In his house in Baghdad, meetings were held at which the participants discussed Ptolemy's *Almagest*, Euclid's *Elements*, and problems derived from the two books. A not yet studied manuscript, *Kalām fī maʿrifat buʿd al-shams ʿan markaz al-arḍ* (Speech about the Knowledge of the Distance between the Sun and the Center of the Earth), might be an extract of his *Zīj* or an independent astronomical treatise. In astrology, he was considered an expert at horoscopes determining an individual's length of life.

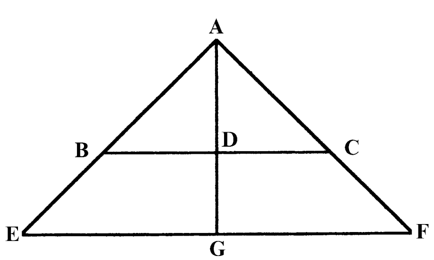
His main achievements in the mathematical sciences are in geometry. He edited or commented on the *Elements*. Extracts of this work are preserved as independent manuscripts containing fragments of his *Ziyādāt fī'l-maqāla al-khāmisa min kitāb Uqlīdis* (Additions to Book V of Euclid's Book) and as quotations of his attempted proof of the parallel postulate (Book I) in Naṣīr al-Dīn al-Ṭūsī's *al-Risāla al-shāfiya ʿān al-shakk fī'l-khuṭūṭ al-mutawāziya* (The Healing Treatise on the Doubt Concerning Parallel Lines). In this treatise, al-Ṭūsī also cites one of al-Jawharī's additions to Book I, namely that the angles contained by three lines drawn from one point in different directions equal four right angles.

Al-Jawharī's attempted proof of the postulate was contained in the same edition of the *Elements* as the aforementioned additional proposition. It evidently was inspired by the proofs of Simplikios (sixth century) and Aghānīs/Aghānyūs (Agapios?, fl. ca. 511), since he used the same variant of the so-called Eudoxos-Archimedes axiom as Aghānīs and at least two propositions attributed by ʿAlam al-Dīn Qayṭar (d. 1251) to Simplikios. Since both proofs were contained in Simplikios' commentary on the definitions, postulates, and axioms, its Arabic translation obviously was made in the first half of the ninth century.

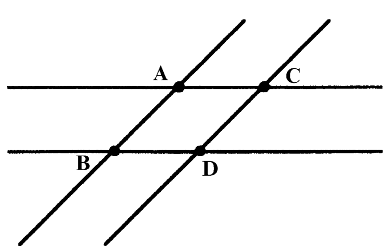
The theorem upon which al-Jawharī's proof is built states principally that if a triangle ABC is divided by a line AD and this line and the two sides AB and AC are extended and cut by a line EF such that $AB = BE$ and $AC = CF$, then $AD = DG$ with G being the point of intersection between line EF and the extension of line AD (see Fig. 1).

The proof of this proposition and consequently the proof of the postulate ultimately depend upon two propositions possibly introduced by al-Jawharī himself. The problem of the whole proof lies in the incomplete proof of the second part of the first of the two theorems, which al-Ṭūsī had already discovered. This second part states principally that the distance between one point of a line and its "corresponding" point on a second, parallel line always equals the distance between a second point on the first line and its "corresponding" point on the second line, $AC = BD$ (Fig. 2). Al-Jawharī's proof of this part not only treats a special case, but also fails to prove the equality of the two joining lines.

The fragment of al-Jawharī's additions to Book V contains three propositions which try to prove Euclid's definitions V, 5 (identity of ratios), V, 7 (one ratio > a second ratio), and the negation of definition V, 5. This illustrates how difficult those definitions were. Usually, a definition is not proven, since it was regarded as an evident assumption or a statement agreed upon between scholars. Al-Jawharī's explanations dressed as



Al-Jawharī. Fig. 1 Jawharī's theorem.



Al-Jawharī. Fig. 2 The distance between one point of a line and its corresponding point on a second, parallel line always equals the distance between a second point on the first line and its corresponding point on the second.

formal proofs do not really clarify those definitions, since all he did was simply to repeat them for special objects, namely, natural numbers.

Al-Jawharī is also credited with the translation from Persian into Arabic of a book about poison of supposed Indian origin, the so-called *Kitāb al-Shānāk* (The Book of Shānāk), for al-Maʾmūn.

See also: ►al-Maʾmūn, ►Astronomical Instruments, ►*Almagest*, ►*Elements*, ►*Zīj*, ►Naṣīr al-Dīn al-Ṭūsī

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Al-Jazarī

Donald R. Hill

Al-Jazarī, Badīʾ al-Zamān Abū'l-'Izz Ismaʿil ibn Al-Razzāz, was an engineer who worked in al-Jazira during the latter part of the twelfth century. His reputation rests upon his book, *Kitāb fī maʿrifat al-ḥiyal alhan-dasiyya* (The Book of Knowledge of Ingenious Mechanical Devices), which he composed in 1206 on the orders of his master Nāsir al-Dīn Maḥmūd, a prince of the Artuqid dynasty of Diyar Bakr. All that we know of his life is what he tells us in the introduction to his book, namely that at the time of writing he had been in the service of the ruling family for 25 years. The book is divided into six categories (*nawʿ*). Each of the first four contains ten chapters (*shakl*), and the last two consist of only five each. The categories are as follows:

1. Water clocks and candle clocks
2. Vessels and pitchers for use in carousals or celebrations
3. Vessels and basins for hand washing and phlebotomy
4. Fountains and musical automata
5. Water lifting machines
6. Miscellaneous

There are many illustrations, both of general arrangements and detailed drawings, and these are of considerable assistance in understanding the text, which contains many technical expressions that have since fallen into disuse. Some 13 manuscript copies, made between the thirteenth and the eighteenth centuries, are extant to bear witness to the widespread appreciation of the book in the Islamic world.

There are, however, no references to al-Jazarī in the standard Arabic biographical works of the Middle Ages, and there is no known translation into a European language before the twentieth century.

Only one of the complete machines, a twin cylinder pump driven by a paddle-wheel, can be said to have direct relevance to the development of mechanical technology. Many of the devices, however, embody techniques and mechanisms that are of great significance, since a number of them entered the general vocabulary of European engineering at various times from the thirteenth century onward. Some of these ideas may have been received directly from al-Jazarī's work, but evidence is lacking. Indeed, it seems probable that a large part of the Islamic mechanical tradition – especially water clocks and their associated mechanisms and automata – had been transmitted to Europe before al-Jazarī's book was composed. Even leaving aside the question of direct transmission, we still have a document of the greatest historical importance. First, it confirms the existence of a tradition of mechanical engineering in the Eastern Mediterranean and the Middle East from Hellenistic times up to the thirteenth century. Al-Jazarī was well aware that he was continuing this tradition and was scrupulous in acknowledging the work of his predecessors, including Apollonius of Byzantium, the Pseudo-Archimedes, the Banū Mūsā (ninth century), Hibat Allah ibn al-Ḥusayn (d. 1139–1140), and a certain Yūnus al-Asṭurlābī.

Other writings and constructions, whose originators were unknown to al-Jazarī, are also mentioned.

Second, his use of and improvement upon the earlier works, together with his meticulous descriptions of the construction and operation of each device, enables us to make an accurate assessment of mechanical technology by the close of the twelfth century.

See also: ►Banū Mūsa, ►Engineering, ►Technology in the Islamic World

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Al-Jurjānī

E. Ruth Harvey

Abū˒l-Fadā˒il Ismā˓īl ibn al-Ḥusayn al-Jurjānī, Zayn al-Dīn, sometimes called Sayyid Ismā˓īl, was the most eminent Persian physician after Ibn Sīnā (Avicenna), and the author of the first great medical compilation written in Persian. Born at Jurjan, 50-mile east of modern Gurgan, east of the Caspian, he was a pupil of Ibn Abī Ṣādiq (d. 1066–1077), who had himself been a pupil of Ibn Sīnā. In 1110 al-Jurjānī entered the service of the ruler of Khwarizm (modern Khiva), the Khwārizmshāh Quṭb al-Dīn Muhammad (d. 1127) and his son Atsiz; later he moved to Marw (Merv) and served the rival sultan Sanjar. Al-Jurjānī died at Marw in about 1136 (AH 531).

Al-Jurjānī's great work is entitled *Dhakhīra-i-Khwārazmshāhī* (The Thesaurus of the King of Kharazm). Comparable in size and scope to Avicenna's *Canon*, the *Thesaurus* is a compendium of medical knowledge and clinical practice. It rapidly became a classic and established the medical and scientific vocabulary in Persian; its influence was extensive and long-lasting. It was translated into Hebrew, Urdu, and Turkish, and remained in use until the nineteenth century. There are many manuscripts, both complete and fragmentary, but no available modern edition (although Keshavarz records an Indian edition of 1865–1866, and one produced in Tehran in 1965).

In addition to the *Thesaurus*, al-Jurjānī composed other works in Persian which appear to be, in the main, abridgements of it. Chief among these is the condensed version called *Mukhtaṣar-i Khuffī-i ˓Alā˒ī* (Abridgement for the Boots of Alā˒) in two long volumes for Shah Atsiz to carry in his tall riding boots. This work was printed in Agra (1852) and Cawnpore (1891), but neither edition is readily available. There are several manuscripts in Turkey, one in the British Library, and an Arabic translation in Paris and at the University of California.

The *al-Agrāḍ al-ṭibbīya* (Aims of Medicine), composed for the vizier of Atsiz, is partly another abridgement of the *Thesaurus* combined with an account of the symptoms and treatment of local diseases. The *Yadgar i-ṭibb* (or Remembrancer) is largely on pharmacology.

Al-Jurjānī's works have not been much studied, and the relationships between the various texts and translations have not been worked out. A work in Arabic, *Zubdat al-ṭibb* (Essence of Medicine), is frequently assigned to him; this is presumably a translation of one of the Persian treatises mentioned above, but it is not clear which one. Some of the other manuscript works ascribed to al-Jurjānī are probably excerpts from his lengthy books.

See also: ►Ibn Sīnā

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Al-Karajī

Jacques Sesiano

Al-Karajī Abū Bakr Muḥammad was a Persian mathematician and engineer. He held (ca. 1010–1015) an official position in Baghdad during which time he wrote his three main works.

1. His *al-Fakhrīfī'l-jabr wa 'l-muqābala* (Glorious on Algebra) contains an exposition of algebra and auxiliary topics (e.g. summing series of integers). The next and larger part is a collection of problems: some are commercial and recreational, but for the

most part they belong to indeterminate algebra. All of the latter sorts are taken from Diophantus or Abū Kāmil.

2. The *Badī*ᶜ *fī'l-ḥisāb* (Wonderful on Calculation) is more original. After restating many of Euclid's theorems, al-Karajī shows how to calculate with square, cubic, and biquadratic roots and with their sums, then how to extract the root of a polynomial in *x* (this is the earliest known mention of the procedure). A second part contains problems on indeterminate algebra. Here, al-Karajī has taken the basic methods used by Diophantus in his problems and classified them, the result being a useful introduction to Diophantus's algebra.
3. The composition of the *Kāfī fī'l-ḥisāb* (Sufficient on Calculation) belongs to the usual duty of a mathematician holding an official position: to write a simple textbook in a way accessible to civil servants and containing the elements of arithmetic with integers and fractions (common and sexagesimal), the extraction of square roots, the determination of areas and volumes, and elementary algebra. All this is illustrated by numerous examples.
4. The ᶜ*Ilal al-jabr wa'l-muqābala* (Grounds of Algebra) is a small compendium on basic algebra (reckoning with roots, solving the basic six forms of the equations of the first two degrees), without resort to any geometrical demonstrations.
5. The *Inbāṭ al-miyāh al-khafīyah* (Locating Hidden Waters) was written after al-Karajī's return to Persia. It is concerned with finding subterranean water, extracting it, and transporting it in accordance with the soil's configuration.

Other, lost works of al-Karajī's are known to have dealt with indeterminate algebra, arithmetic, inheritance algebra, and the construction of buildings. Another contained the first known explanation of the arithmetical (Pascal's) triangle; the passage in question survived through al-Samaʾwal's *Bāhir* (twelfth century), which heavily drew from the *Badī*ᶜ.

Although much of his work was taken from others' writings, there is no doubt that al-Karajī was quite an able and influential mathematician. However, the quality of his writings is uneven, as he seems to have worked hastily sometimes.

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Al-Kāshī

Boris Rosenfeld

Al-Kāshī, or al-Kāshānī (Ghiyāth al-Dīn Jamshīd ibn Masᶜūd al-Kāshī (al-Kāshānī)), was a Persian mathematician and astronomer. He was born in Kāshān in northern Iran, and worked at first in Herat (now in Afghanistan) at the court of *khāqān* ("khān of khāns" Shāhrukh, the son of Tīmur). In 1417 he was invited by Ulugh Beg, the son of Shāhrukh, the ruler of Samarqand (now in Uzbekistan) to become the director of his astronomical observatory. His scientific treatises were mostly written in Arabic, and partly in Persian. Al-Kāshī died in Samarqand in about 1430.

Al-Kāshī's main mathematical work is *Miftāḥ al-ḥisāb* (Key of Arithmetic). This work, written in the tradition of Arabic mathematical texts, contains five books (1) Arithmetic of integers, (2) Arithmetic of fractions, (3) Arithmetic of astronomers, (4) Geometry, and (5) Algebra.

In book 1, al-Kāshī considers duplication (multiplication by 2), mediation (division into 2), addition, subtraction, multiplication, and division. As Naṣīr al-Dīn al-Ṭūsī (1201–1274) did in his arithmetic treatise, he also considers extraction of roots of arbitrary integer powers by means of what we now call the Ruffini–Horner method and expresses the approximate value of the root by means of "Newton's binomial formula" for $(a+b)^n$. In book 2, al-Kāshī introduces decimal fractions and calls the digits of these fractions "decimal minutes," "decimal seconds," "decimal thirds," etc. Arithmetic of astronomers considered in book 3 is arithmetic of sexagesimal fractions borrowed by Islamic astronomers from Ptolemy, who in turn had borrowed them from Babylonian astronomers. Islamic astronomers designated figures from 1 to 59 by means of letters, and zero by ō. Like the ancient Babylonians, al-Kāshī extended the sexagesimal system onto integers and called the sexagesimal digits "raised," "twice raised," "three times raised," etc. In book 4, the rules of mensuration of many plane and solid figures, including buildings, cupolas, and stalactite surfaces, are formulated. In book 5, besides explaining the algebraic solution of quadratic equations and equations reducible to them, al-Kāshī discusses the solutions of equations by means of the rule of two errors, actions with roots, algebraic identities, and Thābit ibn Qurra's rule for the determination of amicable numbers. Al-Kāshī claims that he wrote an algebraic treatise with the classification of equations of the fourth degree, and that for every type he proposed the solution by means of the intersection of conics more general than the conics by means of which ʿUmar al-Khayyām solved cubic equations. This algebraic treatise is not extant and since the number of these equations does not coincide with those mentioned by al-Kāshī, this treatise was not finished.

The *al-Risāla al-muḥīṭiyya* (Treatise on Circumference) is devoted to the calculation of the ratio of circumferences of circles to their radii (now this ratio is designated by 2π). Al-Kāshī calculates the perimeters of regular inscribed and circumscribed polygons with 3.2^{28} sides. The number of sides is chosen on the condition that the difference between these polygons for the great circle of the sphere of fixed stars must be less than the "width of a horse hair." The result is expressed in sexagesimal and decimal fractions.

In the *Risāla al-watar wa'l-jayb* (Treatise on Chord and Sine) al-Kāshī calculates the sin 1° according to known sin 3°. This problem was necessary for composition of the tables of sines with five sexagesimal digits in Ulugh Beg's *Zīj-i Ulugh Beg* (Ulugh Beg's Astronomical Tables). This problem was reduced to the cubic equation $4x^3 + q = 3x$ ($x = \sin 1°$, $q = \sin 3°$) and was solved by the method of successive approximations

$$x_1 = \frac{q}{3'},\ x_2 = \left(\frac{q + 4x_1^3}{3}\right), \ldots$$

In the field of astronomy, al-Kāshī was author of *Zīj-i Khāqānī* (Khāqān Astronomical Tables) written in 1413–1414 in Herat. He also composed a treatise on astronomical instruments written in 1416 dedicated to the ruler of Iṣfāḥān Iskandar, who was the nephew of Shāhrukh, and was one of the authors of Ulugh Beg's *Astronomical Tables*. He was also the translator of the last tables from Persian into Arabic. In the treatise *Nuzha al-ḥadāiq* (Delight of Gardens), al-Kāshī describes an instrument for representation of the movements of planets which he invented. He was also the author of numerous other astronomical treatises.

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Al-Khalīlī

David A. King

Al-Khalīlī, Shams al-Dīn Abū ʿAbdallāh Muḥammad ibn Muḥammad, lived in Damascus, ca. 1365. He was an astronomer associated with the Umayyad Mosque in the centre of Damascus. A colleague of the astronomer Ibn al-Shāṭir, he was also a *muwaqqit* – that is, an astronomer concerned with ʿ*ilm al-mīqāt*, the science of timekeeping by the sun and stars and regulating the astronomically defined times of Muslim prayer. Al-Khalīlī's major work, which represents the culmination of the medieval Islamic achievement in the mathematical solution of the problems of spherical astronomy, was a set of tables for astronomical timekeeping. Some of these tables were used in Damascus until the nineteenth century, and they were also used in Cairo and Istanbul for several centuries. The main sets of tables survive in numerous manuscripts, but they were not investigated until the 1970s.

Al-Khalīlī's tables can be categorized as follows:

- Tables for reckoning time by the sun, for the latitude of Damascus
- Tables for regulating the times of Muslim prayer, for the latitude of Damascus
- Tables of auxiliary mathematical functions for timekeeping by the sun for all latitudes
- Tables of auxiliary mathematical functions for solving the problems of spherical astronomy for all latitudes

- A table displaying the *qibla*, that is, the direction of Mecca, as a function of terrestrial latitude and longitude
- Tables for converting lunar ecliptic coordinates to equatorial coordinates

The first two sets of tables correspond to those in the large corpus of spherical astronomical tables computed for Cairo that are generally attributed to the tenth-century Egyptian astronomer Ibn Yūnus.

Al-Khalīlī's fourth set of tables was designed to solve all the standard problems of spherical astronomy, and they are particularly useful for those problems that, in modern terms, involve the use of the cosine rule for spherical triangles. Al-Khalīlī tabulated three functions and gave detailed instructions for their application. The functions are as follows:

$$f_\phi(\theta) = \frac{\sin\theta}{\cos\phi} \quad \text{and} \quad g_\phi(\theta) = \sin\theta\tan\phi,$$
$$K(x,y) = \arccos\left(\frac{x}{R\cos y}\right),$$

computed for appropriate domains. The entries in these tables, which number over 13,000, were computed to two sexagesimal digits and are invariably accurate. An example of the use of these functions is the rule outlined by al-Khalīlī for finding the hour-angle t for given solar or stellar altitude h, declination δ, and terrestrial latitude φ. This may be represented as:

$$t(h,\delta,\phi) = K\{(f_\phi(h) - g_\phi(\delta)),\delta\},$$

and it is not difficult to show the equivalence of al-Khalīlī's rule to the modern formula

$$t = \arccos\left(\frac{\sin h - \sin\delta\sin\phi}{\cos\delta\cos\phi}\right).$$

These auxiliary tables were used for several centuries in Damascus, Cairo, and Istanbul, the three main centres of astronomical timekeeping in the Muslim world.

Al-Khalīlī's computational ability is best revealed by his *qibla* table. The determination of the *qibla* for a given locality is one of the most complicated problems of medieval Islamic trigonometry. If (L, φ) and (L_M, φ_M) represent the longitude and latitude of a given locality and of Mecca, respectively, and $\Delta L = |L - L_M|$, then the modern formula for $q(L, \varphi)$, the direction of Mecca for the locality, measured from the south, is

$$q = \arccos\left(\frac{\sin\phi\cos\Delta L - \cos\phi\tan\phi_M}{\sin\Delta L}\right).$$

Al-Khalīlī computed $q(\varphi, L)$ to two sexagesimal digits for the domains φ = 10°, 11°, …, 56° and ΔL = 1°, 2°, …, 60°; the vast majority of the 2,880 entries are either accurately computed or in error by ±1′ or ±2′. Several other *qibla* tables based on approximate formulas are known from the medieval period. Al-Khalīlī's splendid qibla table does not appear to have been widely used by later Muslim astronomers.

See also: ►Ibn al-Shāṭir, ►*Qibla* and Islamic Prayer Times, ►Ibn Yūnus, ►Sexagesimal System

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Al-Kharaqī

Boris Rosenfeld

Abū Muḥammad ʿAbd al-Jabbār ibn ʿAbd al-Jabbār al-Kharaqī was a Persian astronomer, mathematician and geographer. He was born at Kharaq near Marw and worked at Marw at the court of Saljuq Sultan Sanjar (1118–1157). Al-Kharaqī wrote in Arabic.

His main work was *Muntahā al-idrāk fī taqāsīm al-aflāk* (The Highest Understanding of the Divisions of Celestial Spheres). The work consists of three books: astronomical, geographical, and chronological. It is written in the tradition of Arabic astronomical textbooks initiated by al-Farghānī, continued by Ibn al-Haytham, and widely spread after al-Kharaqī in the form of Arabic and Persian books on the science of cosmography (*ᶜilm al-hayᶜa*). In these books the planets are considered not as supported by imaginary circles according to Ptolemy's *Almagest*, but as supported by massive material spheres in which they move in tubes.

His *Kitāb al-tabṣira fī ᶜilm al-hayᶜa* (Introduction to the Science of Cosmography), written in the same tradition, is the shortened version of the first work, and contains two separate books, "On the Heavens" and "On the Earth."

Al-Kharaqī was also the author of two lost mathematical treatises, *al-Risala al-shāmila* (Comprehensive Treatise), devoted to arithmetic, and *al-Risala al-maghribiyya* (The North African Treatise), on the "calculus of dirham and dinar."

See also: ►Ibn al-Haytham, ►*Almagest*, ►Hayᶜa

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Al-Khāzinī

Julio Samsó

Abū'l-Fatḥ (or Abū Manṣūr) ᶜAbd al-Raḥmān (also called in some sources ᶜAbd al-Raḥmān Manṣūr) was an astronomer and expert in mechanics and scientific instruments. He lived in Marw (Khurāsān) ca. 1115–ca. 1131. A slave (and later a freedman) of Byzantine origin, he was bought by a treasurer (*khāzin*) of the Seljuk court at Marw, called Abū'l-Ḥusayn (or Abū'l-Ḥasan) ᶜAlī ibn Muḥammad al-Khāzin al-Marwāzī, who gave him a good scientific education.

As an astronomer his main work is his *al-Zīj al-Sanjarī*, an astronomical handbook with tables, compiled between ca. 1118 and ca. 1131 and dedicated to the Seljuk Sultan Sanjar ibn Malikshāh (1118–1157). This *zīj* seems to be influenced by the work of Thābit ibn Qurra, al-Battānī and al-Bīrūnī, but parts of it seem to have been checked against a limited number of his own observations (planetary, solar, and lunar in moments of conjunctions and eclipses) made in Marw. He is credited with a careful determination of the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), but he adopts the Battanian value of 23°35′ and concludes (against al-Battānī and most of the successive Islamic astronomical tradition) that this parameter is a constant. His *zīj* includes a rich chronological section and a lot of materials related to the theory of Indian cycles. It also contains very important developments on the theory of planetary visibility as well as a very elaborate set of eclipse tables. He seems to have been interested by the problem of *qibla* determination (attempting to figure out the direction to Mecca) and the canons of his *zīj* mention a double entry *qibla* table computed for each integer degree of difference in latitude (from 1° to 30°) and in longitude (from 1° to 60°) between Mecca and other localities. This *qibla* table seems to be lost and the one ascribed to al-Khāzinī by the fourteenth century author al-Mustawfi does not seem to have anything to do with our author. Al-Khāzinī's *Zīj* was used in Byzantium by Georges Chrysoccoces (fl. ca. 1335–1346) and Theodore Meliteniotes (fl. ca. 1360–1388).

Among his minor astronomical works we find his treatise on instruments (*Risāla fī-l-ālāt*) which deals with observational instruments as well as with analog computers and simple helps for the naked eye. Furthermore, his short treatise on "the sphere that rotates by itself with a motion equal to the motion of the celestial sphere" (*Maqāla li'l-Khāzinīfiittiḥād kura tadūru bi-dhātihā bi-ḥaraka musāwiya li-ḥarakat al-falak wa maᶜrifat al-ᶜamal bihā sākina wa mutaḥ arrika*) –probably the earliest of all his extant works – shows the link between his interest both in astronomy and in applied mechanics. It describes a solid sphere, marked with the stars and the standard celestial circles and half sunk in a box, the rotation of which is propelled by a weight falling in a leaking reservoir of sand. Similar devices were known and built in Classical Antiquity.

The most important of al-Khāzinī's works is probably his *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom), a treatise on the physical principles that underlie the hydrostatic balance as well as the construction and use of the instrument. This work was written in 1121–1122 and dedicated to Sultan Sanjar: the instrument it describes was meant for Sanjar's treasure, for its main application was to discriminate accurately between pure and adulterated metals as well as between real gems and fakes. A similar balance, also called *mīzān al-ḥikma*, had been built by al-Khāzinī's predecessor al-Asfizārī also for Sanjar, but its scales had been destroyed. Al-Khāzini's book is a long work, divided into eight books and 80 chapters, and its quotations bear witness to the Classical sources on pure and applied mechanics that reached the Islamic lands (Aristotle and the pseudo-Aristotelian treatise on mechanical problems, Euclid, Archimedes, Menelaus) as well as to the development of the discipline in Islamic civilization (Muḥammad ibn Zakariyyāʾ al-Rāzī, al-Bīrūnī, Ibn al-Haytham, Abū Sahl al-Qūhī, ʿUmar al-Khayyām). There is nothing specifically new in al-Khāzinī's physical ideas which derive mainly from Aristotle and Archimedes, but his treatise has the obvious interest of its very careful description of a highly precise instrument with which he has been able to calculate tables of the specific gravities of many substances, both metallic, and nonmetallic, attaining, in some cases, results which are correct to within 1%.

See also: ►Thābit ibn Qurra, ►*Zīj*

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Al-Khujandī

Sevim Tekeli

Abū Maḥmūd Ḥāmid ibn al-Khiḍr al Khujandī (ca. 990) was a mathematician and astronomer who lived and worked under the patronage of the Buwayhid ruler, Fakhr al-Dawla (978–997).

In mathematics he worked on equations of the third degree and tried to show, although in an imperfect manner, that the sum of two cubed numbers cannot be another cube $a^3 + b^3 \neq c^3$. His name is included among others such as Abū'l-Wafā al-Buzjanī (940–997), Abū Nasr Manṣūr ibn ʿAlī ibn Irāq (ca. 1000), and Naṣīr al-Dīn al-Ṭūsī (1201–1274) to whom the discovery of the sine law is attributed. The sine law says that if *ABC* is any triangle, then

$$\frac{c}{b} = \frac{\sin\ C}{\sin\ B}.$$

Although we do not have any reliable information on whether al-Khujandī founded an observatory on Jabal Tabrūk, in the vicinity of Rayy, he tells us that he made observations on planets for Fakhr al-Dawla with armillary spheres and other instruments and prepared a *zīj* (astronomical handbook with tables) entitled *al-Fakhrī* based on these observations. According to E. S. Kennedy an incomplete copy of a *zīj* in the Library of the Iranian Parliament (Tehran Ms. 181) may be attributed to al-Khujandī.

His fame depends on an important instrument constructed for the measurement of the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). This instrument surpassed all previous ones in size. Al-Khujandī praises his instrument and says that it is of his own invention. It is a 60° of meridian arc and is called *al-suds al-Fakhrī*, after Fakhr al-Dawla. Although *suds* means the sixth part of a circle (i.e., to say sextant), in reality it is constructed in place of a mural quadrant. As the distance between the summer solstice and the winter solstice is about 47°, a 60° of meridian arc is enough for observations of the sun. It has a radius of about 20 m, and each degree was subdivided into 360 equal parts. Therefore each 10 s portion was distinguished on the scale, and with it the limit of precision had been pushed to seconds.

This arc was constructed between two walls erected on the meridian. On the arched ceiling there was a hole through which the sun's rays passed and there were projections on the divisions of the arc. Al-Bīrūnī tells us that the aperture sank by about a span, and caused a slight displacement of the center of the arc.

In 384 H (AD 994), al-Khujandī observed the summer solstice in the presence of a group of scientists. They gave their written testimony concerning the observations. Although the cloudy weather prevented his observing the winter solstice, he calculated the position of the sun from the observations made preceding the solstice. The result was 23°32′19″. According to al-Bīrūnī, displacement of the center of the arc also affected the result. By comparing this result to the Indian astronomers' and Ptolemy's he deduced that the obliquity of the ecliptic was decreasing. He also fixed the latitude of Rayy (35°34′39″).

He describes a kind of astrolabe which is called *shāmila* (universal instrument) in his *Risāla fī Aʿmāl al-ʿāmma* (Treatise on the Construction of the Universal Instrument). The astrolabe, which carried a stereographic projection of the heavens on a circular plate, is a portable instrument. As we know from existing specimens, they ranged in size from 2 in. to 2 ft in diameter. They were used to measure the altitudes of the sun and to show the places of the stars in certain latitudes. Khujandī's *shāmila* could be used over a larger territory than former ones. He also provides methods of projection concerning intersections of circles of the azimuth by the equator and *muqanṭarāt*. Abū Naṣr Manṣūr mentions al-Khujandī's two methods on this topic. Al-Birūnī, in his *Tahdīd Nihāyāt al-Amākin* (Limit of Ends of Places), states that al-Khujandī was unique in his age for his constructions of astrolabes and other astronomical instruments.

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Al-Khwārizmī

Jacques Sesiano

Al-Khwārizmī, Muḥammad ibn Mūsā, is the earliest Islamic mathematician and astronomer of fame, and his works had considerable influence in the medieval world. His name suggests that he was of Persian origin, but his treatises were written in Baghdād during the caliphat of al-Maʾmūn (813–833).

The *Algebra* (possibly *al-Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa'l muqābala*), al-Khwārizmī's best known work, consists of four parts of very unequal length. The first part explains the fundamentals of algebra: the resolution of the six basic types of equations of first and second degree (with positive coefficients and at least one positive solution), then basic algebraic reckoning (with expressions involving an unknown or square roots); then, six examples of problems each ending with one of the six equations, and lastly various other problems of the same kind. This structure as well as some characteristic features (no symbolism, numbers written in words, illustrations of algebraic rules by geometrical figures) remained customary in early textbooks on algebra. The second part contains a few considerations on the application of the rule of three to commercial transactions. Part 3 covered surfaces and volumes of elementary plane and solid figures, mostly without any use of algebra. The lengthy part 4 is devoted to the application of algebraic methods (or simple arithmetic) to the sharing out of estates in accordance with wills and Islamic legal requirements regarding the parts due to heirs.

Several Latin translations of parts 1 and 2 were made in the Middle Ages.

The *Arithmetic* (possibly *Kitāb al-ḥisāb al-hindī*) exposes the newly introduced Indian positional system of numerals and its use in arithmetical operations and (square) root extraction, for integers and fractions, both common and sexagesimal. This work is lost in Arabic, but has survived in two Latin translations.

The *Zīj al-sindhind* (Astronomical Tables), al-Khwārizmī's best known work in astronomy, is a set of tables based mainly on Indian material. Instructions on the use of the various tables are provided; with their help, one can determine the mean motion of the seven known celestial bodies, also daily motions, sizes, and eclipses of the sun and moon; calendric and trigonometrical tables are included. We do not know the original text, since only a Latin translation of a later reworking has come down to us.

The *Kitāb ṣūrat al-arḍ* (Geography) is a list of longitudes and latitudes of cities, mountains (geographical points along), sea coasts, islands, center points of regions and countries, and detailed courses of rivers. The information is drawn from Ptolemy's *Geography*, but improvements are found, mostly, of course, for the regions under Islamic rule or traveled through by Arabian merchants.

The *Istikhrāj taʾrikh al-yahūd* (Calendar of the Jews) is the oldest extant description of the modern Jewish calendar. After reporting that God inspired it to Moses (its Mesopotamian origin was unknown to al-Khwārizmī), we are told about the year and the intercalation of 7 intercalary months within the 19 year (Metonic) cycle and how to determine on which day *rosh ha-shana* falls. Next we are given the positions of the celestial bodies at the beginning of three eras (Adam, Temple of Jerusalem, and Alexander). Finally, we are taught how to determine the mean positions of the sun and moon for any given date and the time elapsed since their last conjunction.

The *Kitāb al-ʿamal bi'l-asturlāb* (On the Use of the Astrolabe) contains short instructions, but perhaps not in their original form. We are taught how to find altitudes of celestial bodies, and how to determine time or latitudes from celestial observations.

The purpose of another minor work, *Kitāb al-rukhāma* (On the Sundial), is to explain the construction of a plane sundial; the appended tables are given for various latitudes besides that of Baghdād.

A *Kitāb al-ta^c^rīkh* (Chronicle) is known by quotations from other historians; it reported purely historical events and covered at least the years 632–826.

As to lost works, a short treatise *Kitāb ^c^amal al-asṭur-lāb* (On the Construction of the Astrolabe) is attributed by Arabian bibliographers to al-Khwārizmī (it may be extant as an anonymous work). At the end of his *Algebra*, Abū Kāmil explains a short way for calculating the result of the duplication on the chessboard's cells $(1 + 2 + 2^2 + \ldots + 2^{63} = 2^{64} - 1)$, which he attributes to al-Khwārizmī but which appears in no known work of his. Another lost work was concerned with the rule of false position.

Al-Khwārizmī has enjoyed a great reputation, particularly as the first algebraist. Although he seems not to have made a great number of original contributions, he was a learned man of great versatility and didactical ability. His role was primarily that of a disseminator of science in early Islamic times. As some of his works were studied in eleventh century Spain, he played the same role for the Christian world through Latin translations. The latinization of his misread Arabic name as *algorizmus*, later misread as *algoritmus*, later misinterpreted as *algorithmus*, has kept his name if not his fame alive until the present time.

See also: ►Algebra, ►Sundials, ►Astrolabe

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Al-Kindī

George N. Atiyeh

Al-Kindī, Abū Yūsuf Ya^c^qūb ibn Isḥāq, was born ca. 801 in Kūfah and died ca. 866 in Baghdad.

Often called the Philosopher of the Arabs, little is known with certainty about the life of this early Muslim philosopher and scientist. He flourished in Baghdad, then capital of the Abbasid Empire and center of its intellectual life. Greek, Persian, and Indian works were being translated into Arabic and a multitude of religious and other thinkers were developing new and sophisticated schools of thought and literature. The *Mutakallimūn*, Islamic theologians, were actively engaged in controversies over God's attributes and freedom of the will as well as over the methodology of knowledge. During the life of al-Kindī, Baghdad experienced the political ascendancy and fall of the dialectical theological movement of the *Mu^c^tazilah*, a movement that used a rationalistic approach to defend the religious dogmas of Islam. Al-Kindī sympathized with some ideas of this movement such as the uniqueness of God, his justice, and the use of a rational approach in the defense of Islam against its opponents. Also like *al-Mu^c^tazilah*, al-Kindī looked at God as the ultimate source of all being, yet believed his creations were independent in their daily function.

Most of the works of al-Kindī have, unfortunately, disappeared. Ibn al-Nadīm (d. ca. 987), one of the earliest bibliographers of Islam, lists 242 works, mostly essays and epistles, dealing with a wide range of sciences: logic, metaphysics, mathematics, spherics, music, astronomy, geometry, medicine, astrology, theology, psychology, politics, meteorology, prognostics, and alchemy.

The scientific works of al-Kindī are by far the most numerous. In fact there are among the early Arabic authors many who considered him a mere scientist and not a philosopher. Z. al-Bayhaqī (d. 1169), who is often cited, referred to him as an engineer, and Ibn Khaldūn (d. 1406) did not list him among the philosophers. Whatever the case may be, one can find in al-Kindī's presently known works the outline of a philosophical system. Based on his treatise *Fī al-Falsafeh al-ula* (On First Philosophy), al-Kindī defined philosophy as the "knowledge of the realities of things according to human capacity." He stressed the cumulative character of philosophy and the duty to receive the truth gratefully from whatever source it comes. He distinguished between philosophy and theology proper as two different disciplines, both pursuing and reaching the same goal, which is truth. The first pursues it through arduous research and effort, the second through prophetic knowledge which is granted to certain individuals immediately and without any effort. He established the various divisions of philosophy on the basis of the different channels of human knowledge, the sense experience of material entities and that of rational cognition of immaterial ones. First philosophy or metaphysics is concerned with the First Principle, the True One, the Necessary and Uncaused Being who is eternal and infinite. Probably drawing upon the ideas of the pre-Islamic John Philoponus who championed the concept of creation ex nihilo, he opposed the Aristotelian theory of the eternity of the universe. The chief attribute of God, argued al-Kindī, is unity. God is the only real agent or cause in the world. Unlike the Muslim theologians, he did not ignore the role of secondary agents in the process of nature. He established the premise that the causes of generation and corruption are the heavenly bodies, which are superior to the physical bodies and possess intelligence.

The writing of al-Kindī on the soul and the intellect are neither numerous nor comprehensive. Besides his important short treatise *Risālah fī māʿiyat al-ʿaql* (On the Intellect), he wrote *Kalām fī al-nafs mukhtaṣar wajīz* (A Discourse on the Soul Abridged and Concise) where he explains the nature of the union between the soul and the body as different from the union between the elements. Inspired by Aristotelian, Plantonic, and Pythagorean sources, he considered the soul as the principle of life and only accidentally related to the body, being nobler in nature. In his *On the Intellect*, al-Kindī presents a Platonic interpretation of Aristotle's noetics. He defines the intellect as "a simple essence cognizant of things in their true realities." There are four intellects, the first of which is separate and seems to be construed in the image of Aristotle's active intellect. It exists outside the human soul and is the cause of "all intelligible thoughts and secondary intellects." The four intellects – the active, the potential, the habitual, and the manifest or acquired – played an important role in the history of medieval discussions on the nature of the intellect. In his *Risālah fī dafʿ al-aḥzān* (On the Means to Drive Away Sadness), al-Kindī offers practical advice to overcome sorrow based on the principle that true riches are not material by nature. What causes sadness is the loss of externals and the failure to attain what we highly cherish. By despising external things and educating our souls to seek what is spiritual, we avoid the miseries of sorrow.

With many of his scientific works not available, it is difficult to offer a systematic exposition of al-Kindī's scientific works and contributions. They covered almost all fields of the physical sciences and went beyond the mere transmission of Hellenic scientific data by adding to it through observations of his own and some rudimentary experimentation. Al-Kindī took over the Greek scientific heritage which was available in translations or which he had helped to translate, and tried to assimilate, summarize, and at times develop it and experiment with it. In his classification of the sciences, he starts from the idea of a hierarchy of beings according to which the lower sciences deal with sensible beings and higher sciences with the nobler and intelligible beings. There is a close relationship, however, between science and philosophy, especially mathematics, which he considers preparatory and essential to the study of philosophy. He uses mathematical concepts and arguments when discussing infinity and plurality in proving his theory of the unity of God.

Al-Kindī was not satisfied with the role of the transmitter and commentator. In many of his scientific works we feel the surge of an investigative spirit. In works on optics, pharmacology, and music, for example, he provided new data and approaches, thus enhancing our knowledge of these subjects, among many others. At times, he sought to verify some statements through experimentation, as when he shot an arrow in the air to verify Aristotle's statement that substances expand when heated. In his work *Risālah fī ikhtilāf al-manaṣir* (*De Aspectus*), which is based on Euclid and Heron of Alexandria's optics, he rejected the Euclidean theory of the emission of light, and using geometrical arguments, he offered amendments so it conformed with observable data. Furthermore, al-Kindī gave an original interpretation independent from that of Aristotle of the azure blue we see in the sky. He argued that the color we actually see is the reflection of light from vapors and particles of dense bodies carried up into the atmosphere.

Likewise, al-Kindī, in his medical and pharmaceutical works, was a contributor of new ideas trying to improve upon the knowledge of antiquity. In his work on pharmacology *Risālah fī maʿrifat qūwah al-adwīyah al-murakkabah* (translated into Latin as *De medicinarum compositorum grabidus investigandis libellus*), he applied the principles of posology [the study of dosages]. He based the efficacy (*qūwah*) of compound medicine upon geometrical progression. He linked the degree of intensity with the numerical changes in the qualitative forces that produce them. The efficacy corresponds to the proportion of the sensible qualities: warm, cold, dry, and humid. If a compound medicine was to be warm in the first degree, it had to possess double the equable mixture. If it was to be warm in the second degree, it had to possess four times as much, etc.

The same tendency to improve on the ancient sciences is seen in his works on music. For example, he used the letters of the alphabet to designate the notes of the scale. Al-Kindī's musical works in Arabic on the theory of music paved the way for the *Kitāb al-musiqi al-kabir* (Great Book on Music) by al-Fārabī.

Al-Kindī's influence in medieval Europe might not be as great as the other Arabic philosophers such as Ibn Sīnā and Ibn Rushd; he was nevertheless a courageous intellectual and scientist. Whether he was the first philosopher in Islam is still not ascertainable in the absence of many of his philosophical works. There is no doubt, however, that he was the first in Islam to bridge the gap between philosophy and the Islamic dogma, thus establishing the conceptual framework that became characteristic of philosophy in Islam.

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Almagest: Its Reception and Transmission in the Islamic World

Paul Kunitzsch

Around AD 150, Ptolemy wrote his great handbook of astronomy called *Mathematike Syntaxis* (The Mathematical Composition) in the original Greek. Because of its importance, it soon received wide attention throughout the Hellenistic world. Its fame seems to have radiated into the Middle East, because there are hints that the work was known, and perhaps even translated partially or completely, into Middle-Persian (Pahlavi) under the Sassanian ruler Shāhpur I (reigned AD 241–272). A second period of intensive contact of the Persians with Greek science was in the middle of the sixth century, after the closing of the Academy in Athens (AD 529), when several Greek scholars sought refuge in Persia. At this point Ptolemy's work may again have been brought to the attention of Persian scholars. However this was, the first knowledge of the Arabs (who conquered the Middle East and established the Islamic empire of the caliphs around the middle of the seventh century) about Ptolemy and his work betrays Persian influence. The Arabs first knew Ptolemy's astronomical handbook under the title *Kitāb al-majasṭī* (The Book Almagest), which evidently derives from a Greek superlative (*Megiste* [scil. *Syntaxis*], The Greatest Composition). Under this title the book was already known in Arabic–Islamic circles before the translations proper. It would seem that the Arabic spelling *al-majasṭī* is derived from a Middle-Persian form rather than from the Greek directly – a Middle-Persian spelling *mgstyk* is documented, and a form like this may have led to the Arabic spelling *al-majasṭī.* Later, in twelfth-century Spain, the Europeans translated Arabic scientific works into Latin and converted the Arabic *al-majasṭī* into Latin *almagesti*, and henceforth Ptolemy's work has been known in the West under this short title, Latinized from an Arabicized Greek word. It may be added that in the direct transmission, in Greek, the title *Megiste Syntaxis* has not yet been found – here we have only the forms *Mathematike Syntaxis* or *Megale Syntaxis* (The Great Composition).

Direct knowledge of the text of the *Almagest* in Arabic–Islamic science developed through a series of translations from Greek into Arabic. Before the Arabic translations, a translation was made into Syriac, the language common among Christian monks and scholars who later played the main role in the translation of Greek scientific works into Arabic. It is not known when and by whom this Syriac translation was made, but it is probable that the first translators of the work into Arabic knew and used the Syriac version. Still, in the twelfth century Ibn al-Ṣalāḥ had the Syriac version to hand. A first Arabic translation of the Almagest was made some time around AD 800 – its text is now lost, but it was often cited by Arabic–Islamic astronomers and bibliographers as "the first" or "the old" or "the ma'mūnian" translation, after the caliph al-Maʾmūn, who patronized translations and scientific work in general. Traces of it are found in the astronomical work of al-Battānī (d. 929) and in Ibn al-Ṣalāḥ. A second translation was made in 827–828 by al-Ḥajjāj ibn Yūsuf ibn Maṭar in cooperation with a Christian, Sergius the son of Elias. Of it two manuscripts have survived until our times, one complete and the other fragmentary. About 50–60 years later, a third translation was made by Isḥāq ibn Ḥunayn (830–910). It was soon afterward revised by Thābit ibn Qurra (836–901) – of this revised version, nine manuscripts are still extant today.

The two versions of al-Ḥajjāj and of Isḥāq revised by Thābit were received in Muslim Spain – they were both used by Gerard of Cremona for his translation of the Almagest into Latin (Toledo, ca. 1150–1180). Gerard's Arabo–Latin version then remained the standard version of the Almagest in Europe until Renaissance times.

In the following centuries Arabic–Islamic astronomers not only studied the *Almagest* as their main source in astronomy, but they also wrote commentaries on the entire book or on problems of detail. Fuat Sezgin lists more than thirty commentaries, several of which were afterward commented upon themselves. Among the numerous commentators two shall be named here. Ibn al-Ṣalāḥ (d. 1154) is important, because he had to hand five versions of the *Almagest* (the Syriac version, the "old" version, the version of al-Ḥajjāj, the original of Isḥāq's version, and Isḥāq's version as revised by Thābit) from all of which he tried – by comparing the texts and by observing the stars – to establish the best values in longitude and latitude for a selected number of stars from the star catalog in the Almagest. Another famous commentator was Naṣīr al-Dīn al-Ṭūsī (1201–1274) who wrote revisions of many translated Greek mathematical and astronomical texts, which included the Almagest – his *Taḥrīr* (based on the version of Isḥāq as revised by Thābit) survives in numerous manuscripts, but is still unedited.

The last Oriental translation of the *Almagest*, from al-Ṭūsī's *Taḥrīr* into Sanskrit, was made in 1732, in Jaipur, India, by order of Maharaja Jai Singh II.

The title *al-majasṭī/Almagest* became so famous that other authors freely used the name for their own works, both in the East and in Europe, e.g., the *Kitāb al-majasṭī* (The Book Almagest) of the mathematician Abu'l-Wafā˒ al-Būzjānī (940–987 or 998); the *Almagestum novum* of the astronomer Giovanni Riccioli (Bologna, 1651), or even the *Almagestum Botanicum* of Leonard Plukenet (1696).

See also: ►al-Ma˒mūn, ►al-Battānī, ►Isḥāq ibn Ḥunayn, ►Thābit ibn Qurra, ►Naṣīr al-Dīn al-Ṭūsī, ►Abu'l Wafā˒ al-Būzajānī

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Al-Māhānī

Yvonne Dold-Samplonius

Al-Māhānī, Abū ˓Abd Allāh Muḥammad ibn ˓Īsā, was born in Māhān, Kerman, Iran. He lived in Baghdad, ca. 860 and died ca. 880.

Little is known about al-Māhānī's life, and few of his works are extant. In the *Ḥākimite Tables* Ibn Yūnus cites observations of conjunctions and lunar and solar eclipses made by al-Māhānī between 853 and 866. In the only extant astronomical work, *Maqāla fī Ma'rifat as-samt li-aiy sā'a aradta wa-f ī aiy mauḍi' aradta* (On the Determination of the Azimuth for an Arbitrary Time and an Arbitrary Place), al-Māhānī added arithmetical solutions to two of the graphic ones. His method corresponds to the cosine formula in spherical trigonometry, and is later applied by al-Battānī.

Al-Māhānī worked on the fundamental problems of mathematics of his time and is especially known for his commentaries to Euclid's *Elements*, to Archimedes' *De Sphaera et Cylindro* (On Spheres and Cylinders), and to the *Sphaerica* by Menelaus. In the last treatise, now lost, he inserted explanatory remarks, modernized the language, especially the technical terms, and remodeled or replaced obscure proofs. It was revised and finished by Aḥmad ibn Abī Sa˓īd al-Harawī in the tenth century. Al-Ṭūsī considered al-Māhānī's and al-Harawī's improvements valueless and used the edition by Abū Naṣr Manṣūr ibn ˓Irāq. This redaction, the most widely known Arabic edition, is included in the collection of the *Intermediate Books*. These were the books read between Euclid's *Elements* and Ptolemy's *Almagest*.

Of the commentaries to the *Elements* only those to Book V and to Book X are extant. In the former al-Māhānī compared magnitudes by comparing their expansion in continued fractions, referring to Thābit ibn Qurra. Ratio is defined as “the mutual behavior of two magnitudes when compared with one another by means of the Euclidian process of finding the greatest common measure.” Two pairs of magnitudes were for him proportional when “the two series of quotients appearing in that process are identical.” Essentially the same theory was worked out later by al-Nayrīzī. Neither established a connection with Euclid’s definition, which was first done by Ibn al-Haytham. In the commentary to Book X al-Māhānī examined and classified not only quadratic irrationalities, but also those of the third order. In contrast with Euclid, for whom magnitudes were only lines, he considered integers and fractions alike as rational magnitudes, while regarding square and cube roots as irrational ones. Al-Māhānī then explicated the contents of Book X using rational and irrational numbers instead of geometric magnitudes.

According to al-Khayyāmī, al-Māhānī was the first to attempt an algebraic solution of the Archimedean problem of dividing a sphere by a plane into segments, the volumes of which are in a given ratio (*De Sphaera et Cylindro* II,4). He expressed this problem in a cubic equation of the form $x^3 + a = cx^2$, but he could not proceed further. Al-Khayyāmī relates that the problem was thought unsolvable until al-Khāzin succeeded by using conic sections.

See also: ►Ibn Yūnus, ►al-Battānī, ►Thābit ibn Qurra, ►Al-Nayrīzī, ►Ibn al-Haytham, ►ʿUmar al-Khayyām, ►*Elements*

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Al-Majrīṭī

Emilia Calvo

Al-Majrīṭī Abū-l āsim Maslama ibn Aḥmad al-Faraḍī was born in Madrid, Spain in the second half of the tenth century and died in Cordoba ca. AD 1007. He settled early in Cordoba where he studied with Abū Ayyūb ibn ʿAbd al-Gāfir ibn Muḥammad and Abū Bakr ibn Abī ʿĪsà. He was engaged in making astronomical observations in about AD 979; he may have served as court astrologer.

He had a number of disciples who made his work known throughout the provinces of Spain. Among them were al-Kirmānī (d. AD 1066); Abū-l-Qāsim Aṣbagh, known as Ibn al-Samḥ (d. AD 1035) who is the author of a treatise on the construction and use of the astrolabe in 130 chapters and of the *Book of the Plates of the Seven Planets*, of which the original Arabic version is lost. [However, it was translated into Spanish and included in the *Libros del Saber de Astronomía*;] Abū-1-Qāsim Aḥmad known as Ibn al-Ṣaffār (d. AD 1034), who is the author of a treatise on the astrolabe attributed in its Latin version to al-Majrīṭī; Ibn al-Khayyāṭ; al-Zahrāwī; and Abū Muslim ibn Khaldūn of Seville.

Maslama’s most important work is the adaptation of al-Khwārizmī’s astronomical tables (*zīj*) which were elaborated ca. 830. This adaptation is not preserved in his original Arabic form but in a Latin translation made by Adelard of Bath (fl. 1116–1142) and revised by Robert of Chester. The work done by Maslama in this adaptation illustrated his high degree of astronomical and mathematical knowledge.

Another work is an Arabic commentary on Ptolemy’s *Planispherium*, entitled *Tasṭīḥ basīṭ al-kura* (Projecting the Sphere onto a Plane), which deals with the stereographic projection on which the conventional astrolabe is based. This adaptation is only preserved in a Latin version by Hermann of Dalmatia (1143) and in a Hebrew abridgement. This work was the point of departure of a long series of Andalusian treatises on this topic. Maslama also knew the *Almagest* as well as al-Battānī’s tables.

Maslama also wrote a treatise on *muʿāmalāt* (commercial arithmetic) which probably dealt with sales, cadastre (an official record of property ownership and value), and taxes using arithmetical, geometrical, and algebraic operations.

Some other works are attributed to him, such as *Rutbat al-ḥakīm* (The Rank of the Sage), composed after AD 1009, and *Ghāyat al-ḥakīm* (The Aim of the Sage), translated into Spanish in AD 1256 by order of Alfonso el Sabio and distributed throughout Europe under the name of *Picatrix*.

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Al-Maʾmūn

Paul Kunitzsch

Al-Maʾmūn, Abul'-ʿAbbās ʿAbdallāh ibn Hārūn, was born in 786 in Baghdad, and died in 833 near Tarsus, in a campaign against the Byzantines.

Al-Maʾmūn was not himself a scientist. He was the seventh caliph of the dynasty of the Abbassids, son and second successor of the famous caliph Hārūn al-Rashīd (well known from the tales of the Arabian Nights). He ruled the Islamic empire from 813 to 833, at first from Marw (in the Eastern province of Khurāsān, where he was based before his accession), and from 819 from the capital of Baghdad (founded in 762 by the caliph al-Manṣūr). In the intellectual history of the Islamic world and in the history of science, al-Maʾmūn played an important role as an instigator and patron of many important activities. He was a firm adherent of the Muʿtazila, a rational school of Islamic theology which was strongly influenced by Greek philosophy; in 827 he declared Muʿtazilism the official doctrine for the whole empire. His interest in philosophy and the sciences manifested itself in many ways. He initiated and patronized the translation of scientific works, mostly from Greek, but also from Persian and Syriac, into Arabic. One translation (of several successive versions) of Ptolemy's *Almagest*, and two translations (also of several successive versions) of Euclid's *Elements* were distinctly called, after him, "the Maʾmūnian version(s)." In the *Elements*, the theorem I, 15 was given, after him, the nickname *al-maʾmūnī*, "the Maʾmūnian [theorem]." Later, in the medieval Latin translation, this degenerated into *elnefea*, *id est fuga* and, more contracted, *eleufuga* or *elefuga*. In 832 he founded the Bayt al-Ḥikma (House of Wisdom, in continuation of a similar institution established earlier by his father Hārūn), which was established for collecting scientific texts, translation, and teaching. Further, on his order, astronomers carried out new measurements of many of the astronomical parameters transmitted in Greek texts, such as precession of the equinoxes, inclination of the ecliptic, length of the year, length of a degree of geographical latitude, geographical coordinates, etc. For many of these data, they arrived at remarkably better values. The results of the observations made by al-Maʾmūn's astronomers were laid down in a work called *al-Zīj al-mumtaḥan* (The Revised Tables, dated 829–830; in medieval Latin, *Tabulae probatae*); it is only preserved in a reworked form. These values were afterwards widely quoted and used by other Islamic and also medieval Western astronomers. From quotations in the *Elementa astronomica* of al-Farghānī (ninth century), al-Maʾmūn's name entered the West in the forms Almeon (Johannes Hispalensis's Latin translation of al-Farghānī's *Elementa*) and Maimon (Gerard of Cremona's translation of the same). On Riccioli's map of the moon (1651) a crater was called Almaeon (i.e., the aforementioned Almeon); as Almanon the name survives on modern charts, in permanent memory of this remarkable Eastern ruler.

See also: ►Precession of the Equinoxes, ►*Elements*, ►*Almagest*

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Al-Māridīnī, Jamāl al-Dīn, and Badr al-Dīn

David A. King

Jamāl al-Dīn al-Māridīnī was a competent astronomer who lived in Damascus or Cairo ca. 1400. He authored numerous short treatises, mainly dealing with instruments. One of the most remarkable of these instruments is a universal quadrant, the only known example of which is from Spain ca. 1580, made by a craftsman in the Louvain tradition (now in the Adler Planetarium, Chicago). His name indicates that he or his family came from Mardin, now in southern Turkey, but biographical information is lacking; indeed it is not even clear where he worked. He is often confused with his grandson, Sibṭ al-Māridīnī.

Badr al-Dīn al-Māridīnī, known as Sibṭ al-Māridīnī, lived in Cairo, ca. 1460. He was a grandson (Arabic *sibṭ*) of Jamāl al-Māridīnī and was one of the leading astronomers in Cairo. He compiled a large number of treatises, including many short works on the standard instruments of his time, the trigonometric and astrolabic quadrant and sundials. These treatises became extremely popular and exist in hundreds of copies. In fact they were studied by everyone in Egypt who was interested in astronomy in the succeeding centuries. As a result of this, more significant works were forgotten and the level of astronomy declined.

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Al-Masʿūdī (Abuʾ ʻl Ḥasan ʿAlī Ibn al-Ḥusayn al-Masʿūdī)

Mushtaqur Rahman

In the tenth century AD Muslims were arguably the leaders of world sciences, including geography. Many Muslim geographers, including al-Masʿūdī, established the principles of science and research in geography. Al-Masʿūdī's geographic curiosity took him as far as China and Madagascar. His conceptual orientation, which combined geography and history to explain cultural history, made him an outstanding scholar.

Not much is known about al-Masʿūdī's early life and education, except that he was born in Baghdad in AD 893 and died in Old Cairo, Egypt, in AD 956. His two surviving books, *Murūj al-dhahab wa-Maʿādin al-Jawhar* (Meadows of Gold) and *Kitāb al-tanbīh waʾl Ishraf* (Book of Indication and Revision) provide no biographical information. Presumably, his early education was with historians, philosophers, scientists, *ḥadīth* specialists (those who study the words of the Prophet Muḥammad), grammarians, and literary critics. He began his travels at the age of 23 to seek geographic knowledge and ended them when he was 56 years old. He lived and traveled during a period of Islamic Renaissance in many fields including geography.

In his book, al-Masʿūdī described the shape of the earth, seas and their depths, islands, mountains and rivers, mines, marshes, and lakes. He also provided information on inhabited areas and explained why land and sea changed their forms.

As a historian and geographer, al-Masʿūdī broadened the concept of geography by including all the known branches of geography in his discussions. In doing so he benefited equally from the scholarly works of both Muslims and non-Muslims. He quoted quite extensively from Greek, Persian, and Indian sources. Al-Masʿūdī also studied people within their own habitats. To him, "nature" (*ṭabīʿā*) meant the processes of the external physical world. He related those processes to humans in the universe, the activity of God in history, and the growth and development of societies.

An aspect of the development of Arabic geographic literature of his period was the production of maritime literature and travel accounts. Al-Masʿūdī also made important contributions to the field of oceanography, but his reputation as a scholar and scientist is based on his two surviving books on history and natural history.

Al-Masʿūdī had a universal outlook. He focused on a wide range of topics dealing with Islamic and non-Islamic cultural histories and provided elaborate cultural, historical, geographical, ethnological, climatic, and maritime descriptions of the known world of his time. He was a cultural geographer of the first order, and far ahead of his time.

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Al-Muqaddasī

Mushtaqur Rahman

Born at Al-Bayt al-Muqaddas (Jerusalem) in AD 946, al-Muqaddasī (Shams ad-Dīn Abū ʿAbdallāh Muḥammad ibn Aḥmad ibn Abī Bakr al-Bannāʾ), also called al-Maqdisī, made important contributions in regional geography. In his early days he studied Muslim history, especially its political and cultural aspects, civilization, religion, and jurisprudence. To seek knowledge he visited distinguished scholars, met the men of science, and studied in royal libraries at a fairly young age.

Among other Arab geographers of the time, al-Muqaddasī's definition of a region was probably the most original and produced one of the most valuable treatises in Arabic literature, *Kitāb aḥsan-al taqāsim fī maʿrifat al-aqālim* (The Best Divisions for the Classification of Regions). Though al-Muqaddasī belonged to the Balkhī school, he was critical of it and felt that they disregarded real geography. He argued that scientific geography must be based on observation. He critically examined the information presented by Al-Jayhānī, al-Balkhī, Ibn al-Faqīh, al-Jahiz, and others and questioned their methods of acquiring information, their objectives, and their misrepresentations and selectivity of information. Then al-Muqaddasī stated:

> I have endeavored not to repeat anything other writers have written, nor narrated any particulars they narrated, except where it was necessary, in order neither to deny their right nor myself to be guilty of plagiarism, for in any case those alone will be able to appreciate my book who examine the works of those authors or who have travelled through the country, and are men of education and intelligence.

Al-Muqaddasī claimed that no one who had treated geography before him adopted his method or provided the information he did. In order to achieve his objective, he traveled through the Muslim world, with the exception of Spain and Sindh, conversed with scholars, and waited on princes. He discussed matters with judges, studied under doctors of law, frequented the society of men of letters, and associated with people of all classes until he attained what he wanted.

In his book, *Aḥsan al-taqāsim*, al-Muqaddasī divided the Muslim empire into 14 divisions, and treated the Arab world separately from the non-Arab world. Then he described the districts in each division, identifying their capitals and principal cities and giving their towns and villages in due order. Information which did not fit into either the Arab or non-Arab context was treated separately. While treating the regions in their entirety, Al-Muqaddasī provided a regional framework, and can rightly be called the father of regional geography.

See also: ►Geography in Islam, ►The Balkhī School of Arab Geographers

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Al-Muʾtaman ibn Hūd

Jan P. Hogendijk

Yūsuf Al-Muʾtaman ibn Hūd was the king of the kingdom of Zaragoza in Northern Spain from 1081 until his death in 1085. He lived in the Aljafería palace in Zaragoza, which was built by his father Aḥmad al-Muqtadir ibn Hūd (r. 1041–1081), and which is now the site of the Parliament of Aragon. Al-Muʾtaman was interested in mathematics, optics, and philosophy. He wrote a very long mathematical work, the *Kitāb al-Istikmāl* (Book of Perfection), of which large parts have recently been identified in four anonymous Arabic manuscripts in Copenhagen, Leiden, Cairo, and Damascus. A revised version of the whole *Istikmāl* was recently discovered.

In the *Book of Perfection*, al-Muʾtaman divides most of pure mathematics according to a philosophical classification in five "species" (*anwāʿ*). Species 1 deals with arithmetic and the theory of numbers. Al-Muʾtaman summarizes the arithmetical books of Euclid's *Elements*, and he proves Thābit ibn Qurra's rule for amicable numbers. The remaining species 2–5 deal with geometry. Al-Muʾtaman summarizes the works of Greek authors such as the *Elements* and *Data* of Euclid (300 BCE), *On the Sphere and Cylinder* of Archimedes (250 BCE), and the *Conics* of Apollonius (200 BCE). He does the same for Arabic authors as well, such as the *Quadrature of the Parabola* (*Miṣāḥat al-qaṭʿ al-mukāfī*) by Ibrāhīm ibn Sinān (909–946) and the *Optics* (*Kitāb al-Manāẓir*), *On Analysis and Synthesis* (*Fīʾl-taḥlīl waʾl-tarkīb*), and *On Given Things* (*Fīʾl-maʿlūmāt*) by Ibn al-Haytham (965–ca. 1041). The summaries in the *Book of Perfection* show that al-Muʾtaman really understood these works. Often he was able to shorten and generalize their contents quite drastically.

Al-Muʾtaman does not mention his sources, and he does not tell us what his own contributions are. The *Book of Perfection* probably includes some original contributions, such as a construction of two mean proportionals between two given lines by means of a circle and a parabola. A few geometrical theorems occur in the *Book of Perfection* for the first time in history, such as the theorem of Ceva (hitherto named after Giovanni Ceva, who independently discovered it in 1678), and the general proof of the invariance of crossratios under a perspectivity (a special case was proved by Pappus of Alexandria in late antiquity). It seems that al-Muʾtaman intended to add to the *Book of Perfection* a second part on astronomy and optics, but he probably did not have the time to do so.

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Al-Nayrīzī

Sonja Brentjes

Born in Persia, al-Nayrīzī spent most of his life in Baghdad. He was a court astronomer/astrologer of caliph al-Muʿtaḍid (r. 892–902), to whom he dedicated several treatises, among them *Al-Risāla fī aḥdāth al-jaww* (Treatise on Meteorological Phenomena) or *Al-Risāla fī maʿrifat ālāt yuʿlamu bihā abʿād al-ashyāʾ-al-shākhiṣa fī l-hawāʾ wal-latī ʿalā basīṭ al-arḍ wa-aghwār al-audīya wa'l-abār wa-ʿurūḍ al-anhār* (Treatise on the Knowledge of Instruments through which Distances between Distinct Things in the Air or Set up on the Ground and the Depth of Valleys and Wells, and the Widths of Rivers Can be Known). He wrote commentaries on Ptolemy's (fl. ca. 127–167) *Almagest* and his astrological work *Tetrabiblos* and an astronomical handbook (*Zīj*), a longer and a shorter version. And he commented on Euclid's (fl. ca. 300 BCE) *Elements* and his astronomical work *Phainomena* and wrote independent works on the determination of the *qibla*, the direction of Mecca, the spherical astrolabe, methods for solving particular astronomical problems, and astrological subjects.

The longer version of his *Zīj* is said to have been based upon Indian astronomical tradition (*Sindhind*) and used data from the *Zīj* prepared for al-Maʾmūn (r. 813–833). This was criticized by Ibn Yūnus (d. 1009), who pointed out further differences in opinion, especially with respect to the theory of Mercury, the eclipse of the moon, and the parallax. His commentary on the *Almagest*, lost as are his handbooks and his commentary on the *Tetrabiblos*, was quoted by later authors like al-Bīrūnī or Ibn al-Haytham and even occasionally called the best work of this type.

His extant works on the *qibla* and the spherical astrolabe built on the works of earlier scholars are some of the very best summaries on the subject still available. Others of his extant works on astronomy, astrology, geodesy, and meteorology have not yet been seriously studied.

Al-Nayrīzī's commentary on the *Elements* translated by Gerard of Cremona (d. 1187) into Latin includes extracts of the lost Greek commentaries by Heron (second century?) and Simplikios (sixth century) and of Arabic treatises like Thābit Ibn Qurra's alternative proof of the Pythagorean theorem. He omitted Simplikios' own proof of the parallels postulate in favor of that by Aghānīs/Aghānyūs (Agapios?, fl. ca. 511), which is also preserved in his independently transmitted *Al-Risāla al-muṣādara al-mashhūra* (Treatise on the Proof of the Well-Known Postulate).

In Book V, al-Nayrīzī follows a theory of proportion adopted before him by al-Māhānī (d. ca. 880) and, perhaps, Thābit ibn Qurra, a theory based on definitions of ratio and proportion which compared the expansion of magnitudes in continued fractions.

The text of the *Elements* contained in the Arabic manuscripts of al-Nayrīzī's commentary was viewed for a long time as the second version made by al-Ḥajjāj ibn Yūsuf ibn Maṭar. Although it is derived from a text of the Ḥajjāj tradition, al-Nayrīzī evidently edited it using a text of the Isḥāq/Thābit tradition. He changed its language, didactical features, and even letter symbols used for diagrams. He incorporated references to earlier Euclidean theorems, definitions, postulates, or axioms as well as to propositions stated by the Greek commentators. In a similar manner, he edited those texts he added as comments.

See also: ►*Zīj*, ►Thābit ibn Qurra, ►*Almagest*, ►Ibn al-Haytham, ►al-Māhānī, ►Ibn Yūnus, ►al-Bīrūnī, ►*Qibla*

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Alphabet

Sema'an I. Salem

As far as we know, literacy goes back to about 3500 BCE. The earliest people to have left written symbols are the Sumerians, followed by the Egyptians. The earliest clay tablets unearthed in Mesopotamia are picture writings which have not yet been deciphered, but those written after 3200 BCE are clearly Sumerian and their content is well known. Their subject matter includes groups of words, accounts of deeds of sale, and some fragments of early literature.

The Sumerians wrote primarily on clay tablets, producing wedge-shaped characters, which became known as cuneiform script, from the Latin *cunus* (wedge). It is quite probable that the idea of writing was introduced into Egypt from Mesopotamia. Soon after the Sumerians invented their script, the Egyptians formulated their own system, which consists of picture word-signs, and which they called *m-d-w-n-t-r* (speech of the gods), and which is now known by its Greek name, hieroglyphs (sacred, carved letters). The Egyptians then produced a simplified version, which is known as Hieratic (sacred). When the common Egyptians, not only the priests, learned to write, they used a highly simplified form known by the Greek name demotic (popular). Several scholars consider the demotic script a first step toward alphabetic writing.

By about 2000 BCE other forms of writing began to appear in various parts of the Middle East. The Hittites, who lived in modern-day Turkey, introduced a new form of hieroglyphs, consisting of some 70 signs, each of which stood for a simple syllable, and about 100 word-signs. Similar forms of hieroglyphs, consisting of word-signs and syllable-signs, were also used in Crete, Cyprus, Lebanon, Palestine, and Syria. The early script uncovered in Crete is in the form of pictograms and was probably introduced into Crete from Egypt. Although it has not been completely deciphered, it is known that it contains the names of certain gods such as Zeus, Athena, and Poseidon.

All the word-sign methods of writing are complex and difficult to learn, and only professional scribes were able to read and write. To write a letter, keep an account, check a legal document, or read a will, an ordinary person had to rely on the services of trained scribes.

This monopoly on reading and writing persisted until the advent of the alphabet, whose invention is one of the most important and useful inventions of all time. The transformation from word or syllable writing to an alphabetic script is immense – it simplified the process of reading and writing to a degree that enabled a common person to master the art, thus freeing him from the need for professional scribes. Its value lies in its elegance and its simplicity, and in its ability to express all the vocal sounds needed in any language in about two-dozen symbols.

There has always been speculation as to the origin of the alphabet, beginning with the early Greek and Latin authors, who credited the invention of the alphabet to practically every near-eastern country. Diodorus Sciculus states, “The Syrians are the discoverers of the letters, and the Phoenicians having learned them from the Syrians and then passed them to the Greeks.” Pliny, on the one hand, claims that: “the invention of the letter is a Phoenician feat,” and speaks also of a Mesopotamian origin. Tacitus maintains that the alphabet is of Egyptian origin, and adds, “The Phoenicians took all the credit for what they received before passing it on to others.” The various views of the classical authors are mere speculations that demonstrate their awareness of the problem and their cognizance of the importance of the discovery.

Opinions as to the origin of the alphabet are still voiced. There are those who still believe that the alphabet is of Mesopotamian origin – they base their opinion on the Ugaritic script which dates back to about 1400 and which consists of 30 symbols representing 30 consonant letters written in cuneiform script.

The existence of an alphabet in a cuneiform script does not imply, in any way, that the idea of an alphabet originated in Mesopotamia, where there is no evidence that it ever existed. Of the half a million or so cuneiform tablets and fragments of tablets uncovered in Mesopotamia, there is not one that bears a sign of an alphabet.

By about 2000 BCE the Mesopotamian cuneiform system of writing was used throughout the Near East and particularly in Canaan, where the rulers were using it in their correspondence even with the pharaohs of Egypt. When the Ugaritic scribes were writing their alphabet using the wedge-shaped cuneiform signs, the Mesopotamians were still content with their word-symbols.

There are also contemporary scholars who believe that the alphabet is of Egyptian origin; they base their views on the yet undeciphered Sinaitic inscriptions uncovered in 1906 in the Sinai Desert by Sir William Flinders Petrie and which date back to about 1500 BCE. The discovery was hailed by many as the missing link between the alphabet and the Egyptian demotic writing, and led to the belief that the Canaanites learned their method of writing from their contacts with the Egyptians. A recent discovery in the land of Canaan showed that the so-called Proto-Sinaitic inscriptions were used by Semitic people as early as 1700 BCE, and they are purely a Semitic script. The Canaanites, who were working the Egyptian turquoise mines in south-western Sinai, left symbols scribbled on rocks and stones, and some scholars believe that the Canaanite workers learned their signs from their Egyptian lords. The Sinaitic pseudo-hieroglyphic and proto-Canaanitic scripts may at best be considered a first attempt at the complex process that led to the alphabetic script.

The champions of an Egyptian origin support their claims by the presence of simple symbols in the Egyptian hieroglyphs that goes back to about 2000 BCE. Egyptian scribes, like many others, were introducing symbols, which stood for simple sounds or syllables and to a certain degree resemble the symbols of the alphabet. This pseudo-hieroglyph has so many signs that it is considered more syllabic than alphabetic, and instead of simplifying the Egyptian way of writing, it added to its complexity. The Egyptians priests could not relinquish their complex picture word-signs, and kept using them until about AD 500.

The uncovering of Minoan hieroglyphs and other Minoan pictograms in the beginning of this century suggested to the archeologist Sir Arthur Evans that the Phoenician alphabet was itself derived from Crete. On the basis of Evans’ statement, and in spite of the fact that the excavations on the island revealed no alphabetic signs, Glasgow wrote, “We now know, for instance, that the art of writing came from Crete, Phoenicia being the medium.”

Many of the supporters of non-Phoenician origins point out that some of the sounds assigned to the signs that make up the alphabet do not correspond to the Canaanite names represented by the signs. As a matter of fact a few of the signs, only two, do not correspond to any known objects, but as we shall see, all the rest do. The variations may be attributed to the whim of a scribe or scribes, who forsook fidelity in favor of beauty or simplicity. The alphabet evolved for several centuries before reaching its known Phoenician form.

The most probable origin of the invention of the alphabet is the land of Canaan. It seems that a scribe in Canaan conceived of the idea that a language might be written without the numerous signs used in Babylonian cuneiform or Egyptian hieroglyphs. It took a great deal of effort and insight to realize that complex words may be broken down into simple sounds, and that it does not take many of these simple sounds to write an entire language. This is tantamount to saying that the large number of words that forms a language are made up of various combinations of a relatively small number of simple sounds.

Each one of the simple sounds was represented by the picture of a familiar object, whose Canaanite name corresponds to the sound. Thus *beit* (house) stood for the *b* sound and *daleth* (door) stood for the *d* sound – the pictures stood for the simple sounds only and not for the word-sign. In a similar fashion all the consonants that form the language were represented. For reasons yet unknown, the vowels were not considered important enough to play a role in this scheme. This is why it is rather difficult to read modern-day Arabic and Hebrew scripts, where only the consonants are written.

In addition to the script uncovered in the Sinai desert, there are those unearthed in Byblos (Jbayl) and ascribed to the middle of the second millennium BCE. Other proto-Canaanite inscriptions were found in various parts of the Near East, such as Beit Shamesh, Gezer, Lakish, etc. The Gezer calendar is relatively recent – it dates to ca. 950 BCE. The alphabetic signs found in various localities are different – they do not resemble one another. This leads to the speculation that once the often-competing Canaanite clans knew of the magnificent invention, each group began to formulate its own symbols. Thus began the early stages of the alphabet of which several examples have been recovered, but many aspects of its early development are lost.

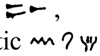
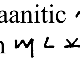
Except for the Ugaritic alphabet, which was written on clay tablets, the few early alphabetic signs found in the land of Canaan were scratched on stones or rocks. Toward the middle of the second millennium BCE Canaan was under the influence of Egypt, and the Canaanite scribes were writing on Egyptian papyrus. Unfortunately, in the relatively damp soil of Canaan, papyrus did not prove to be a durable material, and the early development of the alphabet written on it is lost; the real origins may never be known.

The earliest known pure "alphabetic" signs are the proto-Canaanitic scripts, and they may be considered as first attempts in a long process that led to what we call the Phoenician alphabet. However, on the whole, they do not suggest true alphabetic designations as a large number of the Sinaitic signs are syllabic rather than alphabetic. Although there are a few similarities between the Sinaitic and the Phoenician signs, many are very different, indicating that radical changes had taken place.

The Ugaritic alphabet may be considered a new way of writing the Canaanite script. The Ugaritic literature, written on clay tablets, is the earliest, most comprehensive alphabetic script that has survived. Furthermore, the order of the letters of the alphabet, at least the first few signs, support this possibility – the head of the Canaanite pantheon is El, whose epithet is *thor* (bull). It is most appropriate to put the head of the pantheon at the head of the alphabet, hence the first letter, *aleph*, meaning bull or ox. In the Canaanite mythology, the great gods dwell in large houses, and one often reads about the house of god, and the adobe of El is frequently mentioned. Thus the second letter of the alphabet, b, is represented by *beit* (house); and what is a house without a *daleth* (door), thus d is the fourth letter of the alphabet, followed by *hah* (window). There are several other such conjugate pairs in the Phoenician alphabet: *yad* and *kaff* (hand and palm), *mem* and *nahir* (water and river), and *rosh* and *shin* (head and tooth) (Fig. 1).

The earliest proto-Canaanitic symbols found in Phoenicia belong to the fourteenth century, and the first inscriptions of the Phoenician alphabet, which were left on arrowheads in Jbayl, belong to the twelfth century BCE. It is quite probable that the roots of the Phoenician alphabet go back to the Sinaitic proto-Canaanitic scripts. This hypothesis is strengthened by the few similarities between the Sinaitic and the early Phoenician signs and by the fact that they are listed in somewhat corresponding orders. Thus one may deduce that the formulation of the alphabet was a lengthy process culminated by the Phoenicians easy-to-reproduce form, which replaced the Sinaitic almost syllabic and the Ugaritic cumbersome cuneiform, with simple signs. There are indications that the scribes of Ugaritic, in their later writings, wrote from right to left and dropped a few of their consonants symbols. The Phoenicians continued the process of converging sounds to accommodate sound variations in their standard language, reducing the total number from 30 characters to 22.

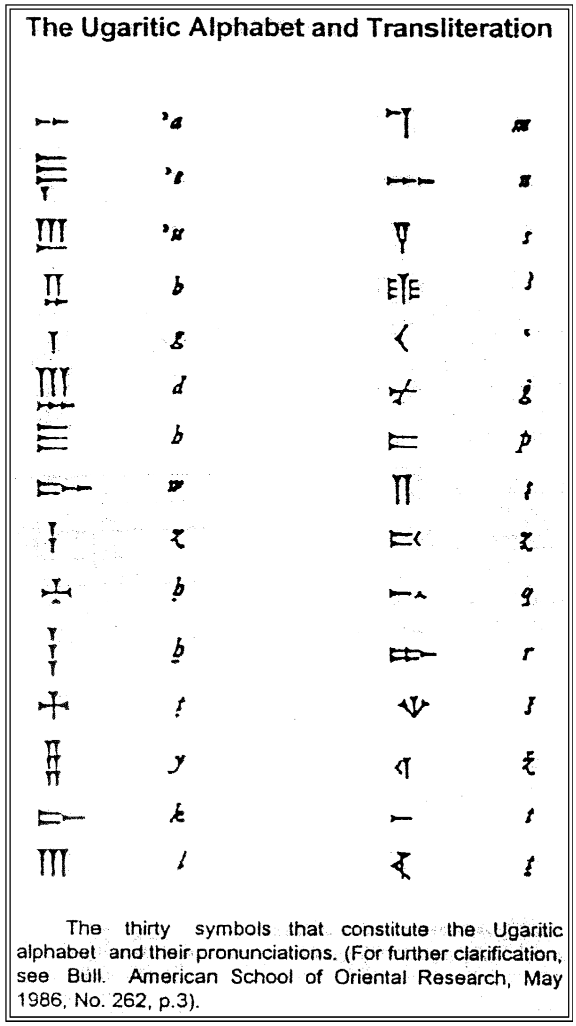
Most recent authors attribute the origin of the alphabet to Phoenicia and more precisely to Jbayl. This is a definite possibility; the invention of the forms of the letters may have taken place in Jbayl. To compare the three scripts, let us reproduce the word "MLK" meaning king and written without vowels:

- Ugaritic ,
- Proto-Canaanitic ,
- Phoenician .

Note the similarity between the Phoenician and the Latin letters. The simplicity of the Phoenician signs rendered them more accessible than all others, and by the end of the second millennium, the Phoenician alphabet became firmly established in the entire land of Canaan.

If doubt persists as to the origin of the invention of the alphabet, it is absolutely clear that the Phoenicians taught the letters to the Greeks and then to the rest of the known world. Some authors recognize the importance of this step and do not speak so much about the invention as about the diffusion of the alphabet. Herodotus is one such author and in one often quoted passage, he wrote, "These Phoenicians who came with Cadmus… among other kinds of learning, brought into Hellas the alphabet, which had hitherto been unknown, as I think, to the Greeks."

The vowels, sometimes erroneously referred to as a Greek contribution, were arrived at either by sheer misunderstanding or because some of the Phoenician consonants were not needed in the Greek language, and the Greeks themselves were having difficulty pronouncing them. Thus the Phoenician aspirate "hah" became a short "e" or *epsilon* in Greek, the aspirate



Alphabet. Fig. 1 The Ugaritic alphabet.

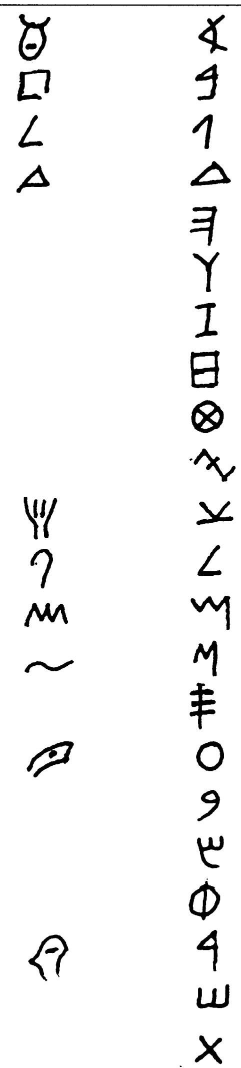
"heth" became a long "e" or *eta*, the semiconsonantal "yad" or "yod" became an "i" or *iota*, and the throaty "ayn" became an "o" or *omicron* (Fig. 2).

The similarities between the old Phoenician and Greek alphabets are apparent; the order to the letters are basically the same and the names assigned to most symbols, which have no significance in Greek, are taken from Phoenician words. In the fifth century BCE the Greek scribes altered the shape of their letters by changing them into their mirror images. In general, minor changes took place whenever the alphabet was adapted to a new language.

The early Greeks expressed their gratitude to their benefactors by referring to their letters as *phoinikeia* (Phoenician objects). An inscription unearthed in Crete contains the verb *poiniazen* (to write) and the title *poinikastas* (scribe).

This alphabet soon spread into the Mediterranean region, or wherever Phoenician and later Greek trading posts were established. This helped in keeping records of commercial transactions and simplified the work of the Phoenicians, the sea traders of the ancient world. While the Phoenicians carried their alphabet with their goods and deposited both all over the Mediterranean world, Western Europe, and Northwest Africa, their cousins, the Arameans, moved with it eastward, where it displaced most of the cuneiform script down the Euphrates and into Persia, then penetrated the western frontiers of India, furnishing the Indians with their Sanskrit alphabet.

The diffusion of the Phoenician alphabet, first into the Greek, then into the Roman cultures, provided the proper tool that fueled one of the greatest cultural explosions the world has ever known.



Caananitic (ca. 1500 BC)	Phoenician (ca. 1200 BC)	Picture represents	Meaning	Greek character	Greek name
		aleph	ox	α	alpha
		beit	house	β	beta
		gamma‘	sickle	γ	gamma
		daleth	door	δ	delta
		hah	window	ϵ	epsilon
		waw	hook	ζ	zeta
		Zayn	–	η	eta
		ḥeth	–	θ	theta
		ṭeh	–	ι	iota
		yad	hand	κ	kappa
		kaff	palm	λ	lambda
		lamed	staff	μ	mu
		myi *or* mem	water	ν	nu
		nahir	river	ξ	xi
		samkeh	fish	o	omicron
		‘ayn	eye	π	pi
		feh or peh	–	ρ	rho
		ṣad	–	σ	sigma
		quof	–	τ	tau
		rosh	head	υ	upsilon
		shin	tooth	ϕ	phi
		tā	cross	χ	chi
				ψ	psi
				ω	omega

Alphabet. Fig. 2 The development of the alphabet.

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Al-Qalaṣādī

Ahmed Djebbar

In the Islamic world of the fifteenth century there was a general halt in research and a lowering of the level of instruction. In mathematics this tendency resulted in a repetitive scientific production made up of poems or commentaries directed at an increasingly narrow public: teachers, *muwaqqits* (astronomers) charged with determining the hours of daily prayers, judicial functionaries, government bookkeepers, etc.

It is in light of this tendency that we can appreciate both the intellectual journey and the scientific contribution of al-Qalaṣādī, one of the last scholars of Andalusian origin who dedicated a large part of his life to disseminating – to the central Maghreb, to Ifriqiya, and to Egypt – what he knew of the Arab mathematical tradition of the preceding centuries.

ʿAlī ibn Muḥammad al-Qalaṣādī was born around 1412 in the Andalusian village of Basta. This small village, which is in the northeastern part of Grenada, was already prosperous in the time of the geographer al-Idrīsī (d. 1153) and continued to be so for two centuries.

We know nothing of al-Qalaṣadī's childhood except that he grew up in his birthplace where he learned the *Quʾrān* from his teacher Ibn ʿAzīz and where he received his first lessons in Arabic and probably also in mathematics. In the course of his adolescence he continued these studies and was taught grammar and mathematics from the arithmetic texts of Ibn al-Bannāʾ (d. 1321), as well as law, the science of inheritance, and calculation.

In 1436, at the age of 24, al-Qalaṣadī left his native village and began his first educational voyage, heading to Tlemcen, the first stop of a long journey to scientific centers in the Maghreb, al-Andalus, and Egypt. The educational voyage (*riḥla* in Arabic) was a medieval tradition, one of whose goals was to allow students to complete their education in various places, taking classes from famous professors.

Al-Qalaṣādī's stay in Tlemcan lasted eight years. His most serious study of mathematics was with az-Zaydūrī (d. 1441). He himself says that az-Zaydūrī taught him the contents of two important texts of Ibn al-Bannāʾ: the *Kitāb al-Uṣūl wa l-muqaddimāt fi l-jabr wa' l-muqābala* (Book on the Foundations and Preliminaries in Algebra and Restauration) and the *Rafʿ al-ḥijāb ʿan wujūh aʿmāl al-hiṣab* (Lifting of Veil on the Science of Calculus Operations).

It also appears that the first scientific works of al-Qalaṣādī were written in Tlemcen, between 1436 and 1444. There were three commentaries on writings on the science of inheritance and a mathematics book entitled *al-Tabṣira* (The Book which Makes Things Intelligible).

In 1444, al-Qalaṣādī left Tlemcen for Tunis, which was at that time one of the most dynamic intellectual centers in the Maghreb. In the *madrasas* (colleges) where he studied, al-Qalaṣādī took courses in Malikite law, the Arabic language, grammar, and the rational sciences. At the same time, he devoted time to his own writing. He published three books on calculation: the *Kashf al-jilbāb ʿan ʿilm al-ḥisāb* (Unfolding the Secrets of the Science of Calculation) in 1445, the *Qānūn fi al-ḥisāb* (Canon of Mathematics), and his commentary entitled *Inkishāf al-jilbāb ʿan qānūn al-ḥisāb* (Explaining the Canon of Mathematics). He also published two works on traditional sciences, *al-Kulliyyāt fi al farā'iḍ* (Collection on Successional Division), and a commentary on it. At the end of his stay in Tunis, in 1447, it appears that he wrote his epistle on irrational numbers entitled *Risāla fi dhawāt al-asmāʾ wa 'l-munfaṣilāt* (Epistle on Binomials and Apothems).

On 30 May 1447, al-Qalaṣādī left Tunis and headed to Cairo and then to Mecca, where he wrote a commentary on the *Farā'iḍ* (Book on Successional Division) of Ibn al-Ḥājib on traditional science. Returning from the pilgrimage, he again stayed in Cairo, teaching and taking classes from several professors, notably Shams al-Dīn al-Samarqandī in rational sciences.

In April 1449, al-Qalaṣādī left Cairo and returned to al-Andalus. In 1451 he returned to his native village of Basta, and then went to Grenada, where he stayed for 30 years. There he studied with eminent professors like the astronomer Ibrāhīm Ibn Futūḥ, who specialized in the study of astrolabes.

A deterioration of the political climate of the interior of the kingdom of Grenada and increasingly worrisome menaces from outside forced al-Qalaṣadī to leave the Andalus once and for all in 1483. He settled finally in Béja in Ifriqiya where he died in 1486, just 6 years before the fall of Grenada.

Mathematical Works of al-Qalaṣadī

Like some of his contemporaries in al-Andalus and the Maghreb, al-Qalaṣādī wrote on many different subjects. In almost all disciplines he also, again like many of his contemporaries, published numerous commentaries on classical texts. But he is, to my knowledge, the only scholar of his era to have written so many works on mathematics.

The mathematical development of al Qalaṣādī seems to have been centered basically on the science of calculation, on the processes of arithmetic and algebraic calculation and their application in the solving of abstract exercises and practical problems – e.g., problems of commercial transaction, monetary conversions, or the division of inheritances.

In algebra, he wrote chapters included in the arithmetical works already noted. In these chapters he treats algebraic operations and the resolution of the canonical equations of al-Khwārizmī. To that we must add his commentary on the algebraic poem of Ibn al-Yāsamīn.

In these texts one finds a peculiarity of the Maghrebian mathematical tradition, the utilization of a certain symbolism to express objects or algebraic concepts such as an unknown, different powers, or equality in equations. For a long time the invention of this symbolism was attributed to al-Qalaṣādī. But the results of recent research now permit us to affirm that this same algebraic symbolism was already in existence in this twelfth century, particularly in the work of Ibn al-Yāsamīn entitled *Talqīḥ al-afkār* (Fertilization of Thoughts), and that it was widely in use in the fourteenth century, in particular by Ibn Qunfudh (d. 1407). The work of al-Qalaṣādī bears witness to the persistence of these symbols and of their widespread use throughout the Maghreb.

In arithmetic, his writings deal essentially with the four arithmetic operations (applied to whole numbers, fractions, and irrational quadratics), with the extraction of the exact or approximate square root of a number, with the rule of three, with the method of false positives, and with other arithmetical procedures such as the breakdown of a number into prime factors and the calculation of the sums of series of natural numbers from their squares and cubes. Again, it is important to note that the techniques used by al-Qalaṣādī in these books are related to techniques already used in the works of al-Ḥaṣṣār (twelfth century) and of Ibn al-Bannāʾ.

The fact that these themes are present in the works of al-Qalaṣādī and his method of treating them leads to the conclusion that in the fifteenth century, the mathematical traditions of al-Andalus and of the Maghreb were unified by being based upon each other. Moreover, if one compares the work of al-Qalaṣādī with that of Ibn al-Bannāʾ, one notices a certain continuity both in form and content. Because of this, one can argue that al-Qalaṣādī is more Maghrebian than Andalusian. This stamp of the Maghreb on the education and work of a scholar from al-Andalus of the importance of al-Qalaṣādī offers proof, moreover, of the decline of scientific activity in al-Andalus in the fourteenth and fifteenth centuries.

On the other hand, when one compares his different works in mathematics, one does not see a noticeable evolution from one book to another, but rather different formulations of classic themes and techniques. Al-Qalaṣādī himself claimed that some of his books were only developments or summaries of previously published works. It is important to note that this process, which was not unique to al-Qalaṣādī and which was already in evidence at the end of the fourteenth century both in the Maghreb and in Egypt, only reflects the continuation in the fifteenth century of the slow decline of scientific activity in the Islamic city. In this difficult context the scientific aptitude of al-Qalaṣādī was not really able to flourish fully, and it is greatly to his credit that he contributed to maintaining the level of scientific activity of that of the fourteenth century in the Andalus and the Maghreb.

See also: ►al-Idrīsī, ►Ibn al-Bannāʾ

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Al-Qūhī (or Al-Kūhī)

Yvonne Dold-Samplonius

Abū Sahl Wayjan ibn Rustam al-Qūhī (or al-Kūhī) probably originated from the village of Quh in the Iranian province of Tabaristan. He worked in Baghdad under the Buwayhid Caliphs ʿAḍud al-Dawla and his son and successor Sharaf al-Dawla. In 969/970 al-Qūhī assisted at the observations of the solstices in Shiraz. These observations, ordered by ʿAḍud al-Dawla, were directed by Abū'l-Ḥusayn ʿAbd al-Raḥmān ibn ʿUmar al-Ṣūfī. In 988 al-Qūhī supervised astronomical observations in the garden of the palace of Sharaf al-Dawla in Baghdad in the company of several magistrates and respected scientists.

Some of al-Qūhī's contemporaries considered him to be the best geometer of his time; al-Khayyāmī held him in high esteem. In the geometrical writings known to us he mainly solved problems that would have led to equations of higher than the second degree. A note by al-Qūhī is added to Naṣīr al-Dīn al-Ṭūsī's redaction of Archimedes' *Sphere and Cylinder* in the Leiden manuscript, on how to construct a sphere segment equal in volume to a given sphere segment, and equal in surface area to a second sphere segment. This problem is similar to but more difficult than the constructions solved by Archimedes in *Sphere and Cylinder* II,6 and II,7. Al-Qūhī constructed the two unknowns, i.e., the radius of the sphere and the height of the segment, by intersecting an equilateral hyperbola with a parabola and rigorously discussed the conditions under which the problem is solvable.

Conic sections provided the tools for several problems, as in the classical problem of trisecting an angle. In the small treatise *Risāla fī qismat al-zāwiya* (On the Trisection of the Angle) al-Qūhī gave a purely Islamic solution by means of an orthogonal hyperbola. This solution was taken over by al-Sijzī. In *Risāla fī istikhrāj ḍil'al-musabba'al-mutasāwi'l-aḍlā*ʾ (On the Construction of the Regular Heptagon) the precise construction is more complete than the one attributed to Archimedes. Al-Qūhī's solution is based on finding a triangle with an angle ratio of 1:2:4. He constructed the ratio of the sides by intersecting a parabola and a hyperbola, with all parameters equal. Al-Sijzī, who claimed to follow the method of his contemporary Abū Sa'ied al-ʿAlā ibn Sahl, used the same principle. A second, different solution by al-Qūhī also exists. One of the most interesting examples of late tenth-century solutions is al-Qūhī's construction of an equilateral pentagon in a given square in *Risāla fī ʿamal mukhammas mutasāwi l-aḍlāʿ fī murabbaʿ maʿlūm* (On the Construction of an Equilateral Pentagon in a Known Square). This solution is based on Books I–VI of Euclid's *Elements*, Euclid's *Data*, and parts of Books I–III of Apollonius' *Conics*. The construction is remarkable, because it contains a proof of the focus–directrix property of a hyperbola with eccentricity $\varepsilon = 2$. It is reasonable to assume that al-Qūhī independently discovered and proved this property, thus going a step further than Apollonius.

In *Risāla fī istikhrāj misāḥat al-mujassam al-mukāfī* (On Measuring the Parabolic Body) al-Qūhī gave a somewhat simpler and clearer solution than Archimedes had done. He said that he knew only Thābit ibn Qurra's treatise on this subject, and in three propositions showed a shorter and more elegant method. Neither computed the paraboloids originating from the rotation of the parabola around an ordinate. That was first done by Ibn al-Haytham, who was inspired by Thābit's and al-Qūhī's writings. Although he found al-Qūhī's treatment incomplete, Ibn al-Haytham was nevertheless influenced by his thinking. Maybe the two met in Basra, where al-Qūhī wrote his correspondence to Abū Isḥaq al-Ṣābī and four books on centers of gravity. Analyzing the equation $x^3 + a = cx^2$, al-Qūhī concluded that it had a (positive) root if $a \leq 4c^3/27$. This result, already known to Archimedes, was not known to al-Khayyāmī, whose analysis is less accurate.

Al-Qūhī was the first to describe the so-called perfect compass, a compass with one leg of variable length for drawing conic sections. In this clear and rather general work, *Risāla fī'l birkar al-tāmm* (On the Perfect Compass), he first described the method of constructing straight lines, circles, and conic sections with this compass and then treated the theory. He concluded that one could now easily construct astrolabes, sundials, and similar instruments. In his *Kitāb ṣan'at al-aṣṭurlāb* (On the Manufacture of the Astrolabe) al-Qūhī used an original method for drawing azimuth circles, based on an analemma, a procedure for reducing problems in three dimensions to two dimensions. A commentary on this work was written by Abū Sa'd al-ʿAlā ibn Sahl. Al-Qūhī's proofs for this construction were reproduced in an inferior form by Abū Naṣr Manṣūr ibn ʿIrāq, who highly esteemed al-Qūhī, in *Risāla fī dawā' ir as-sumūt fī al-aṣṭurlāb* (Azimuth Circles on the Astrolabe).

The correspondence between al-Qūhī and Abū Isḥaq al-Ṣābī contains discussions of the possibility of curvilinear figures being equal to rectilinear figures, the meaning of "known ratio," and whether one can square a parabolic segment by exhausting it with triangles. The first letter especially gives impressive evidence for al-Qūhī's creativity in two theorems on centers of gravity of circular sectors and arcs. In the same correspondence he deducted a value of 28/9 for the ratio of the circumference of a circle to its diameter (π). This result was attacked by Abū Isḥaq and then, almost 150 years later, by Abū'l-Futūḥ Aḥmad ibn Muḥammad ibn al-Sarī. The latter thought that al-Qūhī got swept away by enthusiasm about his result. Also the 27 propositions in *Hādhā mā wujida min ziyādat Abī Sahl ʿalā al-maqālah al-thāniiyah min kitāb Uqlīdis fī al-uṣūl* (Abū Sahl's Additions to Book II of Euclid's Elements) are rather weak and not very clearly stated. Probably, however, those additions, if they were even written by al-Qūhī, were originally only marginal notes in his copy of Euclid's *Elements*.

See also: ►Abū'l Wafāʾ, ►al-Ṣāghānī, ►al-Maghribī, ►ʿUmar al-Khayyām, ►Naṣīr al-Dīn al-Ṭūsī, ►Ibn Sahl, ►Thābit ibn Qurra, ►Ibn al-Haytham, ►Conics, ►Astrolabe, ►al-Ṣūfī

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Al-Rāzī

Albert Z. Iskandar

Abū Bakr Muḥammad Ibn Zakariyyā al Rāzī (Rhazes), the most original physician philosopher of his time, was born in al-Rayy (hence the name, al-Rāzī), now ruins near modern Teheran. Medieval historians wrote more on his copious bibliography than on his life.

Al-Bīrūnī (d. AD 1048 or 1050) writes in his *Risāla fī Fihrist Kutub Muḥammad Ibn Zakariyyā al-Rāzī* (Missive on the Index of Books of Muḥammad Ibn Zakariyyā al-Rāzī) that he was asked by a learned man to compile a bibliography of al-Rāzī. To accomplish this task, he examined many manuscripts, and recorded only those works in which he found al-Rāzī's name mentioned as author in the text. Al-Bīrūnī's method of research undoubtedly resulted in his failure to record some of al-Rāzī's genuine works.

Al-Rāzī advised doctors to practice in densely populated cities, where they could benefit from the experience of many skillful physicians and have the chance to examine many patients. He himself moved from al-Rayy to Baghdad where, in his youth, he studied and practiced the art of healing at its hospital (*bīmāristān*). Later, he returned to al-Rayy, at the invitation of its ruler, Manṣūr ibn Isḥāq, to assume responsibility as Hospital Director. To this ruler, al-Rāzī dedicated two books, *al-Almnṣūrī fī'l Ṭibb* (al-Manṣūrī on Medicine) and *al-Ṭibb al-Rūḥānī* (The Spiritual Physic). These were intended to unite the study of diseases of the body with those of the soul.

Having achieved fame in al-Rayy, al-Rāzī returned to Baghdad to become Head of its newly founded hospital, named after its founder the Abbasid caliph al-Muʿtaḍid (d. AD 902). The last years of his life were spent in al-Rayy, where he suffered from glaucoma (*al-māʾ al-azraq*), and died in AD 932 or 925.

Al-Rāzī's book *Fi'l Shukūk ʿalā Jālīnūs* (Doubts about Galen), so far unpublished, is devoted to the criticism of 28 of Galen's books, beginning with the *al-Burhān* (Demonstration) and ending with *Fi'l Nabḍ* (On the Pulse).

Before embarking on the criticism of Galen, he writes an apology in which he acknowledges his debt to his master, but says that "the art of physic is a philosophy which does not tolerate submission to any authority, nor does it accept any views, or yield to any dogmas without proper investigation." He says Galen himself supported this view. In the closing passage of his introduction, al-Rāzī affirms the validity of his book, saying that none of Galen's predecessors had escaped Galen's own scathing criticism.

To al-Rāzī, progress in scientific knowledge is inevitable. In his treatise *Fī Miḥnat al-Ṭabīb wa Taʿyīnih*, he says "He who studies the works of the Ancients gains the experience of their labour as if he himself had lived thousands of years spent on investigation."

Al-Rāzī also mentions *al-Jāmiʿ al-Kabīr* four times in his book *al-Murshid aw al-Fuṣūl* (The Guide or Aphorisms), which was written to serve as an introduction to medicine. *Al-Jāmiʿ al-Kabī* consists of 12 sections (*aqsām*), of which only two have been recently discovered in manuscripts: *Ṣaydalat al Ṭibb* (Pharmacology in Medicine) and *Fī Istinbāṭ al-Asmāʾ wa'l-Awzān wa'l-Makāyīl* (On Finding the Meaning of Unfamiliar Terms, Weights, and Measures).

His medical prescriptions took into account the patients' social status. For the rich, princes, and rulers, the effective drugs had to be mixed with sweet vehicles, as explained in *al-Ṭibb al-Mulūkī* (The Royal Medicine). For the poor, he wrote a book of recipes entitled *Man lā Yaḥḍuruh al-Ṭabīb* (Who has no Physician to Attend Him) also known by the title *Ṭibb al-Fuqarāʾ* (Medicine for the Poor).

Al-Rāzī argued that the medicinal properties attributed to various parts of animals, vegetables, and minerals should be recorded in books, which he did in his *Khawāṣṣ al-Ashyāʾ* (The Properties of Things). Such properties should neither be accepted nor discarded, unless experience (*al-tajriba*) proves them to be true or false. Physicians should not accept any property as authentic, unless it has been examined and tried.

In theory, al-Rāzī followed Galen, yet he found it necessary to correct him, and in practice, he revived the Hippocratic art of clinical observation. Having read the Hippocratic book *Abīdhīmyā* (Epidemics), he decided to write his own case histories, where he carefully recorded the name, age, sex, and profession of each patient. He also gave an early example of a clinical trial, when he divided his patients suffering from meningitis (*al-sirsām*) into two groups. He treated one group with bloodletting and intentionally, as a control, refrained from applying venesection to the other group.

All these detailed case histories are extant in his private notes which became known after al-Rāzī's death as the *al-Ḥāwī fi'l Ṭibb* (Continens on Medicine). It should be considered a private library of a well read and highly educated physician–philosopher, not a book meant for publication. It is interesting to remark that illnesses which affected al-Rāzī himself are recorded in *al-Ḥāwī fi'l Ṭibb*. In a note, preceded with "*Lī* (mine)," he mentions how he cured an inflammation of his own uvula by gargling with strong vinegar; in another, he jots down the fact that he recovered from a swelling in the right testicle by taking emetics (*muqayyiʾāt*) for a long time.

Al-Rāzī's medical works had great influence on medical education in the Latin West. *Al-Ḥāwī fi'l Ṭibb* was rendered into Latin (*Liber Continens*) by a Sicilian Jew, Faraj Ibn Sālim (Farrajut) in AD 1279. It was printed five times between AD 1488 and 1542. His *Liber ad almansorem*, consisting of ten books, and his *Liber Regius* were very popular among medieval European practitioners. The seventh book of *Liber ad Almansorem* (On Surgery) and the ninth entitled *Nonus Almansoris* (A General Book on Therapy) constituted a part of the medical curriculum in Western universities.

Al-Rāzī established an accurate differential diagnosis, based on clinical observations, between smallpox (*al-jadarī*) and measles (*al-ḥaṣba*). His book *Smallpox and Measles* was translated into Latin (*De variolis et morbillis*), and into other occidental languages and was printed about 40 times between AD 1498 and 1866.

The subject matter in this book is quite original. First, al-Rāzī asserts that Galen knew of smallpox, yet failed to indicate its etiology and to prescribe any satisfactory therapy. Secondly, he lays down his own differential diagnosis by his vivid description of the pustules of smallpox and the rash of measles. In his prognosis of the course of smallpox, he recommends close attention to the heart, the pulse, respiration, and excreta. He outlines his own method of protecting the patient's eyes and elaborates on how to avoid deep facial scarring.

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Al-Ṣāghānī

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Abū Ḥāmid Aḥmad ibn Muḥammad al-Ṣāghānī al-Asṭurlābī was an Arabic astronomer and mathematician. He was born in Chagaian (Central Asia) and worked in Baghdad.

His main work was the *Kitāb fī'l-tasṭīh al-tāmm* (Book of the Perfect Projection on to a Plane) which is extant in two manuscripts. The treatise is devoted to a generalization of the stereographic projection of a sphere on to a plane, usually used in the making of astrolabes. This concerns the projection from a pole of the sphere on to the equatorial plane or a plane parallel to it. Under this projection, circles on the sphere are imaged on to the plane as circles or straight lines. The "perfect projection" invented by al-Ṣāghānī is the projection of the sphere from any point of its axis on to a plane orthogonal to the axis. Under this projection, circles on the sphere are imaged on the plane as conic sections (ellipses, hyperbolas, and parabolas) or straight lines. These descriptions of methods for conics construction are important for geometry. In the treatise, al-Ṣāghānī considers the construction methods for images of different circles of the celestial sphere, such as the celestial equator and its parallels, the horizon and its almacantars, verticals, and one ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The contents of the treatise are explained in detail by al-Bīrūnī (973–1048) in his *Astrolabes*.

Al-Ṣāghānī was also the author of two mathematical treatises, on the construction of a regular heptagon inscribed in a circle, and on the trisection of an angle. He also wrote three astronomical treatises. *Kitāb qawānīn ʿilm al-hay'a* (Book on Rules of the Science of Astronomy) is not extant, but al-Bīrūnī in his *Geodesy* mentioned measuring the value of the angle between the ecliptic and the celestial equator found by al-Ṣāghānī in Baghdad. The second, *Maqāla fī'l abʿād wa'l-ajrām* (Article on Distances and Volumes), dealt with the distances and volumes of planets and stars. The third work was *Fī'l sāʿāt al-maʿmūla ʿalā ṣafāʾiḥ al-asṭurlāb* (On Horary Lines Produced on the Tympanums of Astrolabes).

See also: ►Astrolabe

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Al-Samarqandī

Gregg De Young

Shams al-Dīn al-Samarqandī, as his name implies, was from Samarqand, in what is now Uzbekistan. We know few of his biographical details with any certainty. He is believed to have been active during the second half of the seventh AH/AD thirteenth century, since he composed a star calendar for 675 AH/AD 1276-7 to accompany his *Al-Tadhkira fī'l-Hay'a* (Synopsis of Mathematical Cosmography or Hay'a). Although Naṣīr al-Dīn al-Ṭūsī had gathered many leading intellectuals together at the Marāgha observatory, al-Samarqandī is never mentioned among their number.

Al-Samarqandī's earliest contributions were in the field of logic, but he is best known to historians of science for his brief tract, *Kitāb Ashkāl al-Ta'sīs* (*Book of Fundamental Theorems*), a collection of 35 propositions from Euclid's *Elements* (mostly from Books I and II, although VI, 1 is also included), with abbreviated demonstrations. The treatise is very concise, and is historically better known through the commentary composed by Qāḍīzāde al-Rūmī (died 840 AH/AD 1436). Of special interest has been the "proof" of Euclid's parallels postulate (the fifth postulate of book I) which al-Samarqandī included. Once this "proof" was thought to be the work of al-Samarqandī himself, but now it is frequently ascribed to Athīr al-Dīn al-Abharī (died 663 AH/AD 1265).

See also: ►Hay'a, ►Qāḍīzāde al-Rūmī

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Al-Shīrāzī

John Walbridge

Quṭb al-Dīn Maḥmūd ibn Masʿūd al-Shīrāzī (1236–1311) was a Persian scientist and philosopher. He was born into a medical family in Shiraz in central Iran. His father was a staff physician and ophthalmologist at the newly established Muẓaffarī hospital. As a child he was the apprentice of his father, who died when Shīrāzī was 14. Having assumed his father's position at the hospital, he continued his studies with several other local teachers of medicine and the rational and religious sciences. At this time he began the study of the first book, *al-Kullīyāt* (On General Principles) of Ibn Sīnā's *Qānūn fī 'l-Ṭibb* (Canon of Medicine), the leading medical textbook of the Middle Ages. His father had also initiated him into the Suhrawardī order of Sufis (Islamic mystics).

By the time he reached adulthood, he was in need of advanced medical instruction that could not be provided by the teachers of a provincial city like Shiraz. It would have been normal for him to have gone off earlier to one of the major Islamic cities for advanced studies, but in 1253 the Mongols had invaded the Islamic lands of Central and Southwestern Asia, sacking Baghdad in 1258, so Shīrāzī was confined to his home city until peace was reestablished.

In 1259 Hulegu, the Mongol ruler of Iran, gave a large grant to the famous scientist Naṣīr al-Dīn al-Ṭūsī (1201–1274) to pay for the preparation of a new set of astronomical tables (*zīj*) for use in astrological calculations. Ṭūsī established an observatory in the town of Marāgha, at that time the Mongol capital, and brought together a brilliant team of scientists and scholars. Shīrāzī came to the observatory as a student soon after it was founded. While he was disappointed by Ṭūsī's lack of knowledge about medical theory, he learned a great deal of mathematics, astronomy, and philosophy from him and his faculty, and he soon became the most important student at the observatory. Ṭūsī took him along on his travels and introduced him at court. Shīrāzī also apparently spent some time studying in Qazvīn, Khorasan, and Baghdad with various teachers.

Around 1270 he left the observatory and went to Konya in Anatolia, where he met the famous Sufi poet Rūmī and studied *ḥadīth* (the sayings of Muḥammad) with Ṣadr al-Dīn Qūnawī, the leading disciple of the mystical philosopher Ibn ʿArabī. Soon after he was appointed *qāḍī* (religious judge) of the Anatolian cities of Sivas and Malatya. This was evidently a sinecure to allow him to pursue his scientific work, for his first major work, *Nihāyat al-Idrāk fī Dirāyat al-Aflāk* (The Highest Attainment in the Knowledge of the Spheres), a technical work on mathematical astronomy, was published in Sivas in 1281 and was dedicated to the vizier of the Mongol ruler. Other works on astronomy and mathematics soon followed.

In 1282 he was appointed to a diplomatic mission to Egypt. Though the mission failed in its political objectives, Shīrāzī found three complete commentaries on the first book of Ibn Sīnā's *Qānūn*, along with glosses and other sources. With this new material in hand, he was finally able to achieve his youthful goal of mastering the intricacies of this work. Shortly after his return to Anatolia he published a large commentary on the *Qānūn*. He published second and third editions in 1294 and in 1310, a few months before his death.

Of his personality we are told that he had a sharp wit, and indeed he was a stock character in a certain genre of joke for several centuries thereafter. He was expert in chess and prestidigitation and was a lively conversationalist and lecturer. He was an authority on musical theory, which in the Middle Ages was considered a branch of mathematics, and was a fine player of the *ribāb*, a forerunner of the violin. He seems to have grown more concerned with religious matters as he grew older, although he was a Sufi all his life.

He eventually settled – interrupted by several exiles – in Tabriz, at that time the capital of Mongol Iran. He was an intimate of the court. The funds that supported his scientific work came from a series of viziers and petty rulers. In addition to his works on astronomy and medicine, he wrote on mathematics, philosophy, and the Islamic religious sciences. In his last years he spent less time on the rational sciences and more on religious subjects. He died in relative poverty, having given almost everything he had to charity and to his students and not yet having received the large payment promised for the third edition of his commentary on Ibn Sīnā's *Qānūn*. He was given a lavish funeral by a wealthy student.

Shīrāzī was typical in most respects of Islamic scientists. He was a polymath, interested not only in the corpus of science inherited from the Greeks but also in the religious sciences of Islam. Of the rational sciences it was astronomy and medicine that found the most ready market – astronomy as the handmaid of astrology or for timekeeping in the mosques. The other rational sciences, particularly mathematics, and philosophy, were supported by their more practical subordinate sciences. Sophisticated practitioners of the rational sciences generally drifted to the royal courts, the only reliable sources of funding for such subjects, and became involved in the life and politics of the court – and in its perils.

See also: ►Marāgha, ►Naṣīr al-Dīn al-Ṭūsī, ►*Zīj*, ►Ibn Sīnā, ►Ibn al-ʿArabī, ►al-ʿUrḍī, ►Optics, ►Astronomy

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Al-Sijzī

Yvonne Dold-Samplonius

Al-Sijzī, Abū Sa'īd Aḥmad ibn Muḥammad ibn ʿAbd al-Jalīl, was born in Persia, ca. 945 and died ca. 1020. The name al-Sijzī indicates that he was a native of Sijistān in southeastern Iran and southwestern Afghanistan. This is confirmed, for example, when al-Sijzī refers in his *al-Mudkhal ilā ʿilm al-handasa* (Introduction to Geometry) to a planetarium which he had constructed in Sijistān. Al-Sijzī was already active in 963, when he copied a manuscript of Pappus' *Introduction to Mechanics* (Book VIII of the Collection), and still active in 998, when he completed a treatise on the proof of the plane transversal theorem.

Al-Sijzī's father, Abū'l-Ḥusayn Muḥammad ibn Abd al-Jalīl, was also interested in geometry and astronomy, and al-Sijzī addressed some of his works to him, e.g., *Risālat fī Khawāṣṣ al-qubba az-zā'ida wa-l-mukāfiya* (On Parabolic and Hyperbolic Cupolas), completed in 972. Around 969 al-Sijzī spent some time at the Buwayhid court in Shirāz and assisted in 969/970 at the observations of the solstices conducted by Abd al-Raḥmān ibn ʿUmar al-ṣūfī. There he met a number of important geometers and astronomers, including Abū'l Wafāʾ, Abū Sahl al-Qūhī, and Naẓif ibn Yumn (d. ca. 990).

Al-Sijzī was active in astrology and had a vast knowledge of the literature. He usually compiled and tabulated, adding his own critical commentary, as with three works by Abū Maʿshar and the second of the five books ascribed to Zoroaster. He used Sassanid material and sources from the time of Hārūn al-Rashīd and from the late Umayyad period for a book on general astrology and its history. In his work on horoscopes he gives tables based on Hermes, Ptolemy, Dorotheus, and "the Moderns." Al-Sijzī's tables, together with those of Ptolemy, are quoted by Iḥtiyāzu' l-Dīn Muḥammad in his *Judicial Astrology*. The treatise *Kitāb fī Qawānīn mizājāt al-asṭurlāb al-shimālī maʿa l-janūbī* (On the Astrolabe) deals with the different kinds of astrolabe retes (a circular plate with many holes used on the astrolabe to indicate the positions of the principal fixed stars) with which al-Sijzī was familiar. This treatise is used by al-Bīrūnī in his *Istīʿab al-wujūh al-mumkina fī ṣan 'at al-asṭurlāb* (Book on the Possible Methods for Constructing the Astrolabe).

Al-Sijzī wrote at least 45 geometrical treatises, of which some 35 are extant, and about 14 astronomical treatises. He was well-read and had many contacts with his contemporaries. A number of his works are therefore of unusual historical interest. In *Risālat fī Qismat az-zāwiya al-mustaqīmat al-khaṭṭain bi-ṭalāṭat aqsām mutasāwiya* (On the Division of the Angle into Three Equal Parts) al-Sijzī describes a number of problems, to which various other writers had reduced the problem of the trisection of the angle. The method of "the Ancients" by means of a neusis was not considered a legitimate construction by al-Sijzī. His own construction, by intersecting a circle and a hyperbola, is a variation of the solution by al-Qūhī. The treatise ends with five problems of al-Bīrūnī. Regarding al-Sijzī's construction of the heptagon, this is, according to Jan Hogendijk, to a great extent the history of a dispute between two young geometers, al-Sijzī and Abū'l-Jūd, who were both engaged in plagiarism. In the meantime al-Qūhī solved the problem in an elegant manner.

For the *Geometrical Annotations* (*Kitāb fi l-masā'ili l-mukhṭārati llatī jarat baynahu wa-bayna muhandisī Shīrāz wa-Khurāsān wa-taʿlīqātihi*, Book on the Selected Problems Which Were Currently Being Discussed by Him and the Geometers of Shirāz and Khorāsān, and His (Own) Annotations) al-Sijzī had the example of Ibrāhīm ibn Sinān's *al-Masā'il al-mukhṭāra* (Selected Problems) in mind. A number of the problems and solutions are clearly influenced by or adapted from the *Selected Problems*, but al-Sijzī's treatise is on the whole on a lower level.

The *Misāḥat al-ukar bi-l-ukar* (Book of the Measurement of Spheres by Spheres) is about a surrounding sphere which contains in its interior up to three mutually tangent spheres. Al-Sijzī determines the volume of the solid which results when one deletes from the surrounding sphere all points that belong to the spheres in its interior. He expresses this volume as the volume of a new sphere, and he determines the radius of this new sphere in terms of the radii of the spheres used in the definition of the solid. Al-Sijzī's proofs are trivial consequences of identities for line segments, proved geometrically. The treatise contains 12 propositions, of which proposition 11 and its proof are false for (three-dimensional) spheres. The proposition holds in dimension 4. Perhaps al-Sijzī had four-dimensional spheres in mind, although he does not use them elsewhere in the treatise; perhaps he made a mistake.

His small treatise *Risālat fī Kaifīyat taṣauwur al-khaṭṭain alladhain yaqrubān wa-lā yaltaqiyān* (On the Asymptote, or How to Conceive Two Lines Which Approach Each Other But Do Not Meet, If One Extends Them All the Way to Infinity) is devoted to Apollonius II,14. Some cases, he says, can be solved as explained in his *Kitāb fī tashīl as-subul li-stikhrāj al-ashkāl al-handasīya* (On Facilitating the Roads to the Geometrical Propositions); for others a philosophical method is needed, as Proclus has shown in the definitions of his *Elements of Physics*. The treatise ends with the case where the two asymptotes are two hyperbolas. In *Risālat fī anna 'l-ashkāl kullahā min al-dā 'ira* (On [the Fact] that All Figures Are Derived from the Circle), a treatise until recently attributed to

Naṣir ibn ʿAbdallāh, al-Sijzī describes one of the few instruments that finds the *qibla* (the direction of Mecca) geometrically. He also wrote an original treatise on the construction of a conic compass.

In the introduction to *Risālat fī'l-shakl al-qaṭṭāʿ* (The Transversal Figure), written before 969, al-Sijzī says that he wrote the work having seen neither Thābit ibn Qurra's *Kitāb fī'l-shakl al-mulaqqab bi-l-qaṭṭāʿ* (Book of the Transversal) nor any other work on the topic, except Ptolemy's *Almagest*. The treatise begins with enunciations and proofs of two lemmas, which also appear, in different terms, in the *Almagest*. Following the two lemmas al-Sijzī enunciates and proves his 12 propositions. Aware of the astronomical applications of the theorem he evidently saw the need to provide a complete mathematical basis for these uses. The details of the proofs of all 12 theorems are carried out according to a uniform procedure. This makes the treatise a step toward recognizing the mathematical discipline of trigonometry.

See also: ►Astrolabe, ►Astrology, ►Abū Maʿshar, ►al-Qūhī, ►Ibrāhīm ibn Sinān, ►*Qibla*, ►*Almagest*

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Al-Ṣūfī

Paul Kunitzsch

Al-Ṣūfī, Abu'l-Ḥusayn ʿAbd al-Raḥmān ibn ʿUmar, was born in 903 in Rayy, near modern Tehran, and died in 986.

Al-Ṣūfī was an astronomer in the Arabic–Islamic area. He was of Persian origin, but wrote in Arabic, the language of all science in that time. He was best renowned, and became most influential, through his *Kitāb ṣuwar al-kawākib al-thābita* (Book on the Constellations), written around 964. Knowledge of the fixed stars in Greek-based Arabic–Islamic astronomy was mainly derived from Ptolemy's catalog of 1,025 stars arranged in 48 constellations contained in his *Almagest* (ca. AD 150). Al-Ṣūfī reexamined Ptolemy's values of the star coordinates and magnitudes. In his book, he described all the stars catalogued by Ptolemy, adding his criticism in each individual case. However, in the tables added to his book he nevertheless faithfully rendered Ptolemy's traditional values, adding a constant of 12°42′, for precession, to Ptolemy's longitudes. Only the magnitudes were given according to al-Ṣūfī's own observation. For each constellation he added two drawings, one showing the figure as seen in the sky, the other as seen on the celestial globe. His book and his drawings served as models for work on the fixed stars in the Arabic–Islamic world for many centuries, and became known even in medieval Europe, where his constellation drawings were imitated in a series of Latin astronomical manuscripts (though no veritable Latin translation of his book was made). Apart from this book, al-Ṣūfī left treatises on the use of the astrolabe and the celestial globe, an introduction to astrology, and a short geometrical treatise. His name lives on, Latinized as Azophi, as a name for a crater on the Moon.

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A

Al-Suyūṭī

Anton M. Heinen

Al-Suyūṭī (1445–1505) wrote on just about every discipline that had been recognized, in his time, as having its own method and subject matter. What is most noteworthy is that *hay'a* (cosmology, cosmography, but also astronomy) was among them. The author was in his own estimation an authority in the traditional Arabic and Islamic sciences (*al-ᶜulūm al-ᶜnaqliyyah*, transmitted sciences), especially in grammar, jurisprudence, and in tradition (*ḥadīth*, the Sayings of the Prophet), but in no way in those "Sciences of the Ancients" (*al-ᶜulūm al-ᶜaqliyyah*), which had entered the libraries of Islamic culture through numerous translations from Greek, Syriac, Middle Persian, etc. He even expressed his special hatred for philosophy and logic. The title of his treatise, *al-Hayʾa al-sanīya fī l-hayʾa al-sunnīya*, already reveals the challenge he had in mind: his was to be *the* Islamic cosmology, based on authentic Islamic traditions, the *Sunna*, which so conveniently rhymed with *sanīya* (brilliant, magnificent, glorious). The choice of the technical term *al-hay'a* in the title implies that the author is offering an alternative to those cosmologies based on the principles and methods of pre-Islamic astronomers. As such it is a parallel of his book *al-Ṭibb al-nabawī* (Prophetic Medicine). As the author says himself, it was his goal "that those with intelligence might rejoice, and those with eyes take heed." Actually, the great number of extant manuscripts in our libraries proves that as-Suyūṭī's *Hay'a* attracted more attention than most other contemporary books on the cosmos.

This work is a collection of fragmentary descriptions and explanations of such natural phenomena as the sun, moon, and stars in their celestial spheres, lands and seas, winds and clouds, etc. The distinctive feature is, however, that all these fragments are authenticated in the traditional manner with chains of trustworthy authorities which connect them with Quranic revelation or Prophetic wisdom. As a result, some of the earliest theories about cosmological entities and natural phenomena have been preserved that may elucidate the world-views prevalent among the young Muslim community before they were developed under the impact of the translations from pre-Islamic cultures. It remains doubtful whether even in the Middle Ages a mythical theory about the winds, because of the traditional authorities, would have been accepted with the same truth claim as a modern one. But the fact that the authorities were already interested in the phenomena of nature and cosmos may have opened rather than closed the eyes of the student.

See also: ▶*Hay'a*

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Al-Ṭabarī

Sami K. Hamarneh

Abū'l-Ḥasan ᶜAlī ibn Sahl Rabbān al-Ṭabarī was born in the environs of the city of Marw, in the province of Khurasān in Persia (presently Mary, in Turkmenistan), about AD 783, before the reign of the Abbasid Caliph Hārūn al-Rashīd (786–809). His father Sahl was a prominent citizen of great learning and a highly placed state official. As a religious leader in the Syriac-speaking community, he was reverently called *Rabbān* (from the Aramaic for teacher), and had far-reaching knowledge in theology, philosophy, and medicine.

Sahl took a special interest in his son's upbringing, providing him with the best available educational opportunities. ᶜAli read the best Syriac books and excelled in learning. When he was 14, he turned to medicine. He concentrated there, because he realized he could help the sick and the needy.

From the Marw region, he moved to Tabaristān (Māzandarān, south of the Caspian Sea). Thus he became known as al-Ṭabarī. He was appointed counselor-secretary-scribe to the Prince-Sultan Māzyār ibn Qārin. When the latter rebelled against the Abbasid's authority in open revolt, Caliph al-Muᶜtaṣim sent a powerful army that crushed the mutiny and killed Māzyār in AD 839.

Al-Ṭabarī spoke of it later on as "a tragic episode" which left deep scars that remained until late in his life. Meanwhile, he was summoned to the Caliph's court at the new capital, Sāmarrāʾ. Under the Caliph's influence, al-Ṭabarī renounced his Christian faith and embraced Islam. He continued as a physician during the remaining part of al-Muᶜtāsim's life, and remained there under his successor, his brother al-Wāthiq (843–847).

His good fortune came with the rise of Caliph al-Mutawakkil (AD 847–861). He was promoted to the position of physician-in-ordinary, and also became the Caliph's counselor and trusted companion (*nadīm*). In appreciation, al-Ṭabarī dedicated his best and largest medical compendium, *Firdaws al-Ḥikmah* (Paradise of

Wisdom) to his patron in AD 850. This was the first and most comprehensive medical encyclopedia of its kind in Islam. It took him 20 years to complete. In the introduction, the author stated that the work was to be useful to his medical students as well as to practitioners. He listed five points concerning the importance of the art of medicine:

1. It brings relief and healing to the sick, and consolation to the weary.
2. It successfully diagnoses and skillfully treats ailments, even unseen diseases not easy to discover or observe.
3. It is needed by all, regardless of age, gender, or wealth.
4. It is among the noblest of all callings.
5. The words *ṭibb*, *ṭibābah*, *mu'āssāh*, and *usāt* all relate to medicine and its healing processes.

Al-Ṭabarī then mentioned four virtues that all physicians had to possess in order to be successful and esteemed: *al-rifq* (leniency and kindness), *raḥmah* (mercy and compassion), *qanāᶜah* (contentedness and gratification), and *ᶜafāf* (chastity with simplicity).

Firdaws was divided into seven sections in 30 treatises, composed of 360 chapters in all. They ranged from cosmogony, the nature of man, embryology, and anatomy, to materia medica, psychotherapy, pathology, and surgery. Other topics included theoretical and practical medicine in the Greek and Indian traditions, and rules of conduct with insistence on strict adherence to the highest ethical standards.

Another noteworthy literary contribution was his book *al-Dīn wā'l-Dawlah* (Religion and the State). It represents a defense as well as an exposition of the religion of Islam, the Holy Qurʾān, and the Holy Prophet Muḥammad. It seems temperate, rational, and objective in style and tone, and appears free from misgivings or barren argumentation. It also abounds with quotations from the Bible (in the Syriac version).

In these two works, al-Ṭabarī shed much light on the development and progress of the religious, philosophical, and medical advancements during the first two quarters of the ninth century AD. He died in Sāmarrā ca. 858.

The Kitāb al-Dīn was soon eclipsed during the Islamic Middle Ages, because of a lack of interest in such studies as comparative religion. Only in the twentieth century was the book edited more than once. *Firdaws*, however, has continued to enjoy a good reputation, with a wide circulation throughout the Islamic world. Both works can now be considered classical literary works.

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Al-Uqlīdisī

Jacques Sesiano

Al-Uqlīdisī, Abū'l-Ḥasan Aḥmad ibn Ibrāhīm, wrote an Arithmetic (*Kitāb al-Fuṣūl fi'l-ḥisāb al-hindī*) in Damascus in 952–953. This is a sizable compendium and remarkable as the earliest arithmetic extant in Arabic.

The first part explains the place-value system, the four arithmetical operations (addition, subtraction, multiplication, division), and the extraction of square roots for integers and fractions, both common and sexagesimal. Numerous examples are given. This part is supposed to be accessible to a large audience. The second part develops the earlier topics and adds curiosities or different methods. The third part would seem to be the result of the author's experience in teaching; it consists of explanations and questions with their answers concerning some difficulties the reader might have met in the first two parts. The fourth part contains some digressions about the changes Indian arithmetic undergoes when one uses ink and paper (since Indian computations were made on the dust abacus). In this part al-Uqlīdisī also explains (according to him, better than his predecessors) how to extract cube roots.

Al-Uqlīdisī was concerned with the applicability of arithmetic. How original his work was we do not know. He often claims originality or at least superiority of his teaching, but so do his contemporaries. He does not claim originality, however, for the most important feature of his *Arithmetic*, the first occurrence of decimal fractions (besides the usual common and sexagesimal ones). He uses a mark placed over the last integral unit in order to indicate the separation from the subsequent, decimal part.

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Al-ʿUrḍī

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Muʾayyad al-Dīn ibn Barmak al-ʿUrḍī al-Dimashqī (thirteenth century) was an astronomer, architect, and engineer. He as born in Damascus and first worked in Syria. He did some hydraulic engineering in Damascus and constructed an astronomical instrument for the ruler of Hims (Emessa), al-Manṣūr Ibrāhīm (1239–1245). He also taught *handasa* (architecture or geometry).

In or soon after 1259 he was in Maragha, the capital of the Mongol conqueror Hulagu Khan, the grandson of Genghis Khan. He was one of four astronomers who worked with Naṣīr al-Dīn al-Ṭūsi, the founder of the Maragha observatory. He participated in the organization, building, and construction of the instruments of this observatory, and in the building of a mosque and a palace in Maragha.

The best known al-ʿUrdī's works is *Risāla fī kayfiyya al-arṣād wa mā yukhtāj ilā ʿilmihi wa ʿamalihi min al-ṭuruq al-muwaddiya ilā maʿrifa ʿawdāt al-kawākib* (Modes of Astronomical Observations and the Theoretical and Practical Knowledge Needed to Make Them, and the Methods Leading to Understanding the Regularities of the Stars). Manuscripts of this treatise are extant in Istanbul, Paris, and Teheran. The treatise contains the description of 11 of the most important astronomical instruments of the Maragha observatory which he himself mainly constructed (1) mural quadrant, (2) armillary sphere, (3) solstitial armilla, (4) equinoctial armilla, (5) Hipparchus' diopter (alidade), (6) instrument with two quadrants, (7) instrument with two limbs, (8) instruments to determine sines and azimuths, (9) instruments to determine sines and versed sines, (10) "the perfect instrument" built by him in Syria, and (11) parallactic ruler (after Ptolemy).

Al-ʿUrḍī was also the author of three astronomical treatises: *Kitāb al-hayaposa* (Book on Astronomy) on the motion of planets; *Risāla fī ʿamal al-kura al-kāmila* (Treatise on Construction of the Perfect Sphere); and *Risāla fī'l-taʿrīf al-buʿd bayna markaz al-shams wa'l-awj* (Treatise on the Determination of the Distance between the Center of the Sun and the Apogee).

Al-ʿUrḍī's sons Shams al-Dīn and Muḥammad also worked in the Maragha observatory. Muḥammad (ca. 1280) constructed a celestial globe 150 mm in diameter, which is extant in the Mathematical Salon in Dresden.

See also: ►Maragha, ►Observatories, ►Armillary Sphere, ►Naṣīr al-Dīn al-Ṭūsi

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Anatomy in Ancient India

Lakshmi Rajgopal

"In India I found a race of mortals living upon the earth but not adhering to it; inhabiting cities but not being fixed to them; possessing everything yet possessed by nothing. Apollonius Tyanaeus (Greek thinker and traveller, first century AD)".

The history of India is both fascinating and daunting. The geographical terrain of Bharat (Hindustan), as India was known then, extended far beyond the boundaries of India as they exist now. It is this region that cradled a civilisation in the Indus valley about 5,000 years ago, evidence of which is amply found in Harappa, Mohenjo-daro, Lothal (Gujarat) and other places. There is evidence that ancient Hindus practiced science, especially medical science; they were adept in practical anatomy and knew how to apply anatomical knowledge to the practice of surgery.

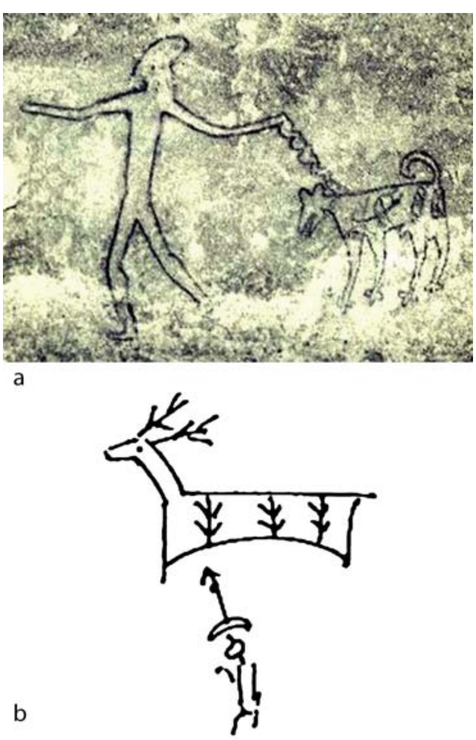
Prehistoric Period

The history of medicine in India can be divided into two broad periods. The prehistoric period ranges from the Stone Age to the beginning of written history. This period can again be subdivided into the early prehistoric period (40000–2500 BCE) and the protohistoric period (2500–1500 BCE). Prehistoric people were wanderers, hunters and worshippers of supernatural phenomena (Subba Reddy 1971). Any anatomical knowledge these men might have possessed was only to use it for hunting and not as a basis for diagnosis and surgical treatment of diseases. There is evidence, in the form of cave paintings (Fig. 1a, b) discovered in Bhimbetaka, near Bhopal in Central India, that superficial anatomical knowledge was used to hunt animals.

These are similar to the Pindal elephant pierced by arrows near its heart and the Niaux bison portrayed with weapons directed at its vital centres; they show that prehistoric man had some knowledge of gross anatomy (Gordon 1949).

Protohistoric Period

The Protohistoric period is the time when the Indus Valley civilisation flourished in northwest India. The people of this civilisation were architects and built planned cities. They were also public health experts, as is evidenced by the wells and bathrooms in the houses and a closed system of drains that have been excavated in Harappa, Mohenjo-daro and other sites. They were also healers, although the practice of healing was more magico-religious, based on rites and rituals (Kutumbiah 1962).



Anatomy in Ancient India. Fig. 1 a, b Cave paintings at Bhimbetaka (reproduced from K. L. Kamath. Prehistoric Paintings, URL: ►http://www.kamat.com/kalranga/rockpain/betaka.htm accessed on 23 Sept. 05).

Historic Period

The historic period of ancient Hindu medicine started with the invasion of the Indus valley by Indo-European tribes such as the Aryans around 1500 BCE. The Vedic period extended from 1500 to 800 BCE. This was followed by the Brahmanic period or the Buddhic period, from 800 BCE to 1000 AD. This was followed by the Mongol period or the Moghul period from 1000 AD onwards (Major 1954).

Vedic Period

The word "Veda" means knowledge – *Ṛgveda* is knowledge of hymns of praise; *Yajurveda* is knowledge of sacrificial formulae; *Sāmaveda* is knowledge of melodies and *Atharvaveda* is knowledge of magic formulae (Major 1954). The Vedas speak about the structure of the body. In the *Ṛgvedic* hymns mention is made of the lungs, the heart, the stomach, the intestines, the kidneys and other viscera (Kutumbiah 1962). Atharvavedic medicine is an amalgam of magico-religious elements consisting of chants and charms and empirico-rational elements which used drugs to cure disease. The *Atharvaveda* gives an impression of the coarser anatomy of the body. There is a hymn in the tenth book which mentions the creation of man describing the articulation of bones (Lanman 1905). *Atharvaveda* also refers to the heart as a "lotus with nine gates". The comparison of the heart with a lotus is very common in Sanskrit literature. When we compare it with present day knowledge, we see that there are indeed three venous openings in the right atrium, four pulmonary veins opening in the left atrium and the pulmonary artery and the aorta leaving the right and the left ventricles, making nine openings in all. The heart, if held upside down, does resemble a lotus bud (Rajgopal et al. 2002). *Atharvaveda* also describes childbirth in some detail.

Brahmanic Period

Vedic books such as *saṃhitās* contained hymns. It was difficult for common people to follow them. So the post-Vedic period saw a lot of literary work which described the Vedic work in simpler language. Thus were born the *Brāhmaṇas* which described and explained the Vedic rites and stories. These were followed by *Aranyakas* which were the continuation of the *Brāhmaṇas* but were meant for people who have entered the third ashram of *Vanaprasta* in life. *Aranyaka* is derived from *arni* meaning wooden sticks, the rubbing of which results in the production of the sacrificial fire. The fire thus produced was used by the Vanaprastis for their day-to-day living (Bodas 1908). Aranyakas were followed by *Upaniṣads*. In fact *Upaniṣads* are part of Aranyakas which treat the higher doctrine of the soul (Upaniṣad = secret knowledge/esoteric lore). Upanishadic knowledge is obtained by the disciples by sitting around a teacher and listening to him in the 'Guru-Shishya' tradition (Udwadia 2000).

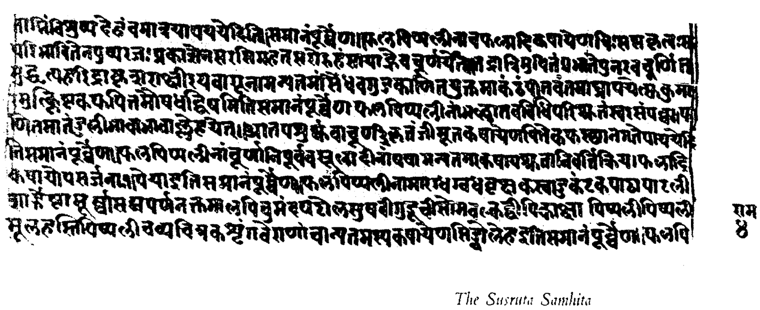
Hindu scriptures had a peculiar way of comparing the structure of human body with things that are metaphysical. In *Satapatha Brāhmaṇa*, Yajnavalkya, who flourished in the court of King Janaka, mentions that the total number of bones in the body is 360 and compares it to 360 days of the year (Hoernle 1907). It is during this period that the science of "Āyurveda" came into being, roughly between 800 and 600 BCE. Āyurveda, or the science of life, was expounded by Brahma and given to the Ashwinikumars; they then taught Indra, who transmitted his knowledge to other priests (Jaggi 1972). This period was the "Golden Period" in the history of Indian medicine.

The Golden Period

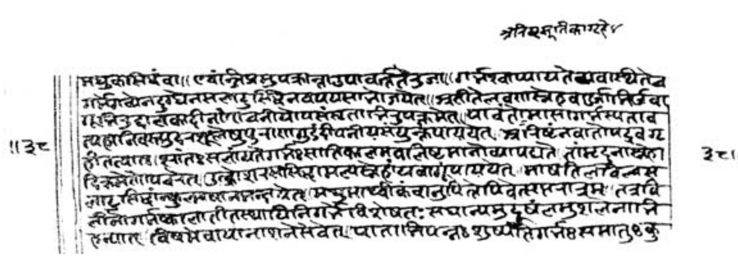
According to the Indian medical tradition, the knowledge of medicine had two origins. On the one hand, it was delivered by the God Indra to the sage Bharadwaja and the latter then handed it over to Punarvasu Ātreya. On the other hand, it descended from Indra to Dhanvantri (also called Divodasa or Kasiraja) and from him to Suśruta. This tradition gives medicine a mythical origin and when traced further leads to historical facts. In the age of Buddha, two great universities existed in India where all forms of science including medical science were taught. They were Benares or Kasi in the East and Takshila or Taxila in the West on the river Jhelum (Hoernle 1907). The leading professor of Medicine in Takshila was Ātreya and the famous teacher of surgery at Benares was Suśruta. They were two stalwarts of Āyurveda and their teachings were compiled in the form of texts. Suśruta's teachings were compiled as *Suśrutasaṃhitā* (Fig. 2).

Ātreya had Agniveśa as one of his disciples, and Caraka was in turn his student. Caraka revised *Agniveśatantra* and it came to be known as *Carakasaṃhitā*. Caraka was the court physician of the celebrated Indo-Scythian king Kanishka and that puts the period of Caraka as 125–150 AD (Bhandarkar 1906) (Fig. 3).

Suśrutasaṃhitā is a great storehouse of Aryan surgery. Though Garrison claims that Indian medicine was weak in anatomy which he attributes to fanciful enumerations (Garrison 1924), it is a fact that to practise the art of surgical healing, one must have sound knowledge of anatomy. Suśruta could not have achieved such mastery over surgery without a thorough knowledge of anatomy. It is precisely for this reason Suśruta insisted that his disciples practice dissection, even though their religion prohibited it. Suśruta had devised his own method of overcoming religious



Anatomy in Ancient India. Fig. 2 A leaf from *Suśrutasaṃhitā* (reproduced from Indian System of Medicine by O. P. Jaggi. New Delhi: Atmaram & Sons).



Anatomy in Ancient India. Fig. 3 A leaf from *Carakasaṃhitā* (reproduced from Indian System of Medicine by O. P. Jaggi. New Delhi: Atmaram & Sons).

cutting open the dead body prohibition by placing the dead body in a cage covered with hemp and then keeping it in a secluded spot in the riverbed which would allow the body to decompose slowly in water. Later the observer gently scraped off the layers of the skin using *kusa* grass and could see both the external and internal aspects (Kutumbiah 1962; Jaggi 1972; Dampier 1942; Clendening 1942) (Fig. 4).

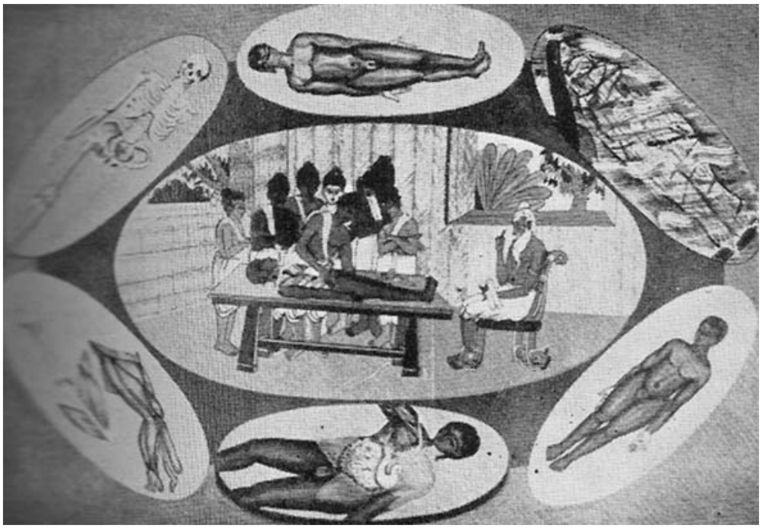
Both Suśruta and Caraka devoted an entire chapter to anatomy, *Sarira Sthana*, in their *Saṃhitās*. Osteology (the study of bones), myology (the study of muscles) and splanchnology (study of the viscera and its organs) are some divisions of anatomy in which these ancient authors excelled. Suśruta noted 300 bones and 210 joints in the body. He also classified joints into eight different types, e.g. *kora* (hinge joint) at the ankles and elbows, and *samudga* or *ulukhala* (ball and socket joint) as in the hip and shoulder. Caraka's anatomy is mainly that of external observation. Caraka described 360 bones and 200 joints. The reason for the discrepancy is that many cartilages, nails and protuberances were counted as separate bones. Suśruta gave the total number of muscles as 500 and specified their distribution as 400 in four extremities, 66 in the trunk and 34 in the head and neck regions. Caraka's description of muscles is quite rudimentary. Besides muscles, both Suśruta and Caraka described 900 *snayus* (ligaments; Kutumbiah 1962).

Suśruta had more thorough and critical knowledge of the internal viscera as is evidenced by his description of the heart and the vessels. He referred to the heart as a lotus bud hanging with its apex downward and also noted 24 *dhamanis*, 700 *siras* and 22 *srotas*. Dhamanis are thick-walled tubes and siras are thin-walled tubes equivalent to present-day arteries and veins. Srotas probably referred to lymphatics. Suśruta observed that all the dhamanis and siras arose from the umbilicus and there were 40 important ducts in the body. Caraka said that the heart was the root of ten dhamanis which run to different parts of the body. Nerves were also classified as ducts and included in the count of vessels.

Suśruta does not state anything of importance concerning the brain but considers the head as the centre of all senses. Both Suśruta and Caraka mention various viscera in the abdomen. The stomach is referred to as *amasaya*; the intestine is called *pakvasaya* and the rectum *gudam*. The uterus is known as *garbhasaya* and the gallbladder as *pitthasaya* (Kutumbiah 1962).

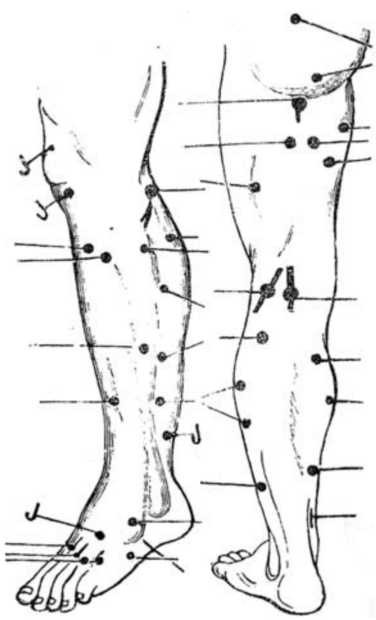
According to Suśruta, apart from dissecting, a student of anatomy should learn the subject and obtain mastery over it by preparing clay models (Fig. 5). Suśruta implored his students of surgery to be careful about 107 vital spots or *marmas* in the body. Marmas are the meeting place of any two or more of the five elements of the body: vessels, muscles, ligaments, bones and joints. The marmas are then classified into five groups (1) *Mamsa* marmas (fleshy); (2) *Sira* marmas (of the vessels); (3) *Snayu* marmas (of the ligaments); (4) *Asthi* marmas (of the bones) and (5) *Sandhi* marmas (of the joints). According to Suśruta, some of them when injured will result in instantaneous death and some others when injured will cause pain and paralysis (Jaggi 1972; Dampier 1942; Clendening 1942; Bhishagratna 1991) (Figs. 6 and 7).

Apart from gross anatomical findings, embryology, the study of the development of the foetus, also achieved a high level in ancient India. Structures such as amniotic membranes are mentioned in the *Bhagavad Gītā* (Needham 1934). Indian anatomists were of the opinion that union of the blood of the mother, called

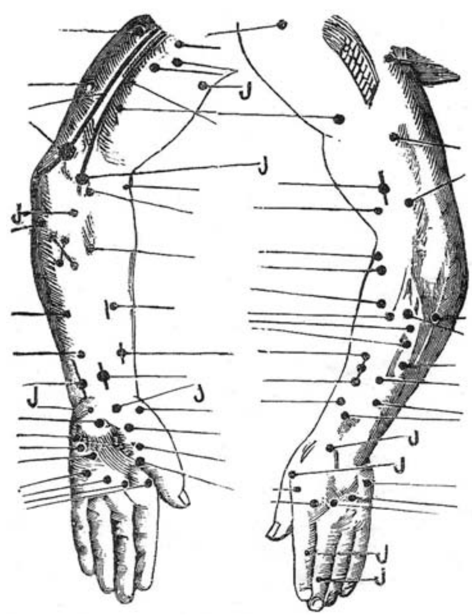


Anatomy in Ancient India. Fig. 4 Preparation of a dead body for dissection (reproduced from the museum guide of the Institute of History of Medicine, Hyderabad).

Anatomy in Ancient India. Fig. 5 Preparation of clay models by students of anatomy (reproduced from the museum guide of the Institute of History of Medicine, Hyderabad).



Anatomy in Ancient India. Fig. 6 Vital spots or *marmas* in the limbs according to Suśruta (reproduced from The *Suśruta Saṃhitā* – English translation by K. K. Bhishagratna. Varanasi: B. Chowkhamba Sanskrit Series Office).



Anatomy in Ancient India. Fig. 7 Vital spots or *marmas* in the limbs according to Suśruta (reproduced from The *Suśruta Saṃhitā* – English translation by K. K. Bhishagratna. Varanasi: B. Chowkhamba Sanskrit Series Office).

sonita and the semen of the father, called *sukra* was responsible for the production of the foetus. They were aware that the mechanism of sex determination took place at the time of fertilisation (Kutumbiah 1962). Moore and Persaud (1999) quote *Garbhoniṣad* (sixth century BCE) which describes the stages of development of the foetus. A 1-day-old embryo is jelly-like and called *kalala*. After seven nights, it becomes vesicular (*Budbuda*) which indeed is the case, as we know now. We call this a blastocyst. After a month it becomes a firm mass and the head is formed after 2 months.

In the third month legs and arms appear distinctively. In the sixth month hair, nail, bones and veins develop. In the eighth month there is drawing of the vital force (*ojas*) from the mother. Indian anatomists believed that the growth of the embryo occurs by a process of layering where at least seven strata are superimposed one upon the other. The seven layers are *avabhasini*, *lohita*, *sveta*, *tamra*, *vedini*, *rohini* and *mamsadhara* (Kutumbiah 1962). They also believed that softer parts of the foetus, such as skin, blood, flesh, fat, navel, heart, lungs, liver and marrow, are derived from the mother and the harder parts, such as the head, nails, teeth, bones and nerves, are derived from the father (Jaggi 1972; Zimmer 1948). The formation of the embryo is also compared with the formation of creamy layers of milk; this similar comparison to the clotting of milk to form cheese has also been used by Aristotle (Needham 1934).

It is possible that Indian thought influenced the schools of Asia Minor and through them those of Greece (Dampier 1942). There is evidence that Indian medical practices spread all over Asia including Indonesia, Tibet and Japan. The translation of Ayurvedic literature into Arabic and Persian in the eighth to eleventh century AD led to its further spread (Lyon and Petrucelli 1987). *Carakasaṃhitā* was translated from Sanskrit into Arabic in the eighth century AD and *Sharaka indianus* appears in the Latin translation of Avicenna, Rhazes and Serapion. *Suśrutasaṃhitā* was translated into Arabic before the end of the eighth century AD as 'Kitab-i-shawshoon–Al-Hindì' and also mentioned as 'Kitab-i-Susrud' by Ibn Abillsaibal. Rhazes often quotes 'Sarad' as an authority in Surgery (Mukhopadhyaya 1913).

The ancient Indian medical doctors can be credited with the inquisitiveness to learn about the structure of the human body and a systematic study of the same. They practised human dissection despite religious restrictions. They also had an appreciation of the relation of anatomy to the practice of medicine. Even if the enumerative method of various parts of the body may minimise their significance, what cannot be denied is that they used their knowledge of anatomy to master surgery and practised medicine in a more scientific way.

See also: ►Surgery

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Ancient Egypt

J. Worth Estes

Humanity was concerned with sickness and death long before the Egyptians appeared along the banks of the Nile. But only from the beginning of pharaonic civilization, about 2900 BCE, do we have evidence of how sickness and trauma were treated in the ancient world. It comes primarily from several monographs, or collations of sections of earlier monographs, written on papyrus. The major medical papyri are, in their probable chronological order:

Veterinary Papyrus of Kahun, ca. 1900 BCE, on the treatment of animals

Gynecological Papyrus of Kahun, ca. 1900 BCE, a fragment of a monograph on the diseases of women

Papyrus Edwin Smith, ca. 1550 BCE, part of a monograph on wounds that also includes a fragment of a work on the heart and vessels called the *Secret Book of the Physician* that was probably composed ca. 3000 BCE

Papyrus Ebers, ca. 1550 BCE, a collection of remedies for several kinds of ailments that contains a longer version of the *Secret Book*

Papyrus Hearst, ca. 1550 BCE, a less systematically organized collection of remedies that duplicates many of those in the Ebers Papyrus

Papyrus Berlin 3038, ca. 1350–1200 BCE, another collection of drug recipes, with another version of the *Secret Book*

Papyrus Chester Beatty, ca. 1250–1150 BCE, a fragment of an earlier monograph on diseases of the anus

Magical Papyrus of London and Leiden, ca. third century AD, containing many examples of spells used in healing rites

From the beginning, magic dominated Egyptian concepts of illness and its treatment. Empiric observations eventually entered therapeutic thinking, but magic was seldom far removed from it. The Egyptians attributed healing powers to a number of their local gods, while Thoth, scribe of the major gods and inventor of the arts and sciences, became a part-time god of medicine. Not until he was deified sometime after 525 BCE did Imhotep, who had been the chief minister of the pharaoh Zoser (reigned 2630–2611 BCE), and the inventor of the pyramid, assume the role of chief god of Egyptian medicine.

Throughout most of the three millennia of pharaonic history, three kinds of healers treated the sick. Two of them, magicians and priests, relied chiefly on magical or religious rituals. The third group, the lay physicians called *swnw* (pronounced something like "sounou"), relied chiefly on surgery and drugs, techniques that were also used by healing priests. How they learned their professional skills is not known, but most probably they learned from their fathers, and all were literate. Interestingly, not all were men: an inscription from the Old Kingdom period (2575–2134 BCE) describes a woman named Peseshet as the Lady Director of the Lady Physicians.

*Swnw*s usually accompanied armies into the field, and were employed at public works sites such as temples, pyramids, and quarries. The oldest known doctor's bill lists payments to a *swnw* who worked at the village of the workmen who built the tombs and temples of Thebes, in about 1165 BCE. Although physicians were paid only about a third as much as construction workers, *swnw*s sometimes achieved very high rank at court, and were rewarded accordingly.

The average age at marriage was 12–13 for women, and 15–20 for men. The fertility rate, at east among the few queens for whom we have data, was lower than might have been expected, about 3.5 births per woman, in part because children were not weaned until they were 3-years old. The average life expectancy at birth was probably about 30 years in the early Old Kingdom, and might have increased to as much as 36 years over the next 2,500 years. Evidence of very old age is scarce among mummies simply because most Egyptians died in their 30s, before the diseases that are typical of old age could have developed. A few kings and priests lived into their 90s, but fewer than 10% of Egyptians lived longer than 40 years. By contrast, about 94% of modern Americans die after age 40, and their life expectancy is about 76. As in most preindustrial cultures, both the population and the average life expectancy rose (and the death rate fell) when the food supply increased, as farmers increased their ability to exploit the Nile with improved irrigation systems.

Egyptians well understood the biological relationships among the testes, penis, semen, and pregnancy. However, because much of their anatomical knowledge came from cattle, they thought that semen was produced in the bone marrow, even if they also knew that removing the testes – castration – prevented any possibility of fatherhood. On the other hand, they knew nothing about the ovaries, and thought that women's role in reproduction was simply to nourish the fully formed seed that the father planted in the fertile uterus. Although the *swnw* did not attend births, he did treat women's medical problems. He attributed menstrual abnormalities to malpositions of the uterus, which meant that many "gynecological" treatments were designed to restore it to its proper position.

It has been difficult to learn much about the actual causes of death in ancient Egypt, despite the hundreds of mummies in the world's museums. Several have been studied nondestructively, using X-rays and CAT scans. Such noninvasive techniques can easily reveal diagnoses such as fractures, dislocations, calcified arteries, and gall stones, but such conditions need not be fatal per se. X-rays of 26 royal mummies from the New Kingdom (1550–1070 BCE) period have revealed more about their age at death, their teeth, and about mummification techniques, than about their illnesses, and even less about the causes of their deaths. The few mummies that have been dissected have provided surprisingly little specific pathological information, partly because most Egyptians probably died of infections that left few anatomical traces, and partly because mummification usually destroyed potentially diagnostic tissues. On the other hand, Egyptians may have been so thinly scattered along the river that many infectious diseases could not easily have propagated themselves. Nevertheless, in some places at least, the population may have finally become sufficiently dense over the centuries to facilitate the spread of such diseases.

Not all evidence of illness in ancient Egypt has come from human remains. A few statuettes show spinal distortions characteristic of tuberculosis of the spine, as do several mummies. Similarly, both a funeral monument and a mummified leg show the dropped foot deformity typical of poliomyelitis (although it could also have been a club foot). Identifiable illnesses are not found in the detailed pictures of everyday life that adorn tombs, since sickness had no useful role in the next life.

In addition to tuberculosis, Egyptians had many of the diseases we have, although in different proportions of the population, plus several protozoal and worm infestations that are still found along the banks of the Nile, such as trachoma and schistosomiasis. Most of the nontraumatic illnesses that occurred in ancient Egypt have not been identified in modern terms, but the Ebers Papyrus shows that the *swnw* classified them by their anatomic location, such as the skin, hair, abdomen, limbs, genitalia, and so on.

The Edwin Smith Surgical Papyrus contains several "firsts" in the history of medicine, including the first written descriptions of any surgical procedures, and the earliest examples of inductive scientific reasoning. The 48 cases described in the monograph are organized anatomically, from the top of the head down through the neck to the upper arm and chest; the scribe stopped transcribing the text when he reached the section on the upper spine. Because many injuries described in the Smith Papyrus were probably battle wounds, its prognostic predictions can also be taken as early examples of systematic battlefield triage.

The original author of this surgical text classified injuries by their extent and severity, and by their localization in bone or flesh, and established a systematic procedure for dealing with each kind of problem. Each chapter is devoted to a different injury, beginning with clinically important phenomena that could be seen or palpated, followed by a diagnosis based on facts elicited during the examination, and concluding with a prognosis. The prognoses are in three standard forms: injuries that are treatable, those of uncertain outcome that the *swnw* will try to treat anyway, and those that are unlikely to respond to any treatment, such as depressed skull fractures and compound fractures. The latter prognosis usually leads to the recommendation that nature be allowed to take its course.

Ancient Egyptian surgery provided simple, practical solutions to a number of self-evident problems. Today, most of it would be called "minor surgery," such as incising and draining abscesses, removing superficial wens, tumors, and so on. Circumcision was practiced on adolescent boys, but by priests, not physicians. The *swnw* did not perform major operations such as amputations, although he did try to reduce simple fractures and dislocations. Penetrating wounds were drained and cleaned. The *swnw* used adhesive plasters, not sutures, to hold wound edges together.

He differentiated between "diseased," or infected, wounds, and "nondiseased" wounds, which we would call "clean." The Smith Papyrus recommends daily inspections so that dressings can be changed when necessary. Many wound ointments were made with honey or the green copper ore malachite. Recent experiments have shown that both substances could have been effective against the kinds of bacteria most often found in contaminated wounds, permitting them to begin healing of their own accord.

When it came to what we now call internal medicine, magicians and healing priests relied largely on spells and incantations to cure their patients, and on amulets, written spells, and repulsive materials like animal feces to drive away or prevent illness. Sometimes they relied on healing statues standing in sacred ponds, so that patients who bathed in the same water would be cured by the god to whom the statue was dedicated. Late in pharaonic history, a patient might be instructed to sleep in a temple, expecting that its god would send him a dream that would reveal his cure, a procedure called "incubation."

The *swnw* might not have understood the underlying pathology of nonsurgical illness, but he had a logical, even if speculative, theory of disease. According to the medical historian Henry Sigerist, "Physiology began when man tried to correlate the action of food, air, and blood." The Egyptians saw the heart as the focal point of that correlation. It was the body's most important organ, and the seat of intelligence and emotion.

The *swnw*, who knew that air is vital to life, thought that it passed through the trachea to both the heart and the lungs. From the heart it traveled, in blood and along with other fluids, to other organs in primary afferent ducts called *metu*. From those organs a series of secondary *metu*, or efferent ducts, led to the surface of the body. The body's secretions and excretions, including phlegm, tears, semen, urine, and even a little blood, escaped through that second set of *metu*. This concept permitted the *swnw* to exploit a fairly plausible theory of disease. He could accept the *metu* as fact chiefly because Egyptians could not differentiate arteries, veins, nerves, and tendons anatomically. They thought that all of them were hollow *metu* that transported disease, in the form of a foul substance called *ukhedu*, to various organs, depending on how many *metu*, and which ones, were involved.

Because decay and foul odor characterize both normal feces and death, the potentially fatal *ukhedu* was thought to originate in the feces as the residue of incompletely digested food. Indeed, postmortem putrefaction is most noticeable in the intestines. Thus, if any *ukhedu* were allowed to accumulate to overflowing within the intestines, the excess would overflow up into the *metu* that normally carry blood from the heart to the intestines, so that the excess traveled backward to the heart. From there it could then enter other primary or secondary *metu* and be carried to other organs. Once it had entered a given *metu*, the *ukhedu* in that vessel could destroy the blood in it, producing pus. When it reached other organs, the pus would settle in and produce disease in them. Thus, the appearance of pus on the surface of a wound was a favorable prognostic sign, inasmuch as it signified that it was escaping and not accumulating within the body. Many treatments were designed to help *ukhedu* escape from the body. For instance, because boils were obviously filled with pus, they were opened so that the dangerous *ukhedu* could escape. Similarly, the standard wound ointments made with malachite or honey would counteract *ukhedu* that surfaced in a wound.

Egyptian drugs included many animal parts. Almost no clinical selectivity was associated with any of them, although ostrich eggs were used somewhat selectively in diarrhea remedies. Most of the animal products used in drugs, such as fat and grease, were used principally as emollients in wound ointments. In addition, the blood of several species was thought to be modestly selective for hair problems and eye trauma. But most animal parts used in drugs were included chiefly because of their magical associations. For instance, since ravens are black, their blood was used to treat the Egyptians' black hair; stallion semen was used to restore sexual drive; and fish skulls appear in headache remedies.

By contrast, the majority of drugs recommended in the Ebers Papyrus was aimed at disorders of the gastrointestinal tract, followed by remedies for the eyes, limbs, and skin. The *swnw* classified accumulations of *ukhedu* in the *metu*-ducts as gastrointestinal disorders, because the *ukhedu* originated in the alimentary canal. Thus, cathartics were usually prescribed to help flush *ukhedu* out of the rectum before it could accumulate to dangerous levels. Although some remedies for disturbances within the *metu* or the intestines do promote bowel movements, many laxative or cathartic drugs were used to treat nonintestinal symptoms. For instance, the mild laxative aloe was sometimes prescribed for eye disease, and the strong laxative colocynth for respiratory ailments. Thus, it seems likely that the *swnw* thought that all cathartics were at least somewhat selective for removing *ukhedu* from both the rectum and the *metu* which distributed it in the body.

Constipation implied that accumulated *ukhedu* could not escape by its usual route through the anus. Indeed, an Egyptian might take strong laxatives 3 days a month just to prevent *ukhedu* from filling up, and overflowing from, his rectum into his *metu*, whence it might reach his heart. Although diarrhea was a frequent complaint, sometimes it was not treated at all, because plentiful stools implied that the bowels were being adequately emptied of the dangerous *ukhedu*.

Honey, the most popular of all drug ingredients mentioned in the papyri, was used not only in wound ointments, but also in both laxatives and antidiarrheals, and in many other remedies. Since it was not used for any one kind of clinical problem more often than another, we can infer that honey was not used very selectively for symptoms associated with any particular organ system. Honey was probably regarded as selective for the *ukhedu*, especially when it appeared in wounds as pus.

The next most frequently used drug was called *djaret*. The word has not yet been convincingly translated, but it was clearly a plant product. Because it appears in about half of all prescriptions for diarrhea, *djaret* was probably thought to have some selectivity for that problem. In addition, it was included in a third of the prescriptions for eye diseases, and may have been thought to be at least modestly selective for them. However, whatever it was, *djaret* was also prescribed for many other disorders, so it must have been regarded as a multipurpose drug, even if as not as a panacea. Frankincense, too, was often prescribed for many illnesses, but it was aimed most selectively at pains of the head and limbs, and less often at intestinal problems. Like the mysterious *djaret*, an antimony ore was applied to eye problems.

The next most frequently used ingredients were applied fairly nonselectively, although some were often used in both laxative and antidiarrheal mixtures. The pulp of the colocynth gourd is a very powerful cathartic that was also used for the latter purpose. Figs were used for abdominal pains and urinary disorders. Malachite was aimed at eye problems; it could not be taken internally because copper salts cause vomiting. It probably first entered medical usage as a topical ointment after long usage as an eye cosmetic. The author of the Ebers Papyrus knew about the laxative property of castor oil, but he included it in only a very few recipes for cathartics; he thought it was better suited for making women's hair grow. Like many other Egyptian remedies, it, too, survived in Western medical usage until well into this century, but as a cathartic, not as a hair restorer. However, most of the 328 different drug ingredients mentioned in the Ebers Papyrus were used for almost any illness.

Although Egyptian physicians prescribed a wide variety of remedies, they appear merely to have dispensed predetermined remedies to patients with similar ailments; the *swnw* seems not to have treated each patient as an individual. That concept would not be introduced until Greek medicine began to flourish in the fifth century BCE. There is no evidence that any of the *swnw*'s remedies, save for malachite and honey, when applied topically, had any truly beneficial effect on the outcome of ancient patients' illnesses, nor is there any modern reason to think so. Although they may not have known it, ancient physicians were able to rely on their drugs, and even on their magical spells, because of the body's impressive ability to use mechanisms such as the immune and inflammatory responses to heal itself of most ordinary ailments. By contrast, Egyptian surgery probably did provide reasonably effective treatments for many traumatic injuries.

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Animal Domestication

Christine M. Rodrigue

Animal domestication is the process by which humans exert direct or indirect, conscious or unconscious influence over the reproduction and evolution of animals that they own or otherwise manage (Rodrigue 1987: 1). There is quite an extensive continuum between wild species utilized as resources by humans and fully domesticated species (Russell 2002; Terrell et al. 2003). The question of "origins" depends on a choice of where to draw the line between "wild" and "domesticated" along this continuum, and that choice is often the basis of arguments about the "earliest domestication" of many species.

A fully domesticated animal exhibits significant genotypic and phenotypic differences from its nearest wild relatives due to its evolution under conditions dominated by humans. The domestication of animals and plants is one of the most important impacts that humans have had on their natural environments, ultimately the root of the contemporary global economic system and its marvels and tragedies. For most of human existence, people did not tend crops and care for animals, living instead as seasonally migratory gatherers, hunters, and fishers of wild food sources.

The Geography of Domestication

The archaeological record of settlements, bones, pollen, and artifacts indicates that settled societies based on plant and/or animal domestication go back roughly 10,000–11,000 years in certain areas of the world. Archaeological research into the earliest domestications has tended to focus largely on the Near East. For example, suggestions of goat (*Capra hircus*) domestication reach back about 10,000 years in western Iran (Zreda and Hesse 2000), sheep (*Ovis aries*) domestication some 10,500 years in northernmost Iraq (Perkins 1964), and pig (*Sus scrofa*) domestication possibly as early as 11,000 years ago in southeastern Turkey (Pringle 1998a; Rosenberg et al. 1998). The early domestication of barley (*Hordeum vulgare*) is evidenced in the Levant some 10,000 years ago, while einkorn (*Triticum monococcum*) and emmer (*T. turgidum*) wheats trace back to southeastern Turkey and northern Syria nearly 11,000 years ago (Lev-Yadun et al. 2000; Özkan et al. 2002). The cultivation and domestication of rye (*Secale cereale*) may well go back 13,000 years (Pringle 1998b). Within roughly a millennium, plant and animal domesticates were joined together in agriculture and husbandry complexes, which quickly spread throughout the ancient Near East and beyond.

Other parts of the world, however, saw similar, apparently independent domestications and assemblages of crop and animal complexes. Some of these include New Guinea with taro (*Colocasia esculenta*), going back 10,000 years, and banana (*Musa* spp.), going back nearly 7,000 years (Denham et al. 2003); eastern China, with rice (*Oryza sativa*) cultivation going back at least 11,000 years (Mannion 1999) and chicken (*Gallus gallus*) domestication nearly 8,000 years (West and Zhou 1988); Southeast Asia, with still controversial signs of cultivated cucumbers (*Cucurbita* spp.), water chestnuts (*Trapa natans*), peppers (*Piper* spp.), almonds (*Prunus dulcis*), and betel nuts (*Piper betel*) dating back 11,000–9,000 years and possible chicken domestication before 8,000 years ago (Gorman 1969; Fumihito et al. 1996; Yen 1977); Africa having domesticated cattle (*Bos taurus*), donkeys (*Equus asinus*), African rice (*Oryza glaberrima*), pearl (*Pennisetum glaucum*) and finger millets (*Eleusine coracana*), sorghum (*Sorghum bicolor*), teff cereal (*Eragrostis tef*), yam (*Dioscorea* spp.), cowpea (*Vigna unguiculata*), okra (*Abelmoschus esculentus*), oil palm (*Elaeis guineensis*), cola (*Cola* spp.), and coffee (*Coffea canaphora*) variously going back 10,000 BP (cattle) to 2,000 BP, with several distinct centers of domestication: northeast Africa, west Africa, and the Ethiopian highlands (Hanotte et al. 2002; Harlan 1971).

In the New World, northwestern South America and highland Mexico began the domestication of gourds and squashes (*Cucurbita* spp.) 10,000–12,000 years ago (Piperno and Stothert 2003), while maize (*Zea mays*) domestication has been traced over 6,000 years before the present (BP) in Mexico (Piperno and Flannery 2001). Potatoes (*Solanum tuberosum*) go back about 8,000 years ago near Lake Titicaca in the Andes (Roach 2002). Other crops domesticated in the New World include tomato (*Lycopersicon esculentum*), peppers (*Capsicum* spp.), tobacco (*Nicotiana tobaccum*), and cacao (*Theobroma cacao*) (Sauer 1969). The New World domesticated few animals, however. Alpaca (*Lama pacos*) and llama (*L. glama*) domestication goes back 6,000–7,000 BP in Peru (Wheeler 2003), as does guinea pig (*Cavia porcellus*) domestication there (Sandweiss and Wing 1997). Turkey (*Meleagris gallopavo*) may go back 500–2,000 years ago in the Pueblo cultures of the American Southwest (Pinkley 1965).

Sequencing of Animal Species Entering Domestication

In terms of the sequence of animals entering domestication, the dog (*Canis lupus familaris*) is widely considered the first domesticate. The oldest tentative identification of domestic dog remains through traditional archaeological methods goes back about 14,000 years in Germany (Benecke 1987). Dog remains are also found dating from 12,000 years ago in Israel (Tchernov and Valla 1997).

DNA analysis has begun to transform the archaeology of domestication, most dramatically in its recent application to a large sample of living dogs of a variety of breeds, in order to determine how far back the domesticated breeds began to diverge from their common ancestor (Vilà et al. 1997). This approach has yielded the startling and still contested figure of 135,000 BP, while analysis of patterns of variation in mitochondrial DNA suggests a concentration of genetic diversity (indicative of an ancestral population) in East Asia with divergence from wolf populations there roughly 15,000 BP (Savolainen et al. 2002). All dogs are now known to be domesticated wolves (hence the Latin species name change from *Canis familiaris* to *C. lupus*), most being descendants of smaller subtropical subspecies. The earliest dogs may have been pets, self-domesticating scavengers, and convenient sources of meat.

Several species entered domestication in a second, nearly simultaneous development from 11,000 to 8,000 years ago: the sheep, the pig, and the goat, as discussed above, and possibly cattle, chickens, and cats (*Felis sylvestris catus*) as well. Domesticated cattle are evidenced in south central Turkey some 8,400 years ago (Grigson 1989; Perkins 1969), but there is recent DNA evidence that a line of cattle was domesticated even earlier in northeast Africa about 10,000 BP (Hanotte et al. 2002). Domesticated chickens appear in northern China around 8,000 years ago (West and Zhou 1988), and mtDNA studies imply they were domesticated sometime before that in Thailand and neighboring areas (Akishinonomiya et al. 1996). Cats may have been domesticated as early as 9,500 years ago, judging from recent finds in Cyprus (Vigne et al. 2004).

A third wave of animal domestications occurred roughly 7,000–5,000 years ago, this time involving the New World, too. The species involved included South American camels – llama and alpaca – in Peru approximately 6,000–7,000 years ago (Wheeler 2003); the pigeon (*Columba livia*) in Mesopotamia and Assyria 6,000–7,000 years ago (von Hünerbein and Rüter 2000: 20); the horse (*Equus caballus*) in the Ukraine, southernmost Russia, and westernmost Kazakhstan, about 6,000 years ago (Vilà et al. 2001); the donkey in northeast Africa and possibly also in Somalia about 5,000 years ago (Beja-Pereira et al. 2004); the Bactrian camel (*Camellus bactrianus*) perhaps 5,000–6,000 years ago in Northwest China and perhaps 4,000–5,000 year ago in Turkmenia and eastern Iran (Wild Camel Protection Foundation n.d.); dromedary (*C. dromedarius*) in the Arabian Peninsula about 5,000 years ago (Larson and Ho 2003); water buffalo (*Bubalus bubalis*) in India and southern Iraq about 5,000–6,000 years ago (National Research Council 1984); yak (*Bos grunniens*) in Tibet around

5,000 years ago (Li et al. 2003); and the silkworm (*Bombyx mori*) in China about 5,000 years ago (Yamauchi et al. 2000: 17).

A number of minor domestications have taken place from that time to this, such as the rabbit (*Orytrolagus cuniculus*), ferret (*Mustela putorius*), cormorant (*Phalacrocorax carbo*), turkey, carp and koi (*Cyprinus carpio*), and goldfish (*Carrasius auratus*). Domestications continue at the present, including parakeets (*Melopsittacus undulatus*), canaries (*Serinus canaria*), diamond doves (*Geopelia cuneata*), mink (*Mustela vison*), laboratory rats (*Rattus norvegicus*), foxes (*Vulpes fulvus*), aquarium fish, and ongoing experimental domestications of livestock, such as eland (*Taurotragus oryx*) and fallow deer (*Dama dama*) (National Research Council Board on Science and Technology for International Development 1991).

Why Domesticate Animals?

Why did people give up the hunting of animals for the work entailed in domesticating them? The factors involved differ by species and human circumstance. The simple human tendency to pet keeping no doubt played a role.

Nomadic hunters–gatherers could have domesticated certain herd animals (Ingold 1980). Such peoples as the reindeer-herding Saami of northernmost Europe sometimes follow the migratory herd species (*Rangifer tarandus*) all year and influence the direction and spatial cohesion of the animals through driving and herding. They selectively cull the animals, which amounts to the evolutionary pressure associated with domestication. The reindeer nomads may have been exploiting reindeer for as long as 20,000 years (NRC Board on Science and Technology for International Development 1991: 285). It is not clear, however, whether migratory herding hunters in the past actually undertook independent domestications of the animals they hunted or adopted the idea later from nearby agriculturalists and associated pastoral nomads.

Settled cultivators may have had a variety of reasons to undertake the control and maintenance of animal populations. Their crops, food stores, and even their salty latrine areas attracted animals, inviting reciprocal exploitation (Zeuner 1963). The small southern wolves would steal scraps of food and may have been tolerated as a garbage disposal system. Fields, grain stores, and latrine areas would attract bovine species. The granivorous and cliff-nesting pigeons would descend on early cereal fields and roost in nearby buildings (Woldow 1972). The opportunities for coevolutionary interactions between people and animals increased once people settled and especially once they took up crop cultivation (Rindos 1984).

Certain scholars have argued that settled cultivators had no particular economic or ecological need for animals, and animal management does entail work and can prove dangerous. They feel that the earliest animal domestications provided sacrifices for sacred rituals or amusement for gamblers (e.g., Isaac 1970). This argument has not done well in archaeological testing (Rodrigue 1992), but the data may not yet be complete enough to dismiss the argument entirely (Akishinonomiya et al. 1996: 6795). Other scholars have worked out coevolutionary ecological contexts for animal domestications (Rindos 1984) and economic arguments relating to relative time costs and resource yields of hunting and husbandry in different contexts (Alvard and Kuznar 2001; Layton et al. 1991).

In some cases, people may have at least partially domesticated an animal species and later abandoned it. Gazelles (*Gazella gazella*), for example, may have been in the process of domestication in the ancient Levant around 11,000 years ago, later being replaced by goats and sheep (Bar-Oz et al. 2004; Legge 1972; Moore et al. 2000). These latter may have had some sort of advantage over indigenous domesticates. Military displacement and conquest of one culture by another could have replaced one constellation of animal domesticates with another. Religious taboos have caused species to be dropped from husbandry in given areas (e.g., pigs in areas of Jewish or Muslim religion).

To resolve these different issues and disputes over their interpretation will take considerable work. Much of the world has never had adequate coverage of its archaeological heritage. Archaeological funding has been biased toward those areas regarded rightly or wrongly by Westerners as somehow connected with their own culture histories, such as the Biblical Levant and Mesopotamia, Egypt, ancient Greece and Rome, Europe, and even Mesoamerica and Peru (due to Mormon religious interest in the region). There are many tantalizing indications that archaeological work in other areas in the non-Western world, applying the many new techniques and technologies available, will transform our present perceptions of the origins of domestication.

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Animal Mummies

SALIMA IKRAM

Although it is commonly known that the ancient Egyptians mummified humans, it is a less well-known fact that they also mummified animals. Animals were mummified for the same reason as humans: to preserve their bodies so that they could live forever. This suggests that a belief in animal souls was a part of Egyptian religion.

Mummification is the preservation of a body through artificial means. In terms of animal mummies it varied somewhat depending on the time period and the type of mummy that was being created. The basic principle, however, remained the same: to desiccate the body using natron (a naturally occurring compound of salt and soda found in the Wadi Natron in Egypt) or even salt. Once the corpse was desiccated, it was anointed with oils and resins and wrapped in linen bandages. There are four types of animal mummies: food offerings, pets, sacred animals, and votive offerings. Pets and sacred animals seem to be the most carefully mummified, while votive offerings are the most carelessly prepared. The preparation of food offerings varies.

Food or victual mummies consist of mummified foods for humans, such as beef ribs, steaks, joints of meat, ducks, and geese that were placed in tombs so the tomb owner could feast for eternity. The meat and poultry was prepared for consumption, so joints are cut, and the poultry is cleaned, ready for roasting. This mummy type was especially common in the New Kingdom (1549–1060 BCE) and the 21st Dynasty (1060–940 BCE).

Pet mummies were of animals beloved of their owners and therefore preserved so that they and their owners could enjoy eternity together. These appear throughout Egyptian history, though the better-known examples come from the New Kingdom and the 21st Dynasty, with the gazelle of Queen Isetemkheb D being an example from the latter period.

Sacred animals were animals that were worshipped during their lifetime as the spirit or *ba* of the god entered them, and upon their deaths mummified as were kings, and buried in sarcophagi which were interred in single or catacomb-like sepulchers. Whilst alive these animals would provide oracular advice. The Apis Bull, a manifestation of Ptah, and the Ram of Elephantine, the manifestation of Khnum are particularly well-known animal incarnations. Although the Apis is known from Dynasty I, the Serapeum at Saqqara where the mummies of these animals were kept dates to the 18th Dynasty (1549–1298 BCE) and later.

Votive offerings consisted of mummified animals that were dedicated to specific deities. Gods had specific animals that were their totems or symbols: cats were sacred to the goddess Bastet, goddess of pleasure, ibises and baboons to the god Thoth, god of learning, etc. These mummified animals were purchased and offered by pilgrims at shrines dedicated to these gods, and finally buried in deep catacombs. The mummified animals would present the prayers of the pilgrim to the god throughout eternity, much in the way votive candles are purchased and burned in churches. This type of mummy was common from the seventh century BCE until the fourth century AD (Fig. 1).

Not all mummy packages contain animals. A group of "fake" mummies, generally found amongst the votive offerings, have come to light during scholarly investigations. These consist of packages that are wrapped to look like real creatures, but either contain fragments of real animals, or rags and bits of mud or wood. In the case of the former the idea is that a part signifies the whole, while in the latter case, one might suggest that the appearance of the package and the identification of the bundle as a certain creature turns it

Animal Mummies. Fig. 1 A mummified cat in a sycamore wood coffin, CG 29783 from the Egyptian Museum, Cairo (photo by Anna-Marie Kellen).

Animal Mummies. Fig. 2 CG 51098 food mummy from the Egyptian Museum, Cairo (photo by Anna-Marie Kellen).

into that animal. Thus, when there was a paucity of actual animals to mummify the embalmers made these substitutions. On a more cynical note, these could be ways of defrauding unsuspecting pilgrims.

In the early days of archaeology most animal mummies were ignored and often discarded, or else taken away as casual souvenirs that illustrated the oddity of the Egyptians; they were never seriously considered as artefacts that could elucidate any relevant aspect of ancient Egypt. However, in more modern times scholars have realized that a study of these mummies can provide information about the fauna of the country and, indirectly, its climate, as well as animal domestication, veterinary practices, human nutrition, mummification itself, and the religious practices of the ancient Egyptians. Examining their wrappings can also inform us about chronological and geographical variations in production practices.

These mummies are currently studied in a variety of ways, all of which tend to be non-destructive. Visual examinations and radiography are most common. Sometimes CT-scans are employed. Destructive studies include tests on the wrappings and the flesh itself in order to determine the types of resins and other embalming materials used.

All sorts of animals were mummified, including: dogs, cats, ibises, raptors, shrews, crocodiles, snakes, cattle, rams, fish, and even scarab beetles. The practice of animal mummification reached is heyday in the Late and Graeco-Roman periods (700 BCE–AD 395), when sacred and votive animal mummies became increasingly popular. The many millions of ibis, cat, and dog mummies that have been found all date to these periods. The majority of animal mummies created in earlier periods belonged to the pet, food, and to some extent, sacred animal genres. Animal mummification ceased in the fourth century AD with the advent of Christianity (Fig. 2).

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Approximation Formulae in Chinese Mathematics

Jean-Claude Martzloff

Approximation formulae may be used for various reasons. In some cases, certain computations (such as for example, the extraction of roots digit by digit) are by nature inexact. It may also be that exact solutions of certain problems are unknown or else that such solutions are theoretically known but deemed too complex, so that users prefer elaborating alternative solutions more or less accurate with respect to a certain context of utilization. The history of Chinese mathematics illustrates well these two aspects of the question.

Remarkably, many Chinese approximation formulae are also attested in Babylonian, Greek, Roman, Indian, and Mediaeval European mathematics. For example, the so-called "Hero's iteration formula" for the approximation of square roots converges quadratically to x is also found in the *Jiuzhang suanshu* (Computational Prescriptions in Nine Chapters, also translated as Nine Chapters on the Mathematical Arts) from the Han dynasty (206 BCE–AD 220).

Hero's iteration formula:
Let $x = \sqrt{n}$. Then, the sequence

$$x_k = x_k = \frac{1}{2}\left(x_{k-1} + \frac{n}{x_{k-1}}\right)$$

The approximation formula for the computation of the area of a quadrilateral by taking the product of the half sum of its opposite sides appears not only in the *Wucao suanjing* (Computational Canon of the Five Administrative Services), and the *Xiahou Yang suanjing* (Xiahou Yang's Computational Canon) (fourth century AD) but also in the Babylonian mathematical corpus,[1] in the writings of the Roman agrimensors (surveyors),[2] in Alcuin's *Propositiones ad acuendos juvenes* (Propositions to Sharpen the Minds of the Youth)[3] and numerous other places. The same remark also applies to the *false* formula for the computation of the area of a segment of a circle:

$$A = \frac{h(b+h)}{2}.$$

In the *Jiuzhang suanshu*. Such examples are much more numerous than historians of mathematics formerly imagined.

This striking phenomenon is an indicator of the strong unity of ancient mathematics. Recent research unceasingly confirms that ancient mathematics were not so much "Chinese" than "written in Chinese," "Indian" than "written in Sanskrit" and so on, even though, by any standard, the cultural imprint they bear is certainly very strong in each case. Nevertheless, this unavoidable conclusion has opened the way to controversial issues, especially when the famous mathematician and historian of mathematics van der Waerden deduced from this that all ancient mathematics have a common Indo-European origin. (Waerden 1983). This new theory has gained little acceptance and it is a fact that it surpasses by far the data on which it is based.

However, Chinese mathematics also contains examples of approximation formulae apparently not attested anywhere else. These all occur in Chinese astronomy and concern astronomical problems such as that of the determination of gnomon shadows or questions of conversions between the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) and equatorial coordinates.

1 More precisely in YBC 4675 (Neugebauer and Sachs 1945: 44–47).
2 References are given in Martzloff 1997: 325.
3 The *Propositiones* have been translated into German by M. Folkerts and H. Gericke, "Die Alkuin Zugeschriben Propositiones ad Acuendos Iuvenes (Aufgaben für Schärfung des Geistes der Jugend)." *Science in Western and Eastern Civilization in Carolingian Times*. Eds. L. Butzer and D. Lohrman. Bale: Birkhaüser Verlag, 1993. 288.

The monograph on mathematical astronomy of the Song Dynasty, the *Songshi* (Song History), an official text compiled between 1343 and 1345, for example, reports that between AD 1102 and 1106, Chinese imperial astronomers devised a new theoretical algorithm for the determination of the length of the shadow of the sun cast by a standard gnomon 8 *chi* (feet) long, each day, at noon, during a whole year. If t = the number of days elapsed since the last winter solstice and

$$s_1(t) = 12.83 - \frac{20,000t^2}{100\left(100,617 + 100t + \frac{10,000t^2}{725}\right)},$$

$$s_2(t) = 1.56 + \frac{4t^2}{7,923 + 9t},$$

$$s_3(t) = 1.56 + \frac{7,700t^2}{13,584,271.78 + 44,718t - 100t^2},$$

at Kaifeng, the Song imperial capital whose latitude is 34°48′45″, the length of the shadow of the gnomon is computed as follows (the original text is formulated in words, with no symbols, but its interpretation is straightforward):

if $t < 662.2$	$l(t) = s_1(t)$
if $< 62.2 < t < 91.31$	$l(t) = s_3(182.62 - t)$
if $< 91.31 < 182.62$	$l(t) = s_2(182.62 - t)$
if $< 182.62 < t < 273.93$	$l(t) = s_2(t - 182.62)$
if $< 273.93 < t < 303.04$	$l(t) = s_3(t - 182.62)$
if $< 303.04 < t < 365.24$	$l(t) = s_1(365.24 - t)$

The various numerical coefficients appearing in these formulae all depend on the lengths of the seasons.)

Chen Meidong, a contemporary historian of Chinese astronomy from the Academia Sinica in Beijing, has compared the results provided by these approximate formulae and those of actual observations (simulated for the years 1102–1106 by using the modern astronomical theory of the sun backward). He has concluded that the error never exceeds 0.02 *chi*, that is much less than a centimeter! Yet Song astronomers were still not satisfied with their approximation and sought new formulae; some of these have reached us. Incidentally, these formulae are vaguely reminiscent of the Indian approximation formula for the sine, cosine, and other trigonometric functions cited in (Gupta 1972). In both cases the approximations use rational fractions.

Another interesting approximation formula occurs in the *Yuanshi* (Yuan History), an official compilation written about AD 1370 but reporting on Guo Shoujing's astronomical reform undertaken one century earlier. (Guo Shoujing (1231–1316) was a specialist on canal draining and astronomy.) Without going into too much detail, we note that Guo's technique was devised to compute certain segments corresponding to given arcs of circles similar to those which arise when converting ecliptic coordinates into equatorial coordinates. For us the question is solved in a relatively simple way by means of spherical trigonometry. But plane and spherical trigonometry were both unknown in China at the time, so that the mathematical techniques of Chinese astronomy had necessarily to rely on approximation formulae. In particular, Guo's technique relied on the three following formulae:

$$(1)\quad p = \sqrt{r^2 - q^2} = \sqrt{(2r - v)v},$$

$$(2)\quad x = p + \frac{v^2}{2r},$$

$$(3)\quad v^4 + (4r^2 - 4rx)\,v^2 - 8r^3v + 4r^2x^2 = 0,$$

where r represents the radius of the "trigonometric" circle, and p, q, and v the sine, cosine, and versed sine of the arc x, respectively.

Formula (1) is exact; (2) and (3) are approximate. The polynomial of the fourth degree in v, (3), is the consequence of the elimination of the half chord p between the second part of (1) and (2); (3) serves to compute v given the arc x by finding a root (in fact the smallest positive one) of (3) by means of a technique similar to that which is usually known as "Horner's method" (from a method attributed to the British mathematician William George Horner (1786–1837) who lived five centuries after Guo Shoujing). Lastly we also observe that Guo Shoujing divides the length of the circumference into as many degrees as there are days in a year (365.25°) and computes the radius of the corresponding circle by dividing the circumference by 3 (i.e., by taking $\pi = 3$). A priori, the reliance on such a value of π would indicate a severe mathematical deficiency. However, when Guo Shoujing devised his techniques, better values of π, such as Zu Chongzhi's (429–500) celebrated approximation $\pi = 355/113$, were currently available in China. In fact, according to Toshio Sugimoto, a mathematical analysis of the above formulae shows that when (1), (2), and (3) are computed using approximations of π better than 3, worse results are obtained! The recourse to approximations disturbs the impeccable logic which would hold if exact representations were used.

These various examples show that approximation formulae are well represented everywhere but that some of them are attested only in China. As recent works by historians of Chinese astronomy indicate, the recourse to such formulae seems typical of Chinese astronomy (see the articles in the journal *Ziran Kexue shi yanjiu*, 1982–1994). Are Chinese approximation formulae really original or are they also found elsewhere? Further historical researches not limited to Chinese mathematics will perhaps shed some light on a question which has never really been studied in depth.

See also: ►Liu Hui and *the Jiuzhang suanshu*, ►Guo Shoujing, ►Zu Chongzhi, ►Pi in Chinese Mathematics, ►Mathematics

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Archaeoastronomy of North Africa

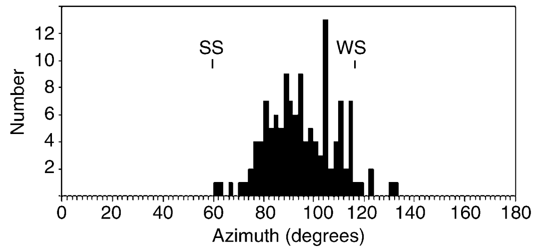
César Esteban

In this article, I review data on orientations of pre-Islamic funerary and religious monuments in North Africa, including Sahara and the Maghreb and excluding Egypt, which has been extensively discussed elsewhere. The time span of the monuments discussed is extremely wide, from the Neolithic up to the Arabic invasion. The main conclusion is that there were enduring patterns in the orientations, very likely related to the ritual or symbolic importance of the rising sun. The overwhelming evidence confirms the strong solar aspects of the North African religion that the ancient writers indicated.

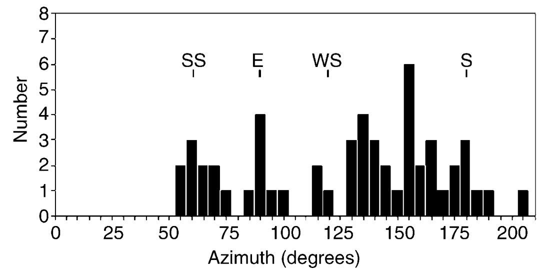
The prehistoric dry stone funerary monuments of the Sahara are called *idebnan* (in plural) and *idebni* (in singular) by the present-day Tuareg. There are several different architectural types and they are distributed in a very extended geographical area. Early European visitors realised that a large proportion of these monuments tend to be orientated with their main distinctive elements towards the east. The earliest type of *idebnan* is called "keyhole monument". Paris (1996) has obtained radiocarbon dates for some of these monuments in Niger (Emi Lulu) finding that they date from 3600–220 BCE. This kind of monument is found even more densely at Tassili (Algeria). Savary (1966) obtained that the orientations of 158 keyhole monuments in Fadnoun (Algeria) lie in the azimuth range where the sunrise (or moonrise) takes place, and can be described as a clear case of sun-rising (SR) custom following Michael Hoskin's definitions (Hoskin 2001: 19–20). Paris (1996) obtained a similar result for the orientations of the corridors of 17 keyhole monuments at Emi Lulu.

Another relevant type of Saharan dry stone prehistoric burial is the so-called V-shape monument which consists of a tumulus and two lines or arms of stones – also called antennae – that could be about some tens of meters or even up to 200 m long (see Fig. 1). These monuments are more concentrated in the Messak Settafet in the Fezzan region of Libya. The earliest monuments of this kind are dated about 3200–2900 BCE (Cremaschi and Di Lernia 1998). Hachid (2000) has compiled data for many *idebnan* in Tassili indicating that the antennae of most of the V-shape monuments of this zone are oriented to the east. Some of them are located in the middle of wonderful landscapes, facing the borders of the impressive mountain ranges of Tassili. Recent statistical studies of the orientations of 49 and 31 V-shape monuments of the Messak plateau (Fezzan, Libya) and Immidir mountains (Algeria) by Gauthier and Gauthier (1999, 2003; see Fig. 1) show that the bisectors of the antennae show a narrow range of orientations also consistent with a SR custom. Other kinds of dry stone monuments as the "platforms cairns with an arm" (Gauthier and Gauthier 1999) and "L shape monuments" (Gauthier

Archaeoastronomy of North Africa. Fig. 1 Example of a typical Saharan V-shape dry stone monument, located 30 km to the southeast of El Aweynat (Fezzan, Libya). Photo by Yves Gauthier (February 2006). Used with his permission.



Archaeoastronomy of North Africa. Fig. 2 Number histogram of orientations of 132 V-shape monuments, "goulets" and "platform cairns with an arm running eastwards" of Immidir (Algeria) and Fezzan (Libya). Data are binned in 2° intervals. SS and WS indicate the azimuths of the rising sun at summer and winter solstices, respectively. Diagram adapted from Gauthier and Gauthier (2003). This is an example of a sun-rising (SR) custom of orientations.



Archaeoastronomy of North Africa. Fig. 3 Number histogram of orientations of 53 dolmens at Elles (Tunisia). Data are binned in 5° intervals. SS and WS indicate the azimuths of the rising sun at summer and winter solstices, respectively; E and S indicate east and south, respectively. Data taken from Belmonte et al. (1998). This is an example of a sun-rising/sun-climbing (SR/SC) custom of orientations.

and Gauthier 2001–2002) of Fezzan, as well as the "goulets" (narrow parts) of Immidir (Gauthier and Gauthier 2003) show exactly the same orientation pattern (Fig. 2).

Later types of Saharan stone burials such as "crater tumulus" and "monuments with an alignment", which are dated from 1900 BCE down to the start of Islamic culture locally, also have their structural elements as well as the head or faces of their skeletons oriented to the east (Hachid 2000). Other Saharan stone monuments – not necessarily related to tombs – as the so-called "horseshoe" structures with a straight line of little towers or altars are usually also oriented to the east, although with a much wider azimuthal distribution (Gauthier and Gauthier 2002). These monuments are also known as "tents of Fatima" and are supposedly rural shrines. However, some kinds of monuments such as the single or triple crescents of the Messak Settafet, some crescents of south Algeria, and the bazina/tumulus with small auxiliary towers of Morocco and Algeria do not follow the typical Saharan orientation customs (Gauthier and Gauthier 2002, 2003, 2005). In fact, the orientations of the last group of monuments could be oriented towards the rising or setting Moon (Gauthier and Gauthier 2005). It would be interesting to reassess the orientation data of Saharan monuments considering the correction due to the real (non-flat) horizon where the monuments are actually facing, a kind of analysis that has not yet been carried out in the area.

Earlier possible evidence of astronomical observances by the Neolithic Saharan people has been found at Nabta Playa in Egypt, on the border of the Libyan Desert (McKim Malville et al. 1998). Here a group of megalithic circles and stone rows dating from some time earlier than 4500 BCE are oriented to the summer solstice or zenith passage of the sun.

Burial monuments of coastal and pre-desert zones of North Africa from the first millennium BCE up to the Islamic conquest are extremely diverse. One can find simple and monumental dolmens, tumuli of very different typology, rock-cut tombs (*hawanat*), hypogaea (the subterraneous portions of a building or subterranean galleries, such as the catacombs), and the later great mausolea. In his magnificent book about protohistoric funerary monuments of North Africa, Camps (1961) admits that the orientation of the main entrances, façades and corridors of those burial monuments is in most cases consistent with a general east–west arrangement. This fact makes one wonder if the protohistoric orientation pattern is related to the ancient Neolithic Saharan traditions discussed above.

Savary (1969) analysed the precise orientations of 13 North African dolmens at Beni Messous (Algeria). He found that the orientation pattern could be classified as a sun-rising/sun-climbing (SR/SC) custom following Hoskin's scheme (Hoskin 2001: 19–20); this definition covers a range of azimuths from about 60° to due south or thereabouts. This range includes the sunrise and the position of the Sun while it is climbing in the sky or around culmination. Belmonte et al. (1998) have measured dolmens in different necropolises of Northern Tunisia. These authors find a clear SR/SC pattern for the orientations of megalithic monuments of the necropolis of Elles (see Fig. 3). A SC and a SR/SC orientation pattern seems applicable to the dolmenic necropolis of Thugga and the complex megalithic tombs of Mactar (see Fig. 4), respectively. On the other hand, the very rough and simple dolmens of Bulla Regia show a highly unusual westerly orientation. Hoskin and Foderà Serio (private communication) and Hoskin (2001) consider that the reason for the orientation of the dolmens in the Tunisian necropolises of Elles, Henchir Midad and some others around the town of Mactar, is simply topographical: they are facing downhill. However, the orientations of Henchir Midad have been further discussed by Belmonte et al. (2003) stressing their astronomical significance. They

Archaeoastronomy of North Africa. Fig. 4 Complex megalithic tomb of Mactar (Tunisia) with six chambers.

Archaeoastronomy of North Africa. Fig. 5 Group of rock-carved tombs (*hawanat*) at Chauach (Tunisia).

Archaeoastronomy of North Africa. Fig. 6 East-facing chapel tumulus of Taouz (Morocco). Photograph reproduced from Belmonte et al. (2002).

have studied the several groups of Numidian dolmens of Northern Tunisia, finding a general SR/SC orientation pattern. Finally, it is remarkable that the orientations of several groups of rock-cut tombs (*hawanat*) of Northern Tunisia analysed by Belmonte et al. (1998, 2003) also show orientations following the typical SR/SC scheme (see Fig. 5).

It is mostly accepted that the North African dolmens were earlier than the Roman conquest, perhaps prior to the Phoenician expansion, and clearly after the Neolithic (Camps 1961: 146–148). The distribution of the North African dolmens along the Maghreb suggests that their origin is not autochthonous and should be the Iberian Peninsula for the monuments of the north of Morocco and Sardinia, Corsica, Italy and/or Malta for the Algerian–Tunisian group (Camps 1961: 149–152, 1995a: 2508–2509). In this context, Camps remarks on the important role that Sardinia could play in this transmission. He notes that Diodorus Siculus (Diodorus V, 8) and later Pausanias affirmed the Libyan origin of the Sards. In fact, Hoskin (2001: 175–192) has found that the 97.7% of around 200 Sardinian dolmens, *corridoi dolmenici* and *tombe di giganti*, show the same orientation custom as the North African dolmenic and *hawanat* necropolises. Therefore, taking into account the differences with respect to the most common ancient Saharan pattern of orientations – which is clearly SR – the data are consistent with an alien origin of the North African dolmens and *hawanat*.

Information about the orientations of the most common protohistoric North African burial monuments – stone and earth tumulus and *bazinas* (classified as autochthonous by Camps 1961: 60–62) – is rather scarce, mostly because of the impossibility of defining an axis of symmetry in most of them. However, we have information about some groups of stone monuments: chapel-tumuli, niche monuments and the great Algerian mausolea. In the case of the chapel tumuli, there are detailed studies of two necropolises of the Tafilatl: the chapel-tumuli of Taouz (see Fig. 6) show an apparent SR custom in their orientation (Belmonte et al. 1999; Castellani 1995), while the monuments at Hassi Beraber seem to be oriented somewhat more southerly, consistent with a SC custom (Castellani 1995). Camps (1961: 180–184 and references therein) reviews data for the chapel-tumuli of the necropolises of Bouia (Tafilatl) and Negrine, pointing out that all the monuments are oriented with their entrances facing east. From published plans of the chapel-tumuli of Djorf Torba, Belmonte et al. (1999) find two predominant orientations, to nearly due east and to southeast. Southeast and east seem also to be the orientation of a sample of circular niche monuments at d'El-Esnam and Kef Sidi Attalah, respectively (see Camps: 1961: 177–178 and references therein). Belmonte et al. (1999) also study 34 skylight-tumuli in the necropolis of Foum al Rjam in the Saharan Morocco, finding a clear SR/SC custom in their orientation.

The most evolved and impressive pre-Islamic burial monuments of North Africa – the Algerian great mausolea (Medracen, Blad el-Guitoun, Tombeau de la Chrétienne, Djedar), which show clear Punic architectural and stylistic influences – have their ceremonial corridors and external platforms oriented towards the east (Camps 1961: 199–205). In particular, the Djedar of north Algeria are especially interesting because of their late chronology, which is as late as the fifth and sixth century AD, just before the Arabic conquest (Camps 1995b: 2419–2422). They represent the end-point of the genuine pre-Islamic North African funerary traditions.

Elements of the proto-Berber culture survived in the Canary Islands until its conquest by the Castilians in the fifteenth century. Belmonte et al. (1997) obtain orientation diagrams of the burial chambers of several important tumular necropolises in the islands of Gran Canaria and Fuerteventura, finding a SR (or sunsetting) custom in the necropolis at Tirba mountain (Fuerteventura) and for the dry stone tumuli of Maipez (Gran Canaria). Perhaps as a reflection of the mixed trends found in the continent, a SC custom is found for the tumuli of Arteara (Gran Canaria).

In the land of the Garamantes (Fezzan, Lybia), one finds burials of very different typology perhaps associated with the different cultural contacts experienced by this warrior people. The extensive excavations carried out by Daniels (1989) point out that the Garamantian tombs are mainly dated from Roman times. Belmonte et al. (2002) have studied the orientation of funerary monuments in some of the most representative Garamantian necropolises as the pyramidal tombs of Charaig and El Hatir (see Fig. 7), the mud-brick tombs of Saniat ben Howedi, and the mastaba-like royal tombs at Germa. The pyramidal tombs are arranged with their four sides oriented approximately to the cardinal points. Many of the tombs of Saniat ben Howedi have stone offering-tables and are facing near due east or due west. The most clear orientation pattern is shown by the mastaba-like and circular tumulus (with a stele showing the relevant direction) of the royal necropolis of Germa; all the tombs measured are oriented to the east, following a clear SR custom. Although the formal similarity to the Egyptian monuments is evident and even the presence of obelisks

Archaeoastronomy of North Africa. Fig. 7 Field of Garamantian pyramidal tombs at El Hatir (Fezzan, Libya).

or stelae in their proximity could suggest a direct Nilotic influence, this is not entirely clear. Camps (1961: 165–166) indicates that the Garamantian monuments are not very different to the pre-Islamic rectangular *bazinas* of late chronology that can be found elsewhere in North Africa, whose geographic distribution cannot be explained by a gradual diffusion from Egypt. Moreover, their orientation pattern is also consistent with the typical customs of the rest of the contemporary North African funerary monuments and especially with the much older and autochthonous *idebnan* of the Fezzan.

It is generally accepted that the impact of the Punic culture was profound and enduring on the Libyan or proto-Berber culture and especially on their religion (Picard 1954; Bénabou 1975: 377–380). There are interesting facts about the orientations of Punic funerary monuments. Belmonte et al. (1998) find a clear SR custom in the early Punic necropolis of Utica and a doubled-peaked distribution centred on the sunrise at the equinoxes and the winter solstice in Menzel Temine and the early Phoenician necropolis of Villaricos in the southern Mediterranean coast of the Iberian Peninsula (Belmonte 1999; his Fig. 5.5). A general east–west orientation is also found for the Punic necropolises of Tipasa in Algeria (Baradez 1969) and of Aïn Dalia Lekbira in north Morocco (Alaoni 2000). González García et al. (2006) have measured a large number of tombs in the Punic necropolises of Sardinia and Ibiza, finding a general tendency of orientations towards the solstices and equinoxes. However, there is not a regular orientation in all Phoenician/Punic necropolises studied. In Byrsa (Carthage), Belmonte et al. (1998) have found a rather unusual south–west distribution. In Dermech (Carthage) the orientations show an azimuth preference between 120° and 160°. Finally, the Maltese shaft tombs and burial chambers studied by Ventura (2000) show a clear preference for the approximate north–south direction. It is also interesting to remark that the general planning of the Punic sacred areas or tofets in Sicily and Sardinia is usually arranged along the cardinal axes (Ribichini and Xella 1994). Finally, an additional interesting archaeological indication was obtained by Carton, who found that in an open sacred area in Thuburnica (Sidi-Ali-Bel-Kassem, Tunisia), all Neo-Punic stelae were orientated to the east (see Leglay 1961: 276). In summary, there is not a regular pattern in the orientations of the Punic tombs, although many necropolises and funerary areas show an east–west custom. This has also been observed in the Phoenician-Punic necropolises of south Spain, where the archaic tombs (eighth–seventh centuries BCE) tend to be oriented to the east and the later ones do not follow that rule so strictly (Ramos Sainz 1986: 32–33).

The Roman custom of building mausolea or monumental tombs was also common in North Africa, especially from western Algeria to Tripolitania.

Belmonte et al. (2002) compiled data on some different monuments of Roman epoch and most of them were oriented following an SR custom. However, the largest concentration of mausolea from the late Roman epoch is in the settlement of Ghirza, in the Libyan pre-desert. The plans published by Brogan and Smith (1984) show that the doorways or the ornamental false doors of the tombs of the northern group show a clear SR custom, whilst the tombs of the northern complex are oriented towards the north (Esteban 2003).

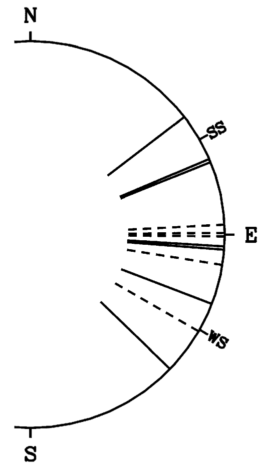
Perhaps the earliest known constructions that can be considered sanctuaries or temples in North Africa to the east of the Nile Valley are of Punic origin. The importance of the orientation in the Punic ritual is documented in a stone inscription found in the zone of Salammbo in Carthage. This stone was an offering placed in a sanctuary dedicated to Baal Hammon. The text indicates explicitly that the stone was orientated with its front side to the sunset and its back side to the sunrise (Xella 1991: 48).

Esteban (2002a) reports that the *decumanus maximus* of Roman Carthage – as well as the layout of the Roman and the Punic city and acropolis – is oriented towards the winter solstice sunrise. This author also compiled the orientations of five Punic and Neo-Punic temples and sanctuaries from published plans and measurements, finding that the temples were orientated towards a fairly narrow zone of the horizon, from 90° to 127°. It is remarkable that three of them are also oriented to or near the winter solstice sunrise.

Esteban et al. (2001) have carried out an extensive survey of the orientations of a large number of Roman and pre-Roman temples of Morocco, Tunisia and Libya. They found that the complete sample of temples built in Roman times show a definite random distribution of orientations. Moreover, there is no correlation between the dedication of the temples and their orientation, except for those dedicated to Saturn. Most of the religious buildings dedicated to this deity are oriented following an SR custom (see Fig. 8).

Saturn was the most important deity worshipped in Northwest Africa in Roman times (Picard 1954: 100–129; Leglay 1966; Bénabou 1975: 370–375) from ancient Numidia to Mauretania (present-day Tunisia to Morocco). Its cult had strong pre-Roman roots and was the inheritor of the ancient cult of the Punic Baal Hammon, who was the most important god of both the rural and Punicised Libyan population, probably because of the strong similarities of the Cartaghinian deity with a former ancient supreme Libyan god (Leglay 1966: 417–447).

The cult to Saturn is almost completely absent in the deeply Punicised Tripolitania (Leglay 1966: 267–268, Brouquier-Reddé 1992: 255–265). In this region Jupiter Hammon was an adaptation of the great god of the Eastern Libyans, the ram-headed Ammon (see Bénabou 1975: 335–338; Mattingly 1994: 167–168). The spread of the cult of Ammon is demonstrated by the many rural (mostly indigenous) temples or *ammonia* for which we have evidence in Tripolitania and among the Garamantes and the Libyan desert oases of Siwa and Augila (Mattingly 1994: 36, 168). Esteban (2003) has collected published data for rural shrines built in Roman times in Tripolitania (Esteban et al. 2001; Brouquier-Reddé 1992, and references therein) and for the Garamantian ashlar masonry temple at Germa (Esteban et al. 2001). It is remarkable that the range of orientations of many of the rural sanctuaries of Tripolitania show an orientation similar to those dedicated to Saturn in the rest of the Maghreb, a fact that could be related to the common pre-Roman substrate in the popular religion in both territories.



Archaeoastronomy of North Africa. Fig. 8 Orientations of temples dedicated to Saturn from Roman North Africa (Esteban 2003). Continuous lines: direct measurements by Esteban et al. (2001); *dashed lines*: orientations obtained from published plans. SS and WS indicate the azimuths of the rising sun at summer and winter solstices, respectively.

Among the Tripolitanian rural shrines, the one of Ghirza (Brogan and Smith 1984: 80–92) is especially interesting due to its strong Punic elements; these make it an unique monument in Tripolitania. Brogan and Smith (1984: 88) suggest that the building was perhaps devoted to the cult of Baal–Saturn in his role of earthly fecundity, but Brouquier-Reddé (1992: 146) proposes that the sanctuary was dedicated to the Libyan bull-headed god Gurzil, son of Ammon. From the plans published by Brogan and Smith (1984: their Figs. 25 and 26), Esteban (2003) finds that the orientation of the building is towards the east, very similar to that of Germa (Esteban et al. 2001) and also consistent with the SR range.

Finally, Esteban at al. (2001) have also measured the orientation of some temples built in the epoch of the Numidian and Mauretanian kingdoms, prior to the Roman annexation of all North African provinces.

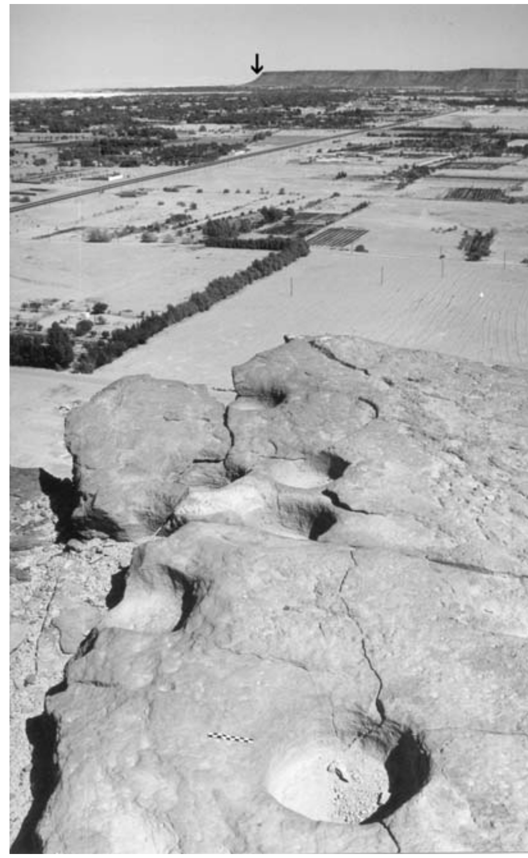
These kingdoms were autochthonous but deeply Punicised in their culture, especially in religion (Camps 1979). All these monuments show orientations consistent with the patterns found for the temples of Saturn and the rural temples of Tripolitania.

The possible astronomical motivation of the orientation patterns of the North African funerary and religious monuments discussed above has further support in some remarkable astronomical markers that have been found in important archaeological sites of the area, from Libya to Morocco.

Belmonte et al. (2002) report the discovery of an impressive solstitial marker over a distant foresight from the east edge of the top of Zinchecra, the capital city of the Garamates of the Fezzan (Libya) and inhabited since the ninth century BCE. The sun at summer solstice rises just on the most conspicuous distant topographical element of the skyline: the intersection of the flat escarpments of the Messak and the southern border of the sand sea of Ubari (see Fig. 9). The discovery of a striking astronomical marker in the first known political centre of the Garamantes gives further support to the importance and continuity of the astral elements of the genuine Libyan funerary and religious world, just before the contacts with the Phoenicians and Greeks.

Esteban et al. (2001) found another possible pre-Roman solstitial marker at the Numidian city of Simithus (Tunisia). From the Roman forum, which is located above the preceding Numidian tombs dated from the fourth to the first centuries BCE, it is possible to see the Numidian sanctuary (dedicated to Saturn in Roman times) just on the top of the Sacred Hill of Simithus. Esteban et al. find that the line-of-sight of the sanctuary as seen from the Numidian tombs at the forum coincides with the summer solstice sunrise. Moreover, a large Numidian monumental tomb is oriented precisely to the hill summit.

The group above found another spectacular astronomical marker in the temple of Apollo of Mactar (Tunisia). The Numidian-Punic traditions were very strong in this city and survived for several centuries after the Roman conquest (M'Charek 1982: 12). The temple is located outside the city; it is oriented east–west and built over a previous Punic or Libyan sanctuary (Picard 1984). The temple faces a small natural cut in a mountain which is exactly where the sunrise takes place at the equinoxes (see Fig. 10). Although the Punic Baal Hammon was conflated with Saturn in most of the Roman province of Africa, there is some controversy that this could be not the case in the region of Mactar (see the discussion by M'Charek 1991 and references therein). Bisi (1978) suggests that in Mactar, the ancient cult of Baal Hammon was assimilated to Apollo, the sun god of the Romans. If this hypothesis is true, the presence of an equinoctial marker at the temple of Apollo would provide proof of the transmission of the solar elements from the ancient Punic-Libyan religion to the Romanised local cults.



Archaeoastronomy of North Africa. Fig. 9 Carved cupmarks at the eastern border of the cliff of Zinchecra, the hilltop fortified capital of the ancient Garamantes of the Fezzan (Libya).The *arrow* indicates the place where the Sun rises at the summer solstice, just on the intersection of the escarpment of the black plateau of the Messak and the sand sea of Ubari.

Another possible relation with the equinoxes has been found at the temple B of Volubilis (Morocco) that shows all the characteristics of the temples of Saturn but lacks a direct confirmation of its dedication. It has a very precise orientation towards the sunrise at the equinoxes (Morestin 1980: 56–57; Esteban et al. 2001) that takes place over the nearby mountain Zerhoun, the most famous holy mountain of Muslim Morocco (see Morestin 1980: 135). The actual Roman building was built over a previous *tofet*, the westernmost Punic funerary sacred area known in Africa.

A last possible equinoctial marker could be at the temple of Saturn at Thugga (Tunisia). As in the case of the temple B of Volubilis, the Roman temple was built over a previous Punic *tofet*. The temple is oriented inside the range of the sunrises but not related to the

Archaeoastronomy of North Africa. Fig. 10 Remains of the Temple of Apollon in Mactar and its eastern horizon. The *arrow* indicates the place where the sunrise takes place at the equinoxes. The *upper left box* shows an enlargement of the horizon, the *white circle* indicates the size of the solar disk (figure reproduced from Esteban et al. 2001 and Esteban 2003).

solstices or equinoxes (Esteban et al. 2001). Esteban (2003) found that the peak of Zaghouan (the highest peak of Tunisia and the most important water source of ancient Carthage) is located very near the point of the horizon where the sunrise takes place at the equinoxes.

As we can see, there are possible equinoctial markers in three sacred areas or *tofets* of important cities of Libyan-Punic origin (Mactar, Volubilis and Thugga). In the three cases, the sanctuaries were re-utilised in Roman times and were dedicated to Saturn (the great North African deity) or to the Roman sun god Apollo. It is interesting to note that several equinoctial markers (analogous to the one found at Mactar) have been found in sanctuaries belonging to the Iberian culture in the southeast of Spain (Esteban 2002b) which was also influenced by the Punic civilisation in many aspects, and especially in its religion. Finally, the discovery of striking equinoctial markers in important pre-Hispanic sanctuaries of the Canary Islands also suggests that this element was important in the ritual of the proto-Berber peoples of the archipelago (see Esteban 2000 and references therein). In the light of the results gathered, it seems very probable that the ancient settlers from the continent imported this astronomical tradition. Very probably, this original population was culturally Punicised to some degree.

See also: ►Obelisks

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A

Architectural Decoration in Islam: History and Techniques

Ruba Kana'an

Architectural decoration has been one of the most resilient of the Islamic arts. The partial and more often overall decoration of buildings has been a characteristic feature of Islamic architecture from the eighth century onwards. Religious monuments as well as secular complexes have been decorated with an array of styles and techniques that reflected the multiplicity of Muslim societies and their cultural expressions. The importance given to decorating one's built environment has also been applied to temporary settlements such as tented encampments.

Up until the eleventh century, most decorative techniques such as the use of decorative brickwork or moulded stucco in the Muslim east, and mosaics, *ablaq* and carved stone in the central Muslim world were inherited from pre-Islamic cultures and societies. Muslim artisans transferred these skills into their respective contexts and adapted them to their architectural needs. It was only in the eleventh to thirteenth centuries that the use of repetitive patterns and intricate designs of geometric, calligraphic, and abstract vegetal

Architectural Decoration in Islam: History and Techniques. Fig. 1 Dome of the Al-Ashrafiyyah Madrasa in Taʿizz, Yemen. 1398–1400. Showing painted decorations and carved stucco.

motifs became the dominant decorative repertoire (Jones 1978). These elements permeated architectural decoration throughout the Muslim world resulting in a new and distinct decorative language (Fig. 1).

Decorative elements such as the use of arabesque, geometric interlace (*girih*) and *muqarnas* or stalactite vaults became widely spread. Common among these decorative elements are notions of modularity, geometry and rhythm. Arguably, these forms are manifestations of a geometric pattern that is based on the subdivision of space, form or surface and the infinite repetition of the structural modules and motifs. Division and repetition, for example, applied to abstract forms of vegetation that are subjected to the rules of geometry and then extended indefinitely in all directions, formed the arabesque. Geometric interlace patterns (*girih*) also follow the same structural principle; these decorative compositions are based on the folding and repetition of regular shapes using circles, triangles and squares. The resulting patterns are purely mathematical and their artistic value lies in the choice of what aspect of the geometric pattern to highlight and which colours to use. (See "The nature of Islamic art", MET timeline ►http://www.metmuseum.org/toah/hd/orna/hd_orna.htm).

Subtle mixtures of geometry and rhythm also characterized the *muqarnas* or stalactite vault which is distinctive to Islamic architecture and decoration. The *muqarnas* is both a structural element filling zones of transition between walls and domes and a decorative element that follows the same structural composition (Fig. 2). *Muqarnas* domes, vaults, niches and decorative friezes are found in different construction materials including brick, stone, wood and stucco all over the Muslim world. (See a good survey of *muqarnas* types and their geographical distribution ►http://www.tamabi.ac.jp/idd/shiro/muqarnas/). In its simplest form the *muqarnas* can be described as layers of superimposed

Architectural Decoration in Islam: History and Techniques. Fig. 2 Mihrab of the mausoleum of Haseki Hürrem wife of Süleyman the Magnificent, Istanbul, Turkey. 1550–1557.

niches that link or decorate two surfaces. The earliest surviving mathematical treatise on *muqarnas* was written during the fifteenth century by the mathematician Ghiyāth al-Dīn Masʿūd al-Kāshī (d. 1429). The treatise was used to inform the simulation of a model of a *muqarnas* in Necipoğlu's book on a Timurid period scroll found in the Topkapi Saray Museum in Istanbul (Asad 1995). The earliest surviving drawing of a *muqarnas*, however, was found in the Takht-i Sulaiman excavations in the northwest of Iran. The plaster panel of (50 × 50 cm) inscribed with a design of a *muqarnas* dating to ca. 1270 currently housed in the archaeological museum of Berlin was drawn into an exact plan (Harb 1978) and later studied and analysed by a numerical geometry group at the University of Heidelberg in Germany. (See the numerical geometry study group ►http://www.iwr.uni-heidelberg.de/groups/ngg/Muqarnas/ and the Takht-I Sulaiman muqarnas drawing ►http://www2.iwr.uni-heidelberg.de/groups/ngg/Muqarnas/Img/suleyman_plate.jpg).

The use of calligraphy in architectural decoration pre-dates Islam. However, after the birth of Islam words and calligraphic compositions became a primary component of a collective aesthetic. Notably, decorative inscriptions were not often applied in isolation as calligraphy was most commonly used as part of an overall composition that at times overlapped with other decorative techniques such as arabesque. Like other decorative forms, calligraphic compositions are based on a modular principle where letters, words, or full

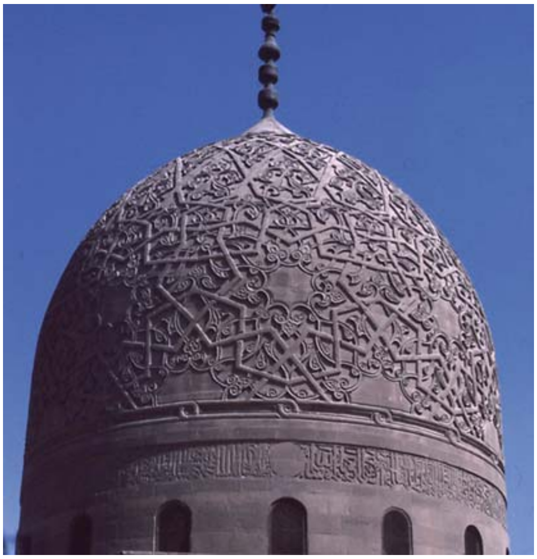
Architectural Decoration in Islam: History and Techniques. Fig. 3 Mihrab of the mausoleum of Gur-i Emir, Samarqand, Uzbekistan. 1404. Decorated with painted and gilded arabesque designs and square Kufic inscriptions.

sentences are subject to geometric rendition and repetition. The purpose, form, content and location of inscriptions on buildings varied according to time and place (Blair 1998). A large percentage of surviving inscriptions are Qur'anic or religious in nature but inscriptions with historical information providing the name of the building's patron, its date of construction and at times the name of a builder are also common (Fig. 3). Whereas Arabic served as the main language for monumental inscriptions, Persian, Ottoman Turkish and in a few cases Pahlavi and Swahili were also used. The location of calligraphy on a building followed stylistic developments and regional variations. Most commonly, calligraphic friezes tend to delineate structural zones in a building such as between walls and zones of transition, the bases of domes, entrances and on the voussoirs (wedge-shaped stone building blocks used in constructing an arch or vault) or tympana (the triangular area in a pediment) of arches. Calligraphy was also used as a form of overall decoration such as the large buff and turquoise brick inscriptions in the *hazārbāf* technique (see below) that adorned walls and minarets of monuments during the Timurid period. (See the Islamic Art and Architecture Organization ►http://www.islamicart.com/main/calligraphy/index.html).

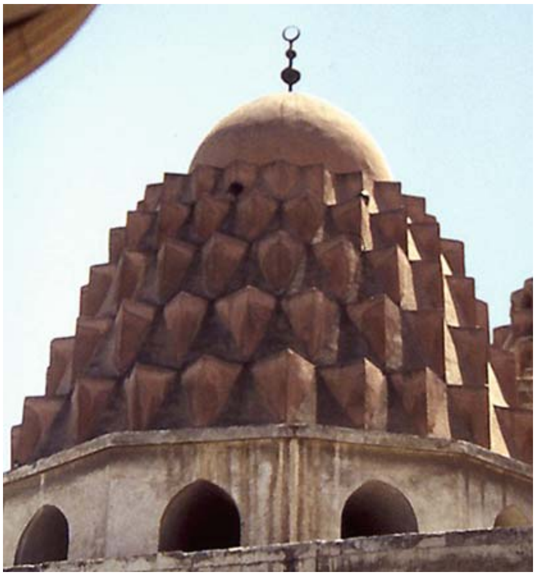
The application of different decorative elements on a building was wide-spread in Muslim architecture. Nevertheless, the form of decoration and its location followed regional preferences and local traditions. For example while monuments of Fatimid and Mamluk Egypt were decorated with carved inscriptions, *ablaq* stonework, and architectonic features, the facades of monuments in Khurasan and Transoxiana were decorated with overall brick patterning, blind arches, glazed and moulded tiles, terracotta inlays, stucco and ornamental inscriptions. Even in buildings where the exteriors were left almost totally unadorned such as the Ilkhanid period mosques of Iran and Iraq (1256–1353), interiors and particularly the mihrab niche was the focus of sumptuous stucco decoration (Fig. 4). So too is the case in fourteenth century North Africa and Spain as for example in the courtyard arcades of the Nasirid palace in Granada or the complex decoration of the Marinid ʿAṭṭārīn Madrasa in Fez built between 1323–1325.

Architectural Decoration in Islam: History and Techniques. Fig. 4 The mihrab of the Shrine of Pir-i Bakran in Linjan, Iran. 1299–1312.

Decorative elements applied to architecture were used singularly or in combinations. Of particular significance was the use of overlapping patterns in two or more dimensions. An example is the tile mosaic design on the dome of the Shah Mosque in Isfahan, Iran (1611–1638), with its ochre lattice screen pattern and white and blue arabesque. Another example with a similar overlapping composition yet a different effect is the stone dome of the Sultan Qaytbay mausoleum in Cairo (1472–1474) with its geometric interlace design and flowering arabesque (Fig. 5). Whereas the former is two-dimensional, the Cairo example has a sculptural effect as both elements are carved in a precise bas-relief. The use of complex and overlapping decorative patterns was also subject to stylistic changes. The pre-Mongol arabesque based on twining vine tendrils and acanthus or palm leaves gave way from the turn of the fourteenth century to lotus scrolls with peony sprays and serrated leaves (*hatāʾī*). This aesthetic became popular in Iran and was later adopted in the early sixteenth century Iznik ceramic tiles produced by the Ottomans.



Architectural Decoration in Islam: History and Techniques. Fig. 5 Dome of the mausoleum of Sultan Qaytbay, Cairo, Egypt. 1472–1474.



Architectural Decoration in Islam: History and Techniques. Fig. 6 Muqarnas dome of the Mausoleum of Nūr al-Dīn in the al-Nūriyya Madrasa, Damascus, Syria. 1168.

The Meaning, Purpose and Transmission of Architectural Decoration: Problems of Interpretation

Because of the perennial emphasis on geometric patterns and abstract vegetal motifs, the decorative language of Islamic architecture is commonly perceived to reflect a Muslim ethos that is aniconic[1] and unchanging. This perception is at the heart of a number of debates in the study of Islamic art and culture including: was the use of geometry and arabesque patterns a reflection of Islam's antipathy to images? Was it a reflection of the special status of mathematics and geometry in Muslim cosmology? Or was it, perhaps, a reflection of a cultural process with its social, political and religious ramifications? These debates represent the two main current schools of thought on the meaning and purpose of architectural ornament: the "iconological" and the "cosmological".

In the iconological approach all works of art, including architectural decoration, are interpreted as visual signifiers of the cultural context which they embody. As such, a work of art has a meaning that is culturally constructed and related to a specific time, place and context of production. It is read and considered as evidence or representation of its context on par with other historical, political, social or literary documents. Such an approach is at the heart of Tabbaa's analysis of the transformation of architectural decoration in the central Muslim lands between the middle of the eleventh and the middle of the thirteenth centuries (2001). He argues that the evolution of an artistic language which is characterized by the use of arabesque, geometric interlace, *muqarnas* vaulting, and monumental calligraphy was largely brought on by a Sunni revival that strived to standardize religious norms in a period of political and sectarian upheaval (Tabbaa 2001: 6). The evolution of the gravity-defying and ever changing effect of the *muqarnas* domes, for example, is interpreted in his study as an embodiment (or abstraction) of the Ash'arite Sunni theology which is based on an occasionalistic cosmology (133). As such, the evolution of the *muqarnas* dome, as well as the other decorative techniques, is explained within a precise political and religious context within which it would have had a symbolic meaning (Fig. 6).

For the proponents of the cosmological approach, geometric and decorative patterns are interpreted as manifestations of underlying principles of faith that are regarded as both universal and timeless. This approach attributes a functional role to ornament that is first and foremost a reminder of the principle of Tawḥīd: the Oneness and Transcendence of the Divine (al-Faruqi and al-Faruqi 1986: 163–169). Islamic art and geometric patterns used in architectural decoration are thus seen as means to reconcile multiplicity with Unity. They depict a physical mathematical pattern which reflects a sacred cosmology. Islamic art is thus regarded as an aniconic art where the spiritual world is reflected through geometry, rhythm, arabesque and calligraphy.

[1] When referring to a deity image, aniconic denotes a symbol which does not attempt an anthropomorphic (humanlike) or representational likeness.

For example, the circle is read as symbol for the origin and the end, an archetypal form from which the three primary shapes (triangle, hexagon and square) emerge (Critchlow 1976). The same ideas are expressed by Burckhardt (1976: 63) who sees geometric interlace as a direct expression of the idea of Divine Unity. Thus unlike the iconological approach, the cosmological approach does not take into account the socio-political context of a decorative programme or the vicissitudes of artistic influences.

These two approaches often regard each other as incompatible. The iconological school sees the attempt to interpret style through faith too speculative and at best normative. Whereas for those who consider Islamic art as an expression of Muslim faith and Divine Unity in particular, the temporal contextual analysis of decorative patterns misses the point. What the two approaches agree on, however, is the need for intermediaries to translate these complex mathematical and philosophical ideas into patterns that could be understood and applied by craftsmen. For example, Nasr explains geometric patterns as being the "results of the vision of the archetypal world by seers and contemplatives who then taught craftsmen to draw them upon the surfaces of tiles or alabaster" (1987: 49). Tabbaa (2001: 100) and Necipoğlu (1995: 123), on the other hand, propose that one of the reasons for the development of these complex and geometrically based decorative techniques is that geometric treatises were increasingly available for artisans. This presumed relationship between the artisan and the mathematician in medieval Islam, however, was dismissed by George Saliba, Professor of Arabic and Islamic science at Columbia University. Saliba argued that based on the available evidence from the few surviving mathematical treatises the assumption is hard to entertain, let alone prove (1999: 641). He also provides textual evidence for the difference in the technical language used by mathematicians and artisans, and the need therefore to avoid the assumption that the presence of mathematical treatises means that they are used or understood by artisans. Theoretical mathematicians, according to Saliba, "rarely taught artisans directly, and seldom wrote for them specifically" (643).

Another important issue that arises in debates about architectural decoration is the manner in which architectural or decorative designs were transmitted. Jonathan Bloom (1993: 25) argues that the form and general characteristics of early mosques were transmitted mostly by example. That is, the general features of one building were copied by another in the same region. Bloom also argues that such buildings could have been described orally or in geographical works, and thus what was transmitted was a notional idea of a building or a decorative detail. These suggestions remain to be fully proven. It is worth noting that there are also a few historical accounts which mention the involvement of patrons in drawing designs of a desired monument, but no material evidence survives before the fourteenth century (O'Kane 1987: 34). In this connection, the presence of a notational convention used by craftsmen based on drawings and models is only attested to from the thirteenth century with the 1270s stucco panel with a *muqarnas* plan (discussed above) as the earliest surviving example. Early drawings on paper survive from the sixteenth and seventeenth century in Tashkent, and the fifteenth and sixteenth century in Istanbul (Necipoğlu 1995). Finally, one of the important ways of transmitting knowledge about decorative techniques and practices was through the movement of craftsmen who brought with them new traditions and technical know-how.

Architectural Decoration by Media

Studies on the building crafts in Muslim societies are sparse and mostly regional or media specific. The best example is Hans Wulff's book on Iran (1966) which provides an invaluable detailed study of building and decorative traditions concentrating on local practices and techniques. Iran's craft industry during the nineteenth and the early twentieth centuries and its encounter with Western technical development are also documented (Floor 2003). For Syria and Egypt dictionaries of traditional crafts (al-Qasimi 1988) and architectural terms (Amin and Ibrahim 1990) provide glimpses into local technical practices. IRCICA, the Research Centre for Islamic History, Art and Culture based in Istanbul has had since 1990 a programme for the study and development of crafts in Muslim societies. The programme hosted conferences and seminars in different regions and recently published some of their proceedings (see ►www.ircica.org). What follows is a summary of the history and techniques of stone, brick, tile and stucco decoration.

Stone

Stone was used as a decorative medium in Syria, Anatolia, Egypt after the eleventh century, Spain, and India (Fig. 7). North Syria, especially the area around Aleppo during the period between the twelfth and fifteenth centuries, seems to have been a source of technical innovation for stereotomic[2] stone techniques that are based on the precise cutting and assemblage of stone blocks (Clévenot and Degeorge 2000: 68). The decorative use of stone exploited the natural variety of stone colours to produce polychrome compositions for the interior and exterior of buildings. Some techniques

[2] Stereotomy is the science or art of cutting solids into certain figures or sections, as arches; the art of stonecutting.

Architectural Decoration in Islam: History and Techniques. Fig. 7 Portal of the Ayyubid palace. Aleppo Citadel, Syria. ca. 1210.

Architectural Decoration in Islam: History and Techniques. Fig. 8 The Fatḥiyyah Madrasa, Damascus, Syria. 1743.

such as alternating the colours of stone courses (*ablaq*) or interlocking the stones of arches (joggled voussoirs) were used in pre-Islamic monuments but became more sophisticated and more widely used after the spread of Muslim culture. Stone mosaic designs of *opus sectile* (pavement or wall decoration made of shaped tiles of coloured marble) and its stone paste derivatives were used only for decorative purposes (Fig. 8). In most cases, however, structural and decorative techniques overlapped. The most common decorative stonework techniques were:

Stone Mosaic

This is a technique that was inherited from the Byzantines in Syria and Palestine. It was used for land covering and paving during the Umayyad periods in Syria and Spain.

Ablaq

This is a simple technique of alternating different colours of stone courses in order to achieve a colouristic impact. The most commonly used colours were light sand or limestone alternating with dark basalt and in some cases a third layer of reddish stone. This technique spread from Syria to Egypt under the Mamluks and Turkey under the Rum Saljuqs and the Ottomans.

Joggled or Interlocking Stones

This is a technique in which stone blocks with precisely cut scallops, zigzags and complex carved profiles were fitted together without the use of mortar. Single or multiple coloured stones were used to create a beautiful effect. Interlocking stones, however, were technically challenging as the desired shape was cut into a regular block that was bonded into the masonry. They decorated horizontal decorative bands on facades or had a structural function in lintels and arch voussoirs.

Muqarnas Vaulting Over Portals

These vaults consist of three or more tiers of staggered *muqarnas* cells usually surmounted by a scalloped or centrifugal half-dome. Muqarnas became the main decorative feature of monumental portals between the thirteenth and the fifteenth century. It seems to have developed in Aleppo in Northern Syria and spread from there south to the rest of Syria and Egypt and north to Anatolia and Turkey.

Monochrome and Polychrome Geometric Interlace

Stone geometric interlace was introduced during the twelfth century and used mostly in the spandrels above arched gates and prayer niches (mihrabs). Technically, the geometric interlaces are different from surface cladding as each component of the geometric interlace is cut on the face of a regular block that is built within the structure of the arch spandrel, and as such, fully bonded to the masonry (Tabbaa 2001: 156).

Stone Cladding and Inlay

This technique included the decorative use of marble panelling which was common in Syria, Palestine and Egypt. Stone inlay in *opus sectile* and marble intarsia reached its apogee under the Mughals of India (Fig. 9). Inlay in hard stones and semi-precious stones (*pietra dura*) where lapis, onyx, jasper, topaz, cornelian and agate were inlaid in marble made its first major appearance in the Tomb of Iltimād al-Dawla in Agra (1622–1668).

Architectural Decoration in Islam: History and Techniques. Fig. 9 Tomb of Akbar. Sikandra, India. 1614.

Stone Sculpture

The most common form of stone sculpture was relief carved inscriptions and decorative patterns. Dense patterns created through carving out or hollowing the stone surface is also demonstrable in the façade of the Mushatta palace in Jordan (ca. 740) currently in the museum of Islamic Art in Berlin. The surface is carved in the form of triangles housing rosettes that are surrounded by dense foliage at times inhabited by birds and mythical creatures. An exceptional example of a more plastic modelling in stone sculpture comes from the portals of the Great Mosque of Devriği in Anatolia built in 1228–1229 (Fig. 10).

Bricks

Decorative brickwork was used to articulate the structural walls of monuments built over a vast area including Iraq, Iran, Afghanistan and central Asia. Brick was readily used as a medium of structure and decoration as it was cheap to make and fast to build. The alluvial plains of the various rivers in the region provided rich sources of clay that were used for manufacturing rammed-earth (*pisé*), mud brick, baked brick and terra cotta in addition to clay pipes and tiling roofs (Wulff 1966: 108–113). Although the size of the brick differed from one region to the other, the overall visual effect of plainly built brick walls was similar. The indigenous builder was able to develop various decorative uses for brick construction based on simple alternate layering of bricks in horizontal and vertical rows creating patterns in the otherwise plain facades. Bricklayers also used half-bricks, quarter-bricks, and moulded bricks along with the full size bricks to create more dynamic decorative patterns (Fig. 11). The ability to design a small composition based on a simple brick pattern and multiply the design vertically and horizontally meant that the bricklayers were able to maximize the effect of the pattern and minimize the human effort.

Architectural Decoration in Islam: History and Techniques. Fig. 10 The northern gate of the Great Mosque of Devriği, Turkey. 1228–1229.

Architectural Decoration in Islam: History and Techniques. Fig. 11 Mausoleum of the Samanids. Bukhara, Uzbekistan. 914/43.

Hazārbāf and Bannā'ī

In addition to the basic technique of forming decorative patterns in brick walls through varying the orientation of bricks, builders used the contrast between light and shadow that resulted from alternating flush and protruding bricks to create intricate decorative patterns. The most widely spread technique of ornamental brickwork is known as *hazārbāf*, from Persian, meaning a thousand twisting or a 1,000 weaving, accentuating the structural similarities between creating continuous brick patterns and weaving a textile. This technique is also known as the *bannā'ī* or the 'builder's art', as the decorative patterns are part of the structure of the building and not an afterthought or a later cladding. Carved brick plugs and carved and moulded plaster joints were developed to enhance the overall effect.

The earliest surviving example of decorative brickwork comes from Abbasid Iraq and dates to the eighth century in (the city gate in Raqqa ca. 772). In the Ukhaydir Palace south of Baghdad (possibly begun around 762) the south wall of the courtyard has an *iwān*[3] with *hazārbāf* decorative patterns using 1/3, 2/3, and full size bricks. Early examples from Iran and Central Asia are later than those in Iraq but more complex. The decorative use of bricks in the tomb of the Samanid ruler Ismāʿīl in Bukhara, Uzbekistan (913–943), for example, created a weaving effect by highlighting the contrast between recessed and protruding bricks in an overall decorative design. This play between shadow and light in brick construction continued to be a dominant decorative medium for building exteriors such as the twelfth century Gunbad-i 'Alawiyān in Hamadan (Iran) where bricks were used to create a 'key' and 'swastika' patterns (Shani 1996: 61) or the minaret of Masʿūd of Ghazna in Afghanistan where the builder used brick layering, brick mosaic, sculpted bricks and brick inscriptions in a sumptuous decorative composition.

Architectural Decoration in Islam: History and Techniques. Fig. 12 Minaret of the Kalayan Mosque. Bukhara, Uzbekistan. 1127.

Glazed Bricks

Glazed bricks were also a pre-Islamic tradition inherited from Babylonian and Achaemenid times. The earliest examples in the eastern Muslim provinces date back to the early twelfth century when moulded tiles or 'end plugs' were used as a contrast to the natural buff colour of bricks. During the twelfth century glazed tiles were used in inscription bands such as the Tower of Jam, Afghanistan (late twelfth century), or the minaret of the Kalayān mosque in Bukhara (1127) (Fig. 12). One might argue that colour was introduced in brick architecture to render the complex decorative and inscription friezes more legible from the distance. Under the Ilkhans (1256–1353) the use of glazed bricks became a prominent feature of monumental architecture as domes and large surfaces were covered in decorative compositions of glazed bricks and tiles. The Timurid opulence of Tamerlane's mausoleum in Samarqand, the Gur-i Emir, (ca. 1400–1404), or the royal necropolis of Shah-i Zand demonstrate the skilful combinations of plain bricks, glazed bricks and glazed tiles that were used to maximize the decorative effect (Fig. 13).

Architectural Decoration in Islam: History and Techniques. Fig. 13 Façade of the Shir Dor Madrasa. Samarqand, Uzbekistan. 1619–1636.

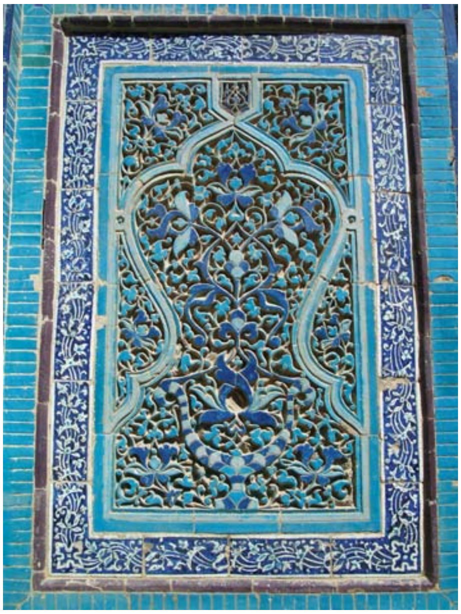
To create glazed bricks, brickmakers used glazes or filmy glass layers that were fired and fused over the porous clay body of the brick for functional and aesthetic reasons. Glazes were added to the brick in a powder format that coated the body and melted in the kiln. The colour and opacity of the glazes were determined by their chemical composition. The most commonly used colours in Iran and the Muslim east were turquoise and blue. These colours were achieved by using an alkaline fluxing agent composed of powdered pebbles and potash for copper oxide and cobalt, respectively (al-Hassan and Hill 1986).

[3] An *iwān* is a large, vaulted chamber with a monumental arched opening on one side.

Glazed Tiles

Decorative tiles comprise glazed slabs made out of clay or frit (stone paste) that were used in a variety of forms and shapes to create impervious surfaces with stunning visual impacts. The surface of the tile can be left plain before glazing but it can also be carved, incised or moulded for additional effect. Glazed tiles were used to cover different parts of a building including walls, domes and zones of transition. The technical know-how and desired final decorative effect dictated the development of the glazed tiles tradition in different regions of the Muslim world. A good, yet incomplete, starting point for the study of Islamic ceramics including glazed tiles is the teaching website developed by the Ashmolean museum in Oxford, UK (see ►http://islamicceramics.ashmol.ox.ac.uk/). Tiles are covered with a layer of glaze and fired in a kiln in the same manner as glazed brick (Fig. 14).

Many decorative techniques were used with glazed tiles including painting in the glaze, under the glaze and over the glaze. Glazes are either transparent or opaque depending on their chemical compositions. They are found in different colours and at times colour combinations. The most commonly used metals by Muslim potters were cobalt for blue, manganese for purple, iron for green, and copper for turquoise. Changing the chemical agent used for fluxing the glaze produced different colours. Copper, for example, turned into green if fluxed with a lead glaze, and turquoise-blue if fluxed with an alkaline glaze. Cobalt turned sapphire-blue in an alkaline glaze, and turquoise in lead glaze (al-Hassan and Hill 1986).



Architectural Decoration in Islam: History and Techniques. Fig. 14 Details of carved and glazed tiles from the Shah-i Zinda necropolis. Samarqand, Uzbekistan. End of fourteenth or beginning of the fifteenth century.

Lustre Tiles

The best-documented tradition of lustre tile production is the city of Kashan in Iran where there is evidence of continuous production between the twelfth and the early fourteenth centuries. Lustre production (for vessels and tiles) requires special materials, double firing and a special kiln. The metal oxides added to the tile after the first firing form a metallic deposit upon firing in a reducing kiln at a much lower temperature. The recipe and the process of making lustre vessels and tiles were described in a 1301 treatise [►http://islamicceramics.ashmol.ox.ac.uk/Glossary/abulqasim.htm] (Allan 1973). Abu al-Qāsim's treatise suggests that that vessels and tiles were covered with an alkaline glaze and fired for 12 h. They would then have six and a half days of cooling in the kiln before the lustre design was applied. The recipe for lustre glaze comprised a mixture of red and yellow arsenic, gold and silver marcasite, yellow vitriol, copper, and silver ground with sulphur dissolved in grape juice or vinegar. The second firing takes place in a low-temperature reducing kiln which allows the metal oxides to fuse with the alkaline glaze and create the lustrous sheen. Star-and-Cross tile patterns with figural and vegetal motifs, at times moulded in bas relief, as well as moulded and painted inscription friezes were the most common patterns of decoration. The buff-and-blue aesthetic that characterises the early use of glazed bricks on the exterior of buildings was also predominant in the decoration of interiors with lustre tiles. Cobalt blue was used to highlight relief-moulded inscriptions on lustre tiles as is clear from the *mihrab* tile now in the Los Angeles County Museum of Art (see ►http://www.lacma.org/islamic_art/figures/fig_a31.htm).

The earliest surviving lustre tiles known to have decorated Muslim monuments are the tiles that adorned the *qibla* wall of the Great mosque of Qayrawan in Tunisia (ca. 862). According to the historian Ibn Nājī (d. 1433), who cites al-Tujībī (d. 1031), some of those tiles were sent from Baghdad but an Iraqi craftsman who knew the lustre technique manufactured some locally. There is also evidence for the use of lustre in Egypt and Syria before the technical know-how was transmitted to the potteries of Kashan in Iran.

Cut Tiles or Tile Mosaic

The earliest examples surviving in this technique are from twelfth century Iran and thirteenth century Anatolia. Technically, tiles are glazed and fired separately and then cut according to the desired design or pattern. They are placed face down and a layer of plaster is applied to the back of the pattern which, once

Architectural Decoration in Islam: History and Techniques. Fig. 15 Detail of a floral tile mosaic from the Gur-i Emir Mausoleum. Samarqand, Uzbekistan. 1404.

dried, turns into a panel that can be easily fitted onto a wall. The same technique is used for the application of tile mosaics on concave or convex curved surfaces. The heyday of the tile-mosaic technique was under the Timurids when designs became increasingly complex with overlapping layers of arabesque and geometric patterns on flat or curved surfaces (Fig. 15). See also the fourteenth century mihrab from Isfahan, Iran currently in the Metropolitan Museum of Art, New York. ►http://www.metmuseum.org/Works_Of_Art/viewOne.asp?dep=14&viewmode=0&item=39.20.

Cut tile mosaic has the advantage of maintaining the brilliance of the colour of each tile. The different coloured tiles are fired separately according to the specific temperature needed by the chemical component that gives the colour of the glaze. (Wulff 1986: 120) In North Africa, there was a phase of experimentation in cutting the *zillīj* components from a clay panel after the first firing and then glazing each piece separately. The result, however, was less precise patterns (shrinkage), and less smooth surfaces, as the glaze would bulge around the sides (Hedgecoe and Damluji 1992). This technique, however, is still practiced in some workshops in Titwan in Morocco.

Tile mosaic technique was the predominant form of tile decoration in North Africa. Known as *zillīj*, the ceramic cut tiles are put together in a complex geometric design. Each component of the *zillīj* is monochromic but the final design is a polychrome matrix. Glazed tiles first appear in North Africa in the archaeological context of tenth century Qal'at Banū Ḥammād, possibly inspired by the Aghlabids, who in turn were copying Abbasid models. During the twelfth and thirteenth centuries glazed tiles were nailed to or embedded in minarets and towers. The *zillīj* tradition in North Africa, however, reached a stunning maturity under the Marinids who ruled from Fez between 1244 and 1465. In Spain *zillīj* became common only during the late thirteenth and early fourteenth centuries. There are some differences in the colour palette between Spain and North Africa as Spanish tiles made more use of various shades of blue using cobalt as a colouring agent. The colour palette also used ochre yellow, copper for green and manganese for purple, brown and black.

The Cuerda Seca (Dry Thread) Tiles

This is a method of painting with different colour glazes on a single tile in order to achieve the overall colouring effect that cut tile techniques provide in a less expensive and less time consuming manner. Tiles were painted with different colours of glazes that were separated by a greasy or wax material that leaves a black matt line between the different glazes when fired. The waxy material stops the colours from running into each other in the kiln and acts as a pencil line or drawing line that defines the different components of a pattern. The tiles, however, were fired at a preset temperature and as a result, the glazes were not fired to their ultimate brilliance (as in the case of separate firings for the different colours). The colours achieved were less brilliant but the method was much faster and cheaper than tile mosaic. This technique started to replace tile mosaic in popularity during the reign of Shah Abbas in Isfahan.

The colour palette of this technique is necessarily limited to the chemicals that melted or fluxed at reasonably close temperatures. The predominant colours used in the *cuerda seca* technique are known as the *haftrang* or seven colours. This range of colours was used in Iran and central Asia from the late eleventh century and reached its apogee in the late fourteenth and early fifteenth centuries. To create overall patterns for large areas square tiles are put side by side and the overall design is transferred on to them. The colour glazes were then added and each tile fired separately (Fig. 16).

Underglaze Painting: Ottoman Tiles and the Iznik Tradition

Blue-and-white underglaze painted tiles evolved in Central Asia and Anatolia during the thirteenth and fourteenth centuries. Their popularity under the Ottomans is linked to a group of Iranian craftsmen known as the 'Masters of Tabriz' who are responsible for the decoration of the Yeşil Mosque in Bursa (1419–1424). The full repertoire of their work included *cuerda seca*

Architectural Decoration in Islam: History and Techniques. Fig. 16 Detail of *cuerda seca* tiles currently embedded in a re-constructed wall in the Topkapi Palace. Istanbul, Turkey. Late fifteenth century.

Architectural Decoration in Islam: History and Techniques. Fig. 17 Underglaze painted tile, Circumcision Room, Topkapi Palace. Istanbul, Turkey. ca. 1520.

tiles, monochrome glazed tiles, and underglaze painted blue-and-white tiles. Tile production in Ottoman Turkey went through various phases of development that became linked to the court workshops from the early sixteenth century (1525–1550 blue and white from the Freer Gallery ►http://www.asia.si.edu/collections/singleObject.cfm?ObjectId=25488). One of the most stunning examples of early Ottoman underglaze painted tiles is a group of large tiles dated to the 1520s now decorating the exterior of the Circumcision Room in the Topkapi Saray (Fig. 17). The tiles are painted in the *sāz* style featuring serrated leaves, lotus blossoms and rosettes inhabited with birds and mythical creatures in a blue and turquoise palette on a white background. This painting style is associated with Shahkulu who served as the court designer between 1526 and 1556. This period of experimentation led to the development of a more natural floral repertoire that featured tulips, carnations, roses and hyacinth, the hallmarks of the exuberant floral style that distinguishes Ottoman decorative language.

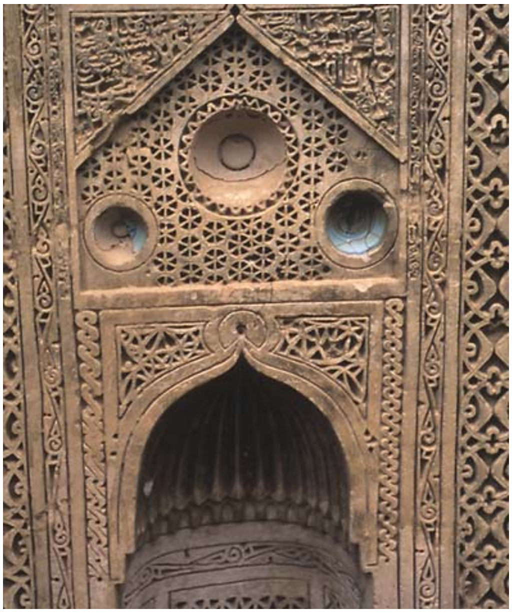
The colour palette of the underglaze painted tiles also went through changes in the early part of the sixteenth century. In addition to blue, turquoise and green, purple was introduced in the late 1540s. It was only in the 1550s when the well known architect Sinan became in charge of the royal workshops of Iznik producing ceramics and tiles that tile sizes became standardized allowing for vast pictorial compositions and monumental calligraphy. It was also under Sinan in 1557 that the colour red was introduced into the palette of Iznik tiles (Fig. 2 above) (1575 typical Iznik with red Freer ►http://www.asia.si.edu/collections/singleObject.cfm?ObjectId=37077).

Stucco

Stucco is a plaster-based decorative medium that was used throughout the Muslim world as a decorative finish as it was cheap and created a considerable effect in a relatively short time. It was perhaps the most common form of decorating building interiors until some of its role was taken over by tile revetments from the thirteenth century. Stucco can be applied to all sorts of surfaces rendering the basic rammed-earth structures (*pisé*) into buildings with sumptuous decoration (Milwright 2001).

Stucco is commonly made out of gypsum, but lime stucco is also used especially for exterior decoration and for rendering exteriors and special features impervious. A watertight variety of stucco made out of lime and wood ashes bonded with goat hair is used for water channels and for decorating buildings in Oman (known as *ṣārūj*) and in Yemen (known as *Qudād*) (al-Radi 1994). In some regions certain substances are rubbed onto the surface of the final pattern to provide a shiny patina. Colour or gold leaf could then be added to the surface.

Stucco is prepared by the calcinations of gypsum or lime through mixing the sifted powder with water while continuously stirring in order to slow down the process of crystallization (Clévenot and Degeorge 2000: 84). It is usually applied in several layers then smoothened. A pattern is then traced either through the use of dry point, ruler and compass or stencil paper which is blotted with charcoal powder. The pattern can be cut out or carved and some of the components further



Architectural Decoration in Islam: History and Techniques. Fig. 18 Evidence of the use of stencils to copy stucco patterns, the mihrab of the Mosque of al-'Uwaynah. Wādī Banī Khālid, Oman. ca. 1540.

Architectural Decoration in Islam: History and Techniques. Fig. 19 Detail of the mihrab of Oljeitu, Friday mosque of Isfahan. Iran. 1310.

articulated through hatching, perforating and quilting (Fig. 18). Decorative patterns could also be moulded onto the wet stucco by pressing a pre-carved mould (probably hardwood) into the last layer of gypsum – each being allowed to set separately providing a faster way of achieving decorative patterns. For stucco grills which were common all over the Muslim world designs were knife cut in semi-set gypsum boards.

The different techniques for cutting and shaping stucco followed regional and historical patterns. In Samarra, the Abbasid capital of the ninth century, three styles of stucco were excavated. Stucco styles developed from hollowed out background creating patterns of vine leaves and grapes to one where the design is abstract and cut in a bevelled style. Stucco panels with the bevelled style were excavated in a house in Nishapur (Iran) and are now in the Metropolitan Museum of art in NY (▶http://www.metmuseum.org/toah/hd/nish/ho_gallery_view.htm). The major change to the stucco tradition, however, took place under the Ilkhans (1256–1353) who decorated the *mihrabs* of their mosques with stucco compositions of arabesque, calligraphy and geometric interlace modelled in plastic compositions in tiers and on different planes. One of the most famous examples is the mihrab built in the winter prayer hall of the Friday mosque of Isfahan during the reign of Oljeitu in 1310 (Fig. 19).

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Architecture in Africa, with Special Reference to Indigenous Akan Building Construction

Tarikhu Farrar

> The hall itself was the chief object that attracted my attention. It was at least a 100 ft in length, 40 ft high, and 50 broad. It had been quite recently completed, and the fresh bright look of the materials gave it an enlivening aspect, the natural brown polish of the wood-work looking as though it were gleaming with the lustre of new varnish. Close by was a second and more spacious hall, which in height was only surpassed by the loftiest of the surrounding oil palms; but this, although it had only been erected 5 years previously, had already begun to show symptoms of decay... Considering the part of Africa in which these halls were found, one might truly be justified in calling them wonders of the world; I hardly know with all our building resources what material we could have employed, except it were whalebone, of sufficient lightness and durability to erect structures like these royal halls of Munza, capable of withstanding the tropical storms and hurricanes. The bold arch of the vaulted roof was supported on three long rows of pillars formed from perfectly straight tree stems; the countless spars and rafters as well as the other parts of the building being composed entirely of the leaf-stalks of the wine-palm (Raphia vinifera). The floor was covered with a dark red clay plaster, as firm and smooth as asphalt. The sides were enclosed by a low breastwork, and the space between this and the arching roof, which at the sides sloped nearly to the ground, allowed light and air to pass into the building. (Schweinfurth 1874, Vol. II: 42–3.)

Famed 19th century botanist, Dr. Georg Schweinfurth, here writes of one of tropical Africa's most remarkable achievements in indigenous architecture and building technology, what he calls the "royal halls" of the Mangbetu kingdom. In the last years of the 1860s, Schweinfurth, traveling with Sudanese merchants, made his way southward along the Nile corridor toward the African interior. Ultimately, he reached the northeast quadrant of central Africa.

Schweinfurth would go on to write voluminously about this central African world. He also produced illustrations in quantity and of considerable quality. From his writings and illustrations we can gain some appreciation of the technological prowess of this region's cultures in the late precolonial era. The grandeur and elegance of the "royal halls" certainly captured Schweinfurth's imagination. So too did the considerable building skills embodied in their construction.

The "royal halls" were merely the grandest expression of the architectural and building skills of the peoples of this part of Africa. Of the more ordinary buildings, dwellings, storage structures, etc., we can also learn something from Schweinfurth's writings and illustrations. He was encountering traditions of architecture and building technology that were indigenous to tropical Africa. Nor should we imagine that the Mangbetu, in this instance, represent some sort of unusual or atypical culture.

The building materials identified by Schweinfurth are familiar from elsewhere in tropical/sub-Saharan Africa. These include types of clay, particularly those deriving from forest and savanna ochrosols and oxysols, and tropical black earths. Also included are various hardwood tree species. Of great importance is the raphia palm. Virtually every part of this useful tree was employed in the building process. The trunk provided posts; the fronds, laths and rafters; and the leaves, roofing or thatch. Rope and twine for binding purposes (binding laths to posts, for example) were also made from the woven fibers of the leaves. These materials were readily available, abundant, and admirably suited to the task of building. As elsewhere in tropical Africa, the peoples of this region mastered their use. This is evident in the way that the materials were processed, in the techniques of building developed in conjunction with their use, and in the final product of the building process. Here, as elsewhere in tropical/sub-Saharan Africa, people constructed houses that were durable, comfortable, and, in today's jargon, "ecologically sound."

The study of African architecture, at least in an academic setting, did not truly develop until the second half of the 20th century. A small, but determined and dedicated body of scholars, not a few of them from Africa, had taken up the challenge to the orthodoxy. Africa (i.e., sub-Saharan/tropical, or Black Africa), they insisted, was indeed a part of the *historical* world and worthy of study as such. Within this group was body of architects, folklorists, a few historians, and others who began to pay serious attention to indigenous African architecture, or what was termed "African traditional architecture." (See, for example, Denyer 1978; Dmochowski 1988 [1958–1965]; Gardi 1973; Gluck 1973 (1956); Hull 1976; Oliver 1971; Prussin 1969.)

Their work, in conjunction with the written accounts of earlier travelers to Africa like Schweinfurth, provides us with a solid foundation on which to continue to piece together something of a coherent picture of the technologies of building developed by the peoples of tropical Africa at earlier periods in their histories. Also useful are recent ethnoarchaeological/material culture studies of "traditional" building where and to the degree that it continues to be practiced. The writer conducted this type of research in southern Ghana, primarily in the Akan region, in the mid-1980s. The information yielded by this research is useful in developing a broader understanding of indigenous building technologies in tropical Africa based on the use of clay, wood, and other plant materials.

The Akan peoples inhabit roughly the southern half of the modern country of Ghana, and spill over into the eastern borderlands of Cote d'Ivoire. They constitute almost half of the population of Ghana, and in terms of history and culture are among the better known of West Africa's peoples. While the so-called "traditional" architecture of the Asante has been studied and is reasonably well known, that of other Akan groups has not received comparable attention, in some cases none at all. The study of Asante architecture has, in general, focused on the products of the building process rather then the raw materials and the building process itself. Considerable attention has been paid to the esthetics of architectural forms, and the uses and meanings that the various forms of enclosed space (e.g., shrine houses, palaces, etc.) were and continue to be imbued with. The focus here is different. Consideration will be given to the materials used in building construction.

In the mid-20th century, the Akan peoples were practicing a number of different building technologies, as were Ghanaians generally. Of these, only two can be described as being "indigenous." The two are *timber frame construction* and *coursed clay construction*. Both types, by the way, were observed by Schweinfurth in the Upper Nile region and northern central Africa, and are widespread throughout tropical Africa. The Akan and other Ghanaian peoples recognize these building technologies as being of considerable antiquity, long predating the colonial era. They have an existence in local oral history, as the writer was to discover to his surprise. Moreover, historical documents (i.e., written documents from the period of early European contact, or ca. 1500–1750) and archaeological evidence firmly support the idea of great antiquity.

Coursed clay construction is related technologically to the building methods known in other parts of the world as pise, tapia, rammed earth, and tauf. The product of this method is a structure with freestanding, solid clay walls. *Timber frame construction* is historically the more widely practiced of the two by the Akan peoples. It starts with a timber framework, which may then be closed in with a panelling of palm-fronds (this is the case with the Mangbetu "royal halls") or bamboo, or with a structure of clay and wood. The two techniques and resulting built forms are distinguished in local terminology. Timber frame construction finished with clay and wood is often referred to by the archaic "wattle and daub" by English speakers, although some more accurately call it "frame and plaster." In southern Africa it is known as "pole and daga."

Of the range of building materials employed in indigenous building construction, plant materials constitute the most varied group. These include a staggering number of hard and soft wood species, including several species of palm, and other woody plants, notably shrubs and lianes. Many of the tree species, especially the palms, provide not only useful timber, but leaves and bark. The leaves are used for thatch and in the manufacture of binding material. Sometimes, fibers, also used in the manufacture of binding material, are derived from the bark. Also included in this group are various species of grass, particularly bamboo and elephant grass.

Earthen materials consist primarily of clays. Most of the soil types of southern Ghana are characterized by strata classified as light to medium clays. These strata lie immediately beneath a layer of sandy to silty topsoil at depths of 20 cm to 2 m (Brammer 1962: 101–20). Light to medium clays are locally described as being "soft." What this means is that they are easily workable. With little difficulty, they can be trodden or mixed with a hoe into the proper consistency for building. The only thing required is the addition of water.

By contrast, those clays that are described as being "hard" are the types that are more suitable for pottery manufacture. Unlike some of the neighboring peoples, notably the Anlo Ewe and the Se (Shai) Dangme who occasionally use such clays for wall construction, the Akan have never used them for this purpose. Kaolin, *hyire* in the Akan language, is a "hard" clay that was used extensively by the Akan, but for the manufacture of white, yellow, or gray wall finish or plaster. At the time of the earliest European contact (the late 15th century), such plasters were a nearly universal feature of buildings in Akan towns.

As mentioned above, the earthen material used in wall construction is found nearly everywhere in the region inhabited by the Akan, lying just beneath the topsoil. The predominant soil types in southern Ghana are savanna and forest ochrosols, and to a lesser extent, oxysols. Tropical black earths are found, but are of limited distribution. From the point of view of agricultural potential, these differences in soil type have significance. In terms of use as building material, they do not. All contain light to medium clay strata.

Color is the primary characteristic by which the Akan distinguish soil types, but always in combination with other characteristics, for example, viscosity. *Notia/dotia*, or *netia/detia* is the generic term for soil. The different soil types are *notia tumtum*, *notia koko*, and *ntwuma*. Ntwuma is a sub-type of notia koko. Notia tumtum, literally, "black soil," refers to two different types of soil, both black in color. No terminological distinction between the two is made, although people are quite clear on the differences in terms of physical properties in general, and specifically with reference to use for building purposes.

One type of notia tumtum derives from the predominant soil type, notia koko (savanna/forest ochrosols). This type results from the decomposition of organic matter, in particular "kitchen" refuse, into the upper strata of notia koko. Thus, it is typical of the soil found under and around middens and other places of refuse deposit, and is also found near habitations. This type of soil is not at all suitable for building purposes, although excellent for kitchen gardens.

The principal type of notia tumtum is a tropical black earth. It is characterized by light to medium clay strata immediately below the topsoil and is thus appropriate for any type of construction. It has never been widely used by the Akan simply because its distribution in those parts of Ghana where they live is limited. In Ghana, tropical black earths are found principally in the coastal savanna (Brammer 1962: 116–7). They do constitute a good part of the soils of the Accra Plains where they are known as *Akuse clays*. There, they are extensively used for building by the Ga and Se Dangme peoples.

Notia koko, literally, "red soil," is the predominant soil type and the most widely used earthen building material. It is used in both timber and clay (wooden frame with clay plaster) construction, and in coursed clay (free-standing, solid clay wall) construction. It is used for walls, floors, courtyards, and hearths.

Ntwuma is described as a distinct type of notia koko. "Ntwuma" has been translated as "hematite" because it is used as a source of red ochre. The quality that makes ntwuma the building material par excellence for construction of solid, free-standing clay walls is its near ideal balance between clay, sand, and silt. It is widely distributed and is often found beneath the more ubiquitous notia koko by digging down to a depth of about a meter where the red earth matrix begins to reveal traces of yellow clay. The type of ntwuma used for plastering floors, courtyards, hearths, and wall bases, on the other hand, is of more limited distribution. It is quarried from special sites. It is distinguished by its deeper red color, presumably reflective of a higher iron content.

As mentioned above, the number of different species of plants that constitute building materials is extensive. F. R. Irvine (1962), in his *Woody Plants of Ghana*, lists 124 species of trees, shrubs, and lianes used throughout Ghana for building purposes, and this is not likely to be a complete listing.

Through several interviews conducted in the Brong-Ahafo region of Ghana, in the settlements of the Nkoransa Traditional Area and in the town of Nkoransa itself during the dry season of 1986–1987, the writer was able to compile a list of nearly 50 plant species used in building construction. Some 35 of these are species of trees and shrubs used to provide timber. An additional 13 species of trees, shrubs, and vines are used in the manufacture of binding material (rope, twine, etc.), plaster, and thatch. The trees that were identified as the main sources for the timber framework were mostly hardwood species. Some softwoods can be used for elements of the framework that do not come into contact with the ground, for example, thatch poles and rafters. But posts and studs require decay and insect resistant hardwoods (For a complete listing of plant species used in building construction along with their scientific names, see Appendix.).

Each tree, shrub, vine, and cane was thoroughly described in terms of its physical properties and its uses. Trees, for example, had the color and texture of their bark, sapwood, and heartwood described, whether or not the wood was soft, medium, or hard, and how resistant to insect attack and to decay. Discussions always went beyond uses in building construction to include information about uses in woodworking, of medicinal properties of bark, roots, fruits, etc., and uses for food, if any. Some species were said to have specific useful "spiritual" (for lack of a more accurate term) properties, and these, too, were described (For a detailed description of the collection and processing of building materials see Farrar 1996: 95–154.).

This vast range of building materials, earthen and plant, is the stuff of indigenous Akan building. In the past, the materials constituted the universe of Akan building materials and were used in the construction of two timber frame architectural forms and one of coursed clay. Of the two timber frame building types, one, the *mpapa-dan* structure, is built entirely of plant materials. The other, the *tare-dan* structure, consists of a timber framework with an infilling and final plastering of clay. The former is normally a type of temporary dwelling, while the latter is designed to have much greater longevity, or at least was so in the past.

The considerable skill that once characterized indigenous building construction was the product of centuries of technological growth. This process involved the acquisition of a profound knowledge of the environment and the multitude of resources therein, and the result was the evolution of architectural forms that were attractive, comfortable, and reasonably durable. The materials used in this type of building construction were widely available and easily accessible to most people. The tools used in their collection and processing were widely possessed. The skills associated with indigenous building were virtually universal, although some builders attained a level of building skill that earned them the status of "masters" in a way that separated them from others. And finally, the pressures placed on precious resources were minimal. These architectural/building traditions of tropical Africa thus represent an intelligent, rational, and efficient use of the local environment. They are yet another reminder of a largely ignored indigenous African technological ingenuity.

Appendix: Timber Used in Building Construction

Unless otherwise stated, the below-listed trees were described by Akan builders as having hard wood. Finer distinctions between hardwoods were made with respect to degree of hardness, resistance to insects and decay, etc., but are not indicated below because of limited space. Some of the characterizations of the hardness of the wood of various species are at variance with those of F. R. Irvine. The writer, in those cases, has stuck with the descriptions given by builders.

Abisiwa – Vitex Doniana.

Adobe – Raphia spp. The part of the tree that is used in the framework is the midrib of the frond. The leaves are used for thatch and in the making of a strong but soft fiber.

Asesea – Trema Guineensis. A fiber is also produced from the bark.

Atoaa – Spondias Monbin. A softwood timber that is not resistant to insects or decay. It is nevertheless occasionally used in the Bono region by "a lazy man who cannot find a hardwood tree," in the words of one Bono builder.

Babadua – Thalia Geniculata.

Dodowa – Sterculia Tragacantha.

Dwini – Baphia Nitida.

Fihankra – Tetrorchidium Didymostemon. F. R. Irvine claims that the wood is "soft and perishable," but Bono and Asante builders maintain that the wood is hard and insect resistant.

Kane – Anogeissus Leiocarpus.

Kokoaa – Identification uncertain. Possibly *Parinari Robusta*.

Kokobata – Pileostigma Thonningii.

Kranku – Butyrospermum Parkii. This is the well-known Shea butter tree.

Krayie – Pterocarpus Erinaceus.

Kwabedua – Dacryodes Klaineana.

Kyiribente – Lophira Alata.

Mmaa Kube – Borassus Aethiopum. Borassus palm.

Moto – Neuropeltis Acuminata.

Mpampuro/mkanpuro – Oxythenantera Abyssinica. Savanna bamboo. Although technically a grass, bamboo is used like timber in the construction of a house framework.

Mpapa – Elaeis Guineensis. Mpapa are the oil palm-frond midribs. The tree is called Abe.

Ngo ne nkyene – Cleistopholis Patens.

Nwoo – Identification uncertain. Possibly *Terminalia Glaucescens*.

Nyame Dua – Alstonia Congensis.

Odum – Chlorophora Excelsa. The leaves are also used for sandpaper.

Odwuma – Musanga Cercopiodes. A softwood timber used only for rafters.

Ofram – Terminalia Superba. A timber of moderate hardness, but not resistant to insects or decay. Used extensively for building purposes in the areas of dense forest.

Opesiakwa – Morinda Lucida.

Pam – Trichilia Heudelotii.

Pampani – Albizia Adianthifolia.

Pepaa/mpepea – Antidesma venosum.

Pinimu – Unable to identify.

Potorodom – Sterculia Rhinopetala.

Prekese – Tetrapleura Tetrapleura; also, *Prosopis Africana*.

Sisi – Identification uncertain. Possibly *Erythrophleum Africanum*.

Wama/awama – *Vitex Mesozygia.*

Fiber/Rope/Cordage Sources

Asense – *Urera* spp. A vine. Fiber is derived from the fibrous, woody interior.

Batatwene – Unable to identify. A vine. Cut and used as is.

Firaye – Unable to identify. A shrub. An extremely soft fiber is derived from the leaves.

Mfun/mfo – *Triumfetta Cordifolia*. A shrub. Fiber is derived from the stems.

Muto – *Neostachyanthus Occidentalis*. A vine. Cut and used as is.

Nem – *Ancistrophyllum Opacum* and *Calumas Deeratus*. The rattan palms. Fiber is derived from the split stems.

Notuo – *Hippocratea Africana*. A vine. Fiber is derived from the fibrous, woody interior.

Ntwea – *Hippocratea Rowlandii*. A vine. Cut and used as is.

Sibre – *Corchorus Aestuans*. A grass. Fiber is derived from the outer skin of the cane.

Sofo – *Christiana Africana*. A tree. Fiber is derived from the bark.

Toa-ntini – *Paullinia Pinnata*. A vine. Cut and used as is.

Sources of Thatch, Plaster, etc.

Asakoo – *Cissus Populnea*. A liane. The root–bark and stems are used in the manufacture of plaster.

Awuromo – Unable to identify. A shrub. The leaves are used for thatch.

Etoo – *Pennisetum Purpureum*. Elephant grass. The blades are used as thatch. The stalks, "hyiridie" (the Akan term), resemble small bamboo stalks and are used to build doors, gates, fences, "bamboo curtains," etc.

Sapotoro – *Grewa Mollis*. A tree. The bark is used in the manufacture of plaster.

Identifications were made with the aid of F. R. Irvine's Woody Plants of Ghana.

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Architecture in Java

Gunawan Tjahjono

This article focuses mainly on the architectural objects of the Javanese people whose worldviews are closely related to the court society of Central Java, Jogjakarta and Surakarta. As architecture concerns ideas of making meaningful space, this article will discuss the spread of ideas represented by various building types.

Throughout their cultural history, the Javanese interacted with five major religions and cultures: Hinduism, Buddhism, and Islam, China and the West (Europe). The most significant influences are from Hinduism and Buddhism, followed by Islam. Chinese carpentry affected East Java and some parts of Central Java. Western culture introduced modern town planning and new building types.

The Javanese House: An Architectural Type

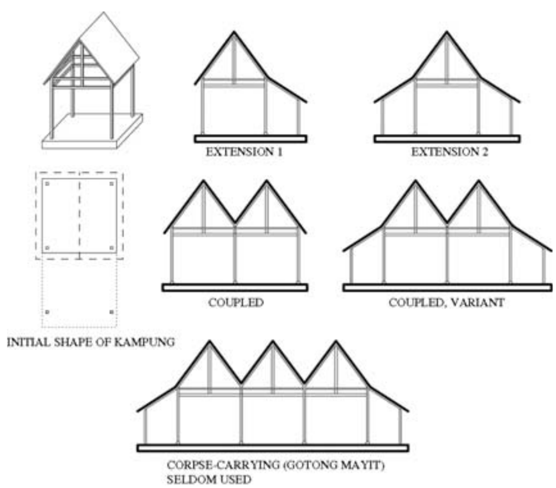
The house is perhaps the first structure human beings constructed to seek shelter. The inherent ideas in a house can thus serve as the architectural basis for other building types, such as temples, cemeteries, and cities. Although there are no remains of ancient houses, as they were constructed with perishable materials, one can trace the tradition of building houses from such remains as palaces and well maintained houses in two Javanese cultural cores around Jogjakarta and Surakarta; and also from the bas-reliefs of temples.

The temples' bas-reliefs illustrate the probable built environment of the Javanese past when stone and wood were the major building materials. Stone appeared in sacred structures, while wood appeared in residential structures. Buildings depicted there are on stilts. Tall pile structures as shown on the bas-reliefs of Central Java's temples can seldom be found in Java now. Low pile structures, as shown on the bas-reliefs of East Java's temples, can still be found in Bali. Thus people in Java probably lived on stilts.

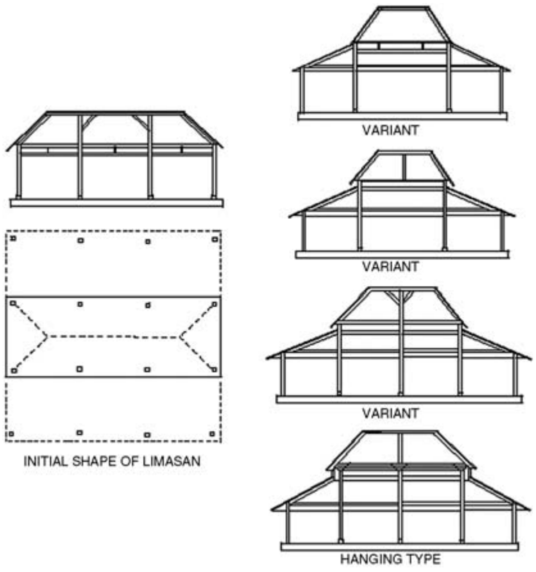
Javanese houses differ in roof shapes but agree in plans. Roof shapes were connected to the social and economic status of the owners. There are three major roof shapes for houses; *Kampung*, *Limasan*, and *Joglo*.

- *Kampung*, also known as *Serotong*, is the simplest shape and is used by the common people. It consists of four main posts braced by a double ring of beams. Two upper posts stand at the middle of one pairs of beams, usually those parallel to the north–south direction, to support the roof ridge beam. Two roof sheets meet at this line and fall away on either side of the beam. The roof can extend in one or two directions at different angles (Figs. 1, 2).
- *Limasan* is a more elaborate *kampung*. It requires more materials and effort to build and is associated with a higher socioeconomic status. It contains eight posts to support its trapezoidal roof. Two transitional posts rise at the middle of the beams that span the interior space between the middle posts. The main roof extends evenly to four sides (Figs. 3, 4).
- *Joglo* looks like a more developed *limasan*. It is more difficult to construct and was the most favorable shape for the nobility. It embodies several distinct features. These include a steeper main roof which resembles a pyramid that comes to two points and four main posts hold layers of wooden blocks which step back in several directions. The outer layer of these blocks holds the roof, while the inner, *Tumpang Sari*, the "essential piling up," divides the ceiling into two inverted pyramids (Figs. 5, 6).

A house consists of at least a basic unit containing essential spatial patterns that all social strata share. All houses have a sanctuary and two storerooms, a clear boundary between the inner and outer domain, and are patterned according to the hierarchy of sacredness of place. The house plan is independent of the roof shape,



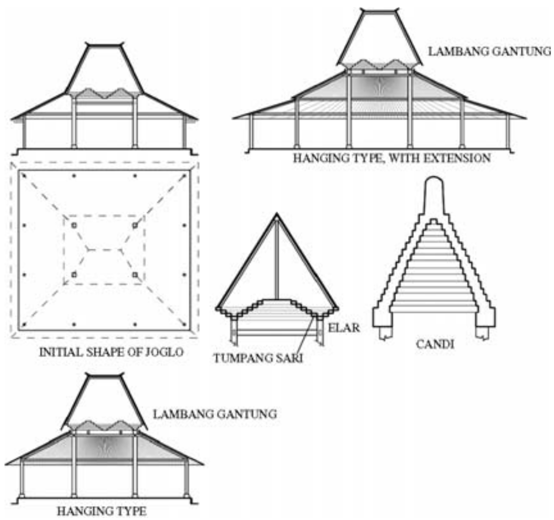
Architecture in Java. Fig. 1 The Kampung (Schematic drawing. Illustrator: Paulus).



Architecture in Java. Fig. 3 Limasan (schematic drawing. Illustrator: Ary Dananjaya Cahyono).

Architecture in Java. Fig. 2 (Photogragh: Author's Collection).

Architecture in Java. Fig. 4 Photo image of a limasan roof (author's collection).



Architecture in Java. Fig. 5 Joglo (schematic drawing. Illustrator: Paulus).

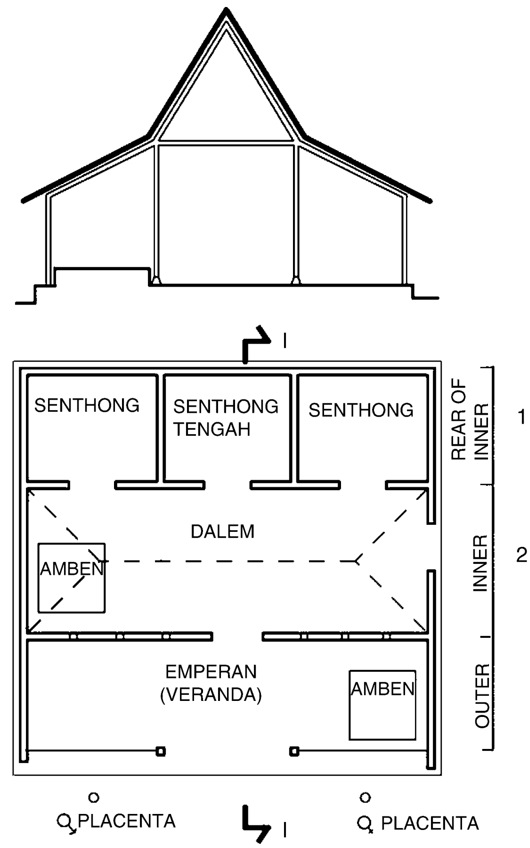
Architecture in Java. Fig. 6 Photo image of Jogo (author's collection).

especially for *kampung* and *limasan*, and to some extent, for *joglo* which has a more elaborate spatial division.

The basic unit of a house is *omah,* which employs a rectangular plan emphasized by a raised floor. It encompasses an inner and an outer domain defined by wall panels. The outer, *emperan* or porch, is about 2 m wide to accommodate the family's more public activities. There is a wide bamboo bench for sitting, lying or sleeping. A wide door at the middle of the front wall connects this domain to the inner part.

The inner, *dalem*, is an enclosed structure which is subdivided into either two: front-rear, or three: front-middle-rear sections along a north–south axis. Each section suggests three spatial domains along the east–west axis. A two-section *dalem* applies usually to a *kampung* or a *limasan* roof, while a three-section one is for a *joglo*.

The middle section, if any, which is defined by four main posts at its center, has no exact usage. The central part was where the incense was burned once a week in honor of the rice goddess Sri, who occupied a permanent place in the house at the center of the rear section.



Architecture in Java. Fig. 7 Plan of a two section Omah (Illustrator: Paulus).

The rear section encompasses three enclosed rooms called *senthong*. The west senthong stored agricultural products. The east one stored other equipment or was sometimes empty. The middle senthong was the most lavishly decorated but the least used part of the house. It was the sanctuary of the rice goddess Sri and thus took the form of a fully equipped bed. The function of this room would be fully revealed during the most celebrated ritual, the wedding ceremony. In this ritual the bride and bridegroom sit at the front of the *senthong tengah*, underneath the house ridge. Now many Central Javanese have transformed the once sacred *senthong tengah* for prayer. Many new houses now do not follow concepts from the recent past but from examples of new models in the big cities (Fig. 7).

An ideal house should have at least two, and if possible, three main structures: an *omah*, a *pendapa,* and a *peringgitan*. Pendapa is a roofed open hall located at the front yard of an omah. Its shape, size and position of posts are often akin to those of the omah. It displays a different spatial quality from that of an omah. It is open, accessible and lighted, while omah is opaque, forbidden and dark. Pendapa is the public domain of a house, a place for gathering and ritual performance and informal entertainment. Peringgitan, which employs a *kampung* or a *limasan* shape, connects pendapa to omah. It is a place for the performance of the shadow puppet play *wayang*, the ritual in Javanese culture that predicted life cycles, harvest, and higher rank career promotions.

The kitchen stays outside an omah, separately built near the well. A well should be the first to be dug out prior to the construction of any erected structure. The well also serves a later developed lavatory which has its own structure at the left and the back of a house compound. As the number of families and income grew, new structures expanded first to the east or to the north, then to the south for pendapa, and next, as needed, to the west to complete the symmetry. In an expanded house, the family lived in the wings and the omah became a real sanctuary.

Most houses in Central Java whose entries were facing south have front, sides, or back yards within a clear boundary marked by a brick wall or low fence. The enclosed wall often has a roofed or unroofed gate, which connects the inner world of family to the outer universe of community. After selecting and purifying a site and after digging out a well, the next step is to determine the location of the omah, as it should always be built first. After setting the omah's position, the team of community volunteers led by a carpenter starts the construction. The basic house plan is a matter of measurement and house shape of affordability. The carpenter will adjust the dimensions derived from the dweller's body to determine the size of the house.

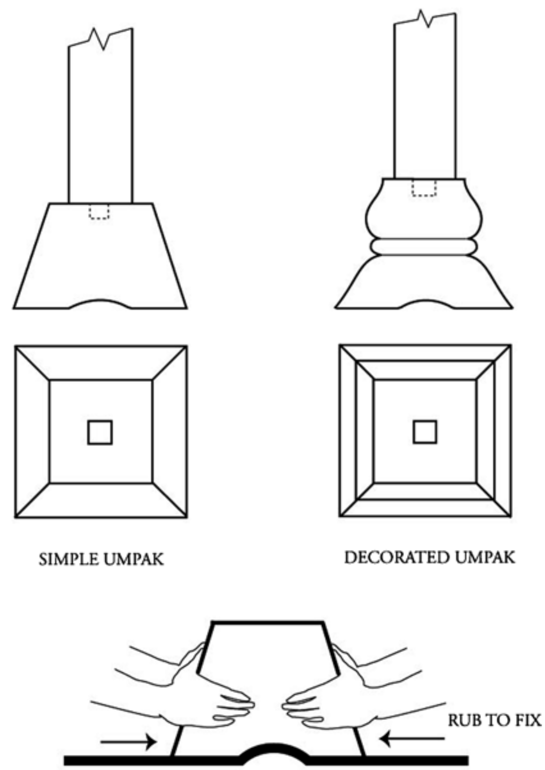
The construction follows this sequence:

1. Dig the well
2. Erect the omah
3. Build the east *gandok* or kitchen
4. Construct the pendapa
5. Finally set up the west gandok
6. Fencing is the last, if needed, to be done

Construction proceeds by leveling the site and improving the strength of the soil by piling bamboo or stones around the edge of the main building. Its floor is often elevated to help drainage. The main posts are usually on *umpaks*, the three dimensional trapezoidal stones which act as transitions between the posts and foundations. The size of the umpak varies, from 20×20 cm^2 to more than a square meter, dependent upon the dimension of the post, which commonly ranges between 12×12 and 40×40 cm^2. Umpak is a structural device which reduces horizontal forces caused by earthquakes. It prevents the posts from the infiltration of ground water. The wooden posts always stand according to the direction of tree growth (Fig. 8).

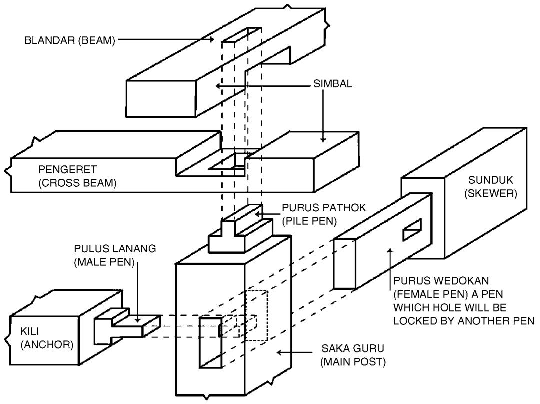
Two or three parallel beams join the post at its top. The posts may directly support roof trusses or roof beams. In the case of joglo, the main posts are usually topped by two sets of inward stepped wooden piles, *tumpang sari,* and outward stepped piles, *elar*. The number of tumpang sari steps reveals the status of the owner. The roof sheet is framed by wood blocks or bamboo sticks (split in half); the smaller blocks or sticks are laid parallel in a horizontal position with some distance between each other. All blocks are in a horizontal position rather than upright which, as seen individually, is more appropriate to the law of force of material (Fig. 9).

The post has pens at both ends; the lower fixes the umpak and the upper plugs in the hole of the main beam, which represents females. At the upper position



Architecture in Java. Fig. 8

Architecture in Java. Fig. 9 Tumpang Sari (Author's collection).



Architecture in Java. Fig. 10 Construction join (Illustrator: Paulus).

of the main post, a hole is cut out to be filled by the pen of a secondary beam which acts as a stabilizer, as opposed to the beam above it. The basic structure is stable upon the completion of all plug-in procedures. The term for pen is *purus* meaning the male sex organ. (Fig. 10).

Modular Coordination and Mobility

The Javanese book of carpenter Kawruh Kalang mentions the basic measurement unit *dim* which is determined by either the length of a foot or the width of a fist. The length of beams and the interval between posts apply the formula $5 \times n \times \text{dim} + m$. The m should be within one to three because four or five dim is considered an inauspicious number for the initial structure, and n is any number defined by a special event such as a wedding. In it a fourfold modular grid based on serving devices is applied. Under such a practice, the interval between the main posts averages 2.5 m, being approximately the width of two floor mats. Plug-in construction join and the application of modular coordination have the flexibility to mobilize the house. A house can be moved after it has been torn down into construction parts and refabricated at other preferable places.

Although there is no concrete proof about the origin of Javanese houses, they can be traced back to agricultural tradition. Buildings for worship or commemoration altered as religion changed. However, the ideas that generate a house remain the source for the spatial arrangement of other buildings.

Buildings for Worship: The Hindu–Buddhist Legacy in Javanese Architecture

Hinduism and Buddhism, whose imprints in Java can be traced back to the fifth century, affected most forms of cultural expression, such as religion, art, (a certain degree of) social organization, technology, language, and statecraft. The intensive ceremonial life filled the interior Javanese landscape with *candis* (temples). Remains of habitats in the forms of foundation stones that spread around various candi complexes indicate that social organization was centered on religious ceremony at the state and, to some extent, the village level.

In prehistoric Java, mountains were the places where the ancestral spirit could be contacted for protection and prevented from their wrath by offerings. *Lingga*, an upright stone and *yoni*, a flat stone plate, were possibly the first erected effigies to consecrate the center of the universe symbolizing creation and fertility. Later on, Hindu Javanese candis were designed to replicate mountains at the high places where spirits of the gods could be induced to go down into a lingga in a cave-like hall. Candis were enclosed by walls to divide the sacred inner from the profane outer. In the inner zone the priests presented offerings, performed prayers, and contacted the gods when they descended to earth. Thus temples were not for holding large numbers of peoples.

As religious buildings, candis were built to last in stone or brick. Archaeologist Jacque Dumarçay observed that the Central Javanese stone candis developed the techniques of interlocking stones articulated with perspective effect to cast expected results. They cut the stones into several modular blocks and created stone courses by joining stones placing one on top of the other without mortar.

The early eighth century Hindu Javanese candi compound is located at the Dieng Plateau. The four major candis known as Arjuna group face west. Candi Arjuna comprises a square room constructed over a pit containing a foundation deposit for ritual. The stone blocks interlocked through tongue-and-groove connections by having cut a section out of each stone in horizontal and vertical directions. The eighth century Buddhist temple compound Candi Sewu's stone wedges were driven between the stone blocks, pushing adjacent sides outward toward the corner of building, strengthening the course and reducing the gap between joints. The ninth century's Candi Loro Jonggrang of central Java exemplifies the greater stone technology achievement in Hindu Javanese candis. Here, according to Dumarçay, the technique of double-leaf walls was adopted by establishing a pair of parallel walls, then filling the gap between them with rubble or unshaped stones by using mud or lime.

The Buddhist legacy Borobudur of the ninth century exemplified such techniques with an adjusted ten-layer *mandala*[1] plan. The 113 m side long square plan base tells the story of a worldly sinful life through carved

[1] Mandalas are geometric designs intended to symbolize the universe.

bas-relief. Ascending from the base are three layers of stepped enclosed roofless corridors with each wall relief describing the world of daily life. Up another three layers one finds on one side a slightly opened corridor which depicts the world of form as the intermediate experience of the last three layers. The last three layers represent the formless world without enclosure so one can also look out against the blank wall. At the top layer, whose center is a *stupa*, you could watch your surroundings as if the whole universe were under your eyes. To experience Borobudur, one ascends nine peripheries of adjusted squares whose size decreases gradually to the top. It brings visitors through a spiral labyrinth route to find nirvana.

Candi Loro Jonggrang exemplified the highest achievement of the Central Javanese Hindu legacy. Consecrated in 856, it was a complex dedicated to Siva and was possibly related to a town of the same size. It consists of three walled courtyards on ascending terraces. The inner two courtyards are concentric and facing east, while the outermost is aligned another way. The terraces are made of heaped-up earth. Eight major sanctuaries fill the upper terrace. Three cruciform plan structures are devoted to the trinity of Hinduism, Siva, Vishnu, and Brahma. Facing each is a smaller structure for vehicles or mounts of the god. Two accompanying candis stand at the south and north entrances of the complex. Two hundred and twenty-four smaller structures fill the four lower terraces of the middle courtyard; those at the corners have two doors and the rest have one door. Such an arrangement recalls the image of mandala (Fig. 11).

Architecture in Java. Fig. 11 Lorojonggrang of Prambanan (author's collection).

Dumarçay concluded from his research on the stone construction of temples in Southeast Asia that Borobudur and Loro Jonggrang applied a perspective principle to create special visual effects in their construction, so that visitors could experience the glory of their existence from various angles. For Borobudur it is at its base that this effect was applied so that its upper terraces would be visible. In Loro Jonggrang it is through the manipulation of the form which enhances the feeling of height.

Buildings for Worship: The Islamic Legacy in Javanese Architecture

Islam spread gradually from the twelfth century on. It began with trade around the ports and then infiltrated the interior of Java. The earlier Islamic buildings retained references from Hindu architectural elements such as ceremonial gateways, split portals and multilayered roofs.

The concept of early mosques in the interior cultural core of Central Java around the sixteenth century resembled that of a house. Dutch scholar de Graaf identified seven distinctive features of these mosques as (1) a square plan, (2) a raised solid floor, (3) a multilevel roof that peaks to one point, (4) a roofed veranda called *serambi* at the front, (5) a *mihrab* – an annex or niche on its western or northwestern edge to indicate the direction of Mecca, (6) encircling by water, which in turn is surrounded by open spaces, and (7) a wall that encloses the whole complex. In addition to those features, the door of early Javanese mosques faced east, with the prayer direction oriented toward the west rather than Mecca.

Of these features, the square plan, raised floor, and walled enclosure can be found in the structure of the remaining Hindu Javanese temples, while the one-point multilevel roof is a common element of the Balinese Meru that existed in East Java before the domination of Islamic culture. The niche, *mihrab*, is a common element in mosques elsewhere in the world; perhaps each regional culture incorporates it differently. The encircling water is an adaptation of a moat appropriated to Javanese cosmology which can be found in old Javanese palaces. *Serambi* is a typical Javanese creation. Separating the sacred domain from other domains is parallel to the division of activity zones in a house. An ideal complete house exemplified such an idea by separating other daily activities from omah, especially the senthong tengah. The spatial quality of a sacred domain, which was usually governed by darkness, as in the main mosque and in the dalem, appeared to dominate Javanese thought (Fig. 12).

The great mosque of Demak of Central Java exemplified all the principles and became the model for

Architecture in Java. Fig. 12 The Great Mosque of Jogjakarta (author's collection).

the subsequent mosque around coastal Java. Its influence continues, as can be seen by the reproduction of its basic shape in the mosques built around Indonesia sponsored by former President Suharto. The four main posts that support the upper roof were originally made by tying pieces of timbers with iron strips.

The additional element in many recently built mosques is the crown, which is now in the shape of a small dome, a result of native adaptation of an outside idea. The onion shaped dome has been associated with Islamic architecture in many parts of the world. However, such a dome has seldom become the main body of the roof in the Javanese mosques. A dome reduced in size is employed as a crown to top the roof. It is interesting to note that any new mosque, whose construction is funded by a special presidential grant, must follow the traditional Javanese two-layer *tajug* roof shape.

The House Extended: Settlement, Palace and City

Settlement patterns in the cultural center of central Java follow the north–south axis. Almost all traditional houses located in this district face south. Some coastal settlements are linearly aligned facing east for the north coast of East Java. The linear arrangement appears in many coastal zones. This is the most practical arrangement considering coastal conditions. Rural houses seldom have pendapa. Housing in the Cilacap, southern Central Java coastal area, has a common hall as a collective pendapa. This instance raises questions as to when the pendapa became the exclusive property of the urban elite.

A concentric settlement called *mager sari*, or fencing the essence, applies in urban Central Java. In it the houses of the wealthy were enclosed by the servants' houses. It is a reflection of a feudal society which illustrates the master–servant relation. The master is the center and the servants are represented by the fence. The palace or *kraton* compound exemplifies these relations.

Kraton refers to the seat of a ruler at a level of king or prince. The term is widely used in many Indonesian Islands such as Sumatra, Java, Kalimantan, Sumbawa, Sulawesi, and Maluku; it is applied not only to an Islamic kingdom, but also a pre-Islamic one. Kraton was a dynasty's center of power, and usually generated an urban environment around it. In Java, e.g., it was the kraton, rather than the territory that identified a kingdom's geographical image.

Most kratons are located on a plain served by a river and its tributaries. In Java, the seat of a kraton was usually backed by a single coned sacred mountain. The Javanese kratons manifest these relations even stronger through axial positioning of the building complex toward the sacred mountain. A kraton comprises several buildings within a clear boundary. Descriptions of such boundaries of older kratons have not been supported by archaeological findings; possibly the materials for the palisades could not survive the tropical climate. The fence can be easily found in more recent kratons. Large kratons, such as those at Banten in West Java, Cirebon in Central Java, Jogjakarta, and Surakarta, had stone-walled boundaries. The wall was a defense device as well as a representation of hierarchical segregation based on status or sacredness.

As an ideal center, the alignment of a kraton reflects the ruler's views on the universe. The kratons of both Jogjakarta and Surakarta expose these images through a series of courtyards and gates lined up on a north–south axis. The axis replicates the directions of the mountain and sea and of cardinal points in Hindu cosmology. The Sultan's residence contains the royal pleasure garden which is located on the outskirts of the inner wall. The main pendapa, where the Sultan held audience, is the only building that faces east. This pendapa created a new east–west axis.

The main pendapa exemplified the most refined construction of a joglo. Timber blocks and rafts frame its roof sheet. The rafts are laid parallel in a horizontal position with some distance between each one. They are tied onto the layers of larger blocks and are arranged in a sun ray or centrally organized pattern. All the blocks are horizontal rather than upright. Dutch architect Maclaine Pont suggested that the Javanese

Architecture in Java. Fig. 13 The Great Pendopo of Jogjakarta Kraton (author's collection).

treated their roof as an entity rather than the sum of individual elements (Fig. 13).

The *alun–alun* or town square is related to the seat of power. Two banyan trees stand at the alun–alun's center to symbolize harmony. The alun–alun was the meeting place of the Sultan and his people. It held major state rituals, festivals, games, and in the past was a place for punishment. The north alun–alun of Jogjakarta still hosts major cultural events today. It is encircled by several important buildings – the state mosque at its west, the main market and a prison at its north, with some other buildings around. The mosque was usually followed by a compound of the *kaum* – the religious experts who initiated religious rites and ceremonies – called the *Kauman*.

The kraton determined the conceptual layout of the city associated with it. From the toponyms one can trace this order in such old towns as Kuta Gede near Jogjakarta and Banten. According to sociologist Selo Soemardjan, the city of Jogjakarta exemplifies the social strata through several rings, which started with the Sultan at the center, with his family around him, and other nobility within the walled compound. Around the wall is the ring of town community surrounded by the rural community. The town community comprises those who have frequent contact with the ruler such as the smiths, the slaughterers, the carpenters, the kaum, and the merchants. The rural community is in charge of cultivating agricultural land.

The layout of both Jogjakarta and Surakarta suggests a Javadvipa, the central continent of the whole cosmos which consists of seven rings of continents separated by seven rings of ocean. Javadvipa contains seven mountains and six plains along a north–south axis, and four mountains and plains along the east–west axis. At the center is the *Mahameru*, the sacred mountain. Both kratons have six courtyards and seven gates with the seat of the sultan at the center to represent this inner cosmos.

This pattern, to some extent, can also be found in a coastal Javanese kraton and its cities. Since the coastal areas had many foreign traders, the ruler also provided a special zone for foreigners which served the same function as a kampung.

Kraton, square, state mosque, and market are the basic features for most Javanese towns. Their appearance set guidelines for building shapes around them. The other governmental centers followed such patterns during the period of Dutch control. The square accommodates recreational activity for the citizen. The mosque also serves as a religious court. The markets have peak activity once a week. There are coastal markets, littoral markets and agrarian town markets. Their location defines the character of the town economy. Such patterns also appeared in other towns, with the office of the ruler at the center and a town square which connected the mosque, marketplace and prison.

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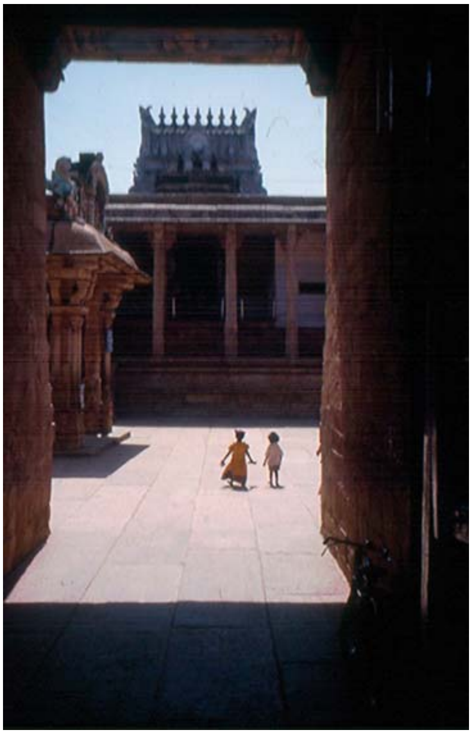
Architecture and Landscape in India

Alexandra Mack

Architecture and landscape are connected on many levels in India. The meanings imbued in the architectural forms create diverse conceptual landscapes overlain on the same geographical area. Architecture defines the landscape, and the presence of different architectural traditions helps create these multiple landscapes. Architecture is used to highlight the landscape's association with the cosmos, with mythological events, with historical and current events, and is also the frame for where people live and work (Mack 2004). This essay will focus primarily, though not exclusively, on architecture built in the Hindu tradition.

The connection between the earthly landscape and the celestial landscape has been apparent in India for thousands of years. There is evidence at Dholavira and other Harappan sites that the cities were planned with axial orientations, apparently following the placement of sky based features (Bisht 2000). Celestial orientations become more apparent in cities and towns built based on the sixth century architectural manuals known as the *vāstuśāstras*, which mandate a grid plan based on the maṇḍala form (Deva 2000). The maṇḍala can take many forms but is essentially a series of concentric geometric figures which represent the structure of the universe. The figures of circle, square, and triangle can be interpreted as representing the elements of light, water, and wind, respectively. They can also represent the four directions, the nine planets, and the three mythic realms (Singh 2000). Maṇḍala-inspired architectural arrangements reflect the cosmological structure in the earthbound landscape, thus connecting the two.

The maṇḍala is frequently represented in Hindu temple complexes and the surrounding towns. This structure is most apparent at sacred sites which serve as pilgrimage centers. The maṇḍala is first reflected at the level of the individual structure of the temple. The geography of the temple is ideally situated on a north-south axis, with enclosure walls and circumambulatory paths creating a series of concentric squares. The *vāstuśāstras* even dictate a formal ritual for measuring and laying out the shrine. Temple towns are frequently laid out to continue the maṇḍala plan, with the temple complex at the center of the town, and streets running around the walls and leading out from the gateways in the cardinal directions (Michell 1993). At Srirangam, the temple is enclosed by seven sets of walls, creating a clear maṇḍala form radiating outward and encompassing part of the town (Fig. 1). Likewise, Madurai and Chidambaram have multiple enclosures around the central temple, with main streets running parallel and perpendicular to the complexes. Some temple towns, such as Kanchipuram and Kumbukonam, house multiple temples, and the spatial arrangement in the town reflects this. Each temple is the center of its own district, and each district has a distinct geometric form. Roadways in these towns tend to link these distinct neighborhoods, forming a unifying whole in that way.



Architecture and Landscape in India. Fig. 1 A view from a gateway into one of the interior courtyards of the Ranganatha Temple at Srirangam shows how the complex is a series of embedded rectangles.

The geometry of the built environment spreads out into the landscape, thus imposing a structure on the landscape through architecture.

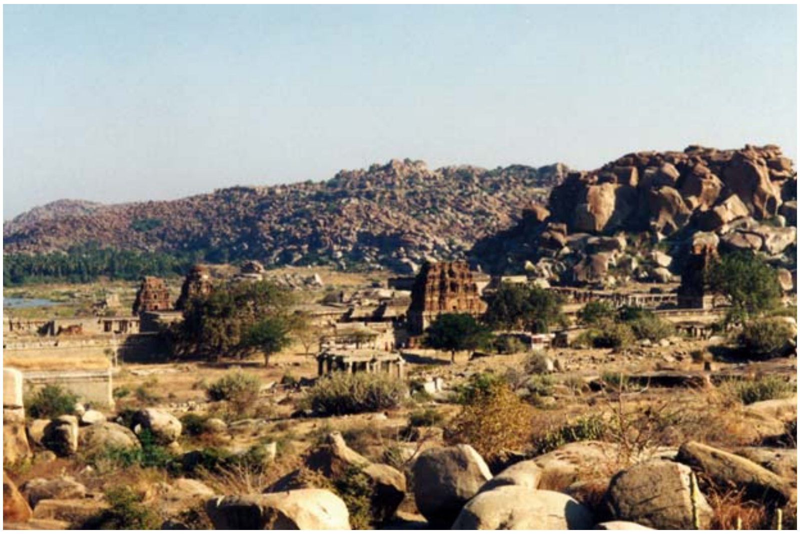
While the built environment can structure the landscape, the physical features of the landscape determine the placement of architecture and influence the nature of the geometric forms of the towns. Vijayanagara is set in a landscape of bouldery granite outcrops, leaving the valleys between as prime construction areas (Fig. 2). Nonetheless, while the landscape strongly influenced the placement of structures, the city nonetheless shows an axial layout and cosmological affinities (Malville 1994).

Circumambulation reinforces the connection of the natural and built environment, and draws connections to the celestial world, since circulatory paths in India are often represented by the maṇḍala. Physically moving though the geometric pattern symbolizes a cosmic journey. The *panchakroshi* route at Varnasi moves pilgrims through 108 shrines spaced in a mathematical pattern which embeds the geography of the site into the psyche of the pilgrim. The 108 shrines also represent a cosmic circuit based on 12 zodiac signs and the nine planets of Hindu mythology (Singh and Fukunaga forthcoming).

While the maṇḍala is an ideal form, influencing architectural constructions, the landscape itself is a key determinant in the location of these structures. Landscape features have sacred qualities, but the built environment is fundamental to imbuing the land with meaning. Landscape and architecture thus are intertwined physically and conceptually. The *vāstuśāstras* prescribe the placement of settlements near water sources, such as river confluences. Rivers represent confluences of sacred and profane and provide homes for deities. Therefore rivers become magnets for settlements and sacred sites, though a nearby water source is essential for sustaining a population, irrespective of the holiness of the site. Most of the ancient towns in India are found of the banks of sacred rivers, such as the Ganga and Yamuna. The seven cities (*Saptāpurī*) of Varanasi, Mathura, Ayodhya, Ujjain, Dvarka, Kanchipuram, and Hardvar are all located on peninsulas, surrounded on three sides by water.

Hills and mountains are also an important landscape element in the Hindu tradition, and like water these features provide domiciles for gods (Fig. 3). The mountain of Tirumula is the home of the god Sri Venkateswara, and the temple there draws the largest number of pilgrims of any Hindu temple. The town of Tirupati at the base of the mountain developed in support of this holy site (Nag and Reddy 1994). The hill at Tiruvannamalai symbolizes the column of fire from which Shiva emerged, and serves as the basis for the conceptual spatial organization for the town. Patterns of movement also serve to connect buildings with the natural landscape. Circumambulatory routes and ritual paths extend far beyond the temple complex, connecting multiple shrines, in cases such as Varnasi, or encompassing the landscape itself, such as the circumambulation of the sacred mountain at Tiruvannamalai, which also includes a journey through the town itself (L'Hernault 1993). These routes blur the line between the built and natural environments.

Beyond the water and hills, entire landscapes are often imbued with symbolic and mythological meaning. Landscapes associated with the Ramayana legend are key examples of this phenomenon, as seen at sites such as Ayodhya, Chirtrakut, and Vijayanagara



Architecture and Landscape in India. Fig. 2 The Vithala temple complex at Vijayanagara is set in a valley below granite outcrops, near the Tungabhadra River.

Architecture and Landscape in India. Fig. 3 A shrine on the top of Malyavanta Hill at Vijayanagara blends with the rocks.

Architecture and Landscape in India. Fig. 4 Humayun's tomb in Delhi sits in man made landscape, where the tanks, gardens, and walkways follow a grid pattern.

(Sinha forthcoming). The pilgrimage circuit at Ayodhya, the site of Rama's birth, takes worshippers to shrines along the banks of the Saryu River, which encircles the town. The river, ghats, and shrines combine to form the total landscape. At Chitrakut, the physical landscape is dominated by the Mandakini and Payasvini rivers, and enhanced by the specific sites associated with Rama and Sita. The area around Vijayanagara is associated with Kishkinda, the monkey kingdom. The Tungabhadra River cuts through the landscape, though the hills form the most significant natural features, and many are associated with the Ramayana—Hanuman is said to have been born on Anjenadri Hill, and Rama and Lakshmana waited out the monsoon on Malyavanta Hill. These hills have been adorned with temples commemorating these events, intertwining the man-made and the natural.

Architectural associations with important events and personages are seen at a variety of sites in India. Stupas, which themselves represent the body of the Buddha, house relics, though in these cases the relics have been brought to the site, and were not necessarily an inherent part of the landscape before construction of the stupa. Elaborate tombs built by Muslim rulers include tanks, gardens, and well-defined paths, creating their own landscape (Fig. 4). Muslim dargahs often attract pilgrims who honor the holy men entombed within, and mark the importance of a specific place on the landscape. Religious claims on the landscape are not necessarily exclusive; multiple religious shrines from different traditions share the landscape at sites such as Ellora and Mathura (Ray 2004).

This historic and mythological significance of the landscape and the associated religious architecture was

Architecture and Landscape in India. Fig. 5 Children playing and grinding food on a side street near the Banashankari temple, occupying the "quotidian landscape."

also used by rulers to lend credence to their claims to power. Basu has argued that the Buddhist Kushan rulers at Mathura built structures specifically to associate themselves with the site's existing sacred geography (forthcoming). Early in the development of the Garhat states of Orissa, forts and settlements were placed on the landscape with defense and supply from nearby villages in mind—forts were protected by hills and jungles. However, rulers maintained their link with the villages by associations with local deities, who were worshipped within the walls (Kulke 1993). This legitimation through the ritual landscape grew in scale as the towns grew. The Ramachandra temple at Vijayanagara was used by the kings to enhance their legitimacy, by associating themselves with the god-king who spent time in the surrounding area. They used the architecture and specifically the placement of the buildings, to build those associations. The temple was built in the heart of the Royal Center, amid palaces and the kings' seat of power. Fritz has argued that the city was planned such that the Ramachandra temple lay at the center of routes of circumambulation and was on an important north-south axis in the city, such that the overall structure of the city was planned to draw associations between the rulers and Rama (Fritz 1986). In this case, the mythic associations of the site were manipulated by Vijayanagara rulers to enhance their own power and to legitimate their rule in the eyes of local chiefs and other high-ranking citizens. However, the sheer act of construction was also used for legitimation, with or without mythic associations. Medieval temples with towering gateways were, and in many cases still are, the most dominant landscape features, and were directly associated with rulers whose funds aided their construction.

While research into the importance of cosmology, mythology, and legitimation have dominated landscape studies in India, the most common usage of the landscape has been for day to day residential and subsistence activities. Most importantly, these activities occur in the midst of all the other happenings. For instance, while axial layouts and cosmological orientations are applied to temples and surrounding towns in order to maintain a ritual integrity, these neighborhoods are also the centers of everyday life. At Srirangam, which was mentioned earlier as an archetypal maṇḍala shape, boys play cricket in the streets on the outer circuits of the walls. A few steps from the primary circumambulatory routes in any temple town leads to residential areas, local shops, and mundane activities—a quotidian landscape (Fig. 5). This overlay of secular and religious use of the same landscape is seen throughout India, at sites sacred to all religious traditions.

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Architecture of the Maori People

Michael Linzey

The most striking fact about Maori architecture is that it is a living presence in the traditional heart of the community. When a New Zealand Maori orator stands to speak in front of a meetinghouse, he (or sometimes soon it may be she) addresses the house directly and in the same breath also addresses the assembled people. This fundamental understanding that the *wharenui* (meetinghouse) is a living presence is richer than any mere simile, it is beyond the idea of a metaphor or a representation in the European sense (Mead 1984). The house is not *like* an ancestor, it *is* the ancestor. Maori people conceive of cosmogenesis as an evolution in three parts: *te kore* is a nothingness condition of endless possibility, *te po* is a long night that is rich in potentiality, and *te ao marama* is the world of light which is to say the actuality of the real world. These three fundamental states of existence are represented on the door lintels of traditional architecture (Simmons 1985. 43–47). This traditional understanding resembles the triadic cosmogony of Peirce (Peirce 1992, v. 1: 285–297); it may not be entirely surprising therefore that the idea of an interconnected life-force, *mauri*, pervades the physical world of the Maori, and that architecture is included in this universal embrace.

I am not talking here about the precontact condition of Maori architecture [about which anyway very little is known (Phillipps 1952.rpar;]. What is more significant is that the Maori comportment toward architecture has survived within a predominantly European ambience of New Zealand life, perhaps indeed it developed more pronouncedly within the clash of cultures that was the introduction of colonialism and the rise of nationalism during the nineteenth and twentieth centuries. Modern Maori are not isolated from the majority culture, just as in New Zealand nothing European can claim to be isolated from the Maori presence. But whereas we sometimes lament the loss of meaning within European architecture, and some even go so far as to say that architecture is dead, the architecture of the Maori by contrast is radically alive. It is a living example of the scientific condition that Peirce called "objective idealism," in which the material world itself is understood to be fundamentally alive.

In the confines of this short article three aspects of the living meaning of Maori architecture are addressed. They are its *faciality*, its *ornament*, and an aspect of its *space*. Relevant terms in the Maori language are *mataihi*, *whakairo*, and *kauhanga*. These are not general terms; they have meanings that are quite specific to architecture. In particular the *wharenui* is often also called (and addressed as) *whare whakairo*, meaning a house that is adorned with pattern. *Mataihi* specifically means the gable-end (the front) face of the *wharenui*, and *kauhanga* or *kauwhanga* is the interior space down the middle of the *wharenui* specifically when it is in a *tapu* or highly potent state. Necessarily these three aspects of architecture have to be addressed separately in this article, but they are not separate, not even interrelated concepts. Rather they are three valences that together go to make up the single meaning of addressing the *mauri* or life force in Maori architecture. If I may follow Peirce for a little bit longer, this triadic situation can be compared to an ordinary street sign. A street sign also *faces* us, *points* out a direction in the world, and *tells* us something about what is happening in that direction. The three valences *together* make up the whole meaning of the sign. A reader may be advised to take in what follows here, necessarily in the sequential order of the text, and then to think about it again in a few days time. Perhaps then some small appreciation may be gained about the liveliness of Maori architecture as a whole triadic sign.

Faciality, *Mataihi*

In Maori, as in most of the Austronesian languages, *mata* is a word that signified the leading part or the growing tip of something. It does not indicate a direction, but a frontal *sense* of direction. As well as meaning a person's face, *mata* can also be a prominent geographical point, like a headland, or a rock which marks the leading boundary between fishing grounds.

The prefix *mata-* is used in words that mean a first appearance, for example *mataika* is the first person slain in a battle. *Mataaho* is the window of a house, metaphorically perhaps we could think of it as the "eye" of the house. *Mataihi* is the gable-end "face" of the meetinghouse. In the *Williams Dictionary of the Maori Language*, the word *mataaho* was recorded as early as the first Edition (1844). *Mataihi* appeared for the first time only in the fifth edition (1917). This is not to say that *mataihi* was not a traditional word, but its architectural meaning was perhaps less obvious to early lexographers than *mataaho* was.

Internationally, the ornamental *mataihi* of the *wharenui* is the best-known icon of Maori architecture, comparable to the full *moko* tattooing of the chiefly face. As often as not it is the stately face of Te Tokanganui-a-noho that has carried this image of Maori architecture to the wider world. Te Tokanganui-a-noho is one of the oldest extant meetinghouses. It was built and reconstructed and relocated over a period of years from 1873 to 1882 under the supervision of a visionary leader of the time, who was also the founder of the Ringatu Church, named Te Kooti Arikirangi Te Turuki (Binney 1995. 272–281). The design of this house not only reaffirmed traditional values in a time at which Maori were experiencing all sorts of upheavals, it was also without doubt the most innovative house of this period and it started many trends that were taken up in later meetinghouses. In particular Roger Neich (1993: 175–185) notes that most of the carvings on the gable-end face of this meetinghouse (with the notable exception of the carved door lintel and doorposts) were brilliantly delineated with polychrome paint; naturalistic flowers and religious symbols were painted on the vertical boards inside the porch, and naturalistic portraits of historic personages were on the door panels.

Almost all modern (postrenaissance) meetinghouses in New Zealand now adopt the traditional gable-end form. However the rectangular plan of the *wharenui* and the characteristic gable-end porch is not the only form in which Maori architecture has ever been expressed. A very traditional *whare wananga* or house of learning named Miringa Te Kakara was first built probably in the 1860s and destroyed by fire in the 1980s. This beautiful work had a distinctive cross-shaped plan and four *mataihi* facing the directions of four mountain ranges. Another memorable image is that of the circular "beehive" shaped assembly house named Hiona which was built early in the twentieth century by Rua Kenena (Binney 1996). An awkward-seeming scaffold, platform and staircase were constructed to one side of Hiona which may have been a necessary substitution for faciality in the form of this work. Many Maori churches too do not display the traditional *mataihi* form. In the case of one early church, Rangiatea, completed in 1851 by the famous chief Te Rauparaha, it is recorded that the Reverend Samuel Williams played an important role in its design when after a dispute and in the middle of the night he cut a 10 foot length off the ridge pole. It is interesting to speculate that the dispute may have been related to a perceived conflict between the more traditional Maori expression of faciality, which would have required the extended ridge pole (*tahu*) to support a gable-end porch, and the shorter inward-looking Christian church form that was eventually adopted.

In the case of the pan-tribal meetinghouse Te Hono-ki-Hawaiki which was recently incorporated in the Museum of New Zealand Te Papa Tongarewa in Wellington, the meetinghouse almost seems to be reduced to a pure expression of *mataihi* or face (►http://www.tepapa.govt.nz/virtualhighlight/Marae_english.html). The designer Cliff Whiting comments that this was partly a result of compromises that were necessary to develop a pantribal *kawa* (protocol). The Maui family group was adopted to embrace the widest possible sector of the population including Maori and Pacific Island people. Te Ati Awa and Ngati Toa, as *tangata whenua*, the local hosts, were made responsible for figures on the *amo*, the two side posts of the meetinghouse, while many other figures on the gable-end have yet to be named at all. Whiting remarks that *iwi* (tribal groups) from all other parts of the country can opt to "come into it" or not as they wish. In this sense the *kawa* of Te Hono-ki-Hawaiki is in a state of incompleteness, like the incomplete, yet to be negotiated political *kawa* of biculturalism in New Zealand. Its *mataihi* signifies a dynamic temporal sense of "facing the future" and of going forward with political intent. It has often been remarked that the classical Maori body "faced" the past and had its back to the future, and the front of a meetinghouse more often represents a region of timeless myth and legend (Neich 1993. 232). This modern version of *mataihi* at Te Papa in effect employs the myth of Maui in a bicultural context in order to "face" an unformed future.

Ornament, *Whakairo*

Whakairo means to adorn with a pattern, to give direction, to form and inform aspects of any artistic construction whatsoever. The word was recorded in the first Edition (1844) of the *Williams Dictionary* but with only the limited meaning of "carved, carving, to carve." The prefix *whaka-*, meaning "toward, in the direction of," first appeared in the third Edition (1871). A 1915 version (which was not a separate Edition) of the *Dictionary* extended the meaning of *whakairo* to include "carve, adorn with carving." Two years later this was replaced with the fuller meaning, "ornament with a pattern, used of carving, tattooing, painting, weaving." Today the meaning of *whakairo* has been further extended to also embrace such activities as sculpture, printmaking and spatial design. Thus a *whare whakairo* may not necessarily be a *carved* meetinghouse at all. The decorative scheme of Rongopai, for example, a beautiful 1887 meetinghouse, comprises "a magnificent statement of tribal identity and joyous optimism" (Neich 1993. 192) that is expressed predominantly through painted figures and patterns rather than through woodcarving.

The architectural meaning of *whakairo* "giving direction" and constructing an orientation for people in the world is expressed in every meetinghouse through the orientation of the *tahu*, the long imposing horizontal ridge pole which is sometimes also called *tahuhu*. The *tahu* or *tahuhu* is normally painted with distinctive *kowhaiwhai* patterns in the interior and carved where it joins with the exterior scheme of the *mataihi* under the roof of the porch. What is however a more fundamental aspect of *whakairo* of the *tahu* is its horizontal *orientation*, its direction in the world.

We might say that Te Kooti was the principal architect not only of the Ringatu Church but also of the meetinghouse in its modern form. Te Kooti adopted the meetinghouse form as a way to subvert the intention of the Christian mission church, or to transform the Christian message according to Maori protocols. In place of the tall closed box and the spire pointing upward to heaven, which was a form of church architecture already familiar in Maori villages throughout New Zealand, Te Kooti emphatically reasserted the authority of the *wharenui* form, and in particular the horizontal *tahu* that points to a real horizon.

Roger Neich (1993: 229–234) describes how the *tahu* not only marks the place of the *marae* (the village and its formal gathering place) as a specific location in the world but also describes a direction within and across this place. Referring specifically to a Ringatu meetinghouse named Tutamure at Omarumutu *marae* near Whakatane, Neich identifies multiple layers of interconnected narratives through which the *tahu* points out and constructs a meaningful direction in the world. Firstly Neich writes it points to the openness of the *marae* forecourt in front of the *wharenui*, and to closure at the rear. Then it points to the ocean and the land, the sea and the forest (pointing out that the technoeconomic resources of the local people are found in front of and behind the house, respectively). The ridgepole of the meetinghouse also points to Hawaiki and New Zealand (as directions in front and behind in cosmological space), and to the canoe immigrants (in this case the Mataatua and Nukutere canoes) and the Tino-o-Toi aborigines (directions of arrival, confrontation and retreat in the sociological space of tribal history).

Almost every *marae* has stories similar to this associated with the horizontal pointing form of the *tahu* of the *wharenui*. The "point" of the meetinghouse is this fundamental *whakairo* gesture. It is interesting to note that the Anglican Holy Trinity Cathedral in Auckland recently extended the nave with a strong *wharenui*-like horizontal gesture, but that the church authorities did not see fit to build a vertical campanile (contrary to the advice of the architect).

A

Space, Kauhanga

Kauhanga is a term that means the interior space of the meetinghouse specifically when it is *tapu*. There are other words also that refer to interior space, for example *tara iti* is the space on the inside left of the *wharenui* and *tara nui* is that on the right (as one enters the house from the front.) Literally *tara* refers to the side walls of the house as well as meaning the inside spaces. Whenever a new *wharenui* is constructed a great deal of negotiation takes place to decide which ancestors and stories should be represented and the most appropriate spatial relationships. Naturally, as with any architectural design, the interior space becomes charged with potential meanings far in excess of what is actually built. The highly potent *tapu* condition of a new meetinghouse is dissipated in ritual processes called *whakanoa*.

The *tapu* space is often implicated in what might be called prophetic lore or *kupu whakaari* that is associated with the opening of meetinghouses. One famous example is a prediction or warning that Te Kooti is said to have made when he attended the reopening of Te Tokanganui-a-noho in 1883. It is recorded that Te Kooti said "The day will come when the God of the Pakeha will whistle in these places,… entering right into the porch of the house and coming straight through the back of it…." (Binney 1995. 278). Te Kooti also said of another meetinghouse, Ruataupare, that "… one wall is arguing against the other, and the door against the back wall." (Binney 1995. 328). This is not the place to enter into the interpretation of these prophetic sayings. What is significant is the fact that the *kauhanga* space of the meetinghouse is implicated in them.

Since Maori architecture is alive and its meaning is alive, therefore it is appropriate to speak to the *wharenui*, and also on occasion to speak as it were *through* the *wharenui*, to allow the architecture of the house to structure and guide what is said. Even on some occasions of *whaikorero* or formal talking it is appropriate that the *wharenui* itself speaks. As Hohepa Kereopa succinctly expressed it, "The whaikorero is based on the idea of how a whare is built" (Moon 2003. 113).

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Architecture in Mesoamerica

Phil C. Weigand

The Mesoamerican world system was composed of a number of closely connected and related but distinct civilizations. The peripheries of the system extended from the southwestern United States of America, in the north, to the borders of Nicaragua, in the south. Each of these component civilizations, while sharing with the larger whole series of cosmological and iconographic concerns, had an unambiguously regional architectural style. The distinct civilizations usually considered, from south to north, are the highland Mayan area (Guatemala), the lowland Maya (the Petén of Guatemala and the Mexican states of Yucatán, Quintana Roo, and Campeche), the Gulf Coast lowlands (Veracrúz and Tabasco), southern Pacific coast (Chiapas and Guerrero), Oaxaca, Central Mexico (the states of Puebla, Tlaxcala, México, and Hidalgo), the Huaxteca (northern Veracrúz and southern Tamaulipas), western Mexico (Jalisco, Michoacán, Nayarit, Colima, and Sinaloa), and northern Mexico (Zacatecas, Durango, Chihuahua, and Sonora, with extensions into New Mexico and Arizona). The architectural styles represented within each region were original and innovative traditions which in some cases lasted for centuries with only cosmetic changes. To speak simply of the existence of pyramids in Mesoamerica is to miss the point: while pyramids of one type or another indeed were pan-Mesoamerican, accompanying them was a remarkable diversity of other building forms, representing styles that still remain difficult to classify. Some areas, such as western Mexico, had a number of radically different architectural traditions through time, while other zones, such as Central Mexico, displayed much more conservatism. Of course, anything approaching a comprehensive survey is not possible in this summary. Important sites, even regions, have been omitted.

Reference and Bibliographical Considerations

There have been many descriptive architectural studies within Mesoamerica. Over the last century of research this orientation has produced a wealth of detail that has never been completely synthesized. The study by Marquina (1951) is a classic of the descriptive school, though there are major area omissions in his text and very little in terms of comparative or integrative commentary. Never-the-less, his text remains the most useful and encyclopedic source available in the Spanish language. In English, other overviews, though also limited in area coverage, have been published by Kubler (1975) and Gendrop and Heyden (1993). Useful general summaries concerning architecture within specific regions of Mesoamerica are in the *Handbook of Middle American Indians* (Wauchope, various dates). In the *Handbook*, surveys on regional architectural traditions include Smith (1965) on the Guatemalan highlands, Acosta (1965) on Oaxaca, and Margain (1971) on Central Mexico.

One of the best sources for specific site details is the journal, *Cuadernos de Arquitectura Mesoamericana*, published by the Facultad de Arquitectura of the Universidad Nacional Autónoma de México. Early numbers of the journal basically followed the Marquina descriptive tradition, though in recent years interest has broadened to include spatial relationships, cultural symbolism, and astronomical considerations. Excellent and more specialized books and monographs on those topics also exist. As examples, for spatial relationships: Mangino Tazar (1990); for cultural symbolism: Kowalski (1999); and for ancient astronomy as viewed through architecture: Aveni (1977). A useful dictionary for architectural terms and terminology pertaining to Mesoamerica has been compiled by Gendrop (1997).

A number of site studies, emphasizing spatial relationships, describe architectural specifics in addition to the character of community settlements patterns. Three representative studies are Millon (1973) on Teotihuacan in Central Mexico, Blanton (1978) on Monte Albán in Oaxaca, and Folan et al. (1983) on Cobá in the lowland Mayan area. Researchers in the lowland Mayan area have produced some of the most detailed descriptive studies. This is no doubt due to the spectacular nature of the soft limestone building tradition in that region, wherein architectural ornamentation and elaboration, often baroque in character, reached a peak of development unequaled in any other area of Mesoamerica. An example is the study of the Río Bec, Chenes and Puuc styles, by Gendrop et al. (1998). In western Mexico, due to the highly geometric character of the early monumental architecture (Weigand 1996), the approach of Chippindale (1986) and Stiny

(1976) has been utilized to determine the rules of formal design employed there.

Architectural Types

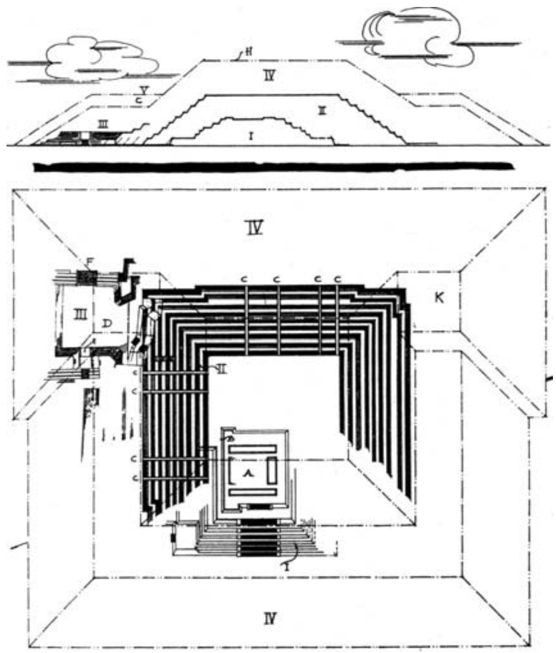
The typology employed *infra* is far from complete, but represents a sampling of building types found throughout pre-Hispanic Mesoamerica.

Pyramids

Urban precincts, as spaces, and the buildings within, are almost universally well organized and formal. Within them are found the most monumental buildings in Mesoamerica, usually pyramids which are often of considerable size.

Among the earliest monumental pyramids is the structure found at La Venta, Tabasco. Located in a tropical rain forest and made from earth, it is badly eroded. Hence, its original shape has generated controversy. Its original shape may have been like a fluted cone, with ten alternating ridges and valleys at regular intervals around the oval base (Heizer 1968). Its original height cannot be determined, but it towered over the flat flood plain that surrounds the site. Apparently, there existed no access ramp or stairway. This structure dates to around 900–400 BCE.

For the Classic period (AD 150–700), while the Pyramid of the Sun at Teotihuacan is the best known, it is not the largest. That distinction belongs to great pyramid at Cholula (Puebla), considered by some to be the largest single structure (by volume) in the Americas. While the pyramid is the greatest single building of the Mesoamerica architectural tradition, it is poorly preserved and understood. This structure eventually covered over 16 ha of surface, and was 55 m high. Some of the 16 ha represent poorly preserved platforms attached to the main body of the pyramid. The basic form is shared with the monumental pyramids at Teotihuacan: square to rectangular and terraced, culminating in a flat surface atop of which was placed a rather small temple (Marquina 1951: 115–125; Fig. 1). The pyramid at Cholula was constructed over a very long period of time, apparently in constant use from around AD 100 to the Spanish conquest in the early sixteenth century. As such, it represents one of the monumental buildings in longest continuous use within the overall area. The material used in construction varied from well-prepared adobe brick to rock and clay fill. The decorative finish, usually described as variations on the *talud–tablero* technique, was painted and highly sophisticated. The *talud–tablero* technique is usually ascribed to influence from Teotihuacan, but in most cases throughout Mesoamerica, including Cholula, this is doubtful. This architectural decorative technique was pan-Mesoamerican, though, very prominent at Teotihuacan.



Architecture in Mesoamerica. Fig. 1 Map of the Cholula pyramid, Puebla, showing plan and profile (taken from Marquina 1951: 119).

The pyramids at Teotihuacan, dating from the Classic period (AD 100–850), as well as adjoining and neighboring structures, have been extensively studied for over a century. The site, while huge (22.5 km^2 – Millon 1973), is still the focus of intensive research. George Cowgill's ongoing project at the Pyramid of the Moon has shown an extremely complex construction history, including prestige burials with sacrifices for this structure, thus supplying documentation equivalent at Teotihuacan for Cholula. The Pyramid of the Sun covered just under 5 ha of surface, and is 61 m high. The restoration of this structure, begun over a century ago, is controversial (Fig. 2). A natural, but improved, cave underneath this pyramid may represent the famed *chicomostoc*, or emergence tunnel through which people of this world originated. A tunnel dug through the Pyramid shows what may be a much earlier structure, perhaps representing a tomb (Millon and Drewitt 1961).

Perhaps one of the best examples of baroque architecture in Mesoamerica is the Pyramid of the Niches at Tajín, Veracrúz. While the substructure as such is comparable to pyramids elsewhere, it is the decorative elements that set it aside (García Payón 1957). Its fine decorative masonry is unique in the non-Mayan regions of Mesoamerica. The niches, 365 in number, set into the ornamental *talud–tablero* facing, probably housed figurines (Fig. 3).

The double pyramid at Tenochitlan, destroyed by the Spanish after they conquered the city in 1521, is the

Architecture in Mesoamerica. Fig. 2 The Pyramid of the Sun, Teotihuacan, State of México (taken from Millon 1973: Plate 24a).

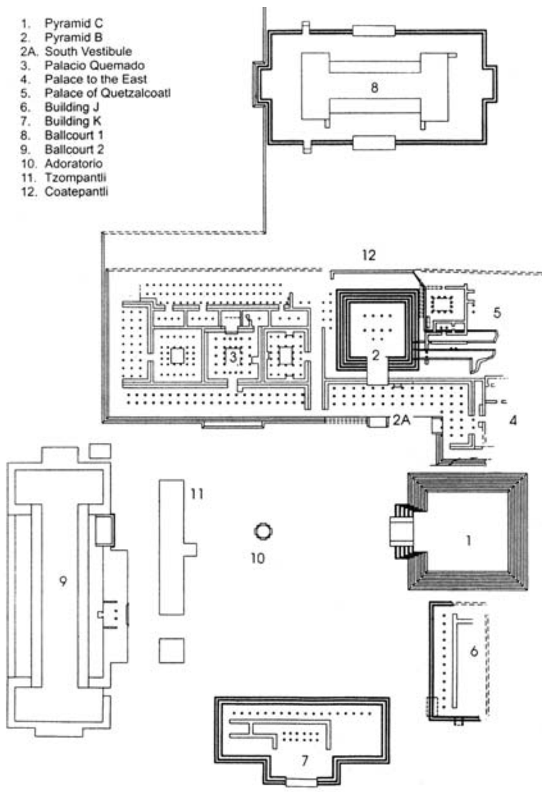
Architecture in Mesoamerica. Fig. 3 Pyramid of the Niches, Tajín, Veracrúz (taken from Porter-Weaver 1981: 244).

most famous of this architectural type. The building has been extensively excavated and restored, and its history and utilization is fairly well understood (Matos Moctezuma 2003). The pyramid was associated with a multiplicity of rooms and adjoining shrines, containing painted murals, rich offerings, and statuary. The "double" term refers to the peak of the pyramid. There, twin temples, each reached by a separate stairway, sat atop a common base. In architectural models and illustrations, this structure is often portrayed as being far more monumental than it actually is. This is apparently due to the centrality given to the Aztecs in the official histories of the Republic.

The small pyramid complex at Tula, Hidalgo, while not impressive if viewed as isolated structures, had extremely complex sculpture and appended buildings. The "atlantean" statues, originally placed atop one of the main pyramids, and the Halls of Columns adjoining that same structure, are unique in Central Mexico (Mastache et al. 2002; Fig. 4).

Pyramids in the Mayan area are unusual for their steepness and height in relation to their bases. The Temple of the Giant Jaguar (also called Temple #1) at Tikal, in the Petén district of Guatemala, is one of the best examples. It had nine terraces, and three rooms at the summit. The rooms' vaults were supported by beams from the sapodilla tree. A large vaulted tomb was excavated in the plaza before this pyramid was finished. On the upper terrace of the pyramid is a limestone temple which has a two-level roof comb. This comb, while adding a decorative element to the building, also increased significantly its overall height. This structure was finished around AD 700 (Coe 1967). Other pyramidal buildings of note are found at Piedras Negras (Houston et al. 2000); Palenque, and its great subpyramid tomb of King Pacál (Ruz Lhuillier 1963); Chichén Itzá (Ruppert 1952); as well as those mentioned in Gendrop et al. (1998). Aside from the decorative sculptures and friezes, some Mayan buildings had elaborate wall murals. The best preserved of these are at the Temple of the Paintings at Bonampác, Chiapas (Ruppert et al. 1955).

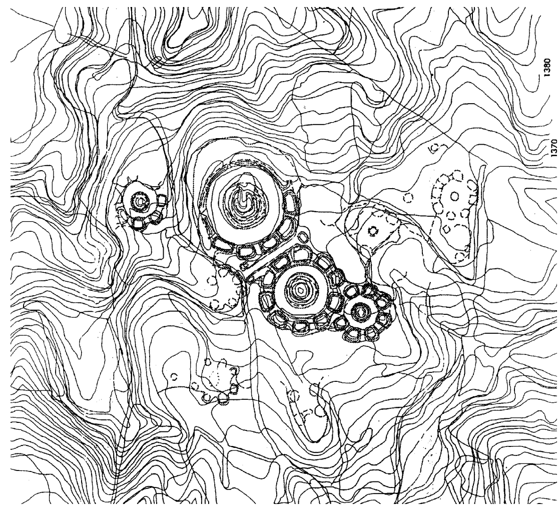
In western Mexico, three sites deserve special note. The Guachimontón precinct, at Teuchitlán, Jalisco, has



Architecture in Mesoamerica. Fig. 4 Plan of the Halls of Columns, and associated buildings, Tula, Hidalgo (taken from Mastache et al. 2002: 92).

ten concentric circular structures, each having central circular pyramids, surrounded by elevated circular patios, which in turn are surrounded by circular banquettes. While some 400 of these precincts have been located to date, this type of architecture morphology is unique in the world repertoire. The largest circle is 128 m in diameter, and 405 m in circumference. The precinct covers 19 ha. The pyramids in these complexes are only attributes of the overall structure. The highest one is 20 m. The outer banquette served as the base for between 8 and 16 platforms, atop of which were large temples. Beneath the platforms are the shaft-tombs, which are full of the figurines that have given the region its fame in the antiquities market. The deepest shaft-tombs are 14–20 m, with between three and five large rooms. These structures date from the late Formative and early Classic period (350 BCE–AD 450; Weigand 1996, 2005; Fig. 5).

Ihuatzio and Tzintzuntzan, Michoacán, are both sites associated with the Tarascan empire of the late post-Classic period (1300-Spanish conquest). Ihuatzio is the earlier site. It has a large double pyramid complex which is partially surrounded by huge walls that clearly limited access to them. The *yácata* style building is also present. *Yácatas* are another unique building form found only in western Mesoamerica. They are large



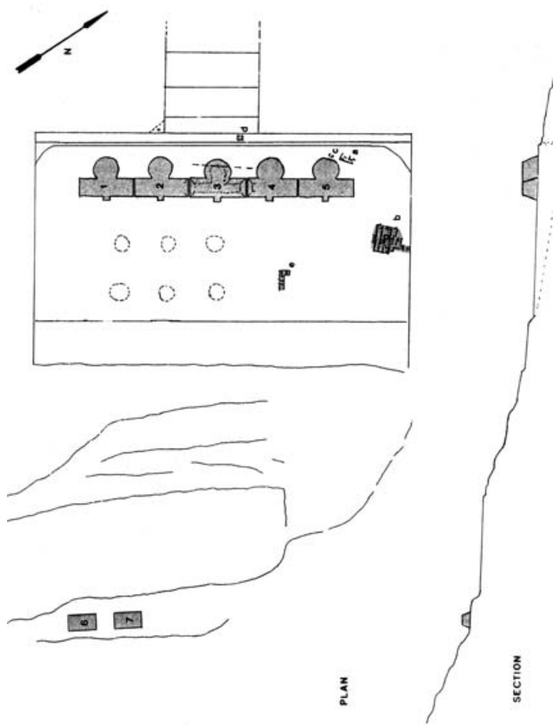
Architecture in Mesoamerica. Fig. 5 The Guachimontón precinct at Teuchitlán, Jalisco (taken from Weigand 1996: 95).

circular altars appended to rectangular platforms. Stairways are at the rear of the structures. The site with the most impressive array of *yácatas* is Tzintzuntzan. Five *yácatas* are lined up atop a huge rectangular platform (Cabrera Castro 1987; Pollard 1993; Fig. 6). Clearly, the *yácatas* and their base platform form a single structure, one of the most monumental of Mesoamerica.

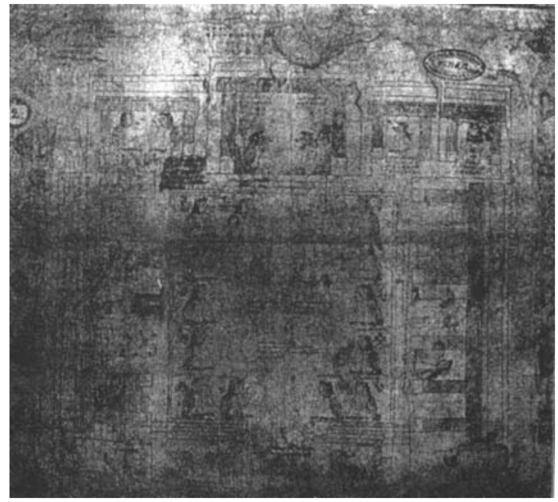
Palaces

These structures, commonly called *tecpan*, abound within the complex sites of Mesoamerica. Although the identification is not certain, the Ciudadela at Teotihuacan is often identified as a *tecpan* (Millon 1973). It is a huge, square structure measuring 400 m to a side. Its interior plaza is a large open space facing a small pyramid complex with complex serpent and rain god heads protruding from its surface (Drucker 1974). It was probably completed around AD 300, if not earlier. Also at Teotihuacan, many sunken patio structures aligning the Street of the Dead have been identified as palaces, or at least as residences of the elite elements that ran the urban complex. Many of these buildings were elaborately decorated with murals and low relief carvings. The Quetzalpapalotl Palace is one of the best examples of this type of building (Acosta 1964). It is a stunning example of a highly complex structure which apparently combined public administrative functions with residential quarters. A magnificent courtyard is bordered by porches. This type of structure is commonly called a *patio hundido*, or a sunken plazuela complex. The palace apparently dates to around AD 500.

The studies by Evans (1998, 2001) constitute the most comprehensive comparative research concerning palace structures in Central Mexico. Since so many of the late palaces in Central Mexico are covered by



Architecture in Mesoamerica. Fig. 6 Map of the *yácatas* at Tzintzuntzan, Michoacan (taken from Pollard 1993: 48).



Architecture in Mesoamerica. Fig. 7 The *tecpan* represented in the Codice of Quinatzín (taken from Weigand and García 1996: 183).

Colonial and contemporary buildings, including that of the last Aztec emperor, Moctezuma II, in Tenochitlan, she has made ample use of ethnohistorical descriptions. In general, the Central Mexican *tecpan* is defined as an open court surrounded by a high banquette on at least three sides and open on one side to community plazas. The Codice of Quinatzín, portraying a Texcoco palace (State of México) clearly shows this type of structure (Fig. 7). Moctezuma's palace is said to have been 200 m to a side, though this structure, buried beneath Mexico City, is no longer visible. The average, however, is considerably smaller: between 60 and 80 m to a side.

Several structures at Monte Albán have been identified as possible palaces (Winter 1974). These structures face the large, rectangular plaza that forms the central feature of the citadel. While they somewhat resemble palace structures at Teotihuacan, and date to approximately the same period, they are much more compact, and with fewer decorative elements. The plazuelas are quite small. Tombs, most probably lineage crypts, are often associated with these structures, and open directly onto the plaza.

At Yagúl, in Oaxaca, a different type of palace structure has been identified. Apparently, six side-by-side structures existed, built during the post-Classic period. Each is characterized by a series of fairly small rectangular patios surrounded by long, narrow rooms. The overall effect is cramped and crowded. The core of these buildings was rough stone and earth, but the exterior decorations were careful and sophisticated, usually plaster or cut stone. Facades and door frames were decorated with small cut stones formed into geometric mosaic patterns (Bernal 1965). This decorative appliqué is similar to that found at Mitla, though the functions of the structures there have not been identified with certainty.

Buildings identified as palaces abound in the Mayan area. Perhaps the best known of these is the Tower Palace at Palenque. This square, four story structure was constructed from finely cut limestone blocks. The floors were supported by wooden beams, instead of corbelled arches so often employed in other palaces and temples throughout the zone. While attached to a palace-like structure, the tower is unusual for its height. A variety of functions have been suggested for the tower per se (Carlson 1976).

From the post-Classic period, the largest visible *tecpan* is found within the village of Oconahua, Jalisco. At 125 m to a side, it conforms rather exactly to the arrangement set out in the aforementioned Codice of Quinatzín. An internal plazuela is surrounded by high platforms, the northern one of which is out-sized at 125 × 50 m. Outside this building is an external plaza measuring 180 × 55 m. Within this plaza were small platforms which served as bases for large stelae. The core of the structure is clay and earth, with some rock. It was finished with cut stone slabs, almost all of which have been looted (Weigand et al. 2005).

Market Places

These spaces were frequent features within Mesoamerican urban spaces. Often, they are hard to identify, and frequently are labeled as just plazas. One of the largest and earliest such spaces has been identified at Teotihuacan (Millon 1973). Across the Street of the Dead from the aforementioned Ciudadela, this open space measures approximately 125 × 250 m. It is surrounded by streets and buildings, some of which are directly associated with the market. Stalls, some of which dealt in obsidian artifacts, were arranged within the plaza of the market. Unfortunately, this space was chosen to house the site museum and a restaurant, and is therefore difficult to appreciate today.

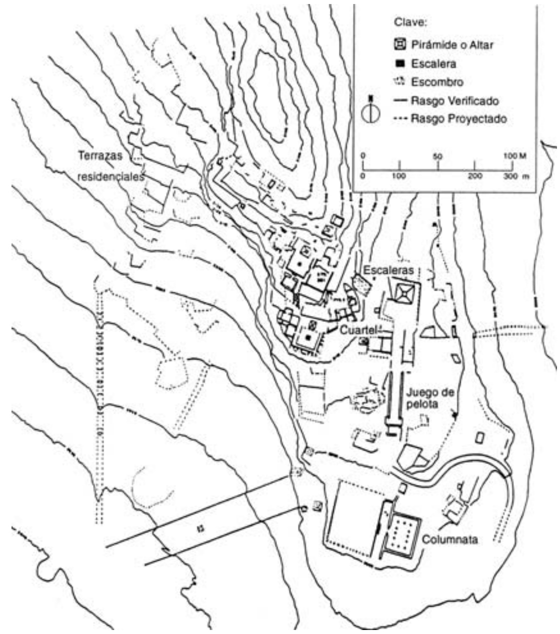
Places identified as markets have been located in the Oaxaca valley, as well, such as at Xaachila. The best information, though, comes from the Spanish sources from the conquest period. These attest to great markets at Cholula and Tlatelolco, in addition to other sites.

Ball-courts

Fortunately, for this type of structure, excellent comparative studies are available. The studies by Taladoire (1981, 1998) are unparalleled in detail, classification, and chronological considerations. A few more recent studies from western Mexico have added detail to his overview (Weigand and García 2005). Taladoire associates the architecture of ball-courts in different areas quite logically with the types of games performed there. Basically, two types of games dominated the Mesoamerican ball-court traditions. One type was the game played off the forearm (*antebrazo*), which required a court that had a hoop and a tall banquette. This is the type of game played at the monumental court at Chichén Itzá, for example. At 135 m in overall length, this court is one of the largest within all of Mesoamerica. The site of Tajín has perhaps the largest quantity of ball-courts, and the decorative elaboration of several is unsurpassed anywhere else. Elsewhere, the game played is called the *cadera*, or hip game. No hoop is required and thus the lateral banquettes are lower than in the *antebrazo* variety. The earliest monumental ball-courts of this type are found in Jalisco, where five buildings have been located and studied. The one at Santa Quitería is 135 m long, and the other four average 110–115 m in total length. The court at the Guachimontones has been restored, and dates to 150 BCE–AD 150 (Weigand and García 2005).

Fortifications

Fortified or defendable sites abound within Mesoamerica. Three strongly fortified sites stand out as excellent examples of military architecture: Tepexi el Viejo in Puebla (Gorenstein 1973), Oztuma in Guerrero (Armillas 1944), and La Quemada in Zacatecas (Armillas 1948; Fig. 8). All three forts share several basic features: located on high, difficult terrain, they are terraced with walls and *revetments*? to make access almost impossible. All have specialized buildings and apparent gateway areas. Ceremonial architecture, while present, is modest and rather inconspicuous. La Quemada is the earliest of these three examples, dating to the AD 600–1100 period, while the other two belong to the Aztec polity. Smaller, but still impressive and earlier forts, can be found at the Peñol de Santa Rosalía, Jalisco (Weigand 1996). Some areas, such as the Caxcan zone of southern Zacatecas, have fortified sites literally on every hill top.



Architecture in Mesoamerica. Fig. 8 The fortified citadel at La Quemada, Zacatecas (taken from Weigand and García 1996: 170).

Architectural diversity characterizes the many traditions of ancient Mesoamerica. This diversity is both temporal and spatial in nature. Some types have not been considered in this survey: specialized shrine sites, such as Malinalco in the State of México; mining complexes, such as those at the Sierra de Navajas in Hidalgo, and Chalchihuites in Zacatecas; ports of trade, such as Xicalanco, between Tabasco and Campeche; elegant burial chambers, such as the monumental shaft-tombs of Jalisco; and the great agricultural field systems such as the chinampas of Jalisco and Central Mexico.

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Architecture in Palestine

Shadi Sami Ghadban

When talking about traditional architecture in this area of the Middle East, it is more correct to identify this architecture by the term "Palestinian Architecture" rather than by "Architecture in Palestine." The second term refers to all architectural styles found in Palestine throughout the different historical periods, from Hellenic, Roman, Byzantine, Umayyad, Abbasid, Fatimid, Crusades, Mamluk, Ottoman, and the British Mandate until today. These architectural styles were mainly popular in major cities like Jerusalem, Jaffa, Acre, and Nablus. In addition, these styles were commonly related to the architecture of the economic and political elite and the urban notables.

On the other hand, the first term "Palestinian Architecture" reflects what is known as "architecture without architects," which has flourished for several centuries in urban and rural areas. It maintained its characteristics until World War I because of the social, economic, and religious factors that reflected the needs and living habits of a particular time, and it directly reflects the interaction between human beings and their environment (Fig. 1).

Prior to the year 1839 (when Ottoman land reforms were applied), land in Palestine was the main source of livelihood and status, with very limited transactions with the regional or world market. The Palestinian community retained a system of agricultural subsistence, employing simple agricultural technology. The community as a whole was considered the unit of taxation by the state, and there were patriarchal households, where the extended family acted as the main unit of production and consumption, and labor was divided along clear gender lines.

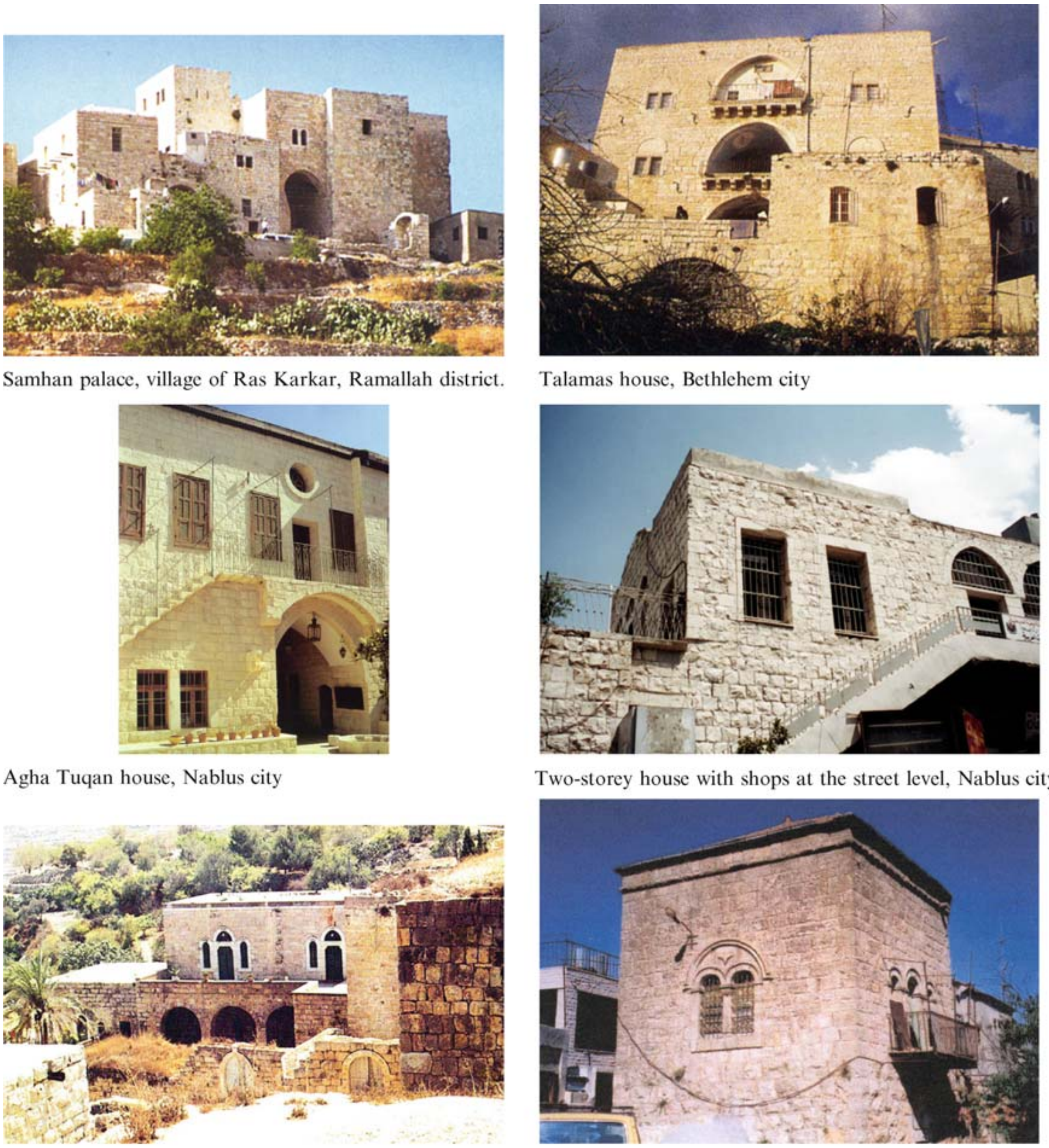
The year of 1832 marked a critical turning point in the history of the region, when Mohammad ʻAli, the Governor of Egypt from 1805 to 1848, occupied Great Syria, including the Palestinian territories, and implemented several land, administrative and economic reforms (Manna' 1999: 161). He gained the support of the European superpowers for his military campaign when he said that he would take into consideration their vital interests in the area, treat the non-Moslem minorities in a better way than the Ottoman Authorities had, and even try to give them equal rights with the Moslems (Scholch 1988: 130–145). This Occupation brought about several developments accompanied by the implementation of several administrative and economic reforms, but they were obstructed by different uprisings and disobediences that occurred in the area (Manna' 1999: 137–138). The Egyptian policy in the Palestinian territories led to increasing European influence in these territories, mainly in Jerusalem. The activities of different missionary groups concentrated on constructing new churches and providing educational, social, and health services to the local population. The first European British Consulate in Jerusalem was inaugurated in this period, which was followed by other consulates during the period 1841–1858 (Spyridon 1938).

In 1839, the Ottoman Sultan Abdul-Majeed came back to power in Great Syria, and this included the Palestinian territories. He was supported by the European coalition established by Great Britain, Russia, Austria, and Prussia (Scholch 1988: 458–475). In his decree, known as *Khat Golkhanah*, issued in November 1839, he expressed his readiness to apply new reforms that were known later as *Tanzimat Khairiah* (Davidson 1973). In addition, the increasing European influence led to an economic amalgamation of the Palestinian territories with the world capital market, and produced an active involvement of the Palestinian local leadership in the continuously changing political circumstances. All these factors shaped the new socioeconomical interactions within Palestinian society.

By the end of the nineteenth century a new eclectic architecture with mixed styles witnessed the western influence that came through the activities of different missionary groups. This development was accelerated during the last three decades of the nineteenth century and continued intensely during the first two decades of the British Mandate (1920s and 1930s) when a rapid construction growth sprawled in both rural and urban areas (Fig. 2). Therefore, by the end of the 1930s, a new architectural fabric began to emerge which greatly affected Palestinian society since the middle of the nineteenth century.

The Tanzimat period represented one historical period of the Ottoman Empire, but for Palestine and other Arabic areas in the eastern coast of the Mediterranean, this period consisted of three major stages:

- *First stage (1840–1856 AC)*. The Crimean war ended and a decree called *Khat Sharif Hamaion* was issued on 18th February 1856. This decree contained several reforms that Sultan Abdul-Majeed addressed to get the support of the European countries for his war against Russia. In this stage the Ottoman Authorities performed reforms similar to those applied by the Egyptian Government (1832–1840). However, the local leadership, mainly in the countryside, rejected them, arguing that they were contradicting with their interests (Abu Izz-Elddine 1928: 95–96).
- *Second stage (1858–1878 AC)*. The Ottoman land reforms (Tanzimat) started in 1858, which aimed to change the communal ownership of land to private ownership. This period, mainly in 1878, evidenced the first parliamentarian experience during Sultan



Samhan palace, village of Ras Karkar, Ramallah district. Talamas house, Bethlehem city

Agha Tuqan house, Nablus city. Two-storey house with shops at the street level, Nablus city

Village courtyard house, Ramallah district. Two-storey house, Al-Bireh city

Architecture in Palestine. Fig. 1 Houses of the economic and political elite at different districts of the Palestinian territories during the eighteenth and nineteenth centuries. Photos are student works from the course "Local Architecture in Palestine", Birzeit University, 1998–2001.

Abdul-Hameed the Second's rule. New fundamental changes affected not only the relations between the state and the Palestinian local leadership, but also had an extensive effect on the socioeconomical, cultural, and living conditions of the Palestinian local society.

- *Third stage (1878–1919 AC)*. During this stage the integration of the local economy into the world trade market and acceleration of the European influence in the area continued. However, there was a growing trend toward improving the infrastructure, mainly in the fields of transportation, communication, education, and governmental administration. It was also around this time that Palestinian immigration to both Americas increased and the immigrants started sending back money to their families in Palestine to build their future houses. In addition, this period included the expansion of Jewish emigration and construction of new settlements with imported architectural styles.

Partial view of the old city of Ramallah, where the old fabric is scattered by the modern buildings constructed in the area.

Partial view of the old city of Nablus, surrounded by the new modern urban structure

Architecture in Palestine. Fig. 2 Images demonstrating the rapid construction growth outside and within the historical fabrics in Urban Areas. Photos by the author.

The 1840s was a decade rich with events assumed by several historians as indicators for the beginning of a new history in the Palestinian territories. As a result, new architectural systems, i.e., new building styles and forms, use of new materials and methods of construction were imported and implemented, but within the framework of the local knowledge in the area (Fig. 3).

Factors Influencing Palestinian Traditional Architecture

Several factors bear upon the development of Palestinian traditional architecture.

Geography

A distinguishing part of Palestine is its geographical location along the eastern Mediterranean coast. It has a key location between Asia and Africa, and has a specific character as a Holy Place for Judaism, Christianity, and Islam. Altitudes, which range from 394 m below sea level to 1,400 m on the mountainous chain parallel to the coast, allow the existence of a diverse landscape. The mountains shape the nature of the Palestinian territories and control climate and rainfall.

Many influences affected the Palestinian land, and large-scale architectural activities took place during the rule of foreign powers such as the Romans, Crusaders, Mamluks, or Ottomans. Despite the fact that these activities reveal strong local characteristics, they are of foreign origin. Therefore, independent Palestinian architecture was limited to housing structures and modest religious and public buildings. The influence of geography can be observed in the adoption of certain types of construction, architectural forms, orientation, and the arrangement of buildings. The articulation of plan, elevations, simplicity of masses, and the habit of one or two-story constructions are largely caused by the predominant conditions in the three main geographical zones of the country: the coastal area, the highlands and the Jordan valley (Fig. 4).

Natural Building Materials

Palestinian territories have an unusual geology because of their location between Great Syria and the Sinai Peninsula, where different geological formations produced a unique topography, diverse both in form and structure.

The mountainous area consists of hills, valleys, and gorges, where the geological strata are easily accessible. These strata usually consist of sandstone between limestone, and are cut up by various clefts, mainly in the Hebron, Bethlehem, and Nablus areas.

The abundance of stone in the country offers the opportunity for good masonry construction. The continuous use of stone has produced stonemason's families who passed on their accumulated skills from generation to generation, evolving a mastery and tradition of design in stone that is largely responsible for the homogeneous character of Palestinian architecture (Figs. 1 and 3).

Mud is limited to the Jordan valley and some coastal areas, mainly Gaza, because of their geological conditions. The fairly dry climate in these areas allows the application of mud brick (adobe) structures.

For many centuries, the use of wood for construction was limited to some kinds available in the area, such as one-palm trees and olive trees and rarely poplar, willow, walnut, and maple. Wood is mainly used for doors, windows, some furniture, and for roof construction.

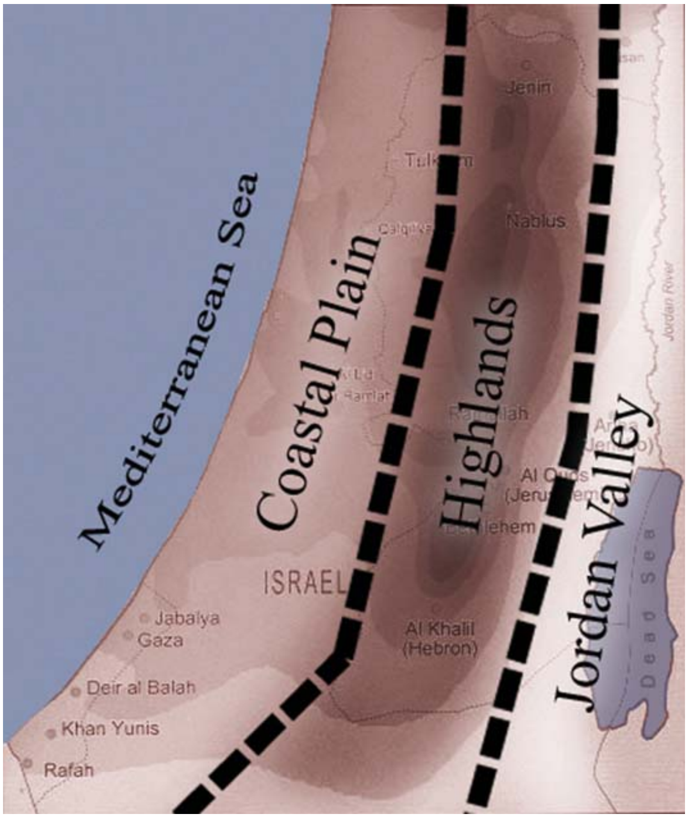
The Climate

There are four climatic zones in the Palestinian area: the coast area, the western slopes of the mountainous area, the eastern slopes and the Jordan valley and the desert. The annual climatic cycle of the country consists of

Architecture in Palestine. Fig. 3 Houses and buildings with new architectural types, forms, new materials and methods of construction. Photos are student works from the course "Local Architecture in Palestine", Birzeit University, August 2000.

four hot dry summer months, a mild autumn with little rainfall, a rainy winter with snow down to 700 m and an early spring with the last rainfall in April.

The architecture of Palestine is a synthesis between local environmental conditions and the formulas of the philosophy of life, art and design prevailing in the entire Mediterranean region. The massive construction in stone or mud-brick in terms of a wall's thickness, height, texture, and verticality, satisfies to a large extent the exigencies of the climate. The roof structure, either flat surfaced from mud, wood, and straw or vaulted mainly from stone, guarantees appropriate temperature insulation and reduces the heat transfer process. Crossventilation is facilitated by openings placed high in the single-spaced structures or by internal windows between rooms and the central space, which is assumed to be the coolest space during the hot daytime (Fig. 5). The open ends of the central space are turned either to



Architecture in Palestine. Fig. 4 An illustration demonstrating the three geographical zones in historical Palestine. Adapted by the author, using as a base a map distributed by Applied Research Institute (ARIJ), ►http://www.arij.org.

the north or to the south in order to avoid deep penetration of the sun's rays. Fortunately, the placement of the house parallel to the contour lines of the slope toward the valley makes its face toward the prevailing wind direction and ensures the desired ventilation.

Socioeconomic Factors

Palestinian traditional architecture has been the result of an experience between human beings and their environment. This dialog has two forms: action and reaction. The action of the human being always produces a reaction in the environment, and vice versa. In both cases, the reaction has two levels: an unconscious reaction and a conscious reaction that needs to be reinforced and enhanced.

Palestinian traditional architecture has been very resonant in functional, constructional, and artistic approaches during the last 120 years. When the changeable living conditions of the Ottoman Reforms and the English Mandate caused some elements of traditions and values to loose their initial meaning, they had to be replaced by new ones with a function closer to the new requirements that still responded to certain sociohistorical conditions.

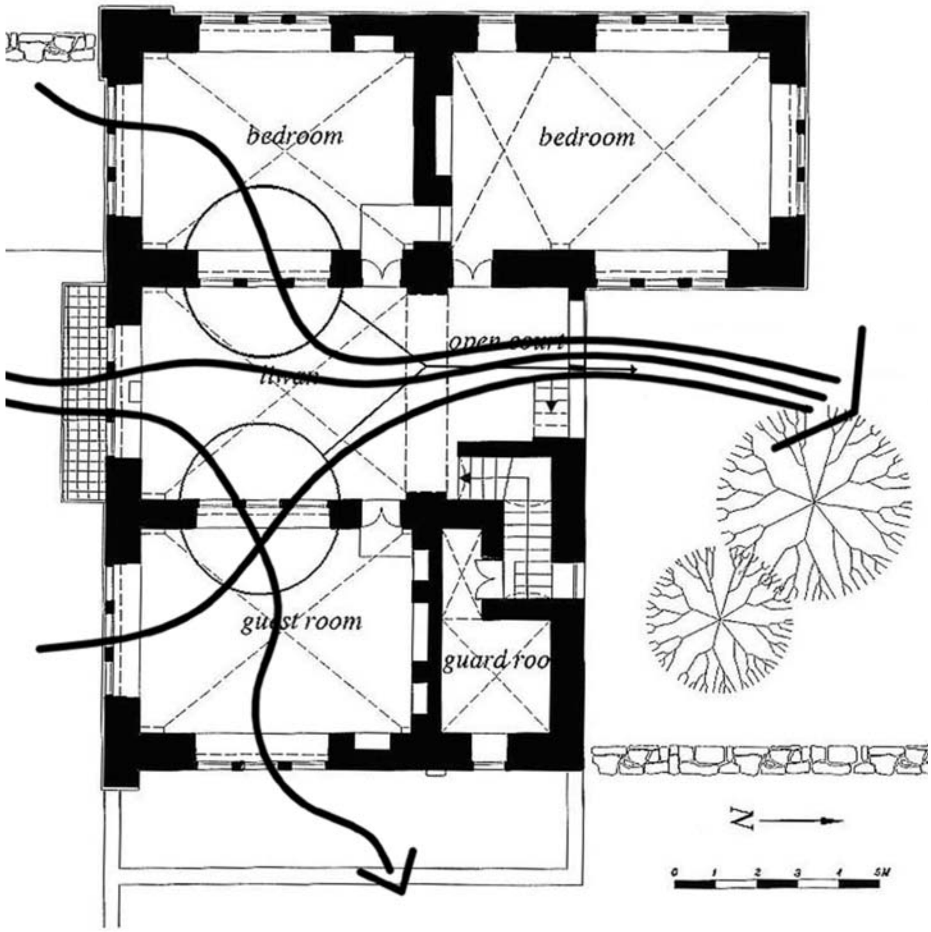
In this regard, there is a substantial importance to specific Palestinian local forms of production, religious customs, beliefs, traditions, mental adaptation, self-confidence, and spirit of people, because all of them are determined by local physical, geographical, and climatic conditions.

The religious affiliation of the Palestinian family did not affect the distribution of house types in Palestine. The conditions of living either in the mountains, valley, or in the coast areas were essentially the same for all religious communities, and all families adhered to a strong paternalistic structure. Great class discrepancies were unknown and the social structure was egalitarian.

On the other hand, the Islamic influence has been very strong in artistic and architectural forms and details, but there is very little Islamic influence in the planning of the houses. They were simple and straightforward, and that includes the lack of specialized spaces as well as a lack of privacy for the individual.

The House

Prior to the Ottoman Reforms (Tanzimat), land in Palestinian Territories was the main source of livelihood and status, and the Palestinian community



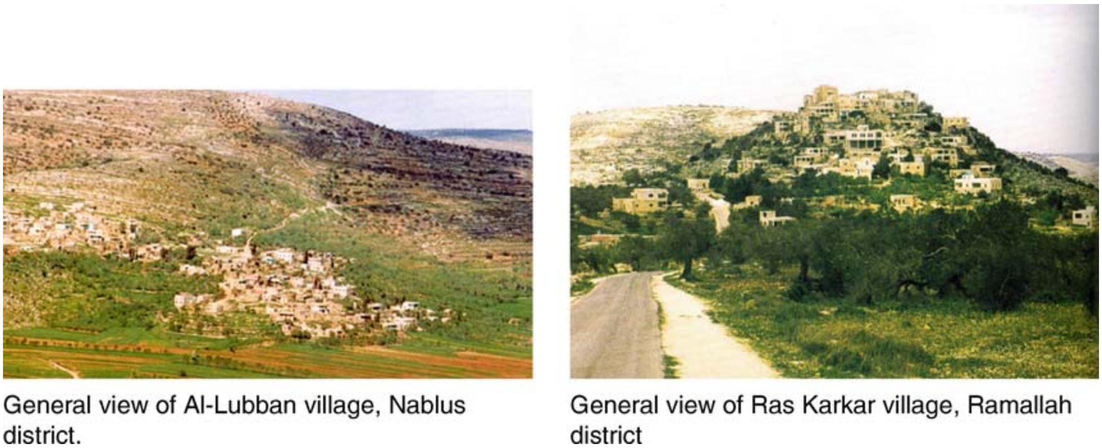
Architecture in Palestine. Fig. 5 A house plan showing the crossventilation system imposed by the central hall system used for functional organization of the internal spaces. A student work from the course "Local Architecture in Palestine", Birzeit University (1998–2001).

employed simple agricultural technology. A system of agricultural subsistence was retained, with very limited transactions with the regional or world market. The village as a whole and not the individual was considered the unit of taxation by the state. The community had patriarchal households, the extended family acting as the main unit of production and consumption, and labor was divided along clear gender lines (A'miry and Tamari 1989: 11–15).

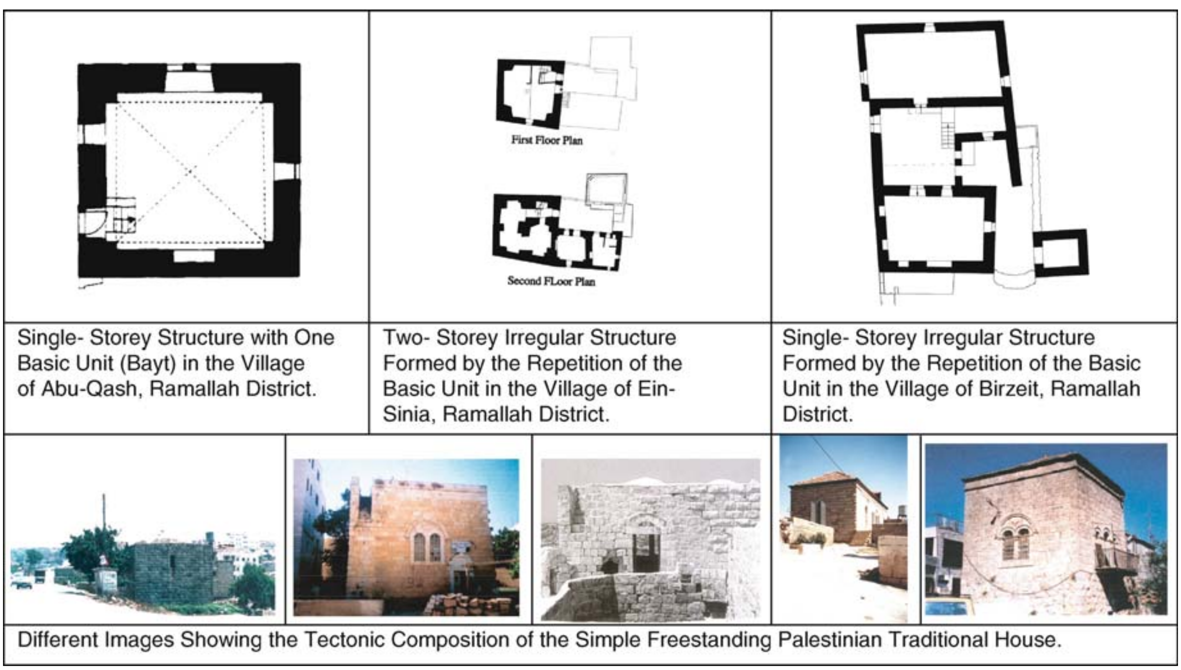
The Palestinian village has had an outstanding harmonic panoramic form and a dimensional connection with the existing environment where the built up area grew together with the land, but revealed its own main image (Fig. 6). This local rural process could be described as a classical expression of organizing the habitation process by spontaneity, intuition, and a connection with site topography. The socioeconomic organization of the built environment before 1832 evoked the implementation of one of two main systems:

- The single-storey freestanding structure, which consists of a square or rectangular space (*bayt*) with a low entrance (*bab*), ventilation opening below the roof (*taqat*), and one or a pair of two small windows (*mijwiz*) (Fig. 7).
- The clustered and concentric patterns of spatial organization, where houses and other structures have formed the traditional clustered fabric. The pattern was produced by repetition of the single-storey structure, as each house unit was adjacent to other house units at least from two sides, as the back of the structures formed a part of the periphery protecting the inner courtyard (Fig. 8).

Both systems were built either from natural stone and roofed by traditional crossvaults or with mud mixed with straw and roofed by a wooden flat structure. The free grounds between the structures mainly were used for agriculture, livestock, and/or for future expansion.



Architecture in Palestine. Fig. 6 Images demonstrating the panoramic form and dimensional connection with the existing environment in rural areas. Photos by the author.

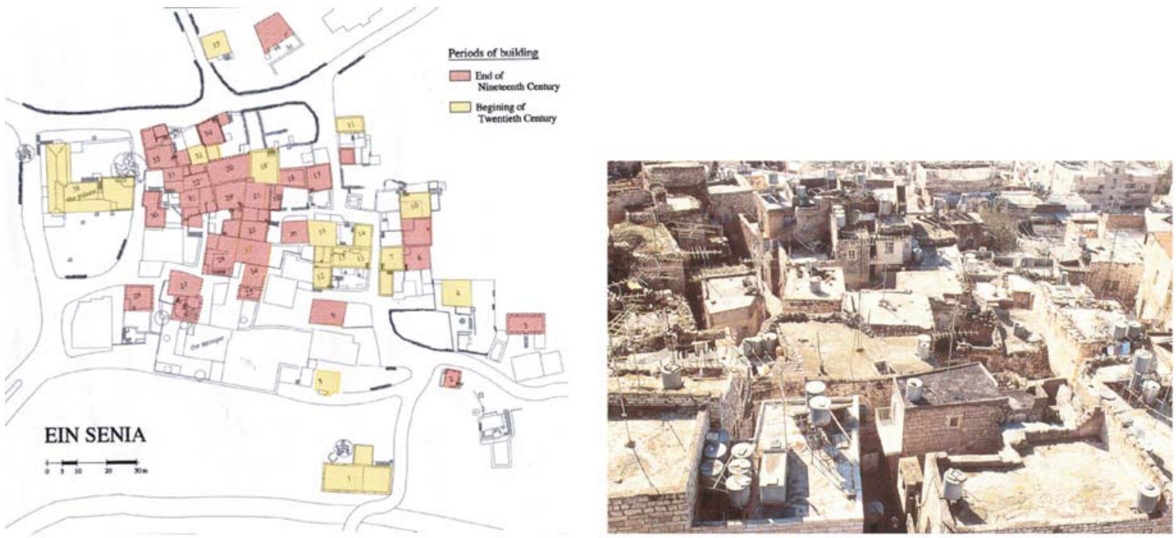


Architecture in Palestine. Fig. 7 Single and Multi Storey Freestanding Structures, consisting of a Square or Rectangular Space (Bayt), and a Pair of Two Small Windows (Mijwiz). Student works within the Course "Local Architecture in Palestine", Birzeit University, 1999–2000.

Initial Forms of the Traditional House

Today, there are still some examples that demonstrate the initial forms of the Palestinian vernacular house before 1850, but most of them have been extensively restored that they can no longer belong to any specific period. Three original forms of this architecture are still used as spaces for living, agricultural, and stock-breeding activities. Mostly, they are located in the hilly areas, villages or within the large historical cities. The general characteristics of these forms are as follows:

- *Caves*: they are considered the first habitation structure used by Palestinians for living purposes. Mostly, they are located at the eastern slopes of the Jordan Valley (winter pastures) and at the western mountains of the Palestinian territories (summer pastures). These caves are either natural, or have been rehabilitated to meet new living requirements (Fig. 9a). Each cave consists of one open space articulated into different zones by means of harmony between the various social, functional and aesthetic



Master Plan of the Old Quarter In the Top View of the Old Quarter In the City Village of Ein-Senia, Ramallah of Bethlehem, Bethlehem District.

Architecture in Palestine. Fig. 8 Two images showing the Clustered and Concentric Pattern of the Spatial Organization at the Urban and Rural Palestinian Areas. Student Works within the Course "Local Architecture in Palestine", Birzeit University, 1999–2000.

elements. Furthermore, some of these caves continue to host several living activities as a major element in the further extension of the living environment.

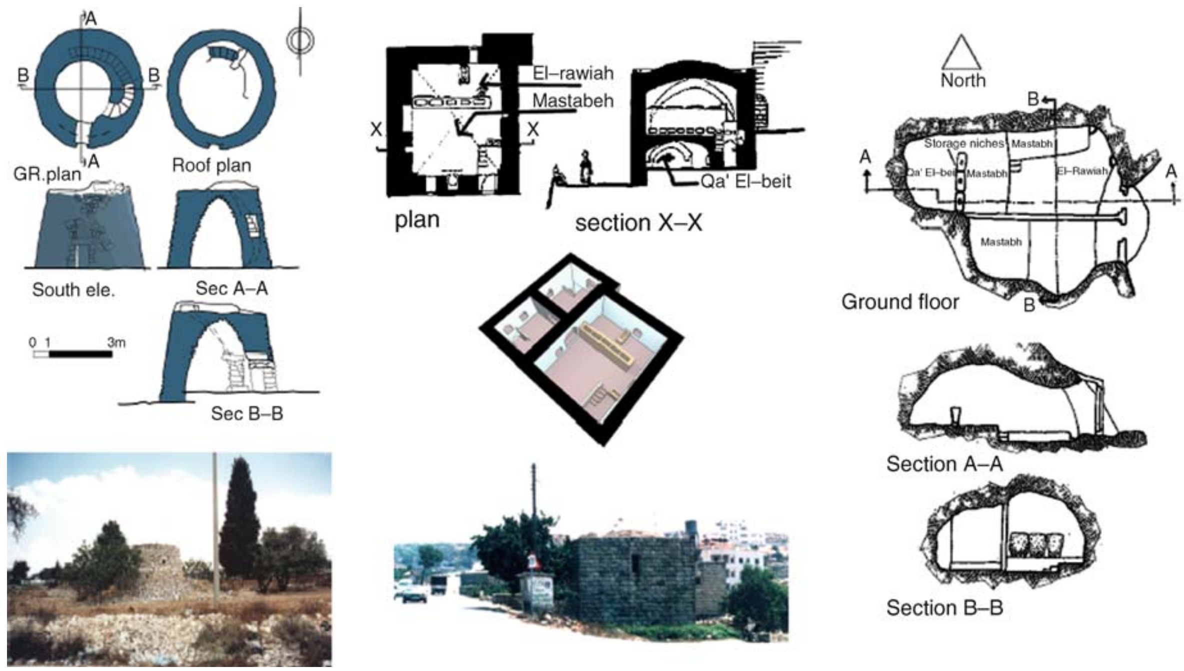
- *Watching Towers (Mantarah)*: a freestanding stone structure that imitates tectonically the vernacular typical house, but with different function and details. Usually, they are located outside the rural or urban fabrics, on the top of hills between fig and olive trees and pastures. These structures had multifunctional purposes as places for watching and cultivating land, summer vacations, storage places and bases for winter agricultural activities. Each watching tower is divided vertically into two or three levels. It consists of a ground floor for livestock and storage, a first floor for living and a second floor in the form of an open terrace used for multipurpose activities. This structure exists in both rectangular and circular plans (Fig. 9b) and all levels are accessible by an internal staircase.
- *Shepherd's House*: this model represents the most popular form of the Palestinian vernacular house with a simple single-storey square structure, built from the limestone rock abundant in the surrounding areas, and has only one low arched entrance (Fig. 9c). Walls are massive, sometimes 1 m thick, in order to support the heavy stone crossvault of the roof. The elevations are free of any window openings apart from small ventilation holes. The three-dimensional development of the shepherd's house produced three well-defined and integrated domains (A'miry and Tamari 1989; Hamdan 1996): (a) the multipurpose space for living (*Mastabeh*), (b) the animals' space (*Qa' El-beit*), and (c) the food storage space (*El-rawieh*).

These three domains were available at all three forms, with certain discrepancies according with physical and environmental needs.

New Forms of Palestinian Traditional Architecture

Palestinian traditional architecture is a product of the cultural development of the East Coast of the Mediterranean basin. Historical events caused a great dislocation of ethnic groups and populations with different public systems, specific customs, and intertwined cultural traditions. Appropriate conditions for mutual influence were established during the formation, development and enrichment of traditions and values. Several new forms of the Palestinian traditional house were created. They reflect the sociopolitical changes, which took place after the Tanzimat (reforms) period in 1842 and brought about essential transformations in the traditional structural of the Palestinian society:

- Creation of modern state institutions, mainly in the large cities, that led to immigration toward the new urban centers. This phenomenon led to major growth in the population inside the boundaries of the Old City. As a result, the existing structure became incapable of assimilating the augmenting needs of the population, and people started moving outside the Old City, creating new urban centers that were in the beginning juxtaposed to the frontiers of the Old City.
- Decline in the power of the village sheikh (Ruler).



Architecture in Palestine. Fig. 9 Original initial forms of the Palestinian vernacular house. Photos and drawings by the author.

- Changes in land tenure due to the Ottoman land reforms (Tanzimat), and privatizations of the main means of production: the land. The new ownership policies allowed foreign citizens to buy and register lands in their names. Foreign religious missions, relief agencies and consulates started their activities and gradually built up their religious, educational, health, and residential compounds.
- Growing integration of the local economy in the world trade market. This had an effect over all agricultural, trade and investment structures in Palestinian society.
- Formation and dissemination of a new culture in addition to the prevailing Islamic one.
- Changes in the occupational structure of the local population.
- Aggravation of social contradictions.
- Active emigration among the young Palestinian generation toward the American continent and Europe, in order to avoid the obligatory military service forced by the Ottoman authorities. Most of the immigrants started sending back their savings to invest them in Palestine by building mansions that reflected the new lifestyle of an affluent social class that was in formation in most Palestinian urban sites around that time.

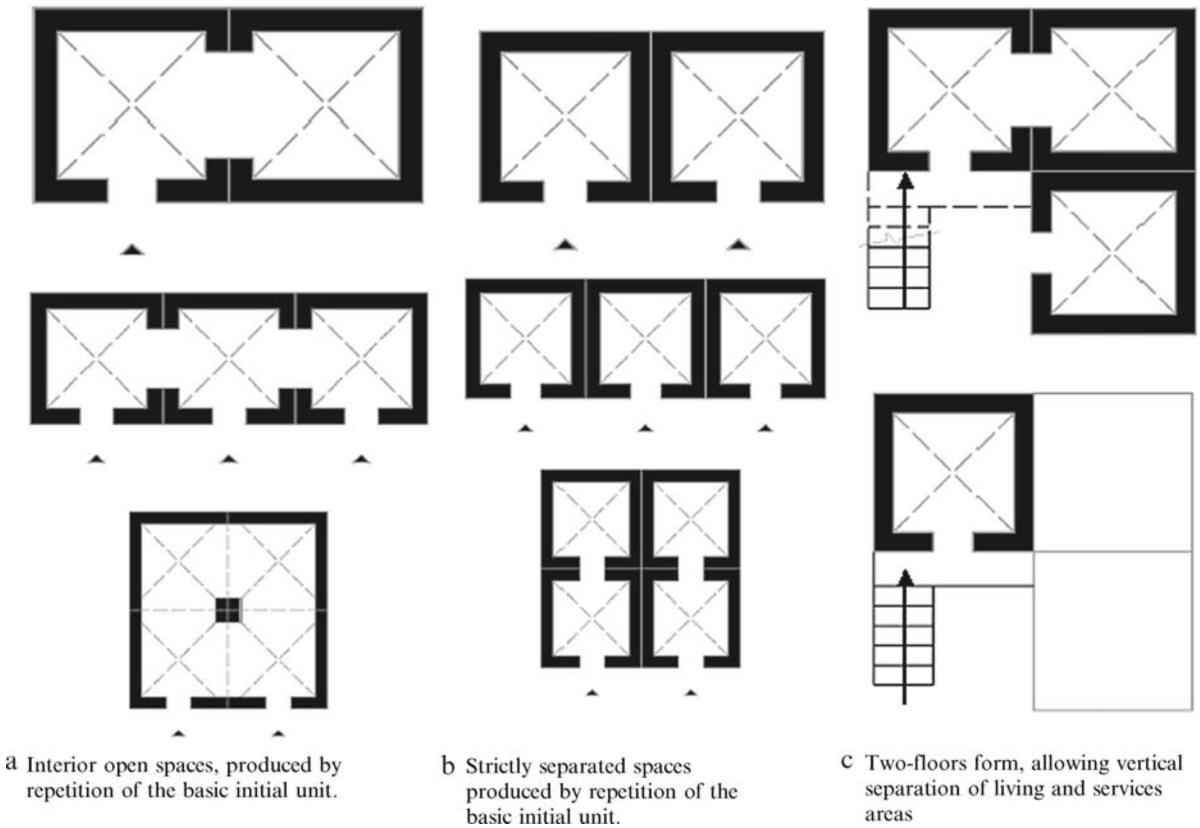
Rectangular House with Repetitive Initial Units

The term "Repetitive Initial Units" is used here to express the way this type of traditional house was produced. It consists of a repetitive arrangement of the rectangular or square initial model in a horizontal or vertical direction producing a composite structure (Fig. 10). Further development of this system initiated other more advanced forms of this architecture:

- Enlarging the space by means of one or more interior supports producing large open spaces with an internal system of pillars or vaulted roofs and enclosed by bearing walls (Fig. 10a). Mud and stone were both used.
- Strict separated spaces with sharp rectangular corners and increased rigidity of forms. In this way the organic unity of the interior space is reduced (Fig. 10b). Roofing was implemented by barrel vault or cross-vault structure, and both invited the addition of an upper floor. This form was mainly produced by stone material.
- Adaptation of a two-floor form of stone construction, which was very significant since it allowed the vertical separation of the living and service areas. This system ended the cohabitation of people and animals, symbolizing their emancipation from unremitting toil (Fig. 10c). The connection between floors was always external.

The Court House

The court denotes an open space delimited by wings and connected to the surroundings or the main alley by a main door or gate. This schema was



Architecture in Palestine. Fig. 10 Basic schemas of the rectangular traditional house. For existing examples refer to Figs. 7 and 9. Drawings by the author.

predominantly applied in the main villages and towns, because of the clustered character of the construction fabric (Fig. 11). In this case building units are arranged in an L or U shape and rarely in a closed square or rectangular shape.

The house built around a courtyard is fairly extensive and contains well-oriented wings that offer privacy and safety and form a reception space and daily activities area for the family. The courtyard was enriched by the addition of a covered terrace on one side called *Liwan*, which served as an extension toward a significant orientation like a valley, seashore or another nice view.

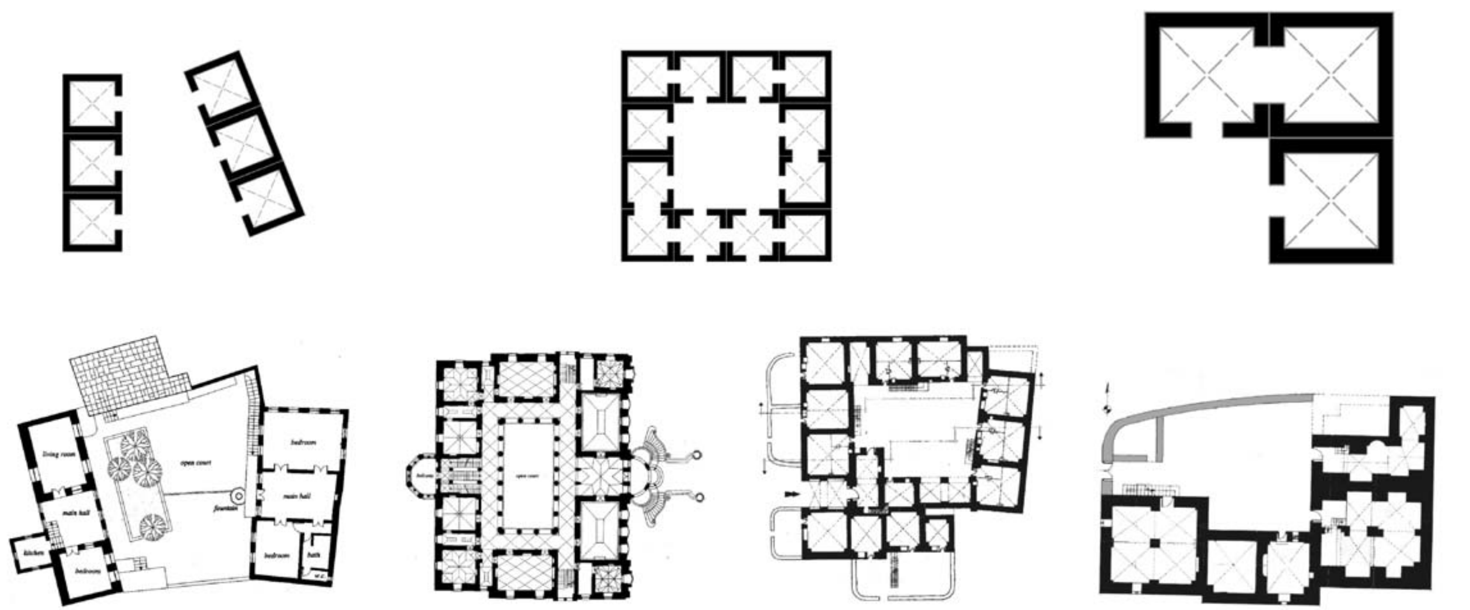
The Gallery House

The gallery (*Riwaq*) indicates a covered space, which opens to the outside through a series of supports such as colonnades or arcades. In the Mediterranean two forms of the gallery are popular. The first is a gallery that exists as an addition of a covered open space, mainly produced by ornamental plants or grapevines and therefore called a passive gallery. The second one is the active version of the gallery and is designed as an open corridor that functions as a traffic or transitional area linking different components of the building (Fig. 12). As a rule the gallery is greater in length than in depth. In general the gallery is reached either directly from the surroundings, if the terrain slope allows that, or by a courtyard in front. In contrast with the closed rectangular type the gallery building expresses three major trends (Ragette 1974: 44): (a) appreciation of the gentle climate and the natural beauty of the region; (b) a feeling of confidence to the inhabitants, and (c) an increasing emphasis on life within the family.

In the majority of cases the gallery building has two floors, the lower of which is vaulted and the upper is flat-roofed or with tiled pitched roofs (imported from Europe in the nineteenth century). In its formal expression the gallery building presents the greatest possible contrast to the closed rectangular type. The continuous arcade or colonnade provides the feeling of openness and expresses the superior social standing of the building's owners.

The Central Hall House

Although this type appears in Palestine at a later date than the other mentioned types, it became the most popular form of traditional house by the second half of the nineteenth century (Fig. 13). It has one, two, or three floors, and one or more entrances. In addition the central hall has a full depth, subdivided or surrounded



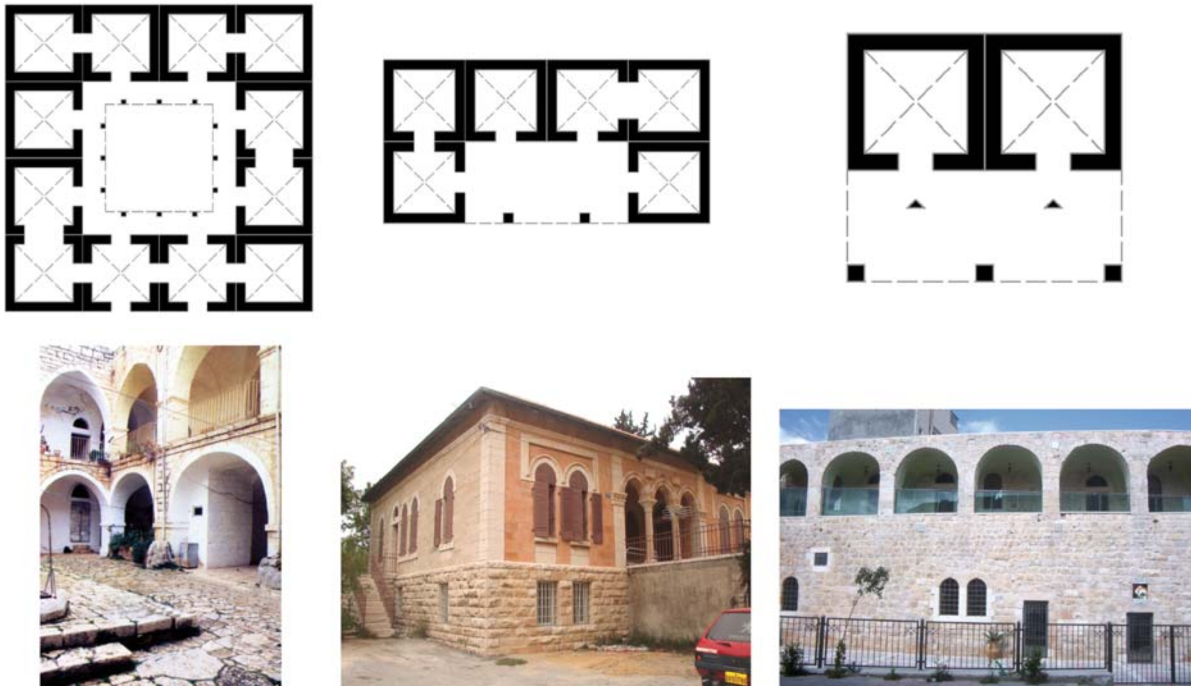
U- Shape of the Court House-Tuqan Palace, Nablus, Nablus District.

Closed Shape of the Court House-Jaser Palace, Bethlehem, Bethlehem District.

Closed Shape of the Court House-Suhweel Palace,A'bueen Village, Ramallah District.

L-Shape of the Court House-Example from Ein-Senia Village, Ramallah District.

Architecture in Palestine. Fig. 11 Basic schemas of the court traditional house. Drawings by the author.



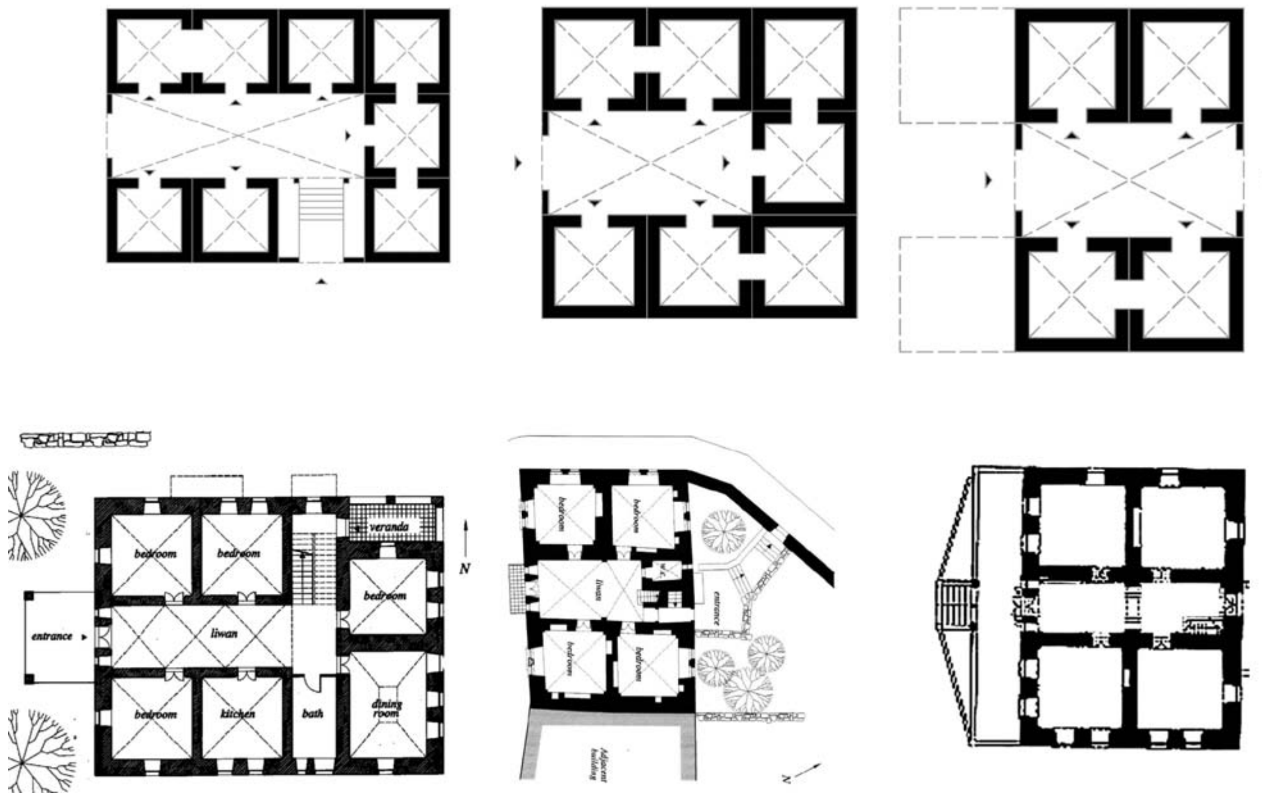
Architecture in Palestine. Fig. 12 Basic schemas of the gallery traditional house (Active Version). Photos and drawings by the author.

by rooms from three sides. A symmetrical composition prevails when the entrance leads directly to the central hall, while the corridor to the central hall disturbs the symmetry when the entrance is lateral.

By the end of the nineteenth century, due to western influence, the central hall system was adopted widely and the design became increasingly formal. The houses turned into veritable villas that majestically dominated their surroundings outside the Old City walls. Often, the central hall house was built of stone. The lower floor was vaulted and the upper either vaulted, roofed with steel beams or timbered with red tiles.

This descriptive analysis of Palestinian traditional architecture shows that transformations in the structure of Palestinian society reflect not only the achievements of Palestinian ethnic groups, but also those realized by interaction with western identities. In this way both traditional creativity and "formal architecture" have been rationalized:

1. This architecture is a product of a simple and frugal society creating its habitat with elementary means, but also with an understanding of the functional requirements and the potential of the materials available.
2. The artistic quality of the buildings created in the second half of the nineteenth century was not totally dependent upon imported models. The stylistic self-sufficiency of the country's architecture has continued to be expressed through numerous variations of locally rooted traditions, as well as mastery of a craft.
   a. The color and texture of the natural stone contribute to the homogeneous and organic character of Palestinian architecture. The stone finishing reveals an intimate knowledge of the material acquired by generations of stonemasons. The use of color for decorative effects is limited to a few elements at entrances, windows, or arches. Palestinian architecture is more restrained in this regard than Arab architecture in general, where structural clarity is sometimes masked by decorations.
   b. The form's simplicity of the traditional building, the massing of single buildings as well as groups of buildings and the adherence to a uniform scale are the basic means of creating harmony between house and landscape, house and house or village and landscape. The juxtaposition of houses creates a repetitive rhythm of mass and void that covers the land without destroying its relief. The human scale is maintained in the traditional architecture, where the principal masses, as masonry works, automatically introduce a clear definition of scale. Yet each gate, door, window or arch dimension is in reasonable relation to necessity and importance.
   c. The shapes of walls and roofs normally adhere to the simple geometry of squares, rectangles and



Architecture in Palestine. Fig. 13 Basic schemas of the central hall traditional house. Drawings by the author.

trapezoids. Spans and cantilevers are strictly limited. The repetitions of similarly shaped openings reinforce continuity and their irregular distributions within one elevation sometimes create pleasant diversity.

3. Palestinian traditional architecture occupies its place naturally and without pretension. It is imbedded in a landscape humanized by countless terraces, and built of the materials furnished by the environment. The balance of massing and the harmony of forms were exemplary, and the arrangement of the houses reflects deep understanding of the environment, and is indicative of a remarkable social balance.
4. However, by the end of the nineteenth century this architecture lost two of its most important qualities: the flexible inner space and public participation in the building process.

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Arithmetic in India: *Pāṭīgaṇita*

Takao Hayashi

Pāṭīgaṇita, which literally means "mathematics (*gaṇita*) by means of algorithms (*pāṭī*)," is the name of one of the two main fields of medieval Indian mathematics, the other being *bījagaṇita* or "mathematics by means of seeds." The two fields roughly correspond, respectively, to arithmetic (including mensuration) and algebra.

The compound *Pāṭīgaṇita* seems to have come into use in relatively later times. In older works, the expressions, *gaṇitapāṭī* and *gaṇitasya pāṭī* (mathematical procedure, i.e., algorithm), are common, and sometimes the word *pāṭī* occurs independently. *Pāṭīgaṇita* is also called *vyaktagaṇita* or "mathematics of visible (or known) [numbers]," while *bījagaṇita* is called *avyaktagaṇita* or "mathematics of invisible (or unknown) [numbers]." Some scholars maintain that the word *pāṭī* originated from the word *paṭṭa* or *paṭa* meaning the calculating board, but its origin seems to be still open to question.

The division of mathematics (*gaṇita*) into those two fields was not practiced in the *Āryabhaṭīya* (AD 499), which has a single chapter called *gaṇita*, but it existed in the seventh century, when Brahmagupta included two chapters on mathematics in his astronomical work, *Brāhmasphuṭasiddhānta* (AD 628). Neither the word *pāṭī* nor *bījagaṇita* occurs in the book, but chapter 12 (simply called *gaṇita*) deals with almost the same topics as later books of *pāṭī*, and chapter 18, though named *kuttaka* or the pulverizer (solution of a linear indeterminate equation), has many topics in common with later books of *bījagaṇita*. Śrīdhara (ca. AD 750) is known to have written several textbooks of *pāṭī* and at least one of *bījagaṇita*.

Extant works of *pāṭī* include Śrīdhara's *Pāṭgaṇita* (incomplete) and *Triśatikā* (and *Gaṇitapañcaviṃsi*?), Mahāvīra's *Gaṇitasārasaṃgraha* (ca. AD 850), chapter 15 (*pāṭī*) of Āryabhaṭa's *Mahāsiddhānta* (ca. AD 950 or 1500), Śrīpati's *Gaṇitatilaka* (incomplete) and chapter 13 (*vyaktagaṇita*) of his *Siddhāntaśekhara* (ca. AD 1050), Bhāskara's *Līlāvatī* (AD 1150), and Nārāyaṇa's *Gaṇitakaumudī* (AD 1356).

A book (or chapter) of *pāṭī* consists of two main parts, namely, fundamental operations (*parikarmāṇi*) and "practical problems" (*vyavahārāḥ*). The former usually comprises six or eight arithmetical computations (addition, subtraction, multiplication, division, squaring, extraction of the square root, cubing, and extraction of the cube root) of integers, fractions, and zero, several types of reductions of fractions, and rules concerning proportion including the so-called rule of three (*trairāśika*). The latter originally consisted of eight chapters (or sections), i.e., those on mixture (*miśraka*), mathematical series (*śreḍhī*), plane figures (*kṣetra*), ditches (*khāta*), stacking [of bricks] (*citi*), sawing [of timbers] (*krākacika*), piling [of grain] (*rāśi*), and on the shadow (*chāyā*).

To this list of the practical problems, Śrīdhara added in his *Pāṭīgaṇita* one named "truth of zero" (*śūnyatattva*). A large portion of the work including that chapter is, however, missing in the only extant manuscript. The way the *Gaṇitasārasamgraha* of Mahāvīra divides its contents into chapters is unusual, but still it can be characterized as a book of *pāṭī*. It is quite rich in mathematical rules and problems.

In his *Līlāvatī*, Bhāskara separated the rules on proportion from the arithmetical computations, and created with them a new chapter named *prakīrṇaka* (miscellaneous [rules]), in which he also included the *regula falsi*, the rule of inverse operations, the rule of sum and difference, etc. After the ordinary topics of practical problems, he treated *kuṭṭaka* as well as *ankapāśa* or the nets of numerical figures (combinatorics). Written in elegant but plain Sanskrit and organized well, the *Līlāvatī* became the most popular textbook of *pāṭī* in India.

In his *Gaṇitakaumudī*, Nārāyaṇa included in the practical problems not only *kuṭṭaka* and *aṇkapāśa*, but also *vargaprakṛti* or the square nature (indeterminate equations of the second degree including the so-called Pell's equation), *bhāgādāna* or the acquisition of parts (factorization), *aṃśāvatāra* or manifestation of fractions (partitioning), and *bhadragaṇita* or mathematics of magic squares. These topics had already been dealt with to a certain extent by his predecessors, but he developed them considerably. He also investigated new mathematical progressions, some of which turned out to be useful when Mādhava (ca. AD 1400) and his successors obtained power series for the circumference of a circle (or π), sine, cosine, arctangent, etc.

See also: ►Āryabhata, ►Śrīdhara, ►Mahāvīra, ►Bhāskara, ►Nārāyaṇa, ►Combinatorics, ►Magic Squares, ►Mādhava

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Arithmetic in Islamic Mathematics

Julian A. Smith

Mathematics flourished during the golden age of Islamic science, which began around the seventh century AD and continued through to about the fourteenth century. Both arithmetic and algebra were advanced dramatically by Muslim mathematicians, who adopted Indian innovations such as decimal numbers and considerably extended them – they also developed earlier Greek concepts of geometry, trigonometry, number theory and the resolution of equations. Islamic mathematicians did far more than just copy Greek and Indian techniques – their additional researches developed and systematized several fields of mathematics. Even modern mathematical language, including terms like "algebra", "root" and "zero", owes an important debt to Arabic scientists. Algebra, for example, comes from the ninth-century Arabic Astronomer and mathematician al-Khwārizmī (ca. 780–ca. 850), whose book *Algebra* (*al-Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa 'l-muqābala*) described techniques of transposing quantities from one side of an equation to another (*jabr*), then simplifying them (*muqābala*).

Yet while Arabic contributions to algebra have been widely discussed by historians of science and culture, their parallel work in arithmetic has been until recently far less well known. During the early nomadic period of Arabic history, numbers were given names – and around the time of the Prophet Muḥammad (ca. 570–632), the letters of the Arabic alphabet were often used as numerals. However, it was not until the rise of Islam in the seventh and eighth centuries that a recognizably modern system of arithmetic was developed. Muslim arithmetic operations were largely based on ancient Greek definitions, but Islamic scholars pioneered new techniques, including the network or lattice method (*shabaqah*) to multiply numbers, and various techniques of long division.

Muslim mathematicians are best known for their contributions to the pivotal system of modern "Hindu–Arabic numerals" – i.e. the technique of expressing all numbers through the repeated use of a few basic symbols. Though originally invented in India, Arab scholars dramatically improved both the writing and manipulation of decimal numerals, and also developed the Hindu idea of positional notation. It is not known exactly when Indian mathematicians began using decimal numbers, but they seem to have been in place by the early sixth century AD – astronomer Āryabhaṭa I (476–ca. 550) did not use them, but they were employed in a limited way by the middle of the sixth century. Decimal numbers were quite popular and spread quickly – by the seventh century, they had reached Iraq and the Middle East, and were praised by Syrian Nestorian bishop Severus Sebokht (fl. AD 630), who considered this new Hindu arithmetic "done with nine signs" even more ingenious than the calculations of Greek mathematicians. Arabs began using Hindu decimal arithmetic around the seventh century, but it was not until the ninth century that Arabic works describing this type of reckoning appear. The earliest known Arabic treatise on decimal arithmetic, *Kitāb al-hisāb al-hindī* (Book of Addition and Subtraction According to the Hindu Calculation), was written by Al-Khwārizmī around AD 800 – the Arabic text is lost, but a twelfth century Latin translation is still extant.

Al-Khwārizmī is better known among historians of Muslim mathematics for his many contributions to algebra. Yet his investigations into arithmetic were equally important, and were so widely read in the medieval Latin West that they later gave Europeans one of their early names for arithmetic, the "algorism" or "algorithm". Al-Khwārizmī's book treated all arithmetic operations, spreading knowledge of Hindu techniques throughout the Muslim world. Another important early treatise that publicized decimal numbers was Iranian mathematician and astronomer Kūshyār ibn Labbān's (fl. 1000) *Kitāb fī uṣūl ḥisāb al-hind* (Principles of Hindu Reckoning), a leading arithmetic textbook.

Coupled to the important development of decimal numbers was the equally significant Arabic use of the *sifr* (meaning "empty"), or zero, again from Indian roots. An early symbol for zero appears in an AD 876 inscription at Gwalior, India; in the Arab world, Kūshyār introduces the zero in the tenth century as a sign to be placed "where there is no number".

Though scholars concede that much of Arabic arithmetic has its ultimate origins in India, Muslim mathematicians were the first to integrate the various discoveries of Hindu mathematicians into a coherent whole. Historian J. L. Berggren, for example, concludes that while the Hindus were the first to use a "cipherized, decimal positional system", the Arabs pioneered in extending this system to "represent parts of the unit by decimal fractions". In Europe, meanwhile, the zero and decimal system were not widely used until the late twelfth century.

Following al-Khwārīzmī, many Arabic mathematicians developed Indian techniques of arithmetic over the next few centuries. The astronomer, translator, and editor al-Kindī (801–ca. 873), for example, wrote several important treatises on arithmetic, including manuscripts on the use of Indian numbers, on lines and multiplication with numbers, on measuring proportions and times, on numerical procedures and cancellation, and many more.

Two centuries later, al-Karajī of Baghdad (fl. 1020) wrote mathematical works that led to his being called "the most scholarly and original writer of arithmetic" by historian Al-Daffa. Al-Karajī's works included a manuscript on the rules of computation entitled *Al-Kafī fī al-Ḥisāb* (Essentials of Arithmetic), and *al-Fakhrī fī' ljabr wa'l-muqābala*, which was named after his longtime friend, the Baghdad grand vizier.

The depth of early Islamic knowledge of arithmetic is often quite unexpected. Arabic mathematicians were well aware of the existence of irrational numbers, and sometimes developed complex theories to explain their properties. Persian poet and philosopher 'Umar al-Khayyām, or Omar Khayyam (ca. 1048–ca. 1122) and Persian astronomer Naṣīr al-Dīn al-Ṭūsī (1201–1274) both argued that every ratio of two magnitudes can be considered a number, whether that ratio be commensurable (rational) or incommensurable (irrational). Islamic arithmetic used many of the same Hindu techniques for operating with irrationals as it did with rationals. Also from Indian sources came various operations with numbers, including transformations such as $\sqrt{x^2y} = x\sqrt{y}$ and $\sqrt{xy} = \sqrt{x}\sqrt{y}$.

Islamic arithmeticians did not accept everything offered them by Hindu scholars. For example, negative numbers, long a staple in Indian arithmetic, were transmitted to the Arab world but rejected by it – Arabic mathematicians instead held that negative numbers did not exist.

Modern notation for fractions is also based in part on Muslim arithmetic. Celebrated Hindu mathematicians such as Bhāskara II (1114–ca. 1185) wrote common fractions by just writing a numerator above a denominator, but the idea of a line of separation between the numerator and denominator was an early Islamic development. Decimal fractions, meanwhile, appear in seminal tenth century Arabic texts, such as the *Kitāb al-fuṣūl fi'l ḥisāb al-hindī* (Book of Chapters on Hindu Arithmetic), written by Damascus mathematician al-Uqlīdisī (fl. 952). In the late twelfth century, al-Samaw'al (fl. 1172) used decimal fractions for division, root extraction and approximation. By the fifteenth century, decimal fractions had been formally named and systematically developed, but they were not widely used in Europe until the Dutch physicist and engineer Simon Stevin (1548–1620) published *La Thiende* (The Tenth) in 1585, and Scottish mathematician John Napier (1550–1617) reintroduced his decimal point in the early seventeenth century.

While Arabic mathematicians pioneered in decimal arithmetic, they also made considerable contributions to the ancient sexagesimal (base 60) system of arithmetic, which had been developed by the Babylonians in Mesopotamia around 2000 BCE. This system was widely used for astronomical calculation throughout the ancient world, particularly in Alexandrian astronomer and geographer Claudius Ptolemy's (ca. AD 100–170) cosmological treatise, *Almagest*, which was later adopted by Islamic scholars as the theoretical base of their astronomy. Sexagesimal addition, subtraction, multiplication and division became so commonplace among Islamic astronomers it was renamed "the astronomer's arithmetic". Arabic astronomers and mathematicians such as Kūshyār and Samarqand's al-Kāshī (fl. 1406–1429) used sexagesimal numbers to determine approximate roots, extract square roots and even find the fifth roots of certain numbers.

Islamic arithmetic was often influenced by the needs of astrology, talismans and sorcery, as in the casting of horoscopes and magic spells. Muslim mathematicians such as Syrian scholar Thābit ibn Qurra (ca. 836–901) and Tunisian historian lbn Khaldūn (1332–1406) studied amicable numbers, or number pairs where the sum of the factors of each number is equal to the other number. Two hundred and twenty and 284 are amicable numbers, because the sum of the factors of 284 (1 + 2 + 4 + 71 + 142) equals 220, and vice versa.

Muslim mathematics was also affected by practical considerations such as problems of inheritance and finance, and the need to calculate events in the lunar-based Islamic calendar. For example, al-Khwārizmī devoted the second half of his treatise on algebra to the question of '*ilm al-farā'iḍ*, or the calculation of shares of an estate given to various heirs. These problems employed the arithmetic of fractions, and were heavily influenced by religious law and custom. A typical example treated by al-Khwārizmī was to calculate the shares of a dead woman's estate that would accrue to her husband, her son, and her three daughters. As the law required that the husband receive a fourth and each son get twice what a daughter would receive, al-Khwārizmī simply divides the estate into 20 parts, giving five to the husband, six to the son, and three to each daughter. Similar problems involved the topic of *zakāt*, which was the calculation of the share of private wealth that various persons would pay to the community each year.

Islamic arithmetic was often ingenious. Arabic scholars gave us much of the modern system of arithmetic, and while many of its foundations were borrowed from Indian and Greek sources, it is clear that Islamic mathematicians united the various strands of arithmetic into a form recognizable to us today.

See also: ►Mathematics, ►Trigonometry, ►Number Theory, ►al-Khwārizmī, ►al-Kindī, ►al-Karajī, ►al-Uqlīdisī, ►Sexagesimal System, ►*Almagest*, ►al-Kāshī, ►Thābit ibn Qurra, ►Ibn Khaldūn, ►Naṣīr al-Dīn al-Ṭūsī

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Armillary Spheres in China

Jiang Xiaoyuan

The equatorial armillary sphere was a traditional Chinese astronomical instrument used to observe celestial bodies in an equatorial coordinate system. Its origin is still not very clear. Astronomer Luoxia Hong (ca. 100 BCE) of the Western Han Dynasty was probably the first maker of this instrument which possessed a very basic form.

The early equatorial armilla was composed of two layers: the outside layer included a meridian circle, equatorial circle, and vertical circle – all three of these were fixed. The inside layer included a polar axis, right ascension circle, and sighting tube. The right ascension circle could rotate around the polar axis, and the sighting tube could rotate in the right ascension circle freely so it could point to everywhere in the sky.

In the Tang Dynasty (AD 618–907), a third layer was added to the equatorial armillary which included an ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) circle and a circle of the moon's path. Astronomers could then measure three coordinate systems with one instrument, but the three-layer armilla was too complex to observe, so from the Northern Song Dynasty (AD 960–1126) a course of simplification was begun. The third layer was canceled, and the so-called "abridged armilla" (*Jian Yi*) appeared. It is in fact two different instruments (one equatorial armilla and one altazimuth) on the same pedestal.

The equatorial armilla was one of the most important astronomical instruments in ancient China. It was the result of the equatorial tradition of Chinese astronomy which lasted more than 2,000 years. In ancient China, armilla (and almost all astronomical instruments) were only made by the imperial government, so their size was always very large.

See also: ►Luoxia Hong, ►Astronomy in China

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Armillary Spheres in India

K. V. Sarma

The armillary sphere, known in Hindu astronomy by the terms *Golabandha* and *Gola-yantra* (Globe instrument), was constructed from early times for study, demonstration, and observation. Among texts and commentaries which have either brief mention or detailed treatment of the armillary sphere, the following might be mentioned: *Āryabhaṭīya* of Āryabhaṭa (b. 476), *Pañcasiddhāntikā* of Varāhamihira (505), *Śiṣyadhīvṛddhida* of Lalla (eighth century), *Brāhmasphuṭasiddhānta* of Brahmagupta (b. 628), *Siddhāntaśekhara* of Śripati (1039), *Sūrya-siddhānta, Siddhāntairomaṇi* (*Golabandhādhikāra*) of Bhāskara II (b. 1114), and *Goladīpikā* of Parameśvara (1380–1460).

The movable and immovable circles which form parts of the instrument are made out of thin bamboo strips, the earth and the celestial bodies are of wood or clay, and the lines are connected by means of strings. The axis is made of iron and is mounted on two vertical posts, so that it is possible to rotate the sphere as needed.

The *Goladípikā* describes the construction of a simple *Golabandha* with two spheres, the inner one representing the *Bhagola* (Starry sphere) moving inside an outer sphere which represents the *Khagola* (Celestial sphere), both fitted on the same central axis. The movements of the planets, etc. are projected and measured on these spheres. A circular loop made of a thin bamboo strip kept vertically in the north–south direction represents the solsticial colure[1] (*Dakṣiṇottara*). Another similar circle fixed to the former in the east–west direction would be the equinoctial or celestial equator (*Ghaṭikā-maṇḍala*). Still another circle fixed around these, cutting them at right angles and making crosses at the four cardinal points, represents the equinoctial colure. The celestial equator is graduated into 60 equal parts and the other two into 360 equal parts. Another circle is fixed passing through the east and west crosses and inclined at 24° north and south of the zenith and the nadir – this would be the Ecliptic (*Apama-vṛtta*). Several smaller circles are now constructed across the solsticial colure on either side of the celestial equator and parallel to it, at the required declinations – these would be the diurnal circles (*Ahorātra-vṛttas*), of different magnitudes. The orbits of the Moon and other planets are now constructed, crossing the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) at the nodes (*pātas*) of the respective planets and diverging from it, north and south, by their maximum latitudes at 90° from the nodes. A metal rod is inserted through the north and south crosses to form the central axis. This figuration is called the Starry sphere (*Bhagola*).

Three circles are constructed outside the *Kha-gola* (Celestial sphere). The horizontal circle is called the horizon (*Kṣitija*), the east–west circle is called prime vertical (*Samamaṇḍala*), and the north–south circle is called the meridian (*Dakṣiṇottara*). A model of the Earth in spherical form is then fixed to the center of the axis. This would be the figuration at zero latitude.

If the armillary sphere is to be used in any other place, two holes are made in the Celestial sphere at a distance equal to the latitude of the place, below and above the south and north crosses, and the axis of the Starry sphere is made to pass through them. It is also necessary, in this case, to construct a circle called the equinoctial colure (*Unmaṇḍala*), which passes through the two ends of the axis and the east and west crosses. To keep the two sets of circles in position, wooden pieces are fixed to the axis in between them, so that the spheres do not get displaced.

The inner Starry sphere revolves constantly, while the Celestial sphere remains stationary, and directions are reckoned therefrom. A diurnal circle with its radius equal to the sine latitude is also constructed with a point on the central axis as the center, just touching the horizon. The sine and cosine of the place can be measured on this circle.

While the armillary sphere described above is more for study and demonstration, certain other texts speak of more circles and also enjoin observation of celestial bodies. Thus *Brāhmasphuṭasiddhānta* (XXI. 49–69) prescribes the construction of 51 movable circles, *Śiṣyadhīvṛddhida* speaks of diagonal circles (*Koṇa-vṛttas*) and spheres for each planet, and *Siddhānta-śiromaṇī* adds a third circle called Dṛggola outside the *Khagola* (Celestial sphere). According to *Śiṣyadhīvṛddhida* the *lagna* (Orient ecliptic point) and time are also found by means of the armillary sphere.

See also: ►Astronomical Instruments in India

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[1] The Colure is a great circle of the celestial sphere through the celestial poles and either the equinoxes or solstices.

Āryabhaṭa

R. C. Gupta

Āryabhaṭa (b. AD 476) was a celebrated astronomer and mathematician of the classical period of the Gupta dynasty (AD 320 to ca. 600). This era is called the Golden Age in the history of India, during which Indian intellect reached its high water mark in most branches of art, science, and literature, and Indian culture and civilization reached a unique stage of development which left its deep impression upon succeeding ages. Āryabhaṭa played an important role in shaping scientific astronomy in India. He is designated as Āryabhaṭa I to differentiate him from Āryabhaṭa II, who flourished much later (ca. AD 950–1100) and who wrote the *Mahāsiddhānta*.

Āryabhaṭa I was born in AD 476. This conclusion is reached from his own statement in the *Āryabhaṭīya*: "When sixty times sixty years and three quarters of the *yuga* (now *Mahā*) had elapsed, twenty three years had then passed since my birth" (III, 10).

Since the present *Kaliyuga* (the last quarter of the *Mahāyuga*) started in 3102 BCE, Āryabhaṭa was 23 years old in 3600 minus 3101, that is in AD 499. The exact date of birth comes out to be March 21st, when the Mean Sun entered the zodiac sign of Aries in AD 476. The significance of mentioning AD 499 is that the precession of equinoxes was zero at the time, so that the given planetary mean positions did not require any correction. According to some commentators, AD 499 was also the year of compostion of the *Āryabhaṭīya*.

We have no knowledge about his parents or teachers, or even about his native place. Āryabhaṭa composed the *Āryahhaṭīya* while living at Kusumapura, which has been identified as Pāṭaliputra (modern Patna in Bihar State), the imperial capital of the Gupta empire. It is possible that Āryabhaṭa headed an astronomical school there.

The association of Patna, where Āryabhaṭa taught and wrote on mathematics and astronomy, with his professional career, does not settle the question of his birthplace, but it may have been a place where he was educated.

Āryabhaṭa's fame rests mainly on his *Āryabhaṭīya*, but from the writings of Varāhamihira (sixth century AD), Bhāskara I, and Brahmagupta (seventh century), it is clear that earlier he composed an *Āryabhaṭa Siddhānta*. Although voluminous, the *Āryabhaṭa Siddhānta* is not extant. It is also called *Ārdharātrika Tantra*, because in it the civil days were reckoned from one midnight to the next. Its basic parameters are preserved by Bhāskara I in his *Mahābhāskarīya* (Chap. VII). Rāmakṛṣṇa Ārādhya (AD 1472) has quoted 34 verses on astronomical instruments from the *Āryabhaṭa Siddhānta*, of which some were devised by Āryabhaṭa himself.

The *Āryabhaṭīya* is an improved work and the product of a mature intellect. Considering the genius of Āryabhaṭa, it is easy to agree with the view that he composed it at the age of 23. The date is also in fair agreement with the recent research and analysis by Roger Billard. Unlike the *Āryabhaṭa Siddhānta*, the civil days in the *Āryabhaṭīya* are reckoned from one sunrise to the next – a practice which is still prevalent among the followers of the Hindu calendar. The *Āryabhaṭīya* consists of four sections or *pādas* (fourth parts):

1. *Daśagītikā* (10 + 3 couplets in Gīti meter)
2. *Gaṇitapāda* (33 verses on mathematics)
3. *Kāla-kriyāpāda* (25 verses on time-reckoning)
4. *Golapāda* (50 verses on spherical astronomy)

That the *Āryabhaṭīya* was quite popular is shown by the large number of commentaries written on it, from Prabhākara (ca. AD 525) through Nīlakaṇṭha Somayāji (ca. 1502) to Kodaṇḍarāma (ca. 1850).

An Arabic translation of the *Āryabhaṭīya* entitled *Zīj al-Ārjabhar* was made in about 800, possibly by al-Ahwāzī. In spite of the *Āryabhaṭīya's* popularity, H. T. Colebrooke failed to trace any work of Āryabhaṭa anywhere in India.

The use of modern scientific methodology, as described by Roger Billard in his *L'astronomie indienne*, along with new ephemerides, clearly shows that both of Āryabhaṭa's major works were based on accurate planetary observations. In fact, the use of better planetary parameters, the innovations in astronomical methods, and the concise style of exposition rendered the *Āryabhaṭīya* an excellent textbook in astronomy. In opposition to the earlier geostationary theory, Āryabhaṭa held the view that the earth rotates on its axis. His estimate of the period of the sidereal rotation of earth was 23 h, 56 min, and 4.1 s, which is quite close to the actual value.

Āryabhaṭa has been also considered the father of Indian epicyclic astronomy. The resulting new planetary theory enabled Indians to determine more accurately the true positions and distances of the planets (including the sun and the moon). He was the first Indian to provide a method of finding celestial latitudes. He also propounded the true scientific cause of eclipses (instead of crediting the mythlogical demon Rāhu). In fact his new ideas gave rise to the formation of a new school of Indian astronomy: the Āryabhaṭa School or *Āryapakṣa*, for which the basic text was the *Āryabhaṭīya*.

Exposition and computation based on the new astronomical theories were made easy by Āryabhaṭa, because of the development of some mathematical tools. One of them was his own peculiar system of alphabetic numerals. The 33 consonants of the Sanskrit alphabet (Nāgarī script) denoted various numbers in conjunction with vowels which themselves stood for no numerical value. For example, the expression *khyughṛ* (=*khu* + *yu* + *ghṛ*) denoted

$$2 \times 100^2 + 30 \times 100^2 + 4 \times 10^3 = 4,300,000,$$

which is the number of revolutions of the sun in a Yuga.

The development of Indian trigonometry (based on sine instead of chord, as the Greeks had done) was another of Āryabhaṭa's achievements which was necessary for astronomical calculations.

Because of his own concise notation, he could express the full sine table in just one couplet, which students could easily remember. For preparing the table of sines, he gave two methods, one of which was based on the property that the second order sine differences were proportional to sines themselves.

Āryabhaṭa seems to have been the first to give a general method for solving indetermininate equations of the first degree. He dealt with the subject in connection with the problem of finding an integral number N which will give a remainder r when divided by an integer a, and s when divided by b. This amounts to solving the equations

$$N = ax + r = by + s.$$

Although at present the topic of indeterminate analysis comes under pure mathematics, in ancient times it arose and was used for practical and astronomical problems. In fact, Āryabhaṭa successfully used his theory of indeterminate analysis to determine a mean conjunction of all planets at the zero mean longitude at the start of the *Kaliyuga* (3102 BCE). Recently it has been shown that his algorithm solves more general problems than the Chinese remainder theorem, and works irrespective of the sign of numbers.

The solution of a general quadratic equation and the summation of certain series were some other algebraic topics dealt with by Āryabhaṭa. The methods of adding an arithmetical progression were known in all ancient cultures, but he was perhaps the first to supply a general rule for finding the number of terms (n) when the first term (a), the common difference (d) and the sum (s) were given. His solution is a root of the quadratic equation

$$dn^2 + (2a - d)n = 2s,$$

which comes from the usual formula for the sum of an arithmetical progression.

In geometry, his greatest achievement was an accurate value of π. His rule amounts to the statement

$$dn^2 + (2a - d)n = 2s.$$

This implies the approximation 3.1416 which is correct to its last decimal place. How he arrived at this is not known.

From what we know about Āryabhaṭa, it is clear that he was an outstanding astronomer and mathematician. His scientific attitude, rational approach, and mathematical methodology ushered in a new era in the history of the exact sciences in India. It was quite befitting that the first Indian satellite launched on the 19th April 1975 was named Āryabhaṭa.

See also: ►Mathematics in India, ►Astronomy in India, ►Trigonometry in India

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Asada Goryu

Nakayama Shigeru

Asada Goryu (1734–1799) was a Japanese astronomer who was instrumental in turning Japanese astronomy and calendrical science away from the traditional Chinese style and toward Western models.

In adopting the traditional idea of secular diminution of tropical year length, astronomers at the time were required only to account for the ancient records and modern data of Chinese solstitial observations by a single formula. Classical Western data, such as those listed in the *Almagest* of Ptolemy, became available to Asada through the Jesuit treatises. He endeavored to synthesize Western and Chinese astronomy and to give a numerical explanation, by means of a single principle, of all the observational data available to him – old and new, Eastern and Western.

Copernicus appears in the Sino-Jesuit treatises, not as an advocate of heliocentricism but as an observational astronomer and the inventor of the eighth sphere of trepidation. He is said to have believed that the ancient tropical year was longer than that of the Middle Ages, which in turn was shorter than the contemporary constant. Asada, perhaps struck by this passage, formulated a modified conception in which the length of the ancient tropical year tended to decrease until it reached a minimum in the Middle Ages and to grow longer afterward, varying in a precession cycle of 25,400 years.

It is apparent that what Asada really intended to do was account for the newly acquired Western data. His basic goal, that of "saving the ancient records" by numerical manipulation, differs not at all from that of the traditional approach. His consideration of the precession cycle was theoretical decoration.

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Astrolabe

Julian A. Smith

The astrolabe is a portable wooden or metal astronomical instrument which is used to measure the positions and altitudes of celestial bodies, to find the observer's time or latitude, or to solve other mathematical problems. In its complete form, it consists of a main body, or flat plate ("mater" or "mother") to which is attached a series of smaller plates (called climates) engraved with various coordinate lines, according to various latitudes. An alidade, a rotatable straight rule with sights used to find altitudes, is fastened to the back. Attached to the front, above the climates, is a smaller fretted circular plate called the rete – this is a moveable map of the heavers, with pointers indicating various stars. The whole rotating assembly is fastened together by a pin through the center of the mater and climates, and it is secured at the top by a wedge-shaped piece of metal called the horse, after its fanciful resemblance to a horse's head.

To use the astrolabe, an observer would typically rotate the alidade until a star became visible through the sights, and then read its altitude in degrees from a scale on the back of the instrument. Then one would turn the rete until that star corresponded to the almucantar (curves representing parallels to the horizon) for the right altitude. The time could then be determined from the place of the "sun" on the instrument. Astrolabes could measure solar time, sidereal time, and time in unequal hours, depending on how the hour lines were marked.

Although the astrolabe is usually considered an Arabic invention, its true roots go back to the mathematical astronomers of ancient Greece – the word itself comes from the Greek terms for a "star-taking" instrument. Engraving great circles and hour lines demanded considerable skill – in essence, the instrument-maker had to collapse a three-dimensional celestial sphere into the flat, circular plane of the astrolabe. Some historians attribute this discovery to Appolonius of Perga (ca. 262–ca. 190 BCE), but according to Otto Neugebauer, the planispheric or stereographic projection of the heavens upon a flat surface was first accomplished by Greek astronomer Hipparchus of Nicea/Rhodes (ca. 190–ca. 120 BCE). In addition, Hipparchus may have built simple astrolabes, consisting of solid sky maps covered with open networks of lines. Finally, he is credited with developing the projection for an anaphoric clock, an ancestor of the astrolabe. This is an axle with a large circular star map, laid out in a stereographic projection – attached to it is a smaller stationary grill showing the projection of the horizon, and a visible hemisphere for a given latitude. The dial is powered by a clepsydra, and as it rotates, a model of the sun traces out the hours of the day. The anaphoric clock was described by Roman engineer Vitruvius (ca. 25 BCE), and may have been built in the famous Athenian "Tower of the Winds" around 50 BCE.

The first clear descriptions of the construction of the astrolabe occur in the *Planisphere* of Alexandrian astronomer Claudius Ptolemy (ca. 150 AD). By this time, the complexity of various lines had made the astrolabe's covering bulky, a problem Ptolemy solved by switching the lines to the mater and the star map to the rete. The astrolabe was further developed in the works of Greek mathematician Theon (fl. AD 360–380), now lost, and John Philoponus (fl. 520), both of Alexandria. Syrian Severus Sebokht (fl. 630) also wrote an early treatise on the astrolabe.

Medieval Islamic scientists took the basic planispheric astrolabe of Hellenistic astronomers and improved it dramatically between AD 700–1500, applying it to questions of astronomy, surveying, mathematics, geography, and much more. In AD 843, Baghdad mathematician al-Khwārizmī (fl. AD 810–850) claimed his astrolabe could solve 43 problems – a century later, Persian astronomer al-Ṣūfī (AD 903–986) said that it could answer a thousand astronomical questions. David King divides Arabic astrolabe innovations into five basic categories: the making of tables, nonstandard retes, qiblas, multiple climates, and the development of three new forms of the instrument.

Astronomers like al-Farghānī of Baghdad (ca. 830–ca. 861) compiled numerical tables of radii and center distances of both azimuth and almucantar circles for every degree of latitude and azimuth, for every terrestrial latitude. These tables, which exceeded 13,000 entries, were used extensively by Arabic astronomers alongside geometric projections to construct astrolabes for different latitudes. Islamic astronomers also constructed nonstandard retes, which would symmetrically represent the otherwise dissimilar northern and southern halves of the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course). The Oxford myrtle astrolabe is an example.

Arabic astrolabists inscribed specific markings on their instruments, corresponding to Islamic prayer times and directions. By the thirteenth century, they engraved lists of cities with latitudes, longitudes, and Mecca directions, known as qiblas – this would help observers orient themselves for prayers. Arabic astrolabes also developed multiple plates or climates, giving astronomical tables usually found in handbooks or textbooks. An early example is referred to by Abū Jaʿfar al-Khāzin (d. 961/971).

Finally, Islamic scientists developed at least three new types of instrument: the linear, universal and geared astrolabes. The linear astrolabe consists of a series of scales on a stick which represents the meridian for a given latitude, to which are attached a series of threads through which one can perform all the standard operations of an astrolabe. This was invented by Iranian mathematician Sharaf al-Dīn al-Ṭūsī (d. ca. 1213), and was known as "al-Ṭūsī's cane." The universal astrolabe was developed by Ḥabash of Baghdad (d. ca. 864–874), and Alī ibn-Khalaf (al-Shakkāz) in Toledo in the eleventh century, who devised a special shakkaziya plate for it. Though powerful, it was not widely known, and was reinvented in early fourteenth century Syria. This astrolabe could determine the risings, culminations, and settings of celestial bodies at all latitudes using a single plate. Astronomer al-Zarqāllu (Azarquiel) of Toledo (ca. 1029–1087/1100) simplified this by replacing the rete with an alidade having a movable cursor, and by putting the ecliptic and star pointers on the shakkaziya plate. Geared astrolabes contained complex mechanisms to reproduce the motion of the sun and moon mechanically – their date of invention is unknown, but they were described by Persian astronomer al-Bīrūnī (ca. 973–1048).

The astrolabe was reintroduced into Europe from the Arabs by the tenth century. Gerbert of Aurillac, Pope Sylvester II (ca. 945–1003), imported much astronomical knowledge into the medieval Latin west from Islamic sources, and may have used the astrolabe as a teaching tool. Meanwhile, Hermannus Contractus (1013–1054) transmitted many Arabic concepts in his two influential Latin treatises on the astrolabe: *De Mensura Astrolabii* and *De Utilitatibus Astrolabii*. Ptolemy's *Planisphere* was translated by Hermann the Dalmatian in the twelfth century, and in 1276, an influential Arabic astrolabe treatise by the Egyptian Jew Māshāʾallāh (fl. 762–ca. 815) was translated into Latin, where it formed the basis for the first English book on the astrolabe, by poet Geoffrey Chaucer (ca. 1340–ca. 1400) in 1391.

Though the astrolabe was widely developed in Arab countries, it was virtually ignored in the East. Joseph Needham says that Chinese astronomers made no astrolabes of their own, though they did develop the anaphoric clock independently. The reasons are twofold: Chinese scientists instead developed sophisticated globes and armillary spheres quite early, and they lacked the analytical techniques in their mathematical astronomy which led to the stereographic projection in the West. Needham suggests the astrolabe was imported to China from Persia in 1267 by the Maraghan Observatory astronomer Jamāl al-Dīn ibn Muḥammed al-Najārri, but the mathematical projections remained obscure until the arrival of the Jesuits in the sixteenth century.

Indian scientists also borrowed the astrolabe from Islamic sources. Astronomer Bhāskara II (1114–ca. 1184) used spherical astronomy to construct a wheel-like instrument, called the *phalaka yantra*, which essentially served the same purpose as a primitive astrolabe. However, the true planispheric astrolabe, the *ustaralava*, was first imported by Muslims in the thirteenth century – a Damascus astrolabe of 1204 is still preserved in the Rampur State Library. The astrolabe was described in detail in the *Yantrarāja* of Mahendra Sūri in 1370 – this work is based on Islamic sources. Lahore later became a center for its construction, under families of instrument makers like those of Shaikh Allāh-Dad (fl. 1570–1660). Indian astronomers also developed some of the largest astrolabes in the world. The great brass astrolabe at the Jaipur observatory of Sawai Jai Singh (1686/8–1743) is 3 m tall, 2.12 m across, and weighs over 400 kg. Jai Singh's *Yantrarājaracanā* also gives instructions for astrolabe construction based on stereographic projections.

The astrolabe was popular as an astronomical instrument until long after the introduction of the telescope in the early seventeenth century. It survived another century, until it was replaced in the 1730s by English astronomer John Hadley's (1682–1744) reflecting quadrant, a precursor to the sextant.

See also: ►Astronomical Instruments, ►al-Khwārizmī, ►Al-Ṣūfī, ►*Qibla* and Islamic Prayer Times, ►al-Farghānī, ►al-Zarqāllu, ►Māshāʾallāh, ►Sharaf al-Dīn al-Ṭūsī, ►Jai Singh, ►Maragha al-Bīrūnī, ►Bhāskara, ►Mahendra Sūri, ►Abū Jaʿfar al-Khāzin

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Astrology in Babylonia

Nicholas Campion

The rediscovery of astrology in the twentieth century west is one of the principal phenomena in popular culture. Most histories of the subject from Thorndike (1923–1958) to Tester (1987) assume a fundamental conceptual and technical break between Babylonian and Greek astrology in the last centuries BCE, and that western astrology also effectively came to an end in the late seventeenth century, when it lost its intellectual respectability. The Encyclopaedia of Religion (Culianu 1987: 472) stated categorically that 'astrology, a product of Hellenistic civilisation, appeared at the end of the third century BCE', completely denying any Mesopotamian connection. Chambers Encyclopaedia was more circumspect, considering that 'It was in Greece, about the fourth century BCE that astrology underwent a great development and was regarded as regulating all things in the universe, including the fates of men (1970: 724)'. However, while it is clear that astrology, like any other belief system, experiences periods of reinvention as it passes between different cultures and periods, it is possible to identify a fundamental continuity from the earliest Babylonian astrology to the present day. Contemporary popular astrology may therefore be seen as a remarkable revival of the practical applications of an ancient non-Western astronomy, that of Mesopotamia of 4,000 years ago.

Mesopotamian Astrology

The civilisations of Mesopotamia flourished between 2,000 and 5,000 years ago. Like many societies, they adhered to the belief that the terrestrial, physical and human worlds were so intimately connected to the celestial, intangible and divine realms as to effectively constitute a single entity. The natural environment, it was believed, provided the principal means of communication between humanity and the pantheon of invisible gods and goddesses. From this sense that the entire world was alive, there developed various means of reading divine intentions, and the practice of omen (from the Latin meaning 'sign') divination relied on the assumption that any visible natural phenomenon, whether predictable or not, might represent an attempt by a god or goddess to communicate their intentions or instructions to humanity.

Divination took on many forms, from the rolling of dice to the royal reliance on extispicy, or divination from livers. Gradually, over the second millennium BCE, astrology (the divinatory use of celestial phenomena) appears to have grown in importance. As it did so it encouraged the increasing observation of planetary and stellar patterns, and ultimately, by the seventh to eighth centuries BCE, their extrapolation into the future. Thus, by the time that the Greek astronomers first began to speculate on the nature of the heavens, the Mesopotamian astrologers had made the crucial transition from a purely observational astronomy, to one which was both mathematical and predictive.

There are a number of very good reasons for studying the history of Mesopotamian astrology.

Firstly, it offers a point of entry into understanding Mesopotamian culture. Then there is the question of the astronomical records, which were not only used by the ancient Greeks, but are of relevance for modern science. The use of eclipse records to demonstrate that the slowing in the Earth's rotation is much greater than previously thought is ample demonstration of the value of such ancient observations (Stephenson 1998). But there is also the vexed question of the connections between the endeavours of Babylonian astronomers and astrologers and their counterparts in the Greek world, and the extent to which classical culture borrowed from the Mesopotamians. Such issues run to the heart of European respect for the Greeks as inventors of the western rational and scientific tradition, and raise deep questions concerning European self-identity, and the ambivalent relationship between the Occident and Orient. At the broadest level then, we are not just examining the history of culture or science, but touching on issues which are as alive today as they ever were.

Questions of Definition

The interlocking relationship between Mesopotamian astrology and astronomy, has a particular relevance to contemporary debates on the nature of science and perceptions of its relationship with 'superstition' or 'rational' and 'magical' thought. Indeed, no study of Mesopotamian astrology can begin until we have at least acknowledged such questions of definition (Bottéro 1992: 125–137). Indeed, modern comparisons may counter a natural tendency to see ancient cultures as being so inherently different to our own that they can never be approached. All we can do is remember that our descriptions of Mesopotamian thought can never entirely recapture its true nature.

Whereas modern definitions generally categorise astronomy, the observable measurement of the heavens, as scientific, and astrology, the interpretation of those measurements, as superstitious, the Mesopotamian experience suggests that those definitions are fluid and might even be reversed. For the sake of simplicity I shall stick to modern usage and I shall use astronomy when talking specifically about measurement of the heavens, and astrology when discussing the interpretation of those measurements.

The final problem of definition concerns the alternative use of the terms Mesopotamian and the more common Babylonian. Mesopotamia is a geographical designation for much of the area covered by modern Iraq. Between the mid-third millennium and the end of the first millennium BCE the region passed through a series of political eras from the period of the city states of Sumer and Akkad through the Babylonian and Assyrian empires, a second Babylonian empire, Persian and Greek Seleucid periods. Given that Babylon appears to have retained a special cultural status from around 1800 BCE onwards, the terms Babylonian and Mesopotamian are often used interchangeably to describe the astrology of the entire region (Koch-Westonholtz 1995).

The Modern Sources

This is a fast moving field, due to the sheer volume of primary source material which has either only recently become available or is yet to be translated. The difficulties involved in working out what the Mesopotamians actually thought, though, are genuinely problematic. Even slightly differing nuances between different translations can suggest entirely different conclusions. For example, one version of the Moon's function in the creation epic, the Enuma Elish (V.13) – 'When Above' – is to 'to make known the days' (Heidel 1942: 44–5) while another is 'to measure time' (Jacobsen 1946: 181). The latter expands the use of the moon to announce the name or nature of the day, to the notion that in the second millennium BCE the Mesopotamians had a concept of time as a continuous entity which can be understood mathematically.

The Origins of Astrology

In 1997 Carlos Jaschek (135–145) set out a standardised pattern for the development of astronomy, moving from the measurement of solar and lunar risings and settings to the identification of first individual stars and then planets, the creation of calendars (to facilitate political order), and the recognition that celestial movements are periodic, allowing the crucial transmission from an observational to theoretical astronomy. In this process astrology occupies a crucial place between these last two stages, its requirement for correct forecasts eventually making it essential to predict future planetary positions.

However, we really have little idea of how complex divinatory practices evolved in Mesopotamia, although a number of explanations have been proposed. They may, for example, have 'developed from a simple folk practice, capable of giving yes–no answers to specific questions, to a systematised science, covering nearly all observable phenomena and permitting detailed predictions of unanticipated events, as well as giving detailed answers to queries' (Koch-Westonholtz 1995: 14).

All accounts of astrology's origins are speculative, limited as they are by serious source problems and the tendency to apply modern theories in what might be an inappropriate manner. Could the development of astrology be the direct consequence of what we might call an 'environmental theology'? From the title of Jacobsen's description of the Mesopotamian cosmos, 'The Cosmos as a State' (1946), we derive the term Cosmic State to describe societies in which the earthly system is thought to be inseparable from the celestial. The Mesopotamian system was obviously autocratic in the sense that once a royal order had been given only the astrologers could amend it. Actually, even though the king had the power to dismiss or punish astrologers who gave him poor advice, it is a debatable point as to who was the master.

The reasons that one culture should develop a belief in astrology and another should not be found partly in environmental factors. It is useful to make distinctions in this respect between Egyptian culture, which developed a highly codified astral theology, and Mesopotamian, which made the leap from the use of the stars as religious objects to their application to forecasting. It is true that both cultures believed that the stars offered a means of communication between the divine and humanity, and that they applied this knowledge to political management, but astrology is essentially an extrapolation from astral religion, distinguished by its complexity. The most obvious natural difference between the two cultures is found in Mesopotamia's essential physical insecurity (Jacobsen 1946: 126–127). Mesopotamia had no natural boundaries, was surrounded by hostile enemies, and the flooding of the rivers on which its agriculture depended was erratic. By contrast Egypt was well protected by desert, had few neighbours, and could rely totally on the Nile's annual flood. Such environmental factors fed directly into political cosmology and conduct.

The proposition that the development of astrology was a direct response to collective insecurity has been challenged firstly on the general grounds that it represents the inappropriate projection of modern concerns on to an ancient society, and secondly by the specific argument that the omen literature indicates a society which was very certain of its beliefs (Koch-Westonholtz 1995: 17–18).

If the environment produces political forms then politics produces divination. Jacobsen found evidence in the idea of the divine assembly and in mythical claims that the divine pantheon took its decisions democratically, at least in part. In the Enuma Elish (VI.17–18) Marduk assembles the divine council and gives it its orders, yet his supremacy was not unqualified: destiny itself was determined by seven other gods (VI.81). This is a persuasive argument which gives us further insights into the motives behind divination. Not only was the city or temple assembly obliged to ascertain its divine counterpart's views before it could reach satisfactory solutions to the many mundane problems it had to consider, of drainage and irrigation or disputes over field boundaries, but it seems that decisions were reached by consensus. We can imagine situations in which extispicy or the casting of lots might have been the only way to break an impasse. Oppenheim (1977: 208) supports Jacobsen's view that divination emerged as a possible solution to the difficulties involved in political decision making, pointing out that it might have social functions. He drew attention to the casting of lots to determine the division of an estate amongst the sons. We may discern a process by which scientific thought imitated political behaviour.

The second development was the emergence of sacred kingship, an institution which took on different forms in each culture, whether in Egypt or Mesopotamia (Engnell 1943; Frankfort 1948). In Mesopotamia the monarch was but a human servant of the gods whereas the Egyptian pharaoh was himself divine. Babylon was built as the gods' sanctuary on earth and the city's heart was the Esagila, Marduk's temple and the residence of Ea and Enlil. The physical hierarchy of earth and heaven was therefore reflected in a political order in which the king was subordinate to the divine council, headed by Enlil, or to Marduk.

Thus the king's greatest attribute, perhaps even more than military prowess, was the wisdom necessary to navigate his way through a world of omens, dreams and oracles, to understand and heed the advice of the astrologers and to perform the correct action at the appropriate moment. Kingship was a sacred office (Engnell 1943) and divination was no mere optional accessory; it was a central part of the political machinery.

Others have proposed purely religious reasons. Leo Oppenheim has argued that third millennium BCE Sumerian religion was underpinned by an earlier near-Eastern formulation which reveals the existence of 'an age-old pre-deistic deterministic concept of life' (1964: 203–204), and which was conducive to astrology's development. This proposition is supported by the astrologers' letters from the Assyrian period, in which there are frequent references to auspicious times to undertake rituals. The Mesopotamians' purpose was to describe the world. Having done that divination allowed them to participate in its management through divination and, increasingly, astrology.

The Development of Astrology

The earliest examples of astrological practices have been traced to the third millennium, but the arguments are currently widely challenged. In 1939 Jacobsen found evidence of the use of an eclipse in 2403 BCE (1939: 203–204), but his account relies too heavily on the reconstruction of missing words in broken tablets. There are a number of examples of astrological omens dated to the reigns of Sargon of Akkad (ca. 2334–2279 BCE), and Ibi-Sin (ca. 2028–2024 BCE) and Shulgi (ca. 2094–2047 BCE) of Ur (Weidner 1928–1929: 231, 236; Walker 1982: 22). Although some scholars, such as David Pingree (1998: 125) regard these tablets as genuinely Sumerian, there is some scepticism about their precise origin, and it is thought that they may represent later accounts written as if they were omens from earlier times (Rochberg-Halton 1988b: 7, n 32, Koch-Westonholtz 1995: 35). This is a fairly standard practice in prophetic literature, occurring notably, and almost two millennia later in the Book of Daniel, which was written perhaps 300 years after the time in which it is supposedly set. A similar practice is found in extispicy, and there are references to liver omens relating to rebellion against Ibi-Sin apparently written 50 years after the event (Bottéro 1987: 131). There is also the problem that some of the eclipses mentioned could not have occurred as claimed (Koch-Westonholtz 1995: 35).

We do know, however, that the Sumerians watched the sky, naming some of the constellations and planets, and that these played a role in their religion. For example, the goddess Nisaba, who may have been an antecedent of the god Nabu, who himself was associated with Mercury, was said to measure heaven and earth, to know the secrets of calculation and, together with Suen, the lunar deity, to 'count the days'. Her temple in the city of Eresh was called the *e-mul-mul*, the 'House of Stars', and she was the owner of a lapis lazuli tablet which is known variously as the *dub mul-an* or *dub mul-an-ku*, 'the tablet with the stars of the heavens' or 'the tablet with the stars of the pure heavens'. Her associated functions as goddess of grain and as the expert on accounting and the fair management of resources hint at both the practical uses of astronomy and the benefits of a well-regulated calendar in maintaining social order.

A sophisticated astrology had developed by the reign of the Babylonian emperor Ammisaduqa, Hammurabi's great–great grandson, from the survival of the so-called Venus Tablet (Reiner and Pingree 1975; Van der Waerden 1974: II, 50–58). The tablet contains 59 omens based on the first and last visibilities of Venus, each of which will occur twice in one of the planet's 584-day synodic cycles. The omens are grouped into 8-year cycles and have attracted attention partly on account of their use in the dating of Ammisaduqa's reign and hence the chronology of the old Babylonian Empire. Nothing could illustrate better the source problems afflicting Mesopotamian studies, at least before the first millennium: even when we have historical chronicles and astronomical records, it is still impossible to agree on a definitive date. The tablet tells us that by the middle of the second millennium BCE consistent astronomical observations were being made for the express purpose of producing astrological omens, anticipating divine intentions, predicting the weather (and hence agricultural productivity) and preparing for possible political crises. The first omen, which is typical in the information it gives, set the tone:

> In month XI, 15th day, Venus in the west disappeared, 3 days in the sky it stayed away, and in month XI, 18th day, Venus in the east became visible: springs will open, Adad his rain, Ea his floods will bring, king to king messages of reconciliation will send (Pingree and Reiner 1975: 29).

This observation was made in late winter, following the Full Moon (the 15th) in the 11 month. The 3-day period represents the shortest possible time that Venus might be invisible, following its last appearance in the west as morning star and its reappearance in the east as evening star. The omen reveals information about Babylonian astronomy, astrology and politics. Regarding astronomy, it was understood that Venus as morning and evening star was the same body. Second, although their records were based on continual observation, not on extrapolation into the future, it is clear that they did recognise the concept of planetary periods (Pingree 1998: 126) and hence that they either could not or did not feel the need to calculate future planetary positions. Moreover, given that the purpose of the omens was to correlate astronomical patterns with terrestrial events, the tablets have a historical function. The Venus Tablet provides a deeply practical rationale for astrology's apparent popularity: used exclusively by the kings it provided the government with 'the hope of stealing a march on fate and forestalling catastrophe by a timely recognition of divine intentions' (Frankfort 1978: 255).

There are a number of other astrological tablets from the Old Babylonian period, including some eclipse omens, but following the Venus Tablet, the two most substantial sources are Enuma Anu Enlil ('when the gods Anu and Enlil…'), a comprehensive compendium of astrological lore which includes material dating back to the Venus Tablet, and Mul Apin, the first great star catalogue, both of which are known from Assyrian tablets of the early first millennium BCE. However, there are suggestions that both may have been compiled in the second millennium, a far from controversial idea in view of the Enuma Anu Enlil's inclusion of the Venus Tablet. Thus while the first three centuries of the first millennium offer us virtually no sources whatsoever, suggesting that either astrology and astronomy were ignored, or that the records were destroyed or, if they survived, have yet to be discovered, there is circumstantial evidence of intense astrological and astronomical activity over the same period.

The full text of Enuma Anu Enlil was excavated in the ruins of Ashurbanipal's library at the Assyrian capital, Nineveh. It consisted of around 6,500–7,000 omina, grouped into some 70 tablets, of which 13 are now available in translation or transliteration (Reiner and Pingree 1975, 1981; Rochberg-Halton 1988b; Van Soldt 1955; see also Baigent 1994: 67–75; Koch-Westonholtz 1995: 74–82). An indication of the prevailing astronomical priorities is revealed in a breakdown of the topics covered. Twenty-two tablets cover the moon, while a further 18 concern the sun. Of the remainder, five relate to Venus, perhaps four to Mars, two to Jupiter three to thunder and lightning and only one to the Pleiades. The absence of specialised tablets for Mercury and Saturn indicates the lack of attention paid to the planets as opposed to solar and lunar phenomena. The small proportion of material of attention paid to Jupiter is most mysterious in view of the fact that Marduk, the planet's god, was Babylon's presiding deity.

Mul Apin is usually described as an astronomical compendium but clearly served an astrological function (Hunger and Pingree 1989). The extant tablets date from the eighth century, although may either have been compiled by 1000 BCE or be based on observations as far as back as 1350 BCE. The date of its compilation, though, is less important than the fact that, with Enuma Anu Enlil, it indicates that the scholars of the Assyrian Empire were deeply concerned with the mapping and naming of the heavens. This may be why they began to keep comprehensive records of lunar eclipses, beginning on 6 February 747 BCE, in the reign of Nabonassar.

The dramatic reassertion of Assyrian power under Tiglath-Pileser III (745–728 BCE) marks astrology's reappearance on the public stage. The evidence for this lies in the remarkable increase in extant astrological texts, but the reasons are far from clear. Sargon II (721–705 BCE) was perhaps the first of the new line of Assyrian monarchs to take an astrologer on his military campaigns, and an inscription from a tablet in the Louvre recording his attack on Musasir suggests that the timing of his invasion may have been arranged by reference to astronomical factors (Koch-Westonholz 1995: 153).

Astrology was essentially a means of communication, similar to prayer in that it was conducted with an invisible partner, yet in that it utilised the technology of planetary observation and measurement, its function might be comparable to that of modern information technology. Certainly its perceived advantages were similar, and the observation of Jupiter's movements prior to Sargon's campaign offered intelligence of a similar character to that provided by modern satellites in preparing for military action. Modern technology reveals the disposition of enemy forces, while the location of the stars also indicated the strength of Sargon's opponents.

Sargon's lessons were not lost on his successors, Sennacherib (704–681), Esarhaddon (680–669) and Ashurbanipal (668–627). These kings maintained astrologers across the empire who effectively formed a political class, sending reports and letters to the emperor, offering the best possible advice on the basis of their observations (Oppenheim 1969). These paint a portrait of a society in which the scribes maintained their personal relationships with each other and with the king, offering sometimes contradictory advice on astronomical observations and astrological predictions, finding excuses for their mistakes and claiming due credit for their successes (Baigent 1994: 50–57).

The astrologers' communications reveal an astronomy which was still based on daily records, with the result that no stellar observations could be made nor omens taken in inclement weather – except for meteorological ones. It was precisely those elements in astronomy which were unpredictable which preoccupied the Babylonians for, if the cycles of the sun, the moon and the seasons represented the endlessly repeating rhythms of fate, rich variety in natural and celestial phenomena offered a chance to negotiate with fate by opening a dialogue with the gods. Thus astronomy was directed to goals which were theological and political, rather than scientific in the modern sense of examining celestial phenomena for its own sake.

Great emphasis was placed on other meteorologically induced phenomena, such as the presence of haloes around stars and planets, as well as their colour or brightness, all of which were unpredictable. Neither was astrology absolutely distinct from other forms of divination, as Sargon II's inscription makes clear. The sun's main role was as representative of the oracle god, Shamash.

Having made their observations, the astrologers' first task was to communicate their findings to the king and offer whatever advice they felt necessary. This might be no more than to stay in the palace (SAA: 320). The king was also required to pray, offer sacrifices and perform rituals, each of which might have its own auspicious time. When there was no other solution to a threatening omen, a substitute king was appointed (Bottéro 1992: 138–155). A letter from the astrologer Mar Istar suggested that a substitute be allowed to sit on the throne for 100 days before meeting his fate, a euphemism for death (LAS: 292).

The astrological reports are couched in more formal terms than the letters, and tend to concentrate on prediction rather than advice. The information they contain makes no explicit distinction between planets, stars, and other celestial matters: 'If the Pleiades enter the moon and come out to the north: Akkad will become happy; the king of Akkad will become strong and have no rival' (SAA: 443), 'If Adad (the storm god) thunders in Tishri (month 7); there will be hostility in the land' (SAA: 444) and 'If Jupiter passes to the right of Venus: a strong one will conquer the land of the Guti in battle' (SAA: 448).

Political demands heightened the need for accuracy of forecasting and observation and resulted in a renewed attempt to perfect astrology's predictive powers. A further innovation was taken in the mid-seventh century with the production of the so-called Astronomical Diaries, compiled almost continuously for over 600 years from 652–647 BCE (Sachs and Hunger 1998–1999). The diaries are records of astronomical, meteorological and political events, presumably as a means of establishing common patterns. They represent a fresh determination in the ongoing attempt to create an empirically based astrology, in which both planetary phenomena and their relationship to political and economic matters might be properly understood.

It might be that the success of the Assyrian regime encouraged the Diaries' compilation. It may equally be the case that the Empire's collapse in 626 BCE concentrated the astrologers' minds on the maintenance of stability and the need to perfect astrology's ability to predict and avert political crises. The relationship between intellectual endeavour and political change is a complex one. The bulk of extant astrological reports cease about 30 years before the fall of Assyria and, while there might be later examples, we lack the ability to date them with any certainty. It is argued that the evidence for a change in astrology coinciding with the collapse of the Assyrian empire lie in the Chronicles, not the Reports to the kings (Berger 1999). It is, though, the results of this work, not its motives, which proved most important. The period from the eighth to fifth centuries witnessed a scientific revolution, first the creation of mathematical models for the calculation of planetary positions in advance, and secondly the development of horoscopic astrology – planetary omens based on the date of birth – and the invention of astrological techniques which did not require direct observation.

That a cultural revolution occurred under the Assyrian Neo-Babylonian and Persian monarchies is not questioned. But what is not fully understood is its nature, partly because it involved dramatic changes in both astronomy and astrology, paralleled by profound religious developments.

The Ritual Calendar

Astronomy possessed one great function, the improvement and eventual perfection of astrology's role in managing the state. An essential component of political management was the regulation of the calendar. Tablet VI of the Enuma Elish describes how Marduk ordered the Moon to mark out its synodic period, with a hint (the tablets are broken) that its crucial phases signified the moments when he communicated destiny to the watching astrologers, and that these were thus important moments for divination.

Each month began with the rising of the crescent moon; the new moon's first appearance after the spring equinox marked the beginning of the first month, Nisan. The problem, though, was the need to keep the lunar months in some sort of relationship with the solar year, and this necessitated the insertion of intercalary months. The 'Diviners Manual', dating from the early first millennium (Oppenheim 1974) gave the rules for intercalation, although the sheer variety of calendars used in the third millennium and the fact that in the Old Babylonian period 2 or 3 years in a row might contain intercalary months, suggests that there was no single set of recognised systems. It must be possible that divination (perhaps including extispicy) played as much a role on the selection of years for intercalation as did astronomy, and the purpose may have been to shift the average beginning of the year. In addition, kings in the Old Babylonian period often added intercalary months at the beginning of their reigns.

The fear that astronomical phenomena might occur on the wrong day is demonstrated vividly in the astrological reports. The Assyrian astrologer Balasœ advised the king that if the new moon occurs in the first or the full moon is seen on the 14th, then 'the land will become happy', but if the full moon took place on the 12th then 'business will diminish…a strong enemy will oppress the land' and, even though 'the king of Akkad (i.e. Assyria) will bring about the downfall of his enemy', the prognosis is 'bad for Akkad…good for Elam and the Westland (Amurru)', in other words, favourable for Babylon's hostile neighbours (SAA: 87–89).

We also have examples of Marduk's own planet, Jupiter, breaching its order by remaining visible for 5 days longer than expected. The astrologer Mar-Ishtar reported that it appeared on the sixth Simanu (month 3), close to Orion and in the way of Anu, and each of these three factors carried its own warning in the Enuma Anu Enlil. However, the planet then remained visible for another 4 days, an omen so bad that no ritual could appease divine wrath, and all communication with heaven was broken off.

The Planets

Even though the Mesopotamians identified dozens of different deities, and acknowledged the existence of hundreds of others who were not even given names, one god was not necessarily entirely separate to another. Thus, Enlil, the originator of earthly kingship, played a role which tended to merge with that of Marduk, the supreme king, who was himself venerated as the 'Enlil of the gods' (Parpola 1997: LXXIV) or described in terms usually reserved for solar deities.

There is evidence that the planets themselves have been seen as gods (Koch-Westonholtz 1995: 120–121), but the consensus amongst Assyriologists is generally that the planets were not themselves divine, but were manipulated by the gods. Ninurta was normally the god associated with Saturn, but in the Mul Apin (II.i,5) we read about ‘Mercury whose name is Ninurta’. This blurring of identities is of considerable significance for astrology, in which the relationship between gods and planets was similarly flexible.

The astrology of the Enuma Anu Enlil and the Mul Apin tends to make little distinction in terms of astrological significance between the planets and the brightest stars, such as Sirius, or the most prominent constellations, such as Orion or Ursa Major. However, the planets were obviously distinguished by their erratic movements, and were known in Sumerian as the *udu.idim.mes*, or wild sheep (Akkadian *bibbu*). Time and space were as interdependent in the Babylonian cosmos and the crucial considerations in a planetary observation were its position, which indicated the terrestrial region at which the omen was directed and the nature of the predicted event (e.g. being in Scorpio could mean an attack by Scorpions), and time (either of night or month), which might indicate the location of the event. In addition there was the question of whether the phenomena was on time (favourable), early or late (unfavourable).

Attention was paid to a planet’s colour and brightness and careful observations were made of acronycal rising (the last visible rising in the evening after sunset), heliacal rising (first visible appearance on the eastern horizon before sunrise) and heliacal setting (the last visible setting after sunset). The birth charts began to include lunar and planetary latitude as well as zodiacal position.

In the Mul Apin (II.i,1–6) the sun and the five planets are classed as the six gods who travel in the path of the moon. Each planet possessed a range of associations with deities, colours, times of year and with each other. They indicate the presence in Babylonian astrology of one of the central features of classical and medieval astrology, a web of relationships between planets and zodiac signs without which it would often have been impossible to reach a firm conclusion or offer definite advice.

The Sun

The Sun was known in Sumerian as Utu, in Akkadian as Shamash, its *bit nisirtu* (treasure) was the Hired Man (Aries) and in the Mul Apin its corresponding calendric event was the spring equinox. Utu and Shamash are also the names of the solar deities but the two words could mean either the visible body or the hidden power within it, i.e. the god. Shamshu was also used for the solar body.

Nineteen of the tablets in the Enuma Anu Enlil were devoted wholly or partially to the sun, mainly to its rising or eclipses, but its invisibility at night imposed a clear restriction on its astrological use, for however many omens were devoted to its colour or relationship with clouds, as soon as it appeared the stars vanished. However, as a god of justice Shamash became the god to whom oracles were addressed, presiding over the art and science of divination from entrails.

The Moon

The oldest of the Sumerian celestial divinities was the moon god, Nanna or Suen, a name later contracted to Sin, by which the moon is generally known in the cuneiform texts. Nanna may refer specifically to the full moon and Suen to the crescent moon, while there also appears to be a third name, Asim-babbar, the new light. Nanna was the presiding god of third dynasty Ur, and when the moon was invisible Nanna was believed to have gone to the netherworld to judge the dead, along with Utu, and special offerings were made. Fourteen tablets in the Enuma Anu Enlil were devoted to the moon’s appearance and a further eight to lunar eclipses, which were thought to represent a demonic attack on Nanna. Nanna travelled the heavens in a boat and had associations with bulls and cowherds. His *bit nisirtu* was Mul Mul, ‘the Stars’, or Pleiades. Aside from the Enuma Anu Enlil, about half of the astrological reports deal with lunar phenomena. The reasons are obvious, for the moon is the second brightest celestial object after the sun, it possesses the fastest and most dramatic cycle, moving rapidly from one phase to another and, unlike the sun, can be tracked at night and hence form relationships with the stars, visibly passing through constellations.

Saturn

The planet Saturn is sometimes referred to as Ninurta in the texts, but also as *udu.idim.sag.us* (Akkadian *kajamanu*) meaning ‘the steady’ or ‘the stable planet’. Saturn has no single tablet dedicated to it in the Enuma Anu Enlil and only 25 mentions in the reports published by Hunger, in spite of the fact that Ninurta was the son of Enlil and god of the thunderstorm, the spring flood and the plough. Indeed the name may mean ‘Lord Plough’. The god had an earlier form as Imdugud (the hailstone), and was also commonly known as Ningirsu (perhaps indicating the flood waters). He also had a military role as the ‘thunder’ of the war chariot. The planet was also known as Mul Utu, the star of the Sun, a connection which may derive from a shared concern with justice and may be evident in the fact that Saturn's *bit nisirti* is in Zibanitu (Libra), opposite the Sun's in Aries.

Jupiter

We might have imagined that Jupiter, as the planet sacred to Marduk, would have more omens devoted to it than any other planet, and the fact that it does not tells us that astrology was not simply a direct projection of theology on to the stars. It was not thought necessary to devote a large number of omens to the chief god, who merited less attention in the literature than the moon or Venus. The planet Jupiter was given various names. It was known as *sagmegar* ('the bearer of signs to the inhabited world') when it was in the eastern sky, *sulpaea*, ('lord of the bright rising') at its heliacal rising, *nebiru* ('crossing') when culminating at the meridian, *muludaltar* ('the heroic one'), *mul.babbar*, ('the white star'), *Bel* ('lord') or just simply Marduk. Jupiter might signify the moon in what might have been an imitation of Saturn's relationship with the Sun, and although its proximity to the moon was in general a bad omen, its presence during a lunar eclipse cancelled the evil omen. Together with Shamash, Jupiter was 'Lord of the secrets of Akkad', and its brightness was therefore good for the king and the state. It was associated with the summer solstice in the Mul Apin and its *bit nisirti* was the Crab.

Mars

Mars invariably sent evil omens, being associated with Nergal, a god of the underworld, forest fires, fever, plague and war. When the planet was not known directly as Nergal, it was called *sanumma* (different, i.e. hostile), *nakru* (enemy), *sarru* (liar), *lemnu* (evil), *ahu* (strange) or *sa* (red). In the Mul Apin it is referred to as Salbatanu, a name which may mean 'the incalculable star' or 'constantly portending pestilence'. Mars' malefic tendencies were heightened when it was bright, diminished when it was faint, and when it was at its reddest it might signify prosperity but also an epidemic of plague. Its *bit nisirti* was the Goat-Fish and in the Mul Apin it was linked to the winter solstice.

Venus

The planet was the subject of one of the first extant body of omens, and its goddess, the Sumerian Inanna (Akkadian Ishtar) was the most important single female deity, on a par with Sin and Shamash, with whom she forms a trinity, and even with Ea and Enlil. Her worship extended throughout the near East, and in Syria she was known as Astarte (Heimpel 1982). In the texts the planet is usually known as *dil-bat* or *dele-bat*, 'the brightest star', or Ishtar. Although Venus was invariably female there was a Semitic male version of Ishtar, and sometimes the morning star was considered to be male (and malefic). In other traditions it was the evening star that was male. However, this bisexuality does not appear in the extant omen literature and Venus' mere appearance was often considered to be benefic. Venus' *bit nisirti* was Anunitu (Pisces), and the planet was seen as the precursor of spring.

Mercury

Mercury was known as *gu.ud* (Akkadian *sihtu*), 'the jumping one', and in the Mul Apin is consistently linked with Ninurta, the god normally connected with Saturn. Mercury is more usually identified as the planet of Nabu, the son of Mercury, and is therefore connected to the crown prince. Thus, if Mercury approaches Regulus (*mul-lugal*, the 'king-star') this warns of an attempt by the heir to seize the throne (SAA: 245). While Mercury's appearance warned of rain and flood, Nabu himself was the scribe of the gods. In this role he wrote the destinies, announcing divine intentions to the diviners and astrologers, and thus joined Ea and Marduk as a god of wisdom. Mercury's *bit nisirti* was Ab.sin (Virgo) and in the Mul Apin the planet was regarded as the precursor of autumn.

The Development of Birth Charts

There is one notable development in the astrological literature which coincides with the collapse of the Assyrian empire, and that is the apparent termination of the series of astrological reports and letters to the kings. If this is true then one reason could be that the new astronomical accuracy destroyed astrology's theological premise – that the stars and planets could be manipulated at will by the gods and goddesses (Koch-Westonholtz 1995: 51–52; Berger 1999), even if weather phenomena remained unpredictable. Whatever the reason, out of this period emerged the form of divination which has since, more than any other, been associated with the term astrology – the prediction of destiny on the basis of planetary positions at birth.

According to Jacobsen (1976: 108), it was believed in the second millennium BCE that the 'time of the shaping of the child in its mother's womb is one during which it is susceptible to both good and bad influences and so is the moment of birth; an incautious word then may saddle the child with any manner of unpropitious fate'. Given that astrology relied on signs rather than influences, one would still have thought that the diviners present at birth would have been listening keenly to the gods' and goddesses' words expressed through the stars.

It may be that the birth chart was less an entirely new form of astrology than a variant form of divination, one created from the combination of the celestial omens of the Enuma Anu Enlil and the large corpus of birth omina (Rochberg-Halton 1989: 110). Such omens were normally taken from abnormal or 'monstrous' births, mainly of animals, can be dated back to the second millennium BCE, and were collected in the Summa Izbu (Leichty 1970; Jastrow 1914). Some birth omina might include references to the date of birth and probable destiny. There was also, within the near East, a tradition of birth rituals.

Whatever the case, it seems clear that the birth chart was an entirely Mesopotamian invention. There is actually some considerable confusion over the use of the term horoscope. Literally this is translated as 'watcher', 'observer' or 'marker of the hour', the term applied to the sign or degree of the zodiac ascending over the eastern horizon.

The development of birth charts placed fresh requirements on the astronomers, for while astrology had always been based on the observation of nocturnal messages from the gods, and had ignored phenomena which could not be seen, children had a habit of being born during daylight hours. Sachs (1952: 52) speculates that there may therefore have been a halfway stage in which prediction of individual destiny was based on various combinations of visible and invisible planets at birth.

We do know, though, that the earliest surviving birth chart was cast for a nameless child, apparently born on 29 April 410 BCE (Sachs 1952: 54–57). The text gives the date, the names of the child's father and grandfather, Shuma-usur and Shumma-iddina, the relevant astronomical details and just one surviving line of astrological interpretation which Sachs reconstructs as '(Things?) will(?) be good before you'. The rest of the tablet is missing apart from two lines which read 'Month Du'uz, year 12…[ye]ar(?) 8…', suggesting that forecasts for specific dates might have been included.

We can draw various conclusions from this chart, concerning both the history of astrology and the broader cultural context. It is instructive, for example, that Mercury was not given a zodiac sign position, for its proximity to the Sun rendered it invisible, suggesting that it was not taken into consideration. The positive tone of the astrological reading implies that the astrologer may have used the planetary 'rulerships' characteristic of Greek astrology, giving the reading a favourable gloss.

The development of the birth chart opened the door to the full development of Greek horoscopic astrology, the use of ascendants, the 12 houses (divisions of the diurnal circle), and the belief that accurate astrological investigation must be based on exact timing. The path was set for the development of the highly detailed technical procedures of Hellenistic astrology which have survived intact in Indian astrology, were adhered to strictly by medieval astrologers and still form the basis of modern western astrology. The first cuneiform birth chart was discovered in the late nineteenth century and published in 1888. When Sachs published his collection in 1952 there were just six cuneiform birth charts known. By 1989, the total had risen to just 32, including four birthnotes. This must represent a fraction of the charts cast in the Persian and Seleucid eras.

If astronomy's increasing accuracy had provoked a seventh century crisis in astrology, then it is clear that in the fifth century a close and symbiotic relationship had been restored (Van der Waerden 1974: 128). The new astronomy, which calculated planetary positions for decades ahead, may have been both motivated by the new developments in astrology, and made them possible. As to which came first, we cannot say. But new studies suggest that that the priests, the astronomers and the astrologers were usually the same people (Rochberg 1993; Parpola 1993), implying that the intimate relationship between theology, divination and science, was as strong as ever. Here we have a picture of theology encouraging the development of scientific astronomy, rather than inhibiting it.

The other main innovation was the development of the zodiac, the division of the ecliptic into 12 equal divisions. Our earliest evidence for the existence of the zodiac occurs on a lunar tablet dated to 475 BCE, and a tablet of 419 BCE gives the positions of planets in the signs, almost certainly as an aid to drawing up birth charts (Van der Waerden 1952–1953; Koch Westonholtz 1994: 174). The development of the zodiac required the production of another form of astronomical document, the Almanacs, which survive for the years between 262 BCE and 75 CE (Sachs 1948: 279–280; Rochberg 1993: 41).

Babylonian astrology can be described as practical theology, its express function being to enhance dialogue with the gods. Bartel van der Waerden set out a seductively neat scheme in which the development of first millennium BCE astronomy and astrology is related to a steady drift towards monotheism. He identified three main phases in which religion, astronomy and astrology progressed together from the simple observational astronomy, stellar polytheism and omen astrology of the beginning of the first millennium to the monotheistic religion, mathematical astronomy and natal astrology of its end (1974: II, 127–128, 178). This is a point of view challenged by many historians of religion, and as applied to Mesopotamia, the supposed connections between astronomy and religion are roundly rejected by some scholars. At the very least, van der Waerden's generalisations provide a worthwhile inter-disciplinary model for approaching developments in the history of astronomy.

There is one last point to make about the development of the birth chart, and that is that it represented a move away from an astrology which was structured by astronomical observation to one directed by worldly mundane concerns. That is, rather than waiting for a celestial omen to interpret, and having nothing to say if it did not appear, the astrologers were now obliged to construct omens for terrestrial events over which they had no control. Simple observation was no longer enough. The new astrology required that planetary positions should be plotted whether they were visible or not.

The Development of the Zodiac

The mathematical methods used by the Mesopotamian astronomers are well documented (van der Waerden 1974; Neugebauer 1975: II). The three principal priorities of second millennium astronomy were fairly straightforward: to record the rising and setting of stars and planets, and to quantify and calculate such phenomena as the length of lunar visibility in the beginning, middle and end of the month and the length of day through the year. It is the development of the zodiac, though, without which classical and medieval astrology would never have existed in any recognisable form, which is of most immediate interest for the history of astrology. Mesopotamian astronomy's enduring contribution to late astrology is undoubtedly the creation of the 12 signs of the zodiac, the equal-sized divisions of the ecliptic which are the most familiar feature of modern popular astrology. The first step to their formation was the creation of the constellations.

All theories concerning the reasons for the creation of constellations are essentially speculative. The creation of calendars for agricultural purposes, or the use of the heavens for navigation requires only the recognition of single bright stars, not the fabrication of unlikely images such as the Aquarian water-pourer. The creatures identified in the sky are, perhaps, more likely to be the consequence of mythical and religious projections and we may assume that the constellations' creation was initiated at whatever time human beings began observing the heavens, worshipping the stars, keeping a rough calendar, creating art, or all four. Gurshtein (1993, 1998) controversially gives a date of around 14000 BCE for the beginning of this process, and argues that the naming of important constellations was related to precession of the equinoxes and the sun's shift in relation to the stars. Owen Gingerich (1984: 219–220) lent his authority to the possibility that some of the constellations, notably the Great Bear may date from the last ice age. Rogers (1998) suggests that in the Mesopotamian period one set of constellations had religious origins, another agricultural applications.

Individual fixed stars offer a natural frame of reference for locating planetary position and it appears that by the Old Babylonian period, a system had been established which grouped stars according to the calendar. Three groups of 12 stars were arranged in three 'paths' (translated as 'bands' below) across the sky, related to the three creator gods, Anu, Ea and Enlil (Mul Apin: Gap A 1–7, Hunger and Pingree 1989: 88–89; Koch-Westonholtz 1995: 24–25).

The lists of the 36 stars which are divided between the three ways are preserved in three copies known to Assyriologists as 'astrolabes' but to the ancient scribes themselves as the 'three stars each' (Van der Waerden 1949). A system of 36 constellations, the so-called 'decans', which were supposed to rise at intervals of 10 days throughout the year, can also be found on coffin lids from the Egyptian Old Kingdom, from around 2100 BCE, and in the royal tombs of the New Kingdom, ca. 1500–1000 BCE (Neugebauer 1955b; Van der Waerden 1949: 7–8).

The evolution of the 36 stars was accompanied by a parallel development, the differentiation of the 18 constellations 'which stood in the path of the moon', the first known attempt to relate a sequence of constellations to a planet. The full list of these is given in the Mul Apin (I.iv, 33–39, Hunger and Pingree 1989: 68–69):

Mul.Mul The Stars (i.e. the Pleiades)
Mul GALENA The Bull of heaven (Taurus)
Mul SIPA.ZI.AN.NA The True Shepherd of Anu (Orion)
Mul SU.GI The Old Man (Perseus)
Mul GAM The Crook (Auriga)
Mul MAS.TAB.BAGAL.GAL The Great Twins (Gemini)
Mul AL.LUL The Crab (Cancer)
Mul UR.GU.LA The Lion (Leo)
Mul AB.SIN The Furrow (Virgo)
Mul Zi-ba-ni-tu The Scales (Libra)
Mul GIR.TAB The Scorpion (Scorpio)
Mul Pa-bil-sag The god Pabilsag (Sagittarius)
Mul SUHUR.MAS The Goat-Fish (Capricorn)
Mul GU-LA The Great One (Aquarius)
Mul KUN mes The Tails (Pisces)
Mul SIM.MAH The Swallow (SW Pisces)
Mul A-nu-ni-tu The goddess Anunitu Mul HUN-GA The Hired Man (Aries)

This list seems to be a clear attempt to formulate a lunar zodiac based on visible constellations. However, it clearly represents a stage towards the formulation of a solar zodiac and most of the future zodiac signs are identified.

The process by which the establishment of a constellational lunar zodiac and the attribution of astrological meaning to stars or groups of stars led to the creation of the 12-sign zodiac is not clear. Clearly planetary meanings depended partly on their position in relation to the stars, and the Enuma Anu Enlil contains omens such as 'If Mars approaches the Scorpion: there will be a breach in the palace of the prince' (50.111.8a, Reiner and Pingree 1981: 41). However, we cannot be sure whether the crucial factor here was Mars' position in the sky, or whether the constellation Scorpio was thought to contain meaning. The astrological letters and reports contain similar observations, referring to stars as well as constellations, suggesting that in the eighth century there was still no neat and all-encompassing division of the sky into distinct regions.

Van der Waerden speculates that the formulation of 12 signs of 30° each was a projection on to the sky of the 12 months and 360 days of the year. In the Enuma Elish (II, 27–32) Tiamat creates 11 creatures to fight with her, including a few who share identities with constellations, including 'the great lion, the mad dog, and the Scorpion-man'.

The equal-sized signs of the Mesopotamian zodiac were defined by relation to the stars, and lunar tables in the fourth to second centuries BCE indicate that the vernal equinox took place at 8° or 10° Aries, as measured from the vernal point. The zodiac signs evolved as a system of measurement, but were also assigned astrological meanings. Indeed they have been described as 'mighty powers' (Van der Waerden 1952–1953: 224). An additional advantage, though, was to be the ability to tabulate planetary positions in terms of zodiac degrees. The 12 signs did not replace the three ways or constellations, but could be used alongside them. Thus a tablet of 164 BCE records that Halley's comet had been 'seen in the east in the path of Anu in the area of Pleiades and Taurus, to the west… and passed along in the path of Ea' (Stephenson and Walker 1985: 24).

The attention paid to the variable timing of new and full moons gives us an insight into the mind of the Assyrian astronomers. They obviously knew that there was an inevitability about both the moon's synodic cycle, for without it they would not have had the month, and the sun's annual rhythm, for without that there would have been no years. Yet they clearly believed that it was possible for the gods to manipulate the moon's synodic period within certain limits. This might suggest that there was an awareness that the universe operated within mathematical limits, and that the gods and goddesses themselves were subject to the same destinies as was humanity.

A study of planetary measurements in horoscopes (Rochberg 1998) suggests the possibility of continuing theological motivation, for planetary synodic periods were recorded only when the planet occupied the same sign as the Sun. To be sure, this might have been because such information told the astrologer whether the planet was visible or not, but there might also be a trace here of the Sun's growing religious significance. However, even if religious considerations did remain high, increasing levels of observational accuracy were required to provide for astrology's increasing demands in the Persian period, such as the dedekatemoria (see below), divisions of the zodiac signs by 12.

Mesopotamian Cosmology: The Cosmic State

In what sense was Babylonian astrology scientific? There is a clear argument that it was not, given that it did not fulfil one of the criteria of modern science, namely verification of predictions through large samples in controlled conditions. The astrologers' success was measured in terms of one-off forecasts, a satisfactory means of measuring success at the time, if not to modern scientists. When the astrologers were wrong it was seen as a result of human error, not a sign of the fallibility of the essential hypothesis that the stars were conveying messages from the gods. The statement that divination equals science may seem a strange one by modern standards, but not if the definition focuses on the logical procedures of prediction and ignores the surrounding belief system.

The fundamental process involved in all divination was one of circumstantial association. In other words, if event y correlates with sign x, then when x next appears, y will happen. If we again remove the gods from the equation then there is no direct link between x and y. That is, the 'signs indicated events in a variety of ways, mostly by means of schematic symmetries, associations and analogy. The relationship between the sign (*ittu*) and its prediction (*parassu*) had no component of causation, nor necessity of any particular temporal relation, be it synchronistic or sequential' (Rochberg-Halton 1998: 52). Although the gods caused both the omen and the succeeding event, there was no cause and effect relationship between the two. Thus if Babylonian astrology was scientific it was because it relied on a deductive methodology and logical inferences made on the basis of empirical observation, and emphatically not because it posited a set of physical relationships between stars and society.

Larsen argues that if the development of modern science has seen the replacing of 'imaginary representations of "intentional" causes by the representation of unintentional and inevitable relationships' (1987: 208), then by removing the intentions of the gods from the equation, we are left with the inevitable relationship between present omen and future event, between astronomical observation and political action. A relationship which is inevitable rather than intentional, so this argument runs, is scientific.

Babylonian astrology's scientific qualities are also said to be evident in its foundation in empirical observation, its mathematical rigour and the value-free objective procedures which meant that there was no bias in the forecasts, which might imply criticism of the king's conduct as much as praise. Just as scientific method can be seen as a mode of enquiry so astrology might be seen as language, yet one with a code which was written into the fabric of the universe. To this end the Babylonians compiled list of lexigraphical correspondences between stars, gods, mundane objects, terrestrial events and geographical regions which are themselves identified as characteristic of astrology's scientific nature (Larsen 1987).

Christopher Walker concluded his 1982 lecture on 'Episodes on the History of Babylonian Astronomy' in Toronto with a wry comment on the contemporary world: 'That brings Babylonian astrology home to anybody who reads the popular newspapers nowadays' he said, 'and sadly for the historians of science one has to remark that to the Babylonians this represents the goal of their previous researches' (1982: 26). As we prepare for manned flights to Mars and as the Hubble Space Telescope peers into the origins of the universe, tens of millions of people in the western world turn every day for advice or entertainment to the sort of simple omens given to the Old Babylonian monarchs 4,000 years ago. A folkloric approach to the study of contemporary astrology, of the type developed by James Frazer at the turn of the century, would see it as a fossil survival of Babylonian cosmology, retaining the outer forms but not the inner meaning.

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Astrology in China

Ho Peng Yoke

In traditional China there was no distinction between astronomy and astrology. The common word *tianwen* covered both. There was also no distinction between astronomy and astrology in Europe before the end of the seventeenth century. According to the *Oxford English Dictionary*, there were two kinds of astrology (a) natural astrology, which involved the calculation and foretelling of natural phenomena, as the measurement of time, fixing of Easter, predictions of tides and eclipses, and also of meteorological phenomena and (b) judicial astrology, which was the art of judging the reputed occult and nonphysical influences of the stars and planets on human affairs, also known as star divination or astromancy. Since the end of the seventeenth century the term natural astrology was replaced by astronomy and meteorology, while judicial astrology became the astrology commonly known today.

Traditional Chinese astrology included the two elements of natural and occult science. The latter provided the motivating force that enabled Chinese astronomers to produce comprehensive and continuous observational records for almost two thousand years. These records are of interest to modern astronomers, but they were never made with such an intention. They were meant primarily to enable the emperor to have foreknowledge of future events concerning himself, his imperial household, his senior officials, his empire, his subjects, and foreign countries. Astronomical observations also played a part in the calculation of calendars that gave auspicious and ominous times and dates for various kinds of events in daily life, ranging from wedding ceremonies to having a bath or a haircut. Traditional Chinese judicial astrology differs from its counterpart in Europe in that it was tailored exclusively to serve the emperor and not the individual. Officially this system is now obsolete among the Chinese, but unofficially there were some whispers linking the event of the demise of their Great Helmsman to the 1976 Tangshan earthquake. What is popularly known today as Chinese astrology is not the traditional official Chinese astrology referred to above. Official and popular astrology are two different entities.

Official astrology found its place in the "Astronomical Chapters" of the Chinese Dynastic Histories, beginning with the *Shiji* (Historical Memoirs) of Sima Qian (145–186 BCE). Based on the traditional Chinese belief in the close relationship between heaven (*tian*), earth (*di*), and man (*ren*), the emperor was regarded as the representative of heaven on earth – human actions on the part of the emperor and celestial phenomena had mutual effects. Chinese astrologers divided the whole sky visible to them, making the stars and asterisms correspond to geographical regions. Almost all of them corresponded to China and only a few smaller asterisms corresponded to neighboring countries.

The Polar Star, which was supposed to remain stationary, was regarded as the counterpart of the emperor in heaven. Perhaps because there was seldom any bright star near the North Pole, and the scope for making predictions would be much more limited when a star was far away from the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course) beyond the reach of the planets, a number of other stars were also designated to represent the emperor. The asterisms in the circumpolar region, known as the *Ziweiyuan* (Purple Subtlety Enclosure), included those that represented the emperor, the empress, the imperial concubines, and the crown prince. There were stars representing his hierarchy of officials, including ministers and military commanders, and there were stars representing the utilities in the palace, for example the kitchen. The region was enclosed by two chains of stars, representing the walls of the Forbidden City. Many parts of the Forbidden City and the circumpolar region shared the same names. Outside the "walls" of the circumpolar region was the Plough (*Beidou*), an important asterism in both Chinese astrology and Daoism.

Next come the asterisms along the ecliptic. Two other special regions, the *Taiweiyuan* (Great Subtlety Enclosure) and the *Tianshiyuan* (Celestial Market Enclosure), were located there. The former again pertained to the emperor, his household, and his official hierarchy and the latter to the general state of economy in his empire. Distributed along the ecliptic were the 28 lunar mansions. They were used to make a wide range of predictions, from flood and drought in the empire to military activities among the border tribal people. The asterisms near the 28 lunar mansions were also significant. The astrologer could observe, for example, four stars in Pisces, called *Yumyu* (Cloud and Rain) to make a forecast for rain, thus performing the task of the modern meteorologist.

The Sun was the most important astrological object, because it represented the emperor. Solar eclipses and sunspots reflected blemishes on the part of the emperor.

Likewise lunar eclipses referred to the empress. The astrologer looked for the presence of planets, comets, and novae near a particular star or asterism to predict an event and where it would happen. The astrologer also noted changes in the color or brightness and scintillation due to atmospheric conditions. He also observed aurora borealis and clouds, noting their color and shape. These were particularly important in the battlefield for gaining advanced information on enemy movements and the outcome of the combat. The astronomical bureau also produced an astrological almanac using the art of *zheri* (calculations of auspicious and inauspicious days) to work out days and times that were auspicious or unlucky for certain events in private and social life, for example having a bath or a haircut, meeting a friend, doing a business transaction, moving house, and holding a wedding ceremony.

There were often occasions when the astrologer was required to give an answer to a specific event, for example when something was lost, when a candidate set out to take the civil examinations, when two armies were facing each other preparing for battle, and so on. There were three sophisticated techniques of divination which fell within the syllabus of candidates taking examinations in the astronomical bureau in the Song Dynasty, namely *taiyi* (Supreme Unity), *dunjia* (Concealing the *jias*), and *liuren* (Six *rens*). These three methods did not restrict themselves to the imperial family and the official hierarchy.

Naturally the common people also wished to have foreknowledge of their individual fate and destiny. The Chinese developed many systems for this purpose, but none of them relied on direct astronomical observation. In the strict sense of the word they hardly qualify to be called astrology. However they generally employed the results of astronomical observations and calculations by using some or all the elements of year, month, day, and time. Furthermore, at least one of the systems contains traces of Greek and Hindu astrology. There are two systems of fate calculation in general circulation among the Chinese today, namely the *Ziping* method and the *Ziwei doushu* method. These two systems of fate calculation do not rely on direct observations of the stars and in the *Ziwei doushu* horoscopes are worked out without requiring the practitioner to know how to identify the stars that occur in the horoscope.

The history of fate calculation in China is rather obscure as this was not regarded as an orthodox branch of study, and experts writing on this subject often used imprecise language to put off the uninitiated. By the Han period (206 BCE–AD 220), Confucian scholars were talking about three types of human fate (*sanming*). One was endowed during birth and was the only element that could be calculated. One was under the influence of good or evil deeds, and one was governed by catastrophic events that would overrule the first two. It is interesting to draw comparisons with the Han scholars' contemporaries in Europe where the Romans were adopting Stoicism as their state philosophy, believing in the devotion to duty while leaving things to the inevitable. The Chinese had a different belief in life, by talking about three types of life rather than one. To the Chinese it was only the fated life that was predictable, but any predicted event was by no means inevitable. It might be changed according to one's deeds, or by what we nowadays describe as an "act of God". The Chinese system gave encouragement to lead a good life. In this respect it certainly sounded more attractive than Hellenistic astrology.

At first it seems that only the year of birth of the person concerned was taken into account. Even today some Chinese still speak about the "twelve animal cycle" of the years they were born. As time went by, first the month, then the day, and finally the hours (or rather double hour) of birth were gradually included to develop newer systems. The *Ziping* method is one of the most sophisticated systems of fate calculation. It is attributed to Xu Juyi, said to have lived during the latter half of the tenth century. He was the first to use the time of the day for fate calculation. Many books were also attributed to him, but we do not know exactly which were actually written by him. The most authoritative and comprehensive text that we have on the *Ziping* method is the *Sanming tonghui* (Confluence of the Three Fates) written by Wan Minying during the Ming period (1368–1644). Since then the system has frequently been revised to keep abreast with changes in social structure. This can be testified to by the large number of books written on this subject in China, Hong Kong, Japan, and Korea during the past few decades.

However, back in the third century Indian astrology had entered into China when the *Sārdulakarnāvadāna* was translated, introducing the names of the "Seven Luminaries" (Sun, Moon, and the five planets) and the *nakṣatras* (Moonstations). In the year 718 Gautama Siddhārtha translated the *Navagrāha* calendar and introduced the names of two imaginary heavenly bodies, *Rahu* and *Ketu*. Some time afterward a Nestorian named Adam translated a work called *Simenjing* (lit, Book on Four Departments). This book has long been lost, but it could have been a translation of Ptolemy's *Tetrabiblos,* according to recent Japanese authorities on the subject such as Kiyoshi Yabuuchi. Michio Yano has suggested that another book with the title *Duliyusijing* carried the name of Ptolemy in a corrupted form. Hellenistic astrology also went from Persia to China through Korea. Another important route taken by Hellenistic astrology was through India, where it was modified under the influence of Hindu astrology. Tantric monks played an important role in the introduction of this form of astrology to China. Amoghavajra (705–774) produced a book known under its abridged title *Xiuyaojing* (Book on the *Nakṣatras* and the Luminaries), in which the 12 signs of the zodiac appeared for the first time in China. Thus by the eighth century imported systems of astrology with Hellenistic and also often Hindu roots had become quite popular. A number of actual horoscopes cast during the Tang period are preserved in the *Qinding gujin tushu jicheng* (Imperial Encyclopedia), edited by Chen Menglei et al. in 1726.

Changes took place when new ideas came into the same melting pot with something that was originally in it. Traditional Chinese star names and astrological terms were adopted by the new imports. Gradually the latter became sinicized. One can hardly notice the Hellenistic and Hindu origin of the *Ziwei doushu system* by looking at its name alone. We do not know when exactly the term "*Ziwei*" was first used here. During the Tang period several names were used; among them was the term *Taiyi.* The "star" *Taiyi* played the same role as the "star" *Ziwei* in the modern system, and both have somewhat similar reference to the occupant of the most supreme position below or above. The term *Ziwei doushu* first appeared in the title of a book incorporated in the Daoist *Tripitaka*, the *Xu Daozang* in 1607. Similarly traditional fate calculation methods were at the same time influenced by imported cultures. The Ziping system for example employs a cycle of 12 phases, reminiscent of the 12 *Nidānas* in Buddhism.

See also: ►Geomancy in China, ►Lunar Mansions, ►Divination in China

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Astrology in India

Vijaya Narayan Tripathi

In India, astrology, *Jyotiṣa*, is defined as *Jyotiṣam sūryādi grahāṇām bodhakamśāstram*, the system which explains the influences of the sun, moon, and planets.

Indian astrology came explicitly to light around 1200 BCE, when the monk Lagadha compiled the *Vedānga-Jyotiṣa* on the basis of *Vedas*, in which lunar and solar months are described, with their adjustment by *Adhimāsa* (lunar leap month). *Ṛtus* (seasons), years, and *yugas* (eras) are also described. Twenty-seven constellations, eclipses, seven planets, and twelve signs of the zodiac were also known at that time.

In the period from 500 BCE to the beginning of the Christian era some texts were written on the subject of astrology. Nineteen famous sages composed their *Siddhāntas* (texts). *Candra-prajnapti*, *Sūrya-prajnapti*, and *Jyotiṣakaraṇḍaka* were written. The *Sūryasiddhānta*, the ancient text of Indian astrology, was composed around 200 BCE.

In the first five centuries of the Christian era, there were some important contributions by Jain writers. *Angavijjā* is a large collection about *Śakuna* (omens). *Kālaka* and *Ṛṣiputra* also contributed around this time. At the end of the fifth century, Āryabhaṭa I mentioned in his text *Āryabhaṭīya* that the sun and stars are constant and that day and night are based on the movement of the earth.

The period AD 500–1000 was very productive. Lallācārya, the disciple of Āryabhaṭa, composed two texts – *Śiṣyadhīvṛdhi* and *Ratnakoṣa* – dealing with mathematical theories. The astrologer Varāhamihira composed several texts, and his son Pṛthuyaśā composed a brief horary called *Ṣat-Pañcāśikā*. Bhāskarācārya I wrote a commentary on the *Āryabhaṭīya* in the seventh century, and Brahmagupta composed the *Brāhmasphuṭasiddhānta* and the *Khaṇḍakhādyaka* around AD 635. Other scholars wrote commentaries on the texts of their predecessors and independent texts of their own.

In 1000–1500, there was a great deal of enhancement to the literature concerning the construction of astronomical instruments for observation. In the twelfth century, Bhāskara composed the famous text *Siddhāntaśiromaṇi*. The *Līlāvatī* of Rājāditya is another of the texts of that century. In the fifteenth century, Keśava wrote more than ten books, and his son Gaṇeśa composed the *Grahalāghava* at the age of 13.

Many more texts and commentaries were written from the sixteenth century onward. A few noteworthy ones are: *Tājikanīlakaṇṭhī* of Nīlakaṇṭha (sixteenth century), *Meghamahodaya* by Meghvijayagaṇi (seventeenth century), *Janmapatrīpaddhati* by Lābhacandragaṇi (eighteenth century), and the nineteenth century works of astrologer Bāpūdeva Śāstri.

A knowledge of *pañcānga* is a prerequisite to understanding the subject of astrology. This is the fivefold system of *tithi* (lunar day), *vāra* (weekday), *nakṣatra* (asterism), *yoga* (sum of the solar and lunar longitudes), and *karaṇa* (half lunar day). *Tithi*, the lunar date, is the duration of time in which the Moon moves 12°. The 15 *tithis* of the white fortnight (from new moon to full moon) are:

1. *Pratipadā*
2. *Dvitīyā*
3. *Tṛtīyā*
4. *Caturthī*
5. *Pañcamī*
6. *Ṣaṣṭhī*
7. *Saptamī*
8. *Aṣṭamī*
9. *Navamī*
10. *Daśamī*
11. *Ekādaśī*
12. *Dvādaśī*
13. *Trayodaśī*
14. *Caturdaśī*
15. *Purṇimā* (15 × 12° = 180°)

In the black fortnight (from full moon to new moon), the 15th day is called *Amāvasyā* and the remainder are the same as above. *Tithis* are classified into five groups: *Nandā* (*tithis* 1,6,11), *Bhadrā* (2,7,12), *Jayā* (3,8,13), *Riktā* (4,9,14), and *Pūrṇā* (5,10,15).

The seven *vāras* (weekdays) are based on the names on the *grahas*: Sun, Moon, Mars, Mercury, Jupiter, Venus, and Saturn.

Astrology in India. Table 1 Twenty-seven *nakṣatras* (asterisms)

Kṛttikā	*Rohiṇī*
Mṛgaśiras	*Ārdrā*
Punarvasu	*Puṣya*
Āśleṣā	*Maghā*
Pūrvāphālgunī	*Uttarāphālgunī*
Hasta	*Citrā*
Svātī	*Viśākhā*
Anurādhā	*Jyeṣṭhā*
Mūla	*Pūrvāṣāḍhā*
Uttarāṣāḍhā	*Śroṇā*
Śraviṣṭhā	*Śatabhiṣaj*
Pūrva-Bhādrapada	*Uttara-Bhādrapada*
Revatī	*Aśvinī*
Bharaṇī	

There are 27 *nakṣatras* (asterisms) bifurcating the ecliptic into 27 parts, each of 13.33°. These are mentioned in Table 1.

The ecliptic is again bifurcated into 12 parts through *Rāśis* (signs, each of 30°). The 12 signs are equal to 27 *nakṣatras*, or 1 sign = 2.25 constellations. For example, *Aśvīnī*, *Bharaṇī*, and one-quarter of *Kṛttikā* make the sign *Meṣa* (Aries). The remaining three quarters of *Kṛttikā, Rohiṇī*, and half of *Mṛgaśira* make the sign *Vṛṣa* (Taurus). The same pattern holds true for the other signs: *Mithuna* (Gemini), *Karka* (Cancer), *Singh* (Leo), *Kanyā* (Virgo), *Tulā* (Libra), *Vṛścika* (Scorpio), *Dhanu* (Sagittarius), *Makara* (Capricorn), *Kumbha* (Aquarius), and *Mīna* (Pisces). Thus 27 constellations represent 12 signs.

Yoga is the sum of the solar and lunar longitudes. If the sum of their degrees is between 0° and 13.33°, that is called *Viṣkambha Yoga* – from there until 26.66° it is *Prīti* – up to 40° it is *Āyuṣmāna*. The remaining yogas are *Saubhāgya, Śobhana, Atigaṇḍa, Sukarmā, Dhṛti, Śūla, Gaṇḍa, Vṛdhi, Dhruva, Vyāghāta, Harṣaṇa, Vajra, Siddhi, Vyatīpāta, Varīyāna, Parigha, Śiva, Siddha, Sādhya, Śubha, Śukla, Brahma, Aindra*, and *Vaidhṛti* (13.33° × 27 = 360°).

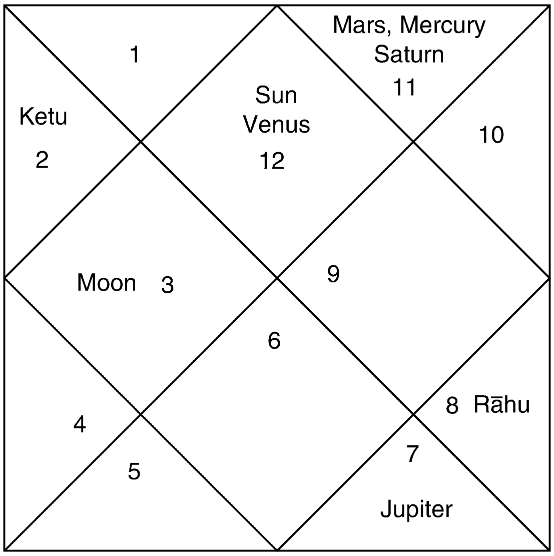
Karaṇa (constant or moveable) is the half part of the *tithi*. Constant *Karaṇa Śakuna* belongs to the second half of *Caturdaśī Catuṣpada* and *Nāga* to that of *Āmāvasyā* in the black fortnight, while *Kistughna* exists in the first half of the *Pratipada* of the white fortnight in every lunar month. The remaining 14.5 *tithis* of the white and 13.5 *tithis* of the black fortnight contain eight rounds of seven moveable *Karaṇas*: *Bava, Bālava, Kaulava, Taitila, Gara, Vaṇija*, and *Viṣṭi*.

The subject matter of astrology may be divided into five groups: *Saṃhitā, Siddhānta, Jātaka, Praśāna,* and *Śakuna*. In ancient India, *Saṃhitā* was the miscellaneous collection of astrological materials out of which the remaining four grew.

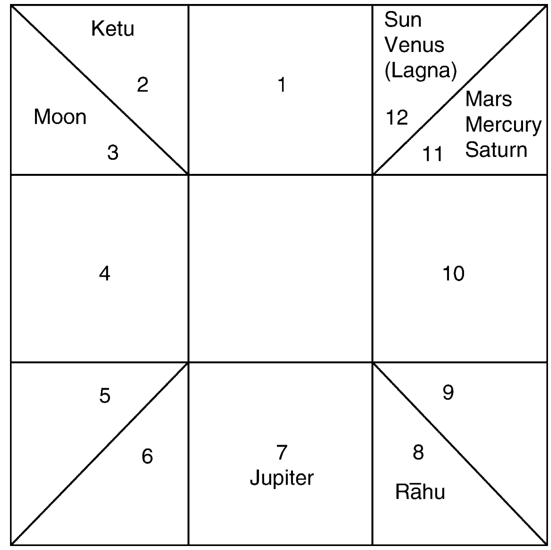
Siddhānta or *Gaṇita* refers to mathematical calculations about time, distance, and position of the planets. On the basis of the proper positions of 12 signs and nine planets, a chart containing 12 chambers may be sketched. In northern, southern, and eastern India, astrologers sketch Charts 1–3 which are called *Janmāṇga* or ascendant.

Astrology in India. Table 2 Positions of *grahas* (planets) on 21 March 1994 at 6:02 a.m. at Varanasi

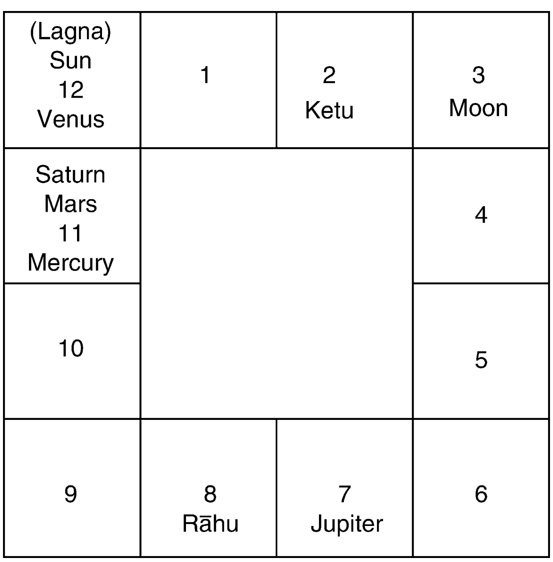
***Grahas* (planets)**	**Sun**	**Moon**	**Mars**	**Mercury**	**Jupiter**	**Venus**	**Saturn**	***Rāhu***	***Ketu***
Rāśi (sign)	11	2	10	10	6	11	10	7	1
Anśa (degree)	6	15	16	9	23	22	8	3	3
Kalā	21	7	57	51	19	13	21	3	3
Vikalā	27	45	18	17	40	8	21	44	44



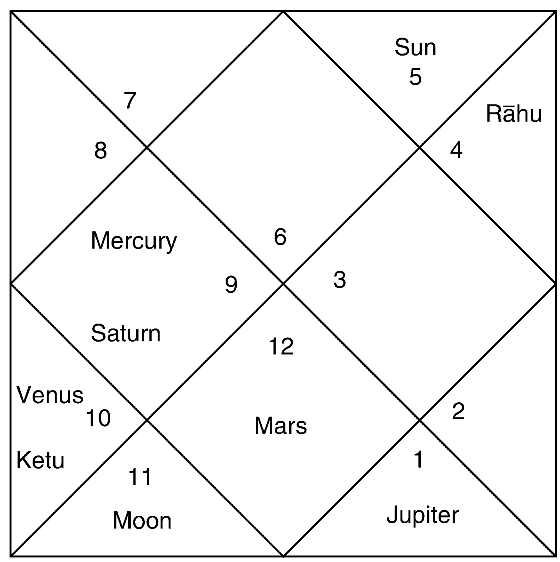
Astrology in India. Chart 1 Ascendant as sketched in northern India.



Astrology in India. Chart 3 Ascendant as sketched in eastern India (West Bengal and Orissa).



Astrology in India. Chart 2 Ascendant as sketched in southern India.



Astrology in India. Chart 4 Navamanśa chart.

Jātaka (native) is the person about whom a prediction is made on the basis of a birth chart. Twelve houses represent the health, wealth, brother/sister, mother, offspring, diseases/enemies, wife/husband, death, fate, father, income, and expenses, as in Chart 1. *Daśās* (periods) are defined in numerous ways. The period of any planet becomes favorable or harmful according to its position and power in the horoscope (Chart 4).

There are many other astrological methods in India. As an example, in the Kerala system, numbers are assigned to alphabets, and the astrologer advises the person to say the names of a flower, river, or god on which the calculation depends.

Astrology is applied to many aspects of Indian life. There are rules concerning times for traveling, planting, and building. Favorable times for the preparation of medicines and treatment are also prescribed.

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Astrology in Islam

Richard Lemay

A few considerations about the historical development of the term and concept of astrology as an intellectual discipline are in order, so as to avoid the many misconceptions that prevail in this field of historical enquiry.

The first question concerns the terminology applicable in medieval Arabic culture. What we consider astrology in our epistemology has very little connection with its medieval definition. Horoscope-making and interpreting are of course part of the game but with a rather remote bearing on its definition as a science in medieval eyes. In the mind of medieval Arab writers there is but one science of the sky with the moving bodies set in it. It was called *ʿīlm an-nujūm* (science of the stars) and it consisted of two distinct treatments of the subject matter of the heavens: a purely mathematical one or *ʿīlm al-falak* corresponding to our astronomy, and a humanistic but rather conjectural one which aimed at deducing from the celestial motions their probable significance for the evolution of human affairs, more directly what we now call astrology. The name for this latter discipline was *ʿīlm aḥkām an-nujūm* (science of the judgments of the stars): hence the new term *scientia iudiciorum* or judicial astrology in medieval Latin culture. The two methods of treatment were indissolubly linked in the overall picture, and it must be further stressed that the dominating interest of medieval Arabic civilization was the "science of the judgments of the stars." On the practical level, the second portion of this dichotomy was considered an art, and the term *ṣanʿa* applied to it was the equivalent of any other trade or profession.

There were three levels through which Arab authors would approach the study of astrology: a first level through the general science of the stars which could be a predominantly philosophical enquiry bordering on what may be actually labeled cosmology. A second level, purely mathematical, consisted of the consideration of the movements of the spheres, of the celestial bodies they contained, and of phenomena affecting them. This approach corresponded more closely to our astronomy. A third level was in the extension of the above observations to judge their probable impact upon human affairs. The technique of these judgments (*aḥkām*) was determined according to very intricate rules embodied in the age-old lore of astrology proper: but the three levels were considered together to constitute the one science of the stars (*ʿilm an-nujūm*).

This tripartite structure of the science of the heavens among medieval Arab writers was not entirely their creation, for the historical event of early Arab conquests of the entire Middle East had put the young Arab civilization in direct contact with both the still active Hellenistic (Alexandrian) world of thought thriving in Egypt and in the Eastern Mediterranean on the one hand, and the very ancient Babylonian, Persian, and even Hindu cultural traditions on the other. In examining medieval Arabic astrology it is wise to keep in mind these major cultural orientations varying in importance according to the stages of those historical convergences. During the first century of Arab conquests, which corresponds roughly with the rule of the Umayyad Caliphate of Damascus (660–750), the predominant cultural influence came from Syria and Egypt, in which Hellenistic culture and further Christianized Hellenism dominated. Even so, the impact of Greek learning was not directly linked at first with classical Greek science or philosophy, but rather with its late Hellenistic phase heavily marked by neo-Platonic and Alexandrian speculation or mysticism (hermeticism). The full force of the Greek example of learning and of its formative impact on Arabic astrology emerged only under the Abbasid rule (beginning in 750), tentatively at first under al-Mansūr (754–775) and Harūn al-Rashīd (786–809), but dramatically under al-Maʾmūn (813–833) through the direct importation of the works of thinkers and of scientists such as Aristotle in physics and cosmology, and of Ptolemy in astronomy/astrology. Al-Maʾmūn established at Baghdad an astronomical observatory and *Bayt al-Ḥikma* (House of Wisdom) endowed with a great library. It was because of these favorable conditions that the science of astrology, like philosophy and medicine, took its definite hue in Arab literature under the label of *falsafa* (a transliteration of the Greek term philosophy). Maʾmūn's patronage brought scientists and philosophers from all over the Muslim empire. It was likely in the midst of this intellectual fervor that the greatest writer in Arab astrology, Abu Maʿshar, came from his native Balkh in Khurāsān (now Afghanistan) to settle in Baghdad. Although Abū Maʿshar's major work, the *Kitāb al-mudkhal al-kabīr* (Greater Introduction to Astronomy, AD 848) was completed during the generation following the death of al-Maʾmūn (AD 833), its success in molding the framework of Arab astrology that merged the diverse astrological traditions of Greece, Persia, and India must be ascribed to the lively interest in *falsafa* engendered by al-Maʾmūn's sponsorship. With Abū Maʿshar's work, Arab astrology acquired its definitive structure, the result of a syncretism of all Middle East traditions under the umbrella of Aristotelian cosmology and Ptolemaean astronomy/astrology.

Abū Maʿshar came to be quoted as the authority, even by those who criticized him (al-Bīrūnī, Ibn Ridwān). His *Kitāb al-mudkhal al-kabīr* became the "bible" of Arabic astrology because it buttressed the science with a theoretical foundation based on *falsafa*, with Persian and Hindu traditions more or less coherently merged into it. Yet it provided only the introductory theory of astrology as part of the science of Nature. Further extension of the science of judgments of the stars to the full range of human affairs was seen as a kind of adjustment to their inevitable cosmic framework. Arabic astrological science came to include these five principal divisions.

1. A theoretical or introductory part (*mudkhal*) exploring its foundations in physical science and metaphysics. Here Abū Maʿshar's *Kitāb al-mudkhal al-kabīr* shared ultimate authority together with Ptolemy's *Tetrabiblos*.
2. A section dealing with Nativities (*mīlād, mawālīd*) which consisted of drawing up diagrams (horoscopes) of the state of the sky at the time of any beginning. Its most natural occasion was at the time of birth (hence "nativities"), or even of conception when possible, and it would be held as an indication of the probable unfolding of the various life circumstances of the individual person or object for whom it was drawn up. It is not without interest to recall that before the establishment of individual identity status such as birth registers, beginning with the sixteenth century in Europe, natal horoscopes constituted the most reliable record of the chronological span of individual lives. Not every one was born of sufficiently wealthy or honorable stock to be able to afford this luxury. Abū Maʿshar himself lamented the fact that he did not know the exact date of his birth, to compensate for which he had drawn up for himself a "general" (approximative) horoscope.
3. Interrogations (*masāʾīl*) which dealt mostly with enquiries about objects hidden or lost, innermost thoughts or intentions, purposes, etc. A kind of oracle, it aimed to assist individuals in their important decision making or help recover missing objects.
4. Elections or Choices (*ikhtiyārāt*), which were concerned with determining the most favorable moment for starting on important undertakings, such as the construction of cities, opening of hostilities in wartime, investiture or inauguration, or starting on a journey.
5. Weather predictions or meteorology, which were almanacs which astrologers operating for courts, cities, or institutions like universities would issue at the beginning of each new year, as part of their official duties. Weather predictions were of course a prime concern in any predominantly agrarian society.

The art or trade of the astrologer on the other hand was referred to by the term *ṣanʿa* and was treated like any other profession. More specialized applications of astrological science still flourished beside the main stream, particularly in medicine where some Greek treatises of Hippocrates (*On Airs* and *De hebdomadibus* for instance) and Galenic ones about duration of pregnancy were merged into astrological prognostication (*taqdimat al-maʿrifa*) and enjoyed enormous vogue among physicians. Finally all sorts of "predictions" or "interpretation of signs" proliferated in a number of specialized practices of quackery into which some pretense of astrological judgments was introduced. Some of these are chiromancy (interpretation of lines of the hand), spatulomancy (interpretation of form of shoulder blade), and sternutomancy (on sneezing).

An influential sequel to Abū Maʿshar's *Greater Introduction* appeared by Aḥmad ibn Yūsuf, a physician, mathematician, and astrologer of the Tūlūnid era (870–904) in Egypt. Aḥmad wrote a chronicle of this Turkish dynasty and he authored several works of mathematics. He put together an astrological compendium which he entitled *Kitāb aṭh-Ṭhamara* (Liber Fructus). Since it comprised 100 short propositions, each one accompanied by a substantial commentary, it came to be designated as *Centiloquium*. In fact its major doctrines are taken straight from Abū Maʿshar's *Kitāb al-mudkhal al-kabīr*. The very passage in Abū Maʿshar's work which probably gave Aḥmad the inspiration for his forgery is met in a special section of the magnum opus (III, 1–2) where Abū Maʿshar enumerates the six benefits to be derived from astrological science, the most alluring of which are the "fructus" (*ṭamara*) to be anticipated from it.

These two works by Abū Maʿshar and by Ibn Yūsuf, respectively, the second in the footsteps of the first, influenced the West from the time of their translation into Latin during the twelfth century until the demise of astrology as a science in the Scientific Revolution of early modern times. The nature, influence, and significance of Arabic astrology in the East and the West during the Middle Ages were polarized around the success of these two major works.

See also: ►al-Maʾmūn, ►Abū Maʿshar, ►Ibn Ridwān, ►al-Bīrūnī

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Astronomical Instruments in India

YUKIO ŌHASHI

Astronomical knowledge in India can be traced back to the Vedic literature (ca. 1500–500 BCE), the earliest literature in India, but no astronomical instrument is mentioned there. Naked eye observations of the sun, moon, and lunar mansions were carried out. It is not clear whether five planets were observed or not.

There is a class of works called *Vedāṅga*, probably composed toward the end of the Vedic period, which is regarded as auxiliary to the Veda. It consists of six divisions, including *Jyotiṣa* (astronomy) and *Kalpa* (ceremonial). The *Kalpa* further consists of four divisions, including *Śulba* (method of the construction of the altar). The earliest astronomical instruments in India, the gnomon and the clepsydra, appear in the *Vedāṅga* literature.

The gnomon (Sanskrit: *śaṅku*) is used for the determination of cardinal directions in the *Kātyāyana-śulbasūtra*. A vertical gnomon is erected on a leveled ground, and a circle is drawn with a cord, whose length is equal to the height of the gnomon, with the center the foot of the gnomon. At the two points where the tip of the gnomon-shadow touches the circle, pins are placed, and they are joined by a straight line. This line is the east–west line.

The annual and diurnal variations of the length of the gnomon-shadow are recorded in the political work *Artha-śāstra* of Kauṭilya, the Buddhist work *Śārdūlakarṇa-avadāna*, and Jaina works such as the *Sūrya-prajñapti*. These records seem to be based on observations in North India.

The clepsydra is mentioned in the *Vedāṅga-jyotiṣa*, the *Artha-śāstra*, and the *Śārdūlakarṇa-avadāna*. It was like a water jar with a hole at its bottom from which water flowed out in a *nāḍikā* (one-sixtieth of a day).

Toward the end of the *Vedāṅga* astronomy period, certain Greek ideas of astronomy and astrology had some influence in India from the second to the fourth century AD. After that, Hindu astronomy (*Jyotiṣa*) established itself as an independent discipline, and several fundamental texts called *Siddhāntas* were composed. I call this period, from about the end of the fifth to the twelfth centuries AD, the classical *Siddhānta* period. The main astronomers who described astronomical instruments are Āryabhaṭa (b. AD 476), Varāhamihira (sixth century AD), Brahmagupta (b. AD 598), Lalla (eighth or ninth century AD), Śrīpati (eleventh century AD), Bhāskara II (b. AD 1114), and the anonymous author of the *Sūrya-siddhānta*. The *Siddhāntas* composed by Brahmagupta, Lalla, Śrīpati, and Bhāskara II contain special chapters on astronomical instruments entitled *Yantra-adhyāya*. The Sanskrit word *yantra* means instrument. No observational data are recorded in the *Siddhāntas*, and the extent of actual observations in this period is controversial. Roger Billard maintained that astronomical constants in the *Siddhāntas* were determined by actual observations, while David Pingree argued that they were exclusively borrowed from Greek astronomy. In this connection, we should note that the method of determination of astronomical constants by means of observations was correctly explained by Bhāskara II. Let us see the instruments in this period.

The gnomon (*śaṅku*) was continually used in this period. The theory of the gnomon – such as the relationship between the length of gnomon-shadow, the latitude of the observer, and time – was developed in this period, and a special chapter called *Tripraśna-adhyāya* in the *Siddhāntas* was devoted to this subject. Trigonometry, invented in India, was fully utilized for this purpose.

The staff (*yaṣṭi-yantra*) is a simple stick, used to sight an object. There are some variations of the staff, such as V-shaped staffs for determining angular distance with the help of a graduated level circle.

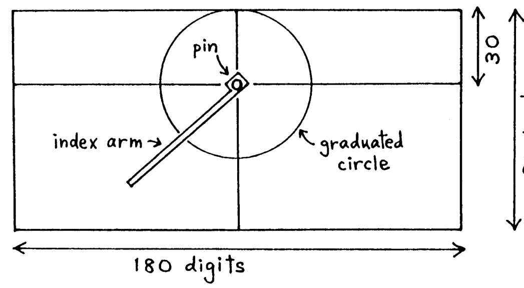
The circle instrument (*cakra-yantra*) is a graduated circular hoop or board suspended vertically. The sun's altitude or zenith distance is determined, and time is roughly calculated from it. Variations of the circle instrument are the semicircle instrument (*dhanur-yantra*) and the quadrant (*turya-golaka*).

A circular board kept horizontally with a central rod is the chair instrument (*pīṭha-yantra*), and a similar semicircular board is the bowl instrument (*kapāla-yantra*). They determine the sun's azimuth, and time is roughly calculated from them.

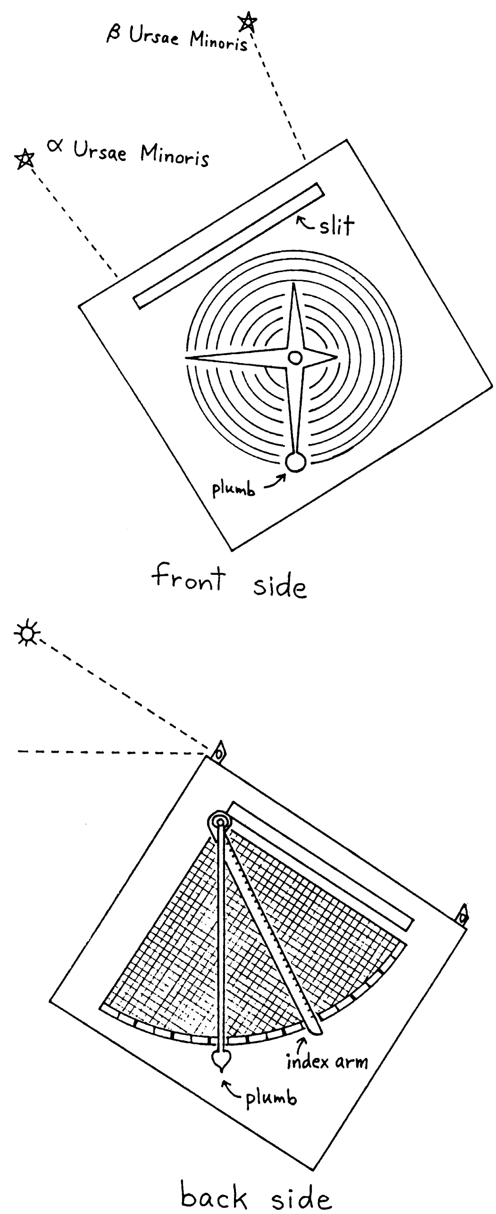
A circular board kept in the equatorial plane is the equator instrument (*nāḍīvalaya-yantra*). It is a kind of equatorial sundial. The combination of two semicircular boards, one of which is in the equatorial plane, is the scissors instrument (*kartarī-yantra*). Its simplified version is the semicircular board in an equatorial plane with a central rod.

The Indian armillary sphere (*gola-yantra*) was based on equatorial coordinates, unlike the Greek armillary sphere, which was based on ecliptical coordinates, although the Indian armillary sphere also had an ecliptical hoop. Probably, the celestial coordinates of the junction stars of the lunar mansions were determined

Astronomical Instruments in India. Plate 1 The clepsydra preserved in Rao Madho Singh Museum, Kota (Rajasthan).



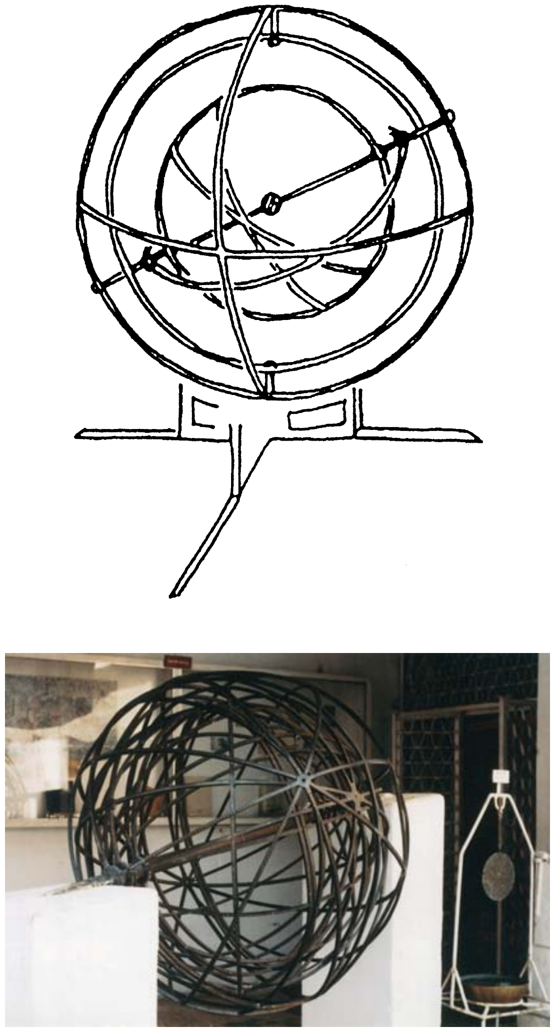
Astronomical Instruments in India. Fig. 1 *Phalaka-yantra*.



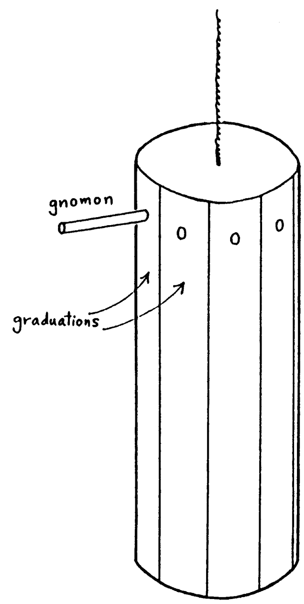
Astronomical Instruments in India. Fig. 2 *Dhruva-bhrama-yantra*.

by the armillary sphere since the seventh century or so (see Plate 2). There was also a celestial globe rotated by flowing water.

The clepsydra (*ghaṭī -yantra*) was widely used until recent times. Unlike the clepsydra of the *Vedāṅga* period, which was the outflow type of water clock, the clepsydra of this period is a bowl with a hole at its bottom floating on water. Water flows into the bowl, and it sinks after a certain time interval. The Chinese Buddhist traveler Yijing (AD 635–713) recorded the actual use of the clepsydra of this type. The clepsydra can be seen in use in a museum at Kota (Rajasthan) (see Plate 1). Several astronomers also described water-driven instruments such as the model of fighting sheep.

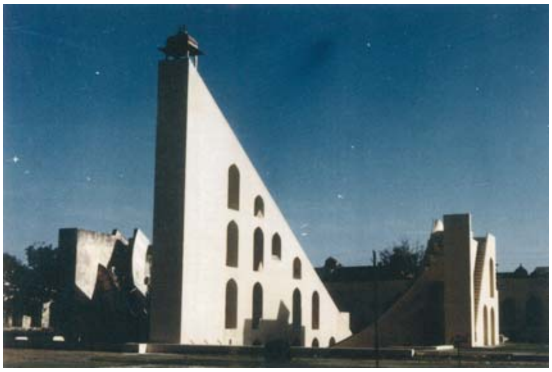


Astronomical Instruments in India. Plate 2 The armillary sphere in the Government Museum, Jaipur (a), and in Rao Madho Singh Museum, Kota (b), (both in Rajasthan).



Astronomical Instruments in India. Fig. 3 *Pratoda-yantra*.

Astronomical Instruments in India. Plate 3 Jai Singh's observatory at Jaipur (Rajasthan), Viewed from its larger Samarāṭ-yantra.



Astronomical Instruments in India. Plate 4 The larger Samarāṭ-yantra in Jai Singh's observatory at Jaipur.

Astronomical Instruments in India. Plate 5 Image of the sun projected on the Ṣaṣṭāṁśa-yantra in Jai Singh's observatory at Jaipur.

The board instrument (*phalaka-yantra*) invented by Bhāskara II is a rectangular board with a pin and an index arm, used to determine time graphically from the sun's altitude (see Fig. 1). This is an ingenious instrument based on the Hindu theory of the gnomon.

The astrolabe was introduced into India from the Islamic world at the time of Fīrūz Shāh (r. AD 1351–1388) of the Tughluq dynasty. Fīrūz Shāh's court astronomer Mahendra Sūri composed a Sanskrit work on the astrolabe entitled *Yantra-rāja* (King of Instruments, the Sanskrit term for the astrolabe) in AD 1370. This is the earliest Sanskrit work on Islamic astronomy. Use of the astrolabe rapidly spread among some Hindu astronomers, and Padmanābha (AD 1423) and Rāmacandra (AD 1428) described the astrolabe in their works.

Some new instruments were made in the Delhi Sultanate and Mughal periods. Padmanābha invented a kind of nocturnal instrument called *dhruva-bhrama-yantra* (polar rotation instrument) (see Fig. 2). It was a rectangular board with a slit and a set of pointers with concentric graduated circles. Adjusting the slit to the direction of α and β Ursae Minoris, time and other calculations could be obtained with the help of pointers. Its backside was made as a quadrant with a plumb and an index arm. Thirty parallel lines were drawn inside the quadrant, and trigonometrical calculations were done graphically. After determining the sun's altitude with the help of the plumb, time was calculated graphically with the help of the index arm.

Later, Cakradhara described the quadrant as an independent instrument, and a more exact method to calculate time was explained.

Astronomical Instruments in India. Plate 6 The Miśra-yantra in Jai Singh's observatory at Delhi.

Another new type of instrument in this period was the cylindrical sundial called *kaśā-yantra* (whip instrument) by Hema (late fifteenth century AD) or *pratoda-yantra* (whip instrument) by Ganeśa (b. AD 1507) (see Fig. 3). It is a cylindrical rod having a horizontal gnomon and graduations of time according to the vertical shadow below the gnomon.

The quadrant and the cylindrical sundial exist in the Islamic world also, but the possibility of their influence on these Indian instruments is still to be investigated.

The Mahārāja of Jaipur, Sawai Jai Singh (AD 1688–1743), constructed five astronomical observatories at the beginning of the eighteenth century. The observatory in Mathura is not extant, but those in Delhi, Jaipur, Ujjain, and Banaras are (Plate 3). There are several huge instruments based on Hindu and Islamic astronomy. For example, the *samrāṭ-yantra* (emperor instrument) is a huge sundial which consists of a triangular gnomon wall and a pair of quadrants toward the east and west of the gnomon wall. Time has been graduated on the quadrants (Plates 4).

By this time, European astronomy had begun to be introduced into India, and Jai Singh had certain information about it. The earliest European style astronomical observatory in India is a private one of William Petrie, an officer of the British East India Company, which was set up in 1786 at his residence in Madras.

See also: ►Observatories, ►Jai Singh, ►Astrolabe, ►Globes, ►Lunar Mansions, ►Armillary Sphere, ►*Śulbasūtras*, ►Gnomon, ►Clocks and Watches, ►Āryabhaṭa, ►Varāhamihira, ►Brahmagupta, ►Lalla, ►Śrīpati, ►Bhāskara II, ►Trigonometry, ►Quadrant, ►Mahendra Sūri

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Astronomical Instruments in the Islamic World

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Most Islamic observational instruments are lost and known to us only through texts. The state of documentation of the other, smaller Islamic astronomical instruments that do survive leaves much to be desired. Many of the most important instruments are still unpublished, and much that has been written on instruments is on a very amateur level. For these reasons a project has been underway in Frankfurt to catalogue all Islamic instruments (and European ones) to ca. 1550 as well as various historically significant later Islamic pieces.

Also the most important writings on instruments have not yet received the attention they deserve. For example, a hemispherical observational instrument for a fixed latitude was devised by the tenth century astronomer al-Khujandī, the leading instrument maker of the early period, and this was modified in the twelfth century to serve all latitudes. There are no surviving examples, and the available manuscripts have yet to be studied. An important work on instruments was compiled in Cairo ca. 1280 by Abū ʿAlī al-Marrākushī – this has yet to be subjected to a detailed analysis. The author collected all of the treatises on instruments known to him and incorporated them into his book. An exciting find of the 1980s was a treatise by the early fourteenth century Cairo astronomer Najm al-Dīn al-Misrī. In this the author described and illustrated over 100 different instrument types, including every kind of instrument known to him as well as those he invented himself. This treatise is now published with an exhaustive commentary. The same holds for the earliest surviving corpus of texts on the astrolabe, quadrant, and sundials by al-Khwārizmī.

Armillary Spheres and Globes

In the eighth century al-Fazārī wrote a treatise on the armillary sphere, called *dhāt al-ḥalaq*, which means "the instrument with the rings." No early Islamic armillary spheres survive, but several other treatises on it were compiled over the centuries. The earliest treatise in Arabic dealing with the celestial globe, called *dhāt al-kursī* (the instrument with the stand) or simply *al-kura* (sphere), was written by Qusṭā ibn Lūqā in the ninth century. This treatise by Qusṭā, who was one of the most important translators of Greek works into Arabic, remained popular for a millennium. Of the various surviving celestial globes, which number over 100, none predates the eleventh century.

The spherical astrolabe, unlike the armillary sphere and the celestial globe, appears to be an Islamic development. Various treatises on it were written from the tenth to the sixteenth century, and only one complete instrument, from the fourteenth, survives. In the ninth century Ḥabash wrote on the spherical astrolabe, the armillary sphere, and the celestial globe, as well as on various kinds of planispheric astrolabes.

Astrolabes

Al-Fazārī also wrote on the use of the astrolabe (Arabic *asṭurlāb*). The tenth century bibliographer Ibn al-Nadīm states that al-Fazārī was the first Muslim to make such an instrument – he also informs us that, at that time, the construction of astrolabes was centered in Harran and spread from there. Several early astronomers, including Ḥabash, al-Khwārizmī, and al-Farghānī, wrote on the astrolabe, and introduced the features not found on earlier Greek instruments, such as the shadow squares and trigonometric grids on the backs and the azimuth curves on the plates for different latitudes, as well as the universal plate of horizons. Also extensive tables were compiled in the ninth century to facilitate the construction of astrolabes.

Another important development to the astrolabe occurred in Andalusia in the eleventh century, when al-Zarqāllu devised the single universal plate (*ṣafīḥa*) called *shakkāziyya* and the related plate called *zarqālliyya* with two sets of *shakkāziyya* markings for both equatorial and ecliptic coordinate systems. The latter was fitted with an alidade bearing a movable perpendicular straight edge (transversal). Several treatises on these two instruments exist in both Western and Eastern traditions of later Islamic astronomy – the Europeans knew of them as the *saphea*. Ibn al-Zarqāllu's contemporary, ʿAlī ibn Khalaf, wrote a treatise on a universal astrolabe that did not need plates for different latitudes. This treatise exists only in Old Spanish in the *Libros del Saber*, and was apparently not known in the Islamic world outside Andalusia. The instrument was further developed in Syria in the early fourteenth century: Ibn al-Sarrāj devised in Aleppo a remarkable astrolabe that can be used universally in five different ways.

The astrolabes made by Muslim craftsmen show a remarkable variety within each of several clearly defined regional schools. We may mention the simple, functional astrolabes of the early Baghdad school – the splendid astrolabe of al-Khujandī of the late tenth century, which started a tradition of zoomorphic ornamentation that continued in the Islamic East and in Europe for several centuries – the very different astrolabes of the Andalusian school in the eleventh century and the progressive schools of Iran in the thirteenth and fourteenth centuries – and the remarkable instruments from Mamluk (thirteenth and fourteenth century) Egypt and Syria. In the early fourteenth century Ibn al-Sarrāj of Aleppo, a school unto himself, produced the most sophisticated astrolabe ever made. After about 1500 the construction of astrolabes continued in the Maghrib, in Iran, and in India until the end of the nineteenth century. Many of these instruments, especially those from Iran, were beautiful objects of the finest workmanship.

Quadrants

Another category of observational and computational devices to which Muslim astronomers made notable contributions was the quadrant, of which we can distinguish three main varieties. Firstly there is the sine quadrant with an orthogonal grid. This instrument, in a simpler form, had already been described by al-Khwārizmī and was widely used throughout the Islamic period. Some Islamic astrolabes display such a trigonometric grid on the back. The grid can be used together with a thread and movable marker (or the alidade of an astrolabe) to solve all of the standard problems of spherical astronomy for any latitude. Secondly there is the horary quadrant with fixed or movable cursor. This instrument is described already in an anonymous ninth century Iraqi source and was likewise commonly used for centuries (albeit usually without the cursor, which is not essential to the function of the device). A set of arcs of circles inscribed on the quadrant display graphically the solar altitude at the seasonal hours (approximately, according to an Indian formula). Other Islamic quadrants from the ninth century onwards had markings for the equinoctial hours. The instrument can be aligned towards the sun so that the time can be determined from the observed altitude using the grid. Again this kind of marking was often found on the back of astrolabes. Thirdly there is the astrolabic quadrant displaying one-half of the altitude and azimuth circles on an astrolabe plate for a fixed latitude, and a fixed ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The effect of the daily rotation is achieved by a thread and bead attached at the center of the instrument rather than by the movable astrolabe rete. The quadrant with astrolabic markings on one side and a trigonometric grid on the other generally replaced the astrolabe all over the Islamic world (with the notable exceptions of Iran, India, and the Yemen) in the later period of Islamic astronomy.

Sundials

We learn from Islamic tradition that the pious Umayyad Caliph ʿUmar ibn ʿAbd al-ʿAzīz (fl. Damascus, 718) used a sundial to regulate the times of the daytime prayers in terms of the seasonal hours. The earliest sundials described in the Arabic astronomical sources are planar, usually horizontal, but also vertical and polar. The mathematical theory for computing the shadow for the seasonal hours at different times of the year and the corresponding azimuths was available from Indian sources, which seem to have inspired the Islamic tradition more than any of the available Greek works. The treatise on sundial construction by al-Khwārizmī contained extensive tables displaying the polar coordinates of the intersections of the hour lines with the solstitial shadow traces on horizontal sundials for 12 different latitudes. The treatise on sundial theory by Thābit ibn Qurra contains all the necessary mathematical theory for constructing sundials in any plane – likewise impressive from a theoretical point of view is the treatise on gnomonics by his grandson Ibrāhīm.

The earliest surviving Islamic sundial, apparently made in Córdoba about the year 1000 by the Andalusian astronomer Ibn al-Ṣaffār, displays the shadow traces of the equinoxes and solstices, and the lines for the seasonal hours as well as for the times of the two daytime prayers. There is a world of difference between this simple, carelessly constructed piece and the magnificent sundial made in the late fourteenth century by Ibn al-Shāṭir, so devised that it can be used to measure time with respect to any of the five daily prayers. In the late period of Islamic astronomy a sundial was to be found in most of the major mosques.

Miscellaneous

Muslim astronomers devised several multi-purpose instruments. Notable examples are the rule (*mīzān*) of al-Fazārī, fitted with a variety of non-uniform scales for various astronomical functions, and the compendium of Ibn al-Shāṭir, comprising a magnetic compass and qibla-indicator, a universal polar sundial, and an equatorial sundial. Of particular interest is three circular qibla-indicators made in Isfahan ca. 1675 (but invented much earlier) which consists of a cartographic grid with Mecca at the center, so devised that the qibla can be read off the outer scale and the distance from Mecca can be read off the non-uniform scale on the diametrical rule.

There are several Islamic treatises on eclipse computers and planetary equatoria for determining the positions of the planets for a given date. With these the standard problems of planetary astronomy dealt with in *zījes* are resolved mechanically, without calculation. Treatises on eclipse computers are known from the early tenth century, and al-Bīrūnī in the early eleventh describes such an instrument in detail. A newly discovered manuscript (not yet available for research) contains a treatise by the tenth century Iranian astronomer Abū Jaʿfar al-Khāzin describing an equatorium called *Zīj* al-Safāʾiḥ (the Zīj of Plates). The only known example of this instrument, made in the twelfth century, is incomplete: it is in the form of an astrolabe with tables engraved on the *mater* and additional markings for the foundation of an equatorium. Otherwise the only known early Islamic treatises on planetary equatoria are from eleventh century Andalusia. The most interesting aspect of the equatorium described by al-Zarqāllu is the ellipse drawn on the plate for the center of the deferent of Mercury – it seems that he was the first to notice this characteristic of Mercury's deferent. Al-Kāshī, the leading astronomer of early fifteenth century Samarqand, has left us a description of a planetary equatorium with which not only ecliptic longitudes but also latitudes could be determined and eclipses calculated.

See also: ►Astronomy, Armillary Spheres, ►Globes, al-Fazārī, Astrolabes, ►Quadrants, al-Khwārizmī, al-Farghānī, al-Zarqāllu, ►Sundials, ►Thābit ibn Qurra, Ibn al-Shāṭir, Maps and Mapmaking, al-Kāshī, al-Khujandī

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Astronomical Instruments in Japan

Nakamura Tsuko

Beginning around the sixth century, Japan was under the strong cultural influence of China (via Korea), and astronomy was no exception. Although by the beginning of the eighth century an institutional form of the Chinese Astronomical Office had been introduced into the Japanese court government along with primitive gnomons and water clocks, astronomy as a science did not become part of Japanese society, and only the astrological aspects of Chinese astronomy survived. This situation continued for many centuries throughout medieval times, partially due to the domestic turmoil caused by frequent civil wars. It was not until after the shogun Tokugawa Ieyasu finally ruled over Japan in 1615 that the Japanese people could afford to nurture their own culture. In the mid-sixteenth century, European astronomy was first brought by the Christian missionaries from Portugal and Spain, though their influence did not last long. The reason was that the shogunal government ousted them because it suspected that the true aim of the Christian missionary activities in Japan was political occupation. Thereafter, import of foreign books relating to the Western religion and culture was strictly prohibited, and only Dutch traders were allowed to come to Nagasaki.

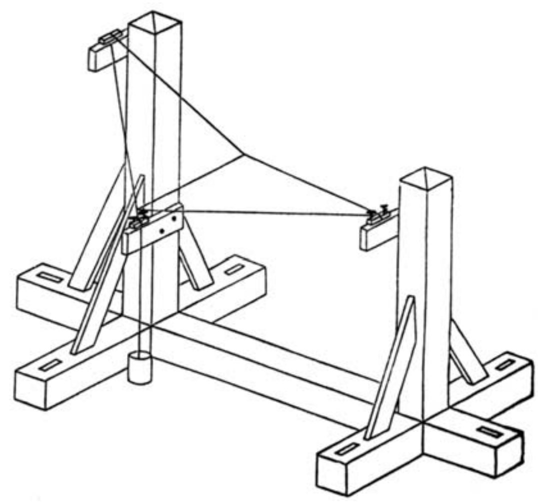
Astronomy as a science and the development of astronomical instruments started from the seventeenth century in Japan (Nakayama 1969). In the 1680s, Shibukawa Harumi was nominated to be the first astronomical officer of the shogunate, after the government adopted his proposed new luni-solar calendar. For observations in this calendar reform, he made a gnomon with an apparatus to sharpen the blurred shadow of the sun. He also constructed an armillary sphere of 90 cm in diameter which was a simplified version of the traditional Chinese armillary sphere, and he measured the positions of many stars with it to produce the first Japanese star map. His compiled star catalog reveals that the observational error of his armillary sphere was about half a degree, though this instrument has since been lost. The only existing armillary sphere actually used for astronomical observations is the one preserved at Sendai City Observatory, which is about 100 cm in diameter and made of bronze with scales of half a degree interval.

After Harumi, there was no one to inherit and develop his scientific achievements till the advent of the eighth shogun Tokugawa Yoshimune in the 1710s. He was deeply interested in the natural sciences and made efforts to organize and cultivate the study of science. In 1729 he relaxed the ban of importing Chinese books written by Jesuit priests in China and also allowed Dutch interpreters at Nagasaki to learn Dutch books. This was because, he recognized the superiority of Western astronomy over Chinese traditional astronomy and planned a calendar reform using Western astronomy. He took some astronomers and mathematicians to the shogunal astronomical office and ordered an optician from Nagasaki to devise good telescopes for astronomical observations. Yoshimune himself was also engaged in astronomical observations by inventing a few new armillary spheres and transit quadrants. Despite Yoshimune's enthusiasm, his intended calendar reform was unsuccessful, due to the poor abilities of the shogunal astronomers and the opposition of the court astronomers based at Kyoto.

Because of the hereditary system for the position of the shogunal astronomers, the scholastic ability of some amateur astronomers overpowered that of the shogunal astronomers around the end of the eighteenth century. The shogunate eventually summoned the two civil astronomers of Osaka, Takahashi Yoshitoki and Hazama Shigetomi, to take leadership for a new calendar reform as the shogunal astronomers (Watanabe 1987). The former was superior in theoretical astronomy and the latter in developing astronomical instruments. Before their nomination to the position, they already possessed some knowledge of Copernican and Keplerian theories of planetary motions learned through Sino-Jesuit astronomical books, and they also devised accurate astronomical instruments by consulting *Lingtai Yizhi* (Astronomical Observatory Instruments, by Verbiest et al. 1674). This book described with many detailed illustrations the structure and usage of several new astronomical instruments constructed by the Jesuit astronomers serving the Qing Dynasty, which were hybrids of the traditional Chinese instruments and European ones invented by people such as Tycho Brahe.

The principal instruments among the ones produced by the Takahashi–Hazama group were the quadrant of 195 cm in radius with a telescope and the wire meridian transit of about 3.6 m in height, both installed at the shogunal observatory of Edo (ancient Tokyo). The quadrant was equipped with a diagonal subscale, which was reinvented by Brahe, so that it could measure stellar positions (altitudes) with an error of 10–15 arcsec. For measuring the meridian-transit time of stars, they used an astronomical pendulum clock which was also devised by the Takahashi–Hazama group with hints from *Lingtai Yizhi*. This astronomical clock could give stellar-transit timings with an accuracy of about one second. Although several such astronomical clocks made before 1850 still exist, all the instruments used at the shogunal observatory of Edo were lost or destroyed in the disorder of the Meiji Restoration in 1868.

Ino Tadataka, one of Takahashi's disciples, conducted a large-scale land survey all over the Japanese archipelago starting from 1800. This was the first scientific expedition of geodesy conducted in Japan. Although the methods of mapmaking and measuring instruments by Ino were not innovative ones, his 16-year-long enthusiasm led him to complete the entire map of Japan. For the fieldwork, he designed and constructed a few portable quadrants for astronomical latitude observations; the most frequently used one has the quadrant whose radius is 115 cm. Analysis of his field notes shows that the accuracy of single observations with this quadrant was about 20–30 arcsec. Ino also used a transportable wire transit (Fig. 1) for observing the meridian passage of stars along with a pendulum clock. This transit instrument was not useful for determining longitudes of triangulation points because of the lack of a precise chronometer, but it was mainly used for maintaining the local time. As for azimuth measurements, he devised semicircular magnetic compasses with an alidade. His 57-volume azimuthal catalog of more than 2,200 triangulation points reveals that the typical error of Ino's azimuth measurements was 5′. All of those instruments are now preserved at Ino's memorial museum. Astronomers of the Takahashi–Hazama group including Ino did not adopt the Vernier subscale but exclusively adhered to the diagonal subscale for precise measurements.



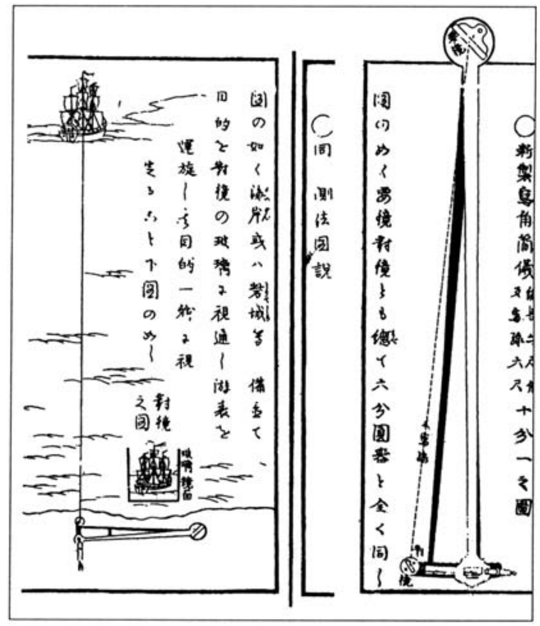
Astronomical Instruments in Japan. Fig. 1 Transportable wire meridian transit used by Ino Tadataka in his land survey expedition of Japan (Otami 1932).

Telescopes

Telescopes in Japan have a fairly long history. As far as historical records tell us, the first introduction of a telescope into Japan goes back to 1613, when a captain of the British East India Company offered a telescope to the first Shogun Tokugawa Ieyasu for trade promotion; this telescope does not seem to exist now. The earliest existing telescope in Japan was the one owned by Tokugawa Yoshinao, the ninth prince of Ieyasu (now preserved at the Tokugawa Fine Arts Museum). Since Yoshinao died in 1650, it means that his telescope was produced in or before that year. Our recent investigation made clear that this telescope was of the Schyrlean type, made of four convex lenses giving erect images, with a magnifying power of about four. Analysis of the design, the fabrication method, the surface decoration of the telescope, and the relating historical episodes all suggest that it was not a Western make at all but produced around the southern coastal area of China, or Taiwan, or Nagasaki, by the East Asians. In the 1720s, the optician of Nagasaki, Mori Nizaemon, responding to the order of the Shogun Yoshimune, produced at least several telescopes for astronomical observations, a few of which still exist. The largest one has a tube length of 340 cm with an objective lens diameter of 73 mm, giving the magnifying power of about 10. It is likely that the shogunal astronomers used this telescope for observations of the planetary surfaces.

Around the 1790s, Iwahashi Zenbei of Osaka started production of refractor telescopes on a commercial basis. His telescopes were characterized by special decorative patterns on the tube surface, so that plenty of imitations and fakes with similar decorations appeared at later times. High-quality telescopes by Iwahashi gave the magnifying power of more than 10–20.

Because the Iwahashi's family continued to fabricate their telescopes for four generations, they are most commonly seen in museum collections and antique markets. All the telescopic tubes and caps from Yoshinao's to Iwahashi's were produced by the traditional technique called *Ikkan-bari*, which utilizes paper and thin wood glued with *urushi* lacquer. In 1834, the gunsmith, Kunitomo Tobei, succeeded in completing his first Gregorian reflector telescope for the first time in Japan (Yamamoto 1937). Currently four brass telescopes of nearly the same size (with an inner tube diameter of 62 mm) are identified as his products. Although it is quite unknown how he could polish the bronze primary mirrors without knowledge of Western modern optics and a mirror-grinding machine, Foucault's method of mirror testing has revealed that at least a few of Kunitomo's telescopes possess parabolic surfaces nearly as accurate as those of contemporary Gregorian telescopes. With one of them, Kunitomo made continuous observations of sunspots for more than 1 year, and during that time he independently discovered the penumbra of the sunspot. It is a shame that his excellent engineering could not find any successors, as pioneering achievements like Kunitomo's have often had a similar fate in the history of Japan.



Astronomical Instruments in Japan. Fig. 2 Drawing of Murata's range finder (1852).

Octants and Sextants

Octants and sextants are certainly worth mentioning in the history of Japanese astronomical instruments. Dutch sailors first brought octants, superb handy navigational and astronomical instruments, into Japan in the 1770s. Because of having no previous information on the principle of an octant and the Vernier subscale inscribed on its arc, both the issues greatly annoyed Japanese astronomers (Nakamura 2002). Only the practical usage of an octant on the sea had been known since 1782, through a Japanese translation of the Dutch book on octants written by Cornelis Douwes (1749). It was not before 1800–1810 that scholars in Japan began to understand how an octant works and the principle of the Vernier subscale. Since at that time the shogunal government kept a strict seclusion policy and prohibited construction of ships large enough to enable remote voyages, the Japanese had no chance to use octants and sextants in ocean navigation. This motivated some people to apply octants in measuring angles of distant targets on the ground. Several books explaining how to use octants and sextants in land surveying were written up to the middle of the nineteenth century. One problem with an octant in measuring angles of ground targets was systematic errors due to the parallax caused by a separation between the two mirrors comprising major components of an octant. On the contrary, some land surveyors, like Murata Sajuro, made positive use of the parallactic problem. He introduced, in his book of 1852, a range finder which is a heavily deformed octant having a very wide mirror separation (Fig. 2); Murata's book describes range finders with mirror separations of 1.8 m, 3.6 m, and 5.4 m. The left panel of Fig. 2 indicates that this instrument was invented for military purposes to measure the distance of a ship on the sea. After the Meiji Restoration of 1868, modern astronomical instruments imported from Europe soon replaced all the Japanese ones.

See also: ►Ino Tadataka

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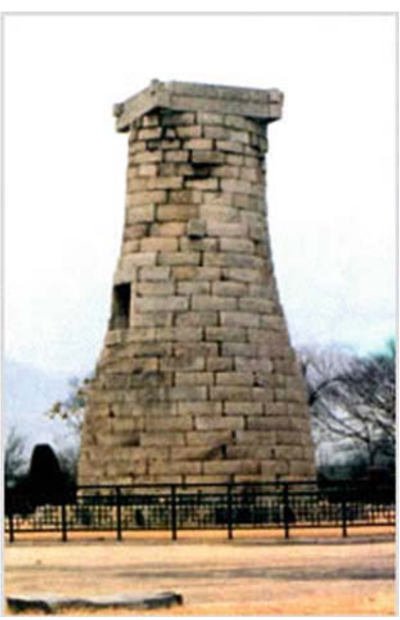
Astronomical Instruments in Korea

YOUNG-HO HAHN

As a country which shares its border with China, ancient Korea also shared many of her neighbor's astronomical achievements. Korea adopted Chinese calendars as a standard and kept identical seasons of the year. But rulers of the Korean peninsula had also tried to establish an independent calendar system, especially during the Chosun dynasty (1392–1910). They attempted to bring out their own almanac at the same level of precision as the Chinese one. Several astronomical projects carried out under the initiative of King Sejong are the best-known examples of such efforts. From 1432–1439 a platform, *Ganeuidae*, for the royal observatory was built in the palace and every necessary astronomical instrument was added to it.

Korea has one of the world's oldest observatories, *Chomsungdae*, shown in Fig. 1. It was built in the early seventh century. Another observatory was constructed in the early tenth century and is also extant. Unfortunately only a small number of astronomical instruments and records prior to the fifteenth century have survived. But, as these observatories show, there had been many attempts to read heavenly phenomena even before the Chosun began.



Astronomical Instruments in Korea. Fig. 1 World's oldest observatory, *Chomsungdae* in Kyongju.

All the astronomical instruments mentioned in this article, although many of them have been lost and are known only through records, are those made during the Chosun period. King Sejong's projects were very important to Korean astronomy. In addition to establishing the first independent calendar, *Chiljeongsan*, various instruments, such as equatorial torquetums [the torquetum or turquet is an instrument designed to take and convert measurements made in three sets of coordinates: horizon, equatorial, and ecliptic], armillary spheres, celestial globes, sundials, and auto-striking clepsydras, were introduced. Some of them were made after Chinese models and others were original. The most comprehensive description of Sejong's instruments is in Needham's *The Hall of Heavenly Records* (1986).

When Japan invaded Korea in 1592 and burnt down the royal palaces in Seoul, almost every instrument was lost, and Sejong's astronomical instruments were burned. Parts of these were restored after the war according to original designs. While the Court of Chosun was struggling to rebuild after successive raids by Manchurian Qing, Jesuit missionaries in China worked to change the Chinese calendar system to that based on Western astronomy. Officials and scholars of Chosun had to confront unfamiliar Western mathematics and astronomy to catch up with the advanced Chinese calendar. Using projection geometry, they made planar instruments such as astrolabes and sundials for themselves. Finally at the end of the eighteenth century, the Korean royal observatory was able to create a pair of unique Western-style sundials.

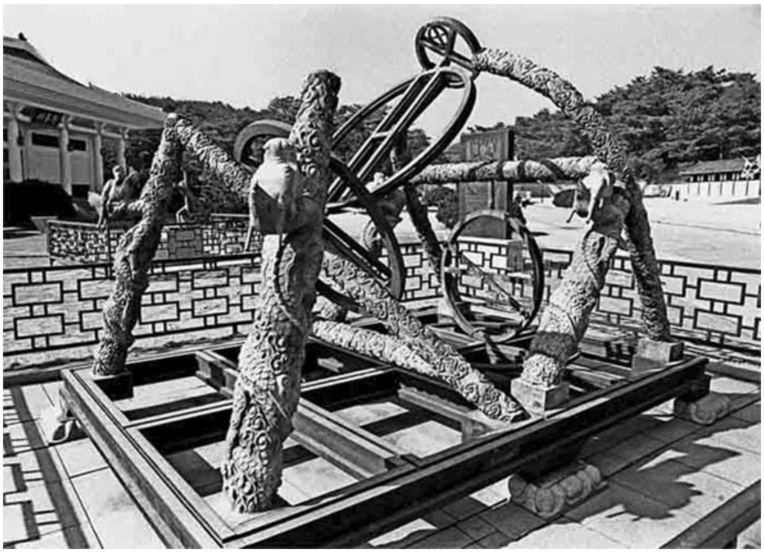
Each instrument that follows is classified according to its structure and function.

Equatorial Torquetums

An approximately 7 m high, 10 m long and 7 m broad platform of the royal observatory was named *Ganeuidae*, because the equatorial torquetum, *Ganeui*, the largest representative of Sejong's observing instruments, was installed on it.

The Korean *Ganeui* was based on Guo Shou-Jing's *Jianyi*, shown in Fig. 2. Guo, of the Chinese Yuan dynasty, invented a new instrument by taking equatorial and meridian rings out and eliminating ecliptic and selenic rings from the traditional armillary sphere. Details of *Jianyi* (literally, simplified instrument) are described and illustrated in Needham's *Science and Civilisation in China*, vol.3 (1959).

Sejong's officials made a wooden prototype and checked the exact polar elevation of Seoul. They completed a bronze-cast *Ganeui* in 1433. Although much simpler in shape than an armillary sphere with multiple-layered rings, the full-scale Simplified Instrument was too large to handle easily. In 1434 King Sejong ordered his scholars to make a smaller version,



Astronomical Instruments in Korea. Fig. 2 Reconstructed Model of Simplified Instrument *Ganeui* in Yeoju.

Astronomical Instruments in Korea. Fig. 3 Reconstructed Model of Small Simplified Instrument *Soganeui* in Yeoju.

Astronomical Instruments in Korea. Fig. 4 Sun-and-Star Time-Determining Instrument *Ilseongjeongsieui* Reconstructed.

and they made two copies of the portable *Soganeui* (Small Simplified Instrument), shown in Fig. 3.

Sejong's astronomers also created a unique observing device, *Ilseongjeongsieui* (Sun-and-Star Time-Determining Instrument). As its name implies, this instrument was both a sundial and stardial. With triple equatorial dial plates, double axially protruded polar-sighting rings, an alidade, and two sighting threads, the direction of the sun and some specified stars near the north pole could be read. This in turn revealed the time of observation. Figure 4 shows the reconstructed model of the round-the-clock time-determining instrument.

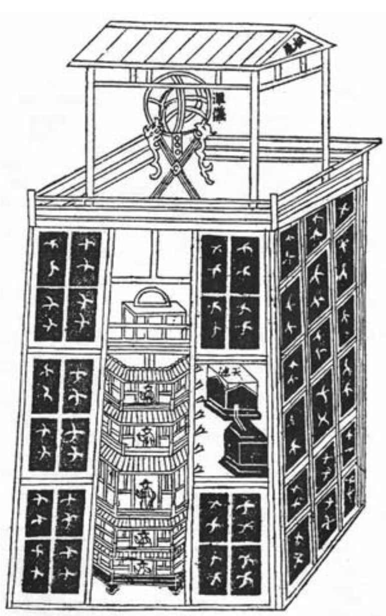
Armillary Spheres, Celestial Globes, and Astronomical Clocks

After Guo Shou-Jing's *Jianyi*, armillary spheres in East Asia were based on the Simplified Instrument, not on platforms of observatories. They became the driving mechanism of the indoor astronomical clock. Although the first Chinese astronomical clock dates back to the second century AD, it was at the end of the eleventh century that Su Sung's *Shuiyunyixiangtai* (Water-Powered Sphere and Globe Tower), appeared in China. The inner rings of the armillary sphere and the star-embedded sphere of the celestial globe were rotated by a water wheel in accordance with each heavenly body. The sketch of the clock tower in Fig. 5 is taken from Su Sung's book, and more details of this gigantic clock may be found in Needham's *Heavenly Clockwork* (1986).

China's long tradition of astronomical clocks culminated in Su Sung's work in the Sung dynasty. During the succeeding Yuan period, such water-driven clocks as Guo Shou-Jing's Lantern Clepsydra and Emperor Shun-Ti's Palace Clepsydra were made. But they were not classified as astronomical clocks because they did not have any devices like spheres or globes to indicate heavenly motions.

King Sejong revived the East Asian tradition of astronomical clocks in Korea by equipping a water-operated sphere and globe near his observatory. Except for the layout and size of the instruments, the basic structure of Sejong's clock is thought to be the same as Su Sung's.

In 1438 the artisan Jang Young-Sil made one more water-powered astronomical clock, *Heumgyonggaknu*, close to King Sejong's inner palace. The Clepsydra of the Respectful Veneration Pavilion, although it vanished long ago, is one of the most spectacular astronomical clocks ever made in Korea.



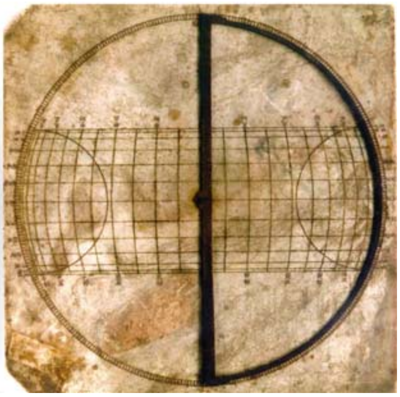
Astronomical Instruments in Korea. Fig. 5 Su Sung's Water-Powered Sphere and Globe Tower.

A ball-shaped golden figure moved round the 7 ft. high mountaintop while keeping the same polar distance and directions of rising and setting to the sun for each season. Below the sun image stood four jade female gods at the four cardinal points, each with an animal-figured direction god. The ringing of a golden bell in the hand of a god and the turning of the accompanying animal god announced the beginning and middle of the double hours. There was a high platform at the southern foot of the mountain, on which hammers struck their respective instruments to announce the assigned double hour or night watch. On the ground level 12 jade gods surrounded the mountain, paired with each hour god. In addition to the extra platform carrying an inclined vessel, there were paintings of rural scenery during the four seasons and wooden carvings of men, birds, and plants.

This splendid clepsydra was totally destroyed and restored twice over 200 years. Two decades after the abolition of *Heumgyonggaknu*, Yi Min-Cheol made an armillary clock as the successor of Jang Young-Sil's clockwork in the mid-seventeenth century. The new armillary clock was derived from Sino-Korean astronomical clepsydras, but it had a considerably different appearance. Yi built a cabinet in which water-operated driving mechanisms and a time-announcing apparatus were contained. An armillary sphere, as a part of astronomical clock, was installed on the plinth connected to the box.

Song Yi-Young, in close cooperation with Yi Min-Cheol, made an additional weight-driven armillary clock at the same time in 1669. Instead of Yi's water-powered device he adopted the driving mechanism that had been applied to Western mechanical clocks. Fortunately, as shown in Fig. 6, an improved version of Song's armillary clock has survived and is preserved in the Museum of Korea University, Seoul.

Astronomical Instruments in Korea. Fig. 6 Armillary clock in the Museum of Korea University, Seoul.

Astronomical Instruments in Korea. Fig. 7 Korean relics of celestial planisphere (left) and universal astrolabe (right).

Needham devoted one whole chapter of *The Hall of Heavenly Records* (1986) to describing this clock; he wrote that the Song Yi-Young/Yi Min-Cheol clock deserved widespread recognition as a landmark in the history of East Asian horology.

Western astronomy and astronomical instruments began to spread to Korean scholars from the early part of the eighteenth century. Hong Dae-Yong made the last astronomical clock in East Asia. He coupled a mechanical clock directly with the sidereal components of his armillary sphere and attached kinds of differential gears to distinguish solar and lunar motions from sidereal movement.

In 1789 the royal observatory made an equatorial armillary sphere to correct the records of meridian transits. Taking a Westernized, Chinese armillary sphere as a model, Kim Young made Chosun's first observing armillary sphere that could measure heavenly bodies at the accuracy level of 15 s.

Astrolabes

The early Jesuit missionaries introduced astrolabes to China. Books on planispheric or universal astrolabes had been published in Chinese during the first quarter of the seventeenth century. However, the actual astrolabes did not arouse as much interest from Chinese scholars as the books introducing those instruments. Thus China did not leave any trace that showed practical uses for Western-style astrolabes except the celestial planisphere, *Pinghunyi*.

More than 100 years later, Korean scholars made all the Western planar instruments for themselves from reading these foreign books. But the planispheric astrolabe was uncommon in Korea too. The plate of the Western astrolabe was replaced with the planispheric star chart in *Pinghunyi*, and the rete was revised simply to an arc of horizon on the eastern instrument as shown in Fig. 7. Although several celestial planispheres have been handed down, universal astrolabes are very rare. Moreover, no planispheric astrolabe has survived.

Astronomical Instruments in Korea. Fig. 8 A scaphe sundial *Angbuilgui.*

Sundials

Ancient Korea contributed to the diversity of sundials by adding her unique shadow-tracking instruments. Especially during King Sejong's reign, several distinguished solar devices were invented and equipped. The best-known representative is the scaphe sundial, *Angbuilgui*. This sundial, shown in Fig. 8, has a hemispherical surface of grid lines. Since the end point of the gnomon coincides with the center of the sphere, the shadow of the sharp end is cast to the grid surface always at a right angle and can be read clearly and accurately even at times near sunrise and sunset. The scaphe sundial was used as a main time indicator throughout the Chosun dynasty.

During the eighteenth century a few horizontal sundials were made; they replaced the role of the scaphe sundial in the Court. The new Western-origin sun trackers had the simple appearance of a flat slab, although the construction of the shadow lines was not easily attainable. Once the geometrical essentials to construct foreign sundials became known, the royal observatory preferred to make horizontal instruments rather than the scaphe sundial with its hemispherical surface of shadow lines.

Among these horizontal sundials, *Ganpyongilgui* and *Hongaeilgui* are quite unique. In 1785 these two were carved side by side on the same 1.3 m-long stone table as shown in Fig. 9. The stone slab with 52 cm width is now preserved in the Royal Relic Exhibition Hall of Deoksu Palace in Seoul.

Ganpyongilgui was based on a Rojas type universal astrolabe and *Hongaeilgui* on a planispheric astrolabe. But the way they were developed was far from simply duplicating the original instruments. The inventor of these sundials, probably one of the high officials of the royal observatory, must have been a master of the principles of planispheric projection to carry out significant modifications for these particular horizontal instruments.

The grid lines of the Rojas type universal astrolabe, *Ganpyongeui* in Korean, can be obtained by an orthographic projection, whose center of projection is at infinity outside the equinox of the celestial sphere. By analogy, it can be said that *Ganpyongilgui* is a Rojas type sundial since its grid lines were also drawn by orthographic projection. The center of projection of this sundial was located at infinity outside the zenith of Seoul. As the center of projection was moved from infinity outside the equinox to that of local zenith, the straight season lines of the astrolabe *Ganpyongeui* were transformed to parallel ellipses of the sundial *Ganpyongilgui* because the inclined circles were projected orthographically.

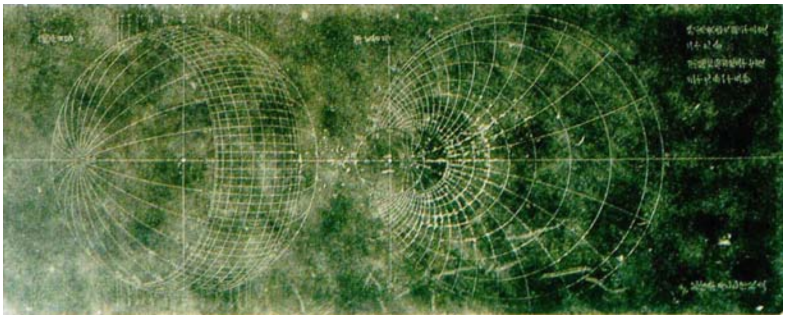
The name of the other sundial was *Hongaeilgui*. Its origin can be traced from the name *Hongaetongheon*, the planispheric astrolabe. The ecliptic on the rete and the lines on the plate of a planispheric astrolabe are obtained by stereographic projection from the south celestial pole. The same rule of projection was followed to get the star chart of a celestial planisphere. Moreover, the season and hour lines of *Hongaeilgui* were also drawn by stereographic projection.

The way to get the grid lines for *Hongaeilgui* is sketched briefly in Fig. 10. Unlike having the center of projection at infinity as in an orthographic projection, the center of the stereographic projection remains on the surface of the celestial sphere. Whenever curves on a sphere are mapped onto a flat surface, there are two characteristic features of the stereographic projection. One is the preservation of the circle and the other the rule of conforming. Every circle on the sphere maps onto a plane as a circle by the rule of preserving the circle. And, according to conforming, two circles that intersect at a certain angle will intersect at the same angle on the mapped surface.

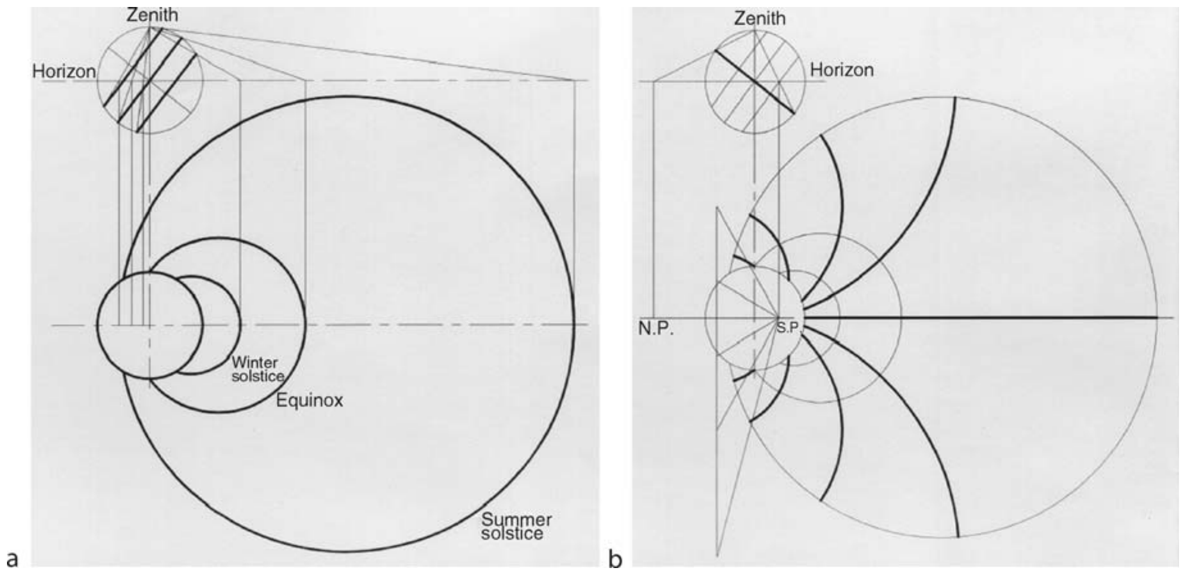
The sun is traced for the Korean planispheric sundial, *Hongaeilgui*. The altitudinal and azimuthal data are cast as shadows of the gnomon onto the surface of the sun tracker. Season and hour lines were constructed as grids on the sundial. By shifting the center of projection to the local zenith, the horizontal coordinates of the sphere were transformed to the polar coordinates. The equatorial coordinates were mapped to the sundial as the bipolar coordinates of the season and hour lines as shown in Fig. 10. The direction of the shadow directly gives an azimuthal coordinate and its length; the altitude of the sun yields a radial coordinate through a simple transformation:

$$\frac{r}{R} = \tan\left(\frac{90^\circ + \beta}{2}\right) = \frac{1+\sin\beta}{\cos\beta} = \frac{1}{a} + \sqrt{1+\frac{1}{a^2}}$$

where r is the radial coordinate, R is the radius of the base circle representing horizon, β is the altitude of the sun, and a is the length of the shadow when the height of the gnomon equals unity. With the polar



Astronomical Instruments in Korea. Fig. 9 *Ganpyongilgui* (left) and *Hongaeilgui* (right).



Astronomical Instruments in Korea. Fig. 10 Stereographic projection of *Hongaeilgui*; (a) season lines, and (b) hour lines.

coordinates of the shadow in hand, the point that specifies the current date and hour would be located from the bipolar coordinates.

This Korean horizontal sundial is more of a graphical calculator than a mere time indicator. Most problems concerning the position of the sun throughout a year could be answered straightforwardly without any further calculation. While keeping the geometric characteristics and drawing procedure unchanged, the well-established astrolabe was completely modified by a Korean expert to an extraordinary sundial.

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Astronomical Monuments in Polynesia and Micronesia

César Esteban

The pre-European inhabitants of the Pacific islands were skillful and frequent inter-island navigators. The most accurate directional indicators used by the Polynesian and Micronesian islanders – still used today in several parts of Oceania – were the rising and setting positions of stars (Grimble 1931; Goodenough 1953; Akerblom 1968; Gladwin 1970; Lewis 1994). The measurement of stellar positions and their movement over the celestial sphere was an important task for the ancient seafarers. In fact, astronomy was treated as a branch of navigation by the ancient Tongans (Collocott 1922) and, as the Jesuit priest Fr. Cantova reported from castaways from Woleai (Caroline Islands) at Guam in 1721, "The only thing they learn are some vague principles of astronomy to which most apply themselves due to its usefulness in navigation" (Lewis 1994: 112). The navigators defined the sailing directions by the use of "star compasses", which divide the horizon into a number of parts identified by the rising and setting positions of the stars. There is ample evidence of the use of a 32-direction "star compass" by the ancient and contemporary navigators of the Caroline Islands (Goodenough 1953: 5–24; Gladwin 1970: 147–165; Lewis 1994: 102–111). The references for the use of a "star compass" in Polynesia are ancient and scarce. The most detailed one is by Andía y Varela, who led a Spanish expedition to Tahiti in 1774 (Corney 1914, 2: 284–285; Lewis 1994: 84).

There are few ethnohistoric references about systematic observation of the Sun or Sun worshiping in Polynesia. For example, Behrens, in 1737, says that in the early morning, Easter Island inhabitants "had prostrated themselves towards the rising sun and had kindled some hundreds of fires which probably betokened a morning oblation to their gods" (Behrens 1908: 133). There are some vague indications of solstitial observation in pre-European Pukapuka and New Zealand (Beaglehole and Beaglehole 1938: 349; Makemson 1941: 85–86) and more explicit ones in Hawai'i (see Kirch 2004a, and references therein). However, the most clear evidence of Sun observations is in Mangareva (Gambier Islands), where Buck (1938: 414–415) indicates that "two stones were set up to form sights" to determine the solstices exactly.

There are several ethnological studies about Polynesian names of stars, constellations, and the calendar, the most important compilations being those by Makemson (1941) and Johnson and Mahelona (1975). In a recent synthesis of historical anthropology, Kirch and Green (2001: 260–276) have reconstructed essential aspects of ancient Polynesian time reckoning and ritual cycle. They describe:

1. An annual seasonal cycle divided in two parts originally based on a wet–dry seasonality and the yam cultivation cycle;
2. A sidereal cycle based on the observation of the heliacal and acronychal rising of the Pleiades (named Mataliki in Proto-Polynesian);
3. An agricultural annual lunar calendar of 13 months; and
4. A system of intercalation for keeping the synchronization between the lunar calendar and solar year. This system was based on the observation of Pleiades risings but, in some cases, at least in Mangareva and Hawai'i, also on solar observations at solstices.

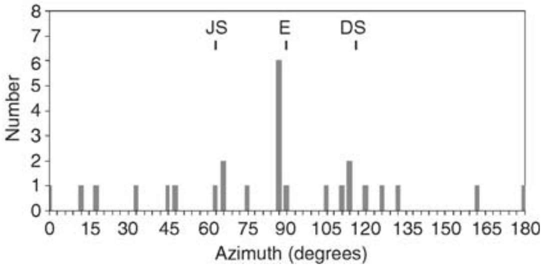
It is surprising that there have been rather few attempts to correlate the ethnographic material about celestial lore and the alignments of the ubiquitous ceremonial stone structures across the whole Pacific area.

There are few archaeoastronomical studies in Polynesia and they are not systematic except for Easter Island and – in recent years – Hawai'i. In the case of Micronesia, the situation is even worse. As far as I know, there has been no archaeoastronomical fieldwork on orientations of prehistoric Micronesian stone monuments. In the following, I will review the main results of different research works in the Pacific area. Not all the islands groups are included because an important number of them are lacking any kind of archaeoastronomical study.

Ferdon (1961) made the first report of astronomical alignments in Polynesia as part of the investigations of the Norwegian Archaeological Expedition to Easter Island in 1955–1956. This author proposed that a group of cup-marked boulders (the so-called Sun stones) at the village of Orongo was oriented astronomically; however a reanalysis made by Lee and Liller (1987) has shown that such claims can be discounted. The archaeologist Mulloy (1975) discovered the unusual orientation of one of the scarce inland *moai* platforms (the moai are the large imposing Easter Island statues): Huri A Urenga, which faces the point where the Sun rises at the June solstice. Liller and Duarte (1986) performed an excellent analysis of the orientations located at this monument, reinforcing the astronomical interest of the site and finding other possible astronomical orientations. Mulloy (1961) and Smith (1961) also reported possible solar alignments in other coastal *moai* platforms of Easter Island, such as those of Vinapu 1 and 2 (December solstice sunrise and equinox sunrise, respectively) and Tepeu (December solstice sunrise).

Liller (1989) has made a systematic study of orientations defined by several hundred *ahu*[1] and *moai* platforms on Easter Island, finding that there is marginal evidence of alignments related to the solstices or equinoxes. He finds a definite trend among coastal *ahu* being oriented parallel to the coast (approximately 90%), with the sculptures or *moai* facing out to sea. Considering the *ahu* with long sides non-parallel to the shoreline (a sample of 26 *ahu*) there is an overwhelming tendency for these monuments to be oriented in the direction of the equinox rising points and an extra one or two *ahu* aligned in the direction of the solstice rising points (Fig. 1). Regarding the inland platforms, Liller finds there is a weak tendency to have the *moai* look in the direction of the rising of the Sun at the June solstice, and Huri A Urenga stands out as the most remarkable case. Very recently, Edwards and Belmonte (2004), considering the outstanding ethnographic importance of Matariki (the Pleiades star cluster see, for example, Van Tilburg 1994: 100–103) and Tautoru (Orion's Belt) as markers of ceremonies and agricultural

[1] An *ahu* is a raised platform inside a temple.

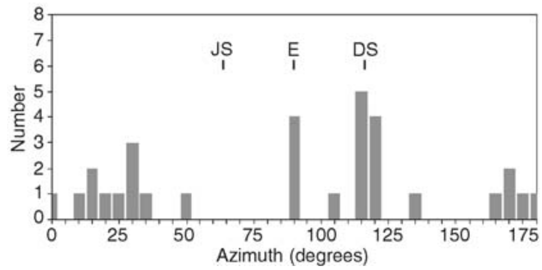


Astronomical Monuments in Polynesia and Micronesia. Fig. 1 Number histogram of the orientations of the perpendicular to the long side of 26 *ahu* within 500 m of the coast and with long axes skewed by more than 20° to the adjacent shoreline of Easter Island measured by Liller (2000b). Data are binned in 3° interval. JS, E, and DS indicate the azimuths of the rising sun at June solstice, the equinoxes, and December solstice, respectively. Note the overwhelming tendency of east–west orientations. Diagram adapted from Liller (2000b).

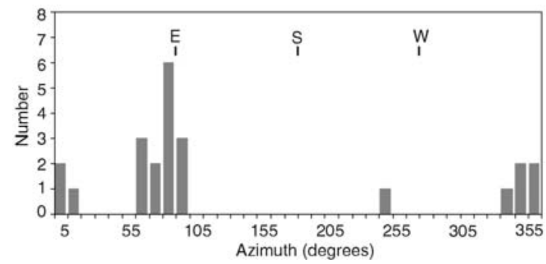
activities in the traditional calendar of Easter Island and the absence of solar references or cults, propose that the aforementioned solstitial and equinoctial alignments of the *ahu* platforms could be interpreted as being instead alignments to the Pleiades and Orion's Belt risings or settings. The declination of those asterisms are incidentally very similar to those of the Sun at the June solstice (Pleiades) and to the Sun at the equinoxes (Orion's Belt).

Since the pioneering studies of the Hawaiian stone temples (*heiau*) by Stokes in 1906–1909 (published in 1991: Stokes 1991), Emory (1924) and Bennett (1931) it has been usually considered that the orientation of the *heiau* was determined by the local topography and environmental considerations, commonly facing the sea or valley. Moreover, as Kirch (2004a) has pointed out, the rich Hawaiian ethnohistory is largely silent about *heiau* orientations. Only the native Hawaiian scholar Malo (1951) indicates that the cardinal directions could have been important for the positioning of the audiences in the *heiau* during the ceremonies. Chauvin (2000) defends the low probability of premeditated solar alignments in the stone temples considering that neither solstices nor equinoxes played any role in the Hawaiian calendar or in religious practices. On the other hand, Kirch (2004a) indicates that the major Hawaiian deities were associated with particular directions and seasonal orientations on the basis of what is known of traditional Hawaiian theology. This assertion suggests that the finding of astronomical alignments in temple platforms may not be disregarded. On the other hand, Ruggles (2001) is also optimistic, at least in the possibility of some symbolic celestial connections in the *heiau* taking into account the large number of names of stars and other celestial objects in the traditional Hawaiian names for places in the landscape. Ethnographical data give evidences of solar observations among the ancient Hawaiians. For instance, Kamakau (1976: 13–14) indicates the existence of persons who observe the stars and a class of priests who advised concerning building and locating temples who were skilled in reckoning the months of the year and following the Sun movement. He (1976: 14) also describes solar observation from the island of Kaua'i based on the rising or setting of the Sun over relevant topographic features of the horizon in particular moments of the year.

Rubellite Johnson carried out the first archaeoastronomical studies in Hawai'i in the 1980s. Da Silva and Johnson (1982) first suggested a possible "astronomical-directional register" in the Ahu a 'Umi Heiau, a platform located on the island of Hawai'i, the highest and the farthest inland heiau of the Hawaiian archipelago. Johnson (1993) also studied the small island of Kaho'olawe, where oral tradition suggested that it had once been a place of important astronomical and navigational activity. Meech and Warther (1996) have made an interpretation of some *hula* or sacred chants of the Hawaiians in terms of astronomical alignments that can be found in the archipelago, specially related to the solstices. However, reassessments based on more precise measurements have shown that the alignments claimed by those authors are not sufficiently precise in most cases (Ruggles 1999). Moreover, the results obtained by Ruggles seem to indicate an interest in solar zenith passage as much as and perhaps more than in the solstices. In a subsequent paper, Ruggles (2001) presents a systematic study in Kaua'i trying to correlate ritual and sky traditions with the architectural alignments of a large sample of *heiau*, a promising new approach in Polynesia where many traditions are still alive or collected in the rich ethnological legacy. In this last study, Ruggles finds no consistent patterns with regard either to orientation upon topographic features or to orientation upon celestial objects, although some intriguing relationships are found in some particular sites. However, other works have been successful in finding rather clear astronomical orientations in ancient Hawaiian temples. Liller (2000a) has studied the orientations of 32 stone temples in the tiny Necker Island. This island has two relevant particularities: (a) it has an astonishingly large number of temples considering the small size of the island; (b) the island center is located almost exactly at the latitude of the Tropic of Cancer in the year AD 1000. This last particularity implies that the ancient inhabitants of Necker would have realized that the Sun was directly at their zenith at midday of the June solstice. In fact, Liller has found that nine of the 32 temples of Necker are aligned with the setting June solstice and/or the rising December solstice (Fig. 2). Finally, Kirch (2004a) has



Astronomical Monuments in Polynesia and Micronesia. Fig. 2 Number histogram of the orientations of the perpendicular to the back side of 32 *stone temples* of Necker Island (Hawai'i Archipelago) measured by Liller (2000a). Data are binned in 5° intervals. JS, E, and DS indicate the azimuths of the rising sun at June solstice, the equinoxes, and December solstice, respectively. Note that the *temples* show two preferred orientations: one east–west and the other around the December solstice sunrise. Diagram adapted from Liller (2000a).



Astronomical Monuments in Polynesia and Micronesia. Fig. 3 Number histogram of the orientations of 23 *heiau* at Kahikinui (Maui Island, Hawai'i Archipelago) measured by Kirch (2004a). Data are binned in 10° intervals. The position of the cardinal points is indicated by letters. The data show three clear concentrations: one facing the east, another facing east–north–east, and a third one facing north, Kirch (2004a) believes these orientations were deliberate and likely related to a particular god of the Hawaiian pantheon.

performed an analysis of the orientations of a sample of 23 *heiau* of Kahikinui (Maui Island). This author has found that temple foundations tended to have three preferred orientations: east, east–north–east, and north (Fig. 3). Kirch has correlated these results with ethnohistoric and ethnographic data proposing that:

a. The east orientations may be associated with god Kane, because this deity was associated with the Sun and the east direction;
b. The east–north–east cluster of orientations may be related to either the summer solstice sunrise or the rising of the Pleiades. In fact the acronychal rising of this asterism determined the onset of the Makahiki season and the new year, this group of temples may be dedicated to the god Lono, who was linked to the annual rising of the Pleiades;
c. The temples oriented to the north face the summit of the high mountain Halekeala ("House of the Sun") and may be dedicated to Ku, a deity linked to high mountains, the sky, and to forest.

Archaeoastronomical studies in islands of Eastern Polynesia, apart from the aforementioned ones for Easter Island and the Hawai'ian archipelago, are very scarce and recent. Liller (1993) presents an analysis of orientation data (obtained from direct measurements by the author and from good quality topographical maps) of over 50 ceremonial stone platforms in various archipelagos of Polynesia (Society Islands, Hawaiian Islands, Rarotonga, and the Trilithon of Tonga) finding no clear astronomical trends except perhaps in some isolated cases. In a subsequent paper, Liller (2000b) gives an excellent review of archaeoastronomical fieldwork carried out in Polynesia and presents some new results based on the reanalysis of large sets of published plans from the literature and some other new data obtained by the author. Concerning the archipelagos of Eastern Polynesia, Liller presents histograms of orientations of temples belonging to the Tuamotus (52 temples) and the Society Islands (105 temples) as well as some preliminary and sparse data of Mangareva, the Cook Islands, and the Australs. The general conclusion of that paper is that the orientation of the Polynesian ceremonial platforms was controlled by the physical situation. Most of the monuments are located on the shore and lie parallel or perpendicular to the immediate shoreline. Astronomical alignments are present only in some isolated cases. The remarkable *mara'e*[2] Tapu-tapu-a-tea, possibly one of the most important in all Polynesia, located on Rai'atea (Society Islands) has its long inland-facing wall oriented to an azimuth of $6^\circ 3'$. Liller (2000b) suggests that the perpendicular to the wall may be oriented to the rising point of the southern portion of the constellation of Orion: perhaps Orion's Belt or Rigel. Other important *marae* of the Society Islands, such as those of Tainu'u (Rai'atea), Matairea-rahi and Anini (Huahine), Marotetina (Borabora), Mahaiatea (Tahiti), and Tetii (Mo'orea), are also oriented to within a few degrees of that of Tapu-tapu-a-tea (Liller 2000b). This finding could be relevant in the context of the ethnohistorical accounts of Henry (1928: 363) who writes the following concerning the birth of heavenly bodies in ancient Tahitian tradition: "the chiefs of the skies… were royal personages… from the period of darkness, and they each had a star. They bore the names of those stars, and those names have been perpetuated in their

[2] *Mara'e* (also spelled *mala'e* or *maa'e*) are stone or coral slab temples.

Astronomical Monuments in Polynesia and Micronesia. Fig. 4 *Left*: The Ha'amonga-a-Maui trilithon seen from the south (Heketa, Tongatapu Island, Kingdom of Tonga). This is a unique monument in Polynesia that stands about 5 m tall. *Right*: View of the eastern horizon as seen from the lintel of the trilithon. The position of the rising points of the Sun at solstices and equinoxes has been cleared of vegetation by the Tongan authorities. The lintel is aligned approximately along the December solstice. The current Tongan monarch, King Taufa'ahau Tupou IV, discovered this alignment. Images taken from Esteban (2002–2003). Reproduced with permission of University of Texas Press.

temples in this world." This account suggests that the finding of stellar alignments in the *mara'e* cannot be considered strange (Kelley and Milone 2005: 347). On the other hand, unpublished archaeological surveys of *mara'e* in the Faaroa Valley (Rai'atea) and Matairea Hill (Huahine) carried out by Edmundo Edwards indicate that a fraction between 20% and 30% of the monuments show solstice orientations, although Liller (2000b) considers that Edward's results, at least for Huahine, are only circumstantial.

As in the case of the aforementioned Necker Island in the Northern Hemisphere, there are several islands of Eastern Polynesia located close to – in this case – the Tropic of Capricorn. Tubua'i (Australs) was located only 23 km north of this tropic in AD 1000 (Liller 2000a). Vérin (1969) found that four out of six mara'e reported on this island show alignment with the December solstice sunset. However, Edwards (2003) indicates that those presumed orientations could be only accidental considering that the nearby shoreline has precisely the same orientation. This last author reports a survey of 92 *mara'e* on Ra'ivavae (Australs), an island also very close to the Tropic of Capricorn, finding that about 14% of the monuments are astronomically oriented. In particular, the large *mara'e* Unuaru (whose walls are not parallel to the shoreline), as well as other mara'e of Ra'ivavae, are oriented very close to the true north.

The Mangareva Islands (also known as Gambier Islands) are the only case in Polynesia where there is unequivocal ethnohistoric evidence for systematic solar observations. The account of the priest Honoré Laval provides a description of traditional Mangarevan time reckoning and the methods of solar observations at solstices and the places where they were performed (Laval 1938: 213–215). Peter Buck (1938) gives another detailed ethnographic account about these activities. Here are some relevant astronomical information (see Kirch 2004b):

a. Solstice observations were used to keep the lunations in sequence with the solar year and to divide the year into two seasons;
b. The locations for solstitial observations are given. The observatory at Atituiti, named Te Rua Ra (the pit of the Sun), is said to be the "most favorable position" for this purpose;
c. In at least one site, upright stones are used to mark the rising Sun at December solstice, and the backsight was a big flat stone;
d. The observation of solar risings and settings on distant topographic markers were used to achieve precision;
e. The movement of a shadow cast by a certain mountain was also used as a solstitial marker.

Kirch (2004b) has rediscovered the precise site of the Atituiti observatory, finding an uncommon platform oriented along the cardinal directions and the central flat boulder where observations were performed. That author has been able to confirm the most important aspects of the ethnohistoric records. For example, the position of the December solstice sunset coincides with the western edge of the high cliff Ana Tetea (the burial place of two renowned high chiefs of Mangareva) on Agakauitai Island; the shadow of Auorotini (Mount Duff) is also cast onto the central flat boulder during the June solstice.

In the Kingdom of Tonga we have a remarkable and unique monument in Polynesia: the Ha'amonga-a-Maui (Burden of Maui) trilithon,[3] which according to tradition, was built in AD 1200 (see Fig. 4). In 1967, the current monarch, King Taufa'ahau Tupou IV, discovered that the lintel is aligned along the sunrise at December solstice; this was later confirmed by Liller

[3] A trilithon is a structure consisting of two large vertical stones supporting a third stone set horizontally across the top.

(1993) and Esteban (2002–2003). According to Collocott (1922), “the Tongan year is said to have begun at about the same time as the Christian year” and this fact would indicate a possible calendrical importance of the December solstice. As has been commented before, Makemson (1941) and other authors state that in most of the Polynesian archipelagos (including Tonga), the new year began in late November or early December with the first Moon after the acronychal rising of the Pleiades. These dates are not far off but obviously do not coincide with the December solstice. In any case, as Esteban (2002–2003) has suggested, the solstitial orientation of the trilithon may be accidental because its axis is roughly parallel to other related archaeological structures and to the nearby shoreline. Some controversy was raised by the presence of an enigmatic zigzag figure carved into the top of the lintel of the trilithon whose axes point roughly to the two rising solstice directions. However, Dhyne (1994) argues that there are reasons to believe that the marks were made relatively recently.

The most common archaeological features of Tonga are round or rectangular mounds of earth with considerable size range. These mounds can be house platforms, burial mounds, *esi* mounds (resting places for members of the chief’s family), and mounds for pigeon snaring (McKern 1929). The *esi* and pigeon mounds are usually situated upon natural rises that command a splendid view of the surrounding countryside. The anthropologist Wragge (see Liller 2000b; McKern 1929: 17) reported that the *esi* platform called Makahokovalu in Uiha Island (Ha’apai group) was a religious site connected with ancient Sun worshipping. However, McKern (1929: 17) and Gifford (1924: 68) failed to find any archaeological or ethnological evidence of Sun worship in the island. Liller (2000b) reports that in McKern’s plan of Makahokovalu the long axis is oriented at an azimuth of 2° (perpendicular 92°) suggesting some solar relation, but this is also the orientation of the nearby shoreline. Esteban (2002–2003) has estimated the approximate orientation of the ramps of the mounds from the plans published by McKern finding no clear trends.

Since the burial mounds of Tongan commoners are just earth mounds, the sites relating to the chief and royal family have stone facing and are often loosely called *langi*. The *langi* are large rectangular monuments with stone slab retaining walls, generally consisting of a number of terraces in the manner of truncated pyramids. One of Collocott’s (1922) informants suggested a connection between the skies and the great burials at Mu’a (Tongatapu Island) and elsewhere, and it is worthy of note that sky and vault are called by the same name: *langi*. In a detailed study of the largest collection of *langi* at Mu’a, Esteban (2002–2003) finds that the general disposition of the tombs is parallel to the shoreline, although much less probable stellar orientations related to sailing directions are also discussed by that author.

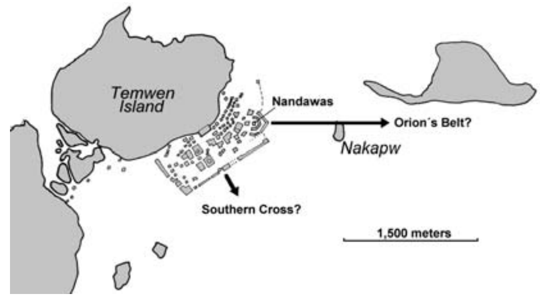
Bellwood (1978) reports that Samoan ethnographic records indicate the existence of open spaces for ceremonies (*mala’e*) as well as god-houses. Scattered among Samoan settlements are the so-called star mounds. They are large, raised platforms with several rounded projections extending from the central area and built with a loose rubble of basaltic stones. The interpretation of star mounds has been controversial. Modern informants tend to view them as pigeon-snaring mounds. No evidence of use for habitation or burial was found. The mounds were perhaps also used for religious purposes, as some ethnological references have pointed out (Davidson 1979) and also for some divination rituals, as it is indicated in the information panels of the Tia Seu Lupe (literally “earthen mound to catch pigeons”) star mound in Tutuila Island (American Samoa). Esteban (2002–2003) considers it impossible to define useful alignments in these kinds of mounds taking into account their common irregular shape and large number of rounded irregular projections.

The island of Sava’i (Independent Samoa) has what is quite probably the largest surviving prehistoric monument in Polynesia, the Pulemelei stone mound. It is a huge flat-topped and roughly rectangular structure that covers 60 by 50 m at the base and is 12 m high. There are slightly sunken ramps to the top on the eastern and western slopes. It was most probably an important ceremonial center. It is located inside a coconut tree plantation, almost completely overgrown, being very difficult to make any precise measurement of the walls or the horizon. However, Talbot and Swaney (1998: 141) and Esteban (2002–2003) agree that the mound is roughly squarely oriented with the cardinal points. In any case, the monument needs to be cleared of vegetation before one can obtain precise bearings of its massive walls and a desirable analysis of the astronomical horizon.

The largest island of the Republic of Palau (in Micronesia) is Babeldaob. From the astronomical point of view, the most interesting prehistoric remains known in Palau are the unique sculpted stone faces at Melekeok, on the eastern coast of Babeldaob. They are nine stones ranging from 1 to 2.5 m in height and arranged very precisely in two rows parallel to the nearby shoreline. All the surviving stones are facing the sea. Morgan (1988: 14–15) collected the following legend concerning the origin of these stones: Odalmelech, the god of Ngermelech Village in Melekeok, “and his councilmen set out to lay a huge stone work over the village ground. That night, they started bringing in huge reef stones for the project, but the work was only partially completed when dawn approached. Odalmelech, seeing that his cohorts could not accomplish the project before daylight, called his crew together and told them of the shame of being caught working in the morning sun. So he ordered his crew to carve all their faces on the monoliths and place them to eternally face the rising sun." This story indicates the possible astronomical motivation of the site. Esteban (2002–2003) finds that the orientation of the faces may be close to the June solstice rising based on the site plan published by Morgan (1988: 13). Direct measurements and additional ethnographic data on the site are necessary to check this suggestive finding.

Nan Madol, in Pohnpei Island (Federated States of Micronesia) is the largest archaeological site in Micronesia and perhaps of all the Pacific Islands. It consists of 92 human-made rectangular islets separated by many waterways. The islets are generally surrounded by retaining walls of long, naturally prismatic basalt which are often built up over foundations of immense basalt boulders. The site was constructed on a reef located in the southeast side of Pohnpei which is called Sounahleng or "Reef of Heaven." All the islets have proper names, and some of them have names related to the sky or stars (Morgan 1998: 66–67). Nan Madol is divided into two areas. The northeast area is Madol Powe, the mortuary zone where the priests dwelled. The southwest area is Madol Pah, the administrative sector, where royal dwellings and ceremonial areas were located.

Most of the islets, and specially those of Madol Pah, are oriented relative to a well-defined northeast-to-southwest axis. Nandauwas, the royal mortuary islet in Madol Powe, which is located on the eastern edge of the whole complex, is the most magnificent example of prehistoric architecture in all of Micronesia. It is interesting to note that Nandauwas and its immediate neighbors are the only islets in Nan Madol which are not oriented along the general northeast-to-southwest axis but along a due east–west axis. Esteban (2002–2003) has made a rough preliminary archaeoastronomical analysis of the main axes of the complex (Fig. 5) based on the 1981 US Geological Survey map (1:10,000) of the zone and the detailed plan of the site published by Morgan (1988: 66–67). The perpendicular to the general northeast-to-southwest axis of most of the islets is facing toward the center of the Southern Cross at the dates of use of the site. On the other hand, the perpendicular to the sea-facing wall of Nandauwas points almost exactly due east, perhaps to the equinoxes or to Orion's Belt. From the works by Goodenough (1953: 5–24) and Gladwin (1970: 148–160), we see that the Southern Cross and Orion's Belt are among the most important asterisms for contemporary navigators of the Caroline Islands because they define the directions of south and due east of their star "compass" (see Lewis 1994: 103). It is worth noting that the orientation of monumental tombs



Astronomical Monuments in Polynesia and Micronesia. Fig. 5 General plan of the archaeological site of Nan Madol (Pohnpei Island, Federated States of Micronesia) and its surroundings (adapted from Morgan 1988; courtesy of the author and the University of Texas Press). A possible astronomical interpretation (Esteban 2002–2003) of the orientations of the main axes of the complex is indicated. Figure taken from Esteban (2002–2003). Reproduced with permission of University of Texas Press.

of other important megalithic sites of Pohnpei seem to be also oriented toward the east, as those of Sapwtakai (see the plan published by Morgan 1988: 83) and Panpei West (see map in Rainbird 2004: 192). It would be very interesting to carry out precise archaeoastronomical fieldwork on Nan Madol (and other megalithic sites at Pohnpei and Kosrae islands) to check if these preliminary findings on the map are correct and explore further the promising astronomical potential of this remarkable site.

See also: ►Astronomy in Hawai'i

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Astronomy

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Astronomy, the study of celestial objects, is a universally human endeavor whose roots lie deeply buried in prehistory. For the sky-watcher devoid of optical aid, the heavens can be thought of as a sort of earth-centered celestial sphere on to which have been sprinkled hundreds of tiny points of light we have called the stars. Half of this inverted bowl of blackness is almost completely dominated by the dazzling presence of the sun, the most prominent and important of the celestial objects. Such is the sun's brilliance that any attempt to view this object directly is to risk serious eye damage or even total blindness. As a result of the earth's spinning motion or rotation, an observer at a given location on the earth sees a sky that alternates between a daytime sky dominated by the sun and a nighttime sky characterized by its absence. As the earth turns on its axis, the sun appears to rise up from a given observer's eastern horizon, pass through a "high noon point" or maximum angle above the horizon, and then descend toward the western horizon. Approximately one half an earth rotation later, the sun once more rises to repeat the cycle. This rising and falling effect is not limited to the sun. As the earth rotates relative to all celestial objects, they too appear to go through the rising and falling diurnal motions of the sun. Since the rate of the earth's rotation is very nearly constant, this diurnal motion of the sun and stars has long been employed as an important and reliable way of measuring time. The earth's rotation also creates the illusion that the stars of the celestial sphere seem to revolve about two imaginary points located exactly opposite each other. One, the south celestial pole, is visible only from the southern hemisphere of the earth, while the other, the north celestial pole, is visible only from the northern hemisphere. The earth's long-term precessional motion carries the locations of these celestial poles along a 47° diameter circular path among the stars once every 26,000 years. From time to time, a relatively bright star can be found near the position of one of the celestial poles for a few centuries. Such is the case at present for the north celestial pole, which is currently located near the fairly bright star Polaris, the Pole Star.

In addition to its daily rising and setting, the sun also appears to travel along a great circle on the celestial sphere, which is called the ecliptic. This latter movement is the direct result of the earth's orbital motion about the sun. As the earth arcs along in its orbital path, the apparent position of the sun relative to the more distant background stars appears to change. For an observer on the earth, the sun thus seems to creep gradually from west to east among the stars, completing an entire 360° journey around the ecliptic in exactly the same 1 year time interval it takes the earth to complete one orbital revolution about the sun. The background stars hence appear to be gradually overtaken in the western sky by the sun as it moves eastward along the ecliptic, engulfed by the solar glare for a month or so, and then reemerge in the predawn sky as the sun leaves them behind in its ongoing easterly movement. The overall result of this annual movement of the sun is a seasonal parade of the heavens in which different stars are visible at different times of the night at different times of the year.

The earth's axis of rotation is also found to be tilted at an angle of 23 1/2 degrees off the vertical to the earth's orbital plane. As the earth orbits the sun, this tilt causes the sun to shine alternately more directly on the northern hemisphere and less on the southern hemisphere and then vice versa over the span of a simple year. This effect is observable as a yearly variation of the sun's highest altitude above the horizon at a given location, and as a change in the time that the sun spends above the horizon. Thus when the sun is shining most directly on the northern hemisphere at the time of the summer solstice, the sun's diurnal motion in the northern hemisphere is characterized by long days and short nights, and in the southern hemisphere by short days and long nights. Half an orbital revolution or 6 months later at the time of the winter solstice, when the sun is shining more directly on the southern hemisphere, the lengths of night and day are reversed. Halfway between these extremes the sun shines directly down on the earth's equator twice each year. On these dates, the lengths of the days and nights all over the earth are equal, except at the poles, and hence these dates are said to be the equinoxes. It is this combination of the tilt of the earth's axis of rotation and the earth's orbital motion that gives rise to our cycle of seasons here on the earth.

Firmly entrenched in second place in the brightness hierarchy of celestial objects is the moon. Although not as important as the sun, the moon, none the less, exerts several significant influences on the earth, most notably as the chief agent by which tides are produced in the world's oceans. The reflected sunlight we receive from the moon is over one million times fainter than that emanating from the sun, and as a result, the moon can be readily viewed against the backdrop of the stars of the night sky. As the moon orbits the earth in space, it appears to traverse a great circle about the celestial sphere in a fashion not unlike the annual motion displayed by the sun. There are however some important differences between the lunar motion and that of the sun. The moon swings along an apparent path that is tilted at an angle of about five degrees to the ecliptic and takes one-twelfth of the sun's time to make a single journey about the celestial sphere. The moon thus moves at an average rate of about half a degree per hour relative to the background stars, an angular speed easily detectable over the course of a single night by a naked eye observer.

Although the moon's half degree angular diameter is almost exactly the same as that of the sun, the diminished brightness of the moon permits us to look directly upon its face without fear or danger. As a result, the moon presents a number of most interesting and fascinating phenomena to the naked eye observer. Perhaps the most familiar of these is the set of seeming shape changes or phases exhibited by the moon as it journeys about the celestial sphere. These phases arise from the fact that as the moon orbits the earth, the half of the moon's spherical surface which faces the sun, and is hence illuminated by the sun's light, is viewed at different angles by an observer situated on the earth. When the moon is very nearly lined up between the earth and the sun, almost all of the moon's sunlit hemisphere faces away from the earth, and all we see of the moon is a very thin crescent of light. As the moon moves toward progressively larger angular distances from the sun, the thickness of the crescent grows or waxes until the angle between the moon and the sun as seen from the earth is 90°. At this point we see exactly one half of the moon's sunlit surface and the moon appears to have a semicircular or "quarter-moon" shape. As the sun–moon angular separation increases past 90°, the moon takes on a bulging or gibbous shape whose thickness continues to grow until the moon is very nearly opposite the sun in the sky. When this configuration occurs, the entire sunlit hemisphere of the moon faces the earth, and the now circular-shaped moon is said to be a "full" moon. After passing through the full phase, the moon's shape changes now proceed in reverse order, successively passing through waning gibbous phases, a second or last quarter phase, and finally a waning crescent phase as the angle between the moon and the sun decreases from 180° to nearly zero. The waning crescent moon eventually slides into the predawn solar glare for a few days and then reemerges as a silvery crescent-shaped "new" moon in the postsunset twilight.

The moon is also unique among celestial objects in that it is the only one for which surface detail can be easily viewed with the unaided human eye. This detail manifests itself in the form of the dark areas on the moon's disk which are called maria or seas and the light areas called continents. This terminology dates back to the Western European Renaissance observers of the moon who imagined the lunar surface to be divided between bright land and dark waters.

In addition to the sun and moon, human beings have recognized since prehistoric times that five other naked eye objects also move about the sky relative to the back-ground stars. These star-like wanderers are called planets, and historically have enjoyed the appellations of the gods and goddesses of ancient Greek and Roman mythology. The five so-called naked eye planets have been named, in order of their increasing distance from the Sun, Mercury, Venus, Mars, Jupiter, and Saturn. A sixth planet, Uranus, possesses a brightness which is just at the limit of naked eye visibility, but the planetary nature of this object does not seem to have been recognized until the English astronomer William Hershel accidentally stumbled upon it in 1781.

Two of the planets, Mercury and Venus, have orbits about the sun which are interior to that of the earth. As a result of this orbital geometry and the sun's gravitationally induced faster orbital speeds, these planets exhibit a marked pattern in their appearances in the earth's sky. In a typical cycle, the planet is first visible as an evening "star" in the west after sunset, then appears to move out to a maximum angle of greatest elongation away from the sun before retreating back into the sun's light. After several days or weeks, the planet reemerges from the solar glare, but this time as a morning "star" in the predawn sky. The planet once more moves out to an angle of greatest elongation and then drops back into the solar light. The swiftly moving planet Mercury goes through a complete cycle of appearances or synodic period in about four months, while Venus, whose orbital speed is more closely matched to that of the earth, takes a year and a half for its cycle of appearances. Typically Mercury's appearances as a morning or evening star last about three weeks, while those of Venus extend over several months at a time.

Visually, the plant Mercury appears in the sky as a sparkling object having a somewhat reddish-orange tint. Its apparent brightness is actually comparable to the brightest stars, but because it is almost always observed in twilight, it is usually not as impressive an object as it otherwise might be. The most spectacular of the naked eye planets and the third brightest object in the sky behind only the sun and moon is the planet Venus. The orbital path of Venus can carry it out to an angle of greatest elongation as large as 47°, or about twice that exhibited by the planet Mercury. Thus it is possible to observe this splendid object for as long as 4 h after sunset or before sunrise. At its greatest brilliancy, the soft white light of Venus has even been observed to cast very faint shadows as it gleams in the darkness of the predawn or postsunset night sky.

The three remaining naked eye planets Mars, Jupiter, and Saturn, move in vast orbits about the sun which are exterior to the orbit of the earth. As a result, these planets appear most of the time to move about the celestial sphere in a fashion similar to the west to east movement exhibited by the sun and moon. The times required for each of these planets to make a complete cycle about the celestial sphere, however, are far longer than those for the sun and moon. Mars, for example, completes a single journey around the celestial sphere in just under 2 years, while Jupiter and Saturn require nearly 12 and 30 years, respectively, to complete similar journeys. As the faster moving earth catches up to and passes one of these exterior planets, the planet exhibits an illusionary phenomenon in the earth's sky called retrograde motion in which the given planet seems to stop its normal west to east motion among the stars, moves "backward" or east to west for several months, stops again, and then resumes its direct or west to east movement. In the midst of its retrograde motion, a given planet will appear to be opposite the sun's position in the celestial sphere as sun from earth. When such a configuration occurs, the planet is said to be "in opposition to the sun," or more simply, "at opposition." At the time of a given planet's opposition, the earth makes its closest approach to the planet, and as a result, the planet shines more brightly than at any other time. Moreover, at opposition the planet rises at sunset, sets at sunrise, and is thus visible throughout the night.

Visually, the planet Mars is perhaps the most remarkable of the exterior planets owing to its distinctly reddish hue. At times of closest approach to the earth, the apparent brightness of this ruddy world is exceeded only by that of the sun, Moon, and Venus. When Mars is not at a close opposition, the fourth brightest object in the sky is the yellowish-white planet Jupiter which shines some ten times more brightly than the average of the brightest of the background stars. The golden-colored planet Saturn is the most distant of the naked eye planets from both the earth and the sun, and thus exhibits a reduced apparent brightness which is comparable to the average of the brightest background stars.

While the paths of the planets about the celestial sphere are not coincident with the ecliptic, they are, none the less, nearly coplanar with it. As a result, the sun, moon, and five naked eye planets move about the celestial sphere in a relatively narrow band of sky centered on the ecliptic which is called the zodiac. Because the sun, moon, and planets move along the zodiac at differing rates, it is possible for objects in the sky to appear to pass close to other objects along the zodiac. When such a passage occurs, the resulting configuration of the two objects is said to be a conjunction. Conjunctions can occur among the sun, moon, and planets, as well as between these moving objects and the bright stationary stars which are to be found along the zodiac. From time to time conjunctions can involve three or more objects, and on rare occasions a conjunction can be so close that the two objects cannot be seen as separate with the unaided eye.

In addition to the imaginary band of planetary paths that is the zodiac, there exists a quite real band of diffuse light, called the Milky Way, which is stationary relative to the stars and girds the celestial sphere like a gigantic faintly glowing heavenly belt. The Milky Way is the naked eye manifestation of the vast galactic system of gas, dust, and stars in which our sun is located. The Milky Way Galaxy, as this system is called, is in the shape of a huge, flat pinwheel which has a substantial bulge at its center. Our sun is situated about two-thirds of the way toward the outer edge of this system, and as a result, our view of the summertime Milky Way in the northern hemisphere is the more prominent one, since at this time we are looking toward the direction in which most of our galaxy is located. On the other hand, in the northern hemisphere winter, our view is now directed away from the galactic center toward the less prominent regions of the galaxy, with the visual result that the wintertime Milky Way is much fainter than its summertime counterpart.

Off the plane of the Milky Way, there exist approximately a dozen or so lesser diffuse objects which are visible to the naked eye and are also set in fixed positions among the stars. Modern telescopic observations reveal that these "fuzzy patches of light" are in reality quite a diverse lot, including clouds of glowing gas, star clusters, and even other galaxies well outside of our Milky Way.

From time to time transitory apparitions and events occur in the sky which can be as awesome as they are spectacular. One such event is a total eclipse of the sun. When the moon passes directly between the earth and the sun, a moving shadow of the moon about 240 km wide is cast upon the surface of the earth. An observer located in the shadow's path will see the sun's disk gradually covered by the dark lunar disk until the sun's light is almost completely blotted out. During this "total" phase of the eclipse, only the light from the sun's outermost atmospheric layers is visible and a darkness comparable to a full moon night descends on the land for a time period ranging from a few seconds to as long as 7 min. Finally the moon moves out of its direct alignment between the earth and the sun, and the sun reemerges to its full disk and full brightness.

The sun, earth, and moon can also align in such a way that the moon passes into the earth's shadow, thereby producing a total eclipse of the moon. When such an event occurs, an observer on the earth sees a full moon gradually enter the curved shadow of the earth. When the moon is totally immersed in the earth's shadow, it can take on a variety of ruddy hues ranging from an almost totally darkened red to a bright coppery shade of red–orange. This illumination even at the total phase of a lunar eclipse is caused by sunlight being refracted on to the moon's surface by the earth's atmosphere. The variety of colorations exhibited during various lunar eclipses is thus the direct result of the weather conditions in the earth's atmosphere, especially the degree of cloud cover at key locations around the earth. Typically the eclipsed moon spends an hour or so in the total phase before reemerging from the earth's shadow and regaining its full moon brilliance.

Every few years or so the night sky is visited by a strange apparition, a diffuse "long-haired" star-like object called a comet. Comets are known to be collections of ices, dust grains, rocks, and frozen gases which wheel about the sun in huge elongated orbits which alternately carry them from relative proximity to the sun out to the most distant parts of the solar system, thousands of earth–sun distances away. As a comet approaches the sun, the sun's radiant energy causes the ices and frozen gases to evaporate into a glowing coma which surrounds the dust and rocks at the comet's nucleus. As this diffuse, star-like object draws ever closer to the sun, the solar proton wind and radiation pressure drive material out of the diffuse head into a long, streaming tail which can extend over millions of miles of space. For several weeks, like a cosmic messenger, a comet will approach the sun, blossom with a flowing tail, and then fade into the cold blackness that is the periphery of the solar system.

The debris left behind by both these interlopers as well as from the formation process of the solar system permeates the interplanetary medium. As the earth sweeps along its orbit, it is constantly bombarded by objects ranging in size from tiny grains of dust up to small asteroids several kilometers in diameter. Fortunately collisions with the latter are extraordinarily rare! When a given interplanetary particle, called a meteoroid, strikes the earth, it does so at speeds as high as 50 km s^{-1}. At such speeds, friction with the earth's atmosphere causes the object to heat up quickly and glow brilliantly as it falls toward the earth. An observer at the earth's surface sees this event as a "falling star" or "shooting star." Most of the time, such objects disintegrate in the upper layers of the earth's atmosphere, but occasionally a meteoroid is able to traverse the earth's atmosphere and strike the earth's surface. Such an object is then referred to as a meteorite.

Occasionally the earth passes through a large stream of meteoric debris left behind by a comet. Under these conditions, large numbers of meteors can be seen in the form of a meteor "shower." During a typical meteor shower, one can see anywhere from 15 to 60 meteors per hour above the normal sporadic or background meteor counts of about six meteors per hour. About three or four times per century the earth strikes a particularly large and dense aggregate of meteoroids. Under these circumstances, thousands of meteors per hour flash across the heavens in a display of celestial fireworks which is unmatched anywhere else in the natural world.

From time to time in the remote recesses of interstellar space a star will end its life in a spectacular event called a supernova explosion. For a few days the energy output of this dying object rivals that of all the stars in an entire galaxy. If a supernova detonation occurs at a distance sufficiently close to the earth, the observed result is the transitory appearance of a "new" star in the terrestrial night sky. For time periods ranging from a few days to several months, the star shines at or near its maximum brightness before fading back into naked eye invisibility. One of the more notable of these objects was observed in the year AD 1054. At its maximum brightness, the supernova of 1054 was nearly three times brighter than the planet Venus and could be readily seen in broad daylight. The remains of this stellar blast can be telescopically viewed today as the tattered and twisted gaseous cauldron called the Crab Nebula.

Unlike the mathematical and monolithic universality which characterized the scientific philosophy emergent from the Western European Renaissance, the explanations tendered for the considerable array of celestial phenomena by non-western cultures as well as those of pre-Renaissance Europe and the Mediterranean were far more qualitative in nature and represented a diversity of ingenious viewpoints that were nearly as numerous as the cultures from which they sprang. Generally such explanations appear in a given culture in the form of myths, legends, and folklore, and pay considerable homage to the observed characteristics of the sky and its resident objects. As such, they represent the beginning attempts on the part of human beings to provide rational explanations consistent with observations for the variety of events which occur in the physical world, thereby making that world more comprehensible.

Perhaps the most familiar example of this process in action is to be found in the myths and legends pertaining to the fixed stars. Out of the more or less random distribution of stars in the night sky, one can imagine a variety of figures, shapes, and patterns not unlike the variety of faces and forms that one often fancies in the puffy clouds of a springtime sky. In some instances, a given pattern of stars can bear a striking resemblance to a familiar terrestrial entity. For virtually every culture, such similarities were not fortuitous, but in fact were intrinsic characteristics of the sky which were significant and demanded explanation. The most common approach was to regard the sky as a kind of "Celestial Hall of Fame" into which various legendary characters from a given culture's folklore had been inducted for various reasons. Such "inductees" thus became figures outlined in stars or constellations. The outline of some of the constellations are so compelling in their shapes that a variety of far-flung cultures would often envision very similar portraits for a given star group. Thus, the stars of the highly prominent wintertime constellation of Orion, for example, seem to outline a very fit and trim individual possessed of considerable physical strength. Thus Orion, the mighty hunter of Greek mythology is also al-Babādur (The Strong One) for the Arabs, the great hunter "Bull of the Hills" for the Blackfoot Tribe of the western Canadian plains, and the "Slender First One" to the Navajos of the American southwest. As one might expect, there is also a considerable amount of variation in the sky pictures of various cultures. Even though the J-shaped array of summertime stars which we call Scorpius the Scorpion has been widely depicted as a celestial version of its earthly arachnid namesake, there are many other interpretations of this asterism from other cultures. The Polynesians, for example, saw this star group as the fishhook of their great hero Maui, while the Chinese viewed it as the noble Azure Dragon, the Bringer of Spring. To the Mayas of Central America these stars represented the death god Yalahau, the lord of blackness and waters.

The constellations through which the sun, moon, and planets travel in their respective journeys about the celestial sphere were quite naturally assigned a particularly significant status as the constellations or signs of the zodiac. Traditionally there are 12 such constellations, each of roughly equal extent along the zodiac, and which include Aries the Ram, Taurus the Bull. Gemini the Twins, Cancer the Crab, Leo the Lion, Virgo the Virgin, Libra the Scales, Scorpius the Scorpion, Sagittarius the Centaur-Archer, Capricornus the Sea-Goat, Aquarius the Water Carrier, and Pisces the Fishes. In addition to the standard 12 constellation zodiacs employed by a majority of the world's cultures, the zodiac has been variously divided throughout human history into as many as 28 constellations by the Chinese and as few as six by the early Euphratean cultures. The denizens of the zodiac exhibit a considerable variation from culture to culture. The Aztec zodiac was graced with the starry presence of a frog, a lizard, a rattlesnake, and a jaguar, while that of the Incas contained a tree, a bearded man, a puma, and the sacred cantua plant.

Numerous explanations were offered for the observed movement of the sun, moon, and planets along the zodiac, virtually all of which centered on the basic idea that only gods and goddesses could possess the power to move among the stars. In the case of the sun the concept was further reinforced by the fact that to look directly on the face of the sun's disk was to incur the sun deity's wrath in the form of severe damage to one's eyes. Thus the sun was the sun god Amon-Ra to the Egyptians and the sun goddess Amaterasu to the early Japanese, and so on.

Eclipses and conjunctions in the sky have also inspired a number of mythologically based explanations. In the Hindu culture, for example, the mortal Rāhu is said long ago to have attempted to partake of the forbidden nectar of immortality. The god Viṣṇu was told of Rāhu's transgression by the sun and moon, and as punishment Viṣṇu proceeded to decapitate Rāhu. Ever since, Rāhu has sought to take vengeance on the sun and moon by pursuing them across the sky in an attempt to eat them. Once in a while, at the time of an eclipse, Rāhu actually catches either the sun or the moon and attempts to devour his prey. As the sun or moon is devoured, it gradually disappears into Rāhu's throat for a time before reappearing at the base of his severed neck as Rāhu attempts to swallow. The entire event is observed here on the earth as an eclipse of the sun or moon.

The sky watchers of antiquity were able to identify a number of basic characteristics relating to the background objects of the celestial sphere. The recognition of the variety of intrinsic colors that characterize the stars, for example, is manifested in names for stars such as the Arabic *Qalb al*ᶜ *Aqrab* (Heart of the Scorpion) for the bright red star Antares located at the center of Scorpius and the Hindu *Rohini* (Red Deer) for the ruddy star Alphard in the chest of the constellation of Hydra the Sea Serpent.

Bright stars near the celestial poles have held great meaning and significance to the watchers of the sky. In the third millennium BCE the north celestial pole was located in the constellation of Draco the Dragon near a second magnitude star called Eltanin. Because the heavens of the day appeared to rotate about this star, it was quite literally regarded as an object of pivotal importance. As a result, Eltanin was worshipped by a number of cultures, including the Egyptians who used this star to align a number of their important buildings and structures. As the earth's axis of rotation has precessed, other stars have taken on the mantle of Pole Star, most notably by the stars Thuban in the constellation of Draco and Kochab in the constellation of Ursa Minor, the Lesser Bear, and in more recent cultures by the star Polaris at the tip of the tail of Ursa Minor. Both Kochab and Polaris were regarded by the Chinese as Da Di the Great Imperial Ruler of the heavens, about whom the other stars circled in homage. The Pawnee tribe of the American plains named Polaris "The Star That Does Not Walk Around." To the Pawnee this star was related to the god Tirawahat, and as such, was chief over all the other stars. It was this star that saw to it the other stars did not lose their way as they moved across the sky.

Attempts to explain the true nature of the diffuse objects that dot the sky are understandably less prolific in light of the difficulties that are often encountered in observing them. The major exception is, of course, the Milky Way. Of the diffuse objects detectable in the heavens with the unaided eye, the Milky Way is far and away the most extensive and prominent. This delicate band of light which is also highlighted by an array of brighter stars has thus inspired a variety of explanations which include its portrayal as a celestial river by the Chinese and Japanese, as a Path of Souls to an eternal home by the Algonquin tribe of the Lake Ontario region of southern Canada, and as a band of glowing cinders by which one could find one's way home when lost in the darkness by the Bushmen of Africa's Kalahari Desert.

As imaginative and rational as they were, however, the explanations advanced by different cultures for the variety of celestial phenomena observed in the heavens generally became intertwined with the religious beliefs and societal mores of these cultures. As a result, there was a marked tendency for the explanations of celestial phenomena to take on dogmatic qualities in which they were seldom questioned or challenged by alternate points of view. Moreover, the lack of a telescopic astronomy placed severe and fundamental limitations on the level of insight that was possible regarding the nature of celestial objects. Thus the explanations proposed for various celestial phenomena tended to remain largely unchanged in a given culture, and whatever changes that did occur were not so much the result of additional observational insights, but rather due to a gradual evolution brought on as these explanations were passed on from generation to generation or from culture to culture. Even while armed with an impressive instrumental technology, however, human beings still continue to struggle with questions relating to the fundamental nature of what we see in the sky.

Certain observable aspects of the heavens readily lend themselves to practical usage here on the earth, and the greatest levels of achievement enjoyed by non-western astronomers have come in the discovery, recognition, and application of these characteristics. Systematic observations of the sky reveal, for example, that many celestial phenomena, most notably the diurnal and annual motions of the sun and the cycle of lunar phases, occur with precise and predictable regularity. This observable fact of the heavens has thus been employed by cultures worldwide as a method of accurate time keeping.

The diurnal rising and setting of the sun, with its alternating cycle of daylight and darkness, is the shortest and most convenient unit of astronomical timekeeping, and as a result human beings the world over have employed it, quite literally, as an integral part of their daily lives. A second, much longer unit of astronomical time is defined by one complete journey of the sun around the ecliptic. This annual astronomical cycle is of considerable importance owing to the fact that it is intimately related to the cycle of seasons which occur here on the earth. The cycle of seasons, in turn, is virtually identical to the cycle of vegetative growth and those of some animal activity and migrations. Thus agricultural methods and hunting techniques developed by various cultures were necessarily tied deeply to the cycle of seasons and the sun's annual journey along the ecliptic. Intermediate in length between the day and the year is the time interval required for the moon to pass through one complete cycle of its phases. The lunar cycle is particularly attractive as a timing cycle due to the fact that the ever-changing shape of the moon is readily observable on a daily basis. Sequences of shapes inscribed on Cro-Magnon cave walls and artifacts strongly suggest their use as lunar phase timing devices in just this fashion. Similar sequences carved by the inhabitants of Nicobar Island in the Bay of Bengal are known with certainty to be employed for this purpose.

Unfortunately these cycles are not quite numerically compatible with each other. For example, there are about 365 days in a year, but in reality it takes the sun precisely 365.242199 days to complete one cycle around the ecliptic. Similarly there are 29.530588 days to a cycle of lunar phases and 12.36827 cycles of lunar phases in a year. These discrepancies can create difficulties if one wishes to reckon the time of the year, the start of a given season, or the date of an important religious holiday by simply counting the number of days which have elapsed from some defined starting point such as the day of a solstice or equinox. If one counts the number of days as the year progresses, for example, one would find that after 365 days had passed, the sun would not quite yet have completed its journey around the ecliptic, and after 366 days had elapsed, the sun would have moved slightly past one complete cycle. Over several years' time such an effect can add up to a significant discrepancy between the sun's actual position along the ecliptic and the position dictated by the day count. As a result, a variety of schemes, called calendric systems or calendars, have been developed by various cultures around the world which are designed to synchronize two or more astronomical cycles. The most familiar of these is the addition of 1 day to our calendar every fourth or leap year in order to keep the day count in a given year in agreement with the sun's actual position along the ecliptic.

A number of ingenious techniques were developed by various cultures to monitor the astronomical timekeeping process. The Aztec Temple Mayor, now buried beneath modern Mexico City, was designed in the fifteenth century with two spires that provided a V-shaped notch through which the rays from a sun rising at the time of an equinox shone on to the temple of Quetzalcoatl. At no other times of the year would a rising sun produce this effect. Thus the Aztec temples served quite nicely and deliberately as a device with which the Aztec calendar could be corrected whenever necessary. Similar structural alignments are to be found at Stonehenge in England, in the temples of ancient Egypt, and among the buildings of the ancient peoples of the American Southwest. The Mayas of ancient Mesoamerica developed not only astronomical alignments for many of their structures, but also an incredibly accurate but somewhat complicated astronomical calendar which was based on the annual solar cycle and the synodic period of the planet Venus. The Maya calendar was accurate to within 1 day every 5,000 years. By contrast, the simpler Gregorian calendar used by contemporary society is accurate to within 1 day in 3,300 years.

In addition to the structural alignments, various cultures have also employed natural terrain as calendar correctors. On the top of Fajada Butte at the mouth of Chaco Canyon in the American Southwest, for example, there stand three rock slabs, each of which is about 3 m in height. On the rock wall behind these slabs a first millennium AD people called the Anasazi carved a spiral petroglyph in such a way that precisely at noon of the day of the summer solstice, a dagger-shaped beam of sunlight would neatly slice the petroglyph exactly through its center. Through this clever manipulation of sunlight, the Anasazi were able to mark the time of the summer solstice precisely.

The Hopi and Zuni tribes, also of the American Southwest, make use of a so-called sunrise horizon calendar. As the sun moves along the ecliptic, the points of sunrise and sunset along the horizon at a given location exhibit an annual cyclic shift in which the sunrise and sunset points appear to migrate along the horizon from south to north while the sun is moving from the winter solstice to the summer solstice and then north to south along the horizon while the sun is moving from the summer solstice to the winter solstice. As the sunrise and sunset points pass over various key landmarks along the horizon, each passage is taken as a signal to begin the appropriate agricultural activity such as planting various crops, harvesting, etc.

In addition to timekeeping, earth–sky relations can also be employed to find one's way about the surface of the earth. Such techniques are referred to overall as celestial navigation and have been of considerable importance to human cultures, particularly those which are maritime in nature. There are a number of aspects of the heavens which readily lend themselves as navigational aids. As the earth spins on its axis, for example, a star at or near the celestial pole will not appear to change its position in the sky significantly. More importantly, the point on the horizon directly beneath such a star will also remain in a relatively fixed position as well. Thus for observers in the northern hemisphere, the relatively bright star Polaris is located very close to the north celestial pole, and the point on the horizon directly beneath this signpost star has been used for centuries by northern hemisphere peoples to mark the direction we call north.

Other cultures took advantage of the fact that the angular distance of the pole star above the horizon as well as the locations of the rising and setting points of bright stars and constellations along the horizon changed with one's location on the earth's surface. Thus the Caroline Islanders of the central Pacific skillfully navigated by means of this star compass in which 32 points on the horizon were defined by the rising and setting points of bright stars and constellations such as Vega, the Pleiades, Antares, and the Southern Cross. The Polynesians employed a device called the sacred calabash, which was a gourd into which four holes were bored at the same height near the neck. The gourd was then filled with water to the level of the holes. Using the water level as a horizon, altitudes of stars were then measured by sighting through one of the holes over the opposite edge of the gourd. Thus armed with what was in effect the equivalent of our modern sextant, the Polynesians became most adept at deep-water navigation.

Systematic observations of the heavens also reveal that there exist a number of correspondences between celestial events and configurations and natural phenomena here on the earth. For example, the Egyptians recognized that the annual flooding of the all-important Nile River was at hand when the bright star Sirius made its heliacal rising or first appearance out of the predawn solar glare. The Incas of the South American Andes Mountains noticed that the cantua plant blossomed beautifully each year when the sun was located in our zodiacal constellation of Cancer, but which they named appropriately from their observations as the asterism of the sacred cantua plant. The heliacal risings of the bright stars Rigel, Aldebaran, and Sirius served to warn the tribes of the high plains of western America that cold weather was at hand. In light of such readily observable earth–sky correspondences, it was very logical to assume that similar correspondences exist between celestial phenomena and human affairs. Thus evolved the endeavor which we now call astrology.

Whether the astrological leap of logic from earth–sky to human–sky correspondences is a valid one has, of course, been a topic of considerable debate for many centuries, and since the 1600s the premise that such human–sky correlations exist has been emphatically rejected by western science. Nevertheless, astrology, more so than either timekeeping or celestial navigations, demands access to careful and ongoing observations of the entire heavens for the purpose of interpreting the significance here on earth of what is seen to occur in the sky, and whenever possible, to predict future events in the sky as well. Thus a well-developed astrology in China was certainly an important factor in the preparation of the earliest known star catalog in the fourth century BCE, and in the recording of a variety of celestial events, most notably the transitory appearances of sunspots and astrological omens such as comets, which were referred to as *huixing* (broom stars or sweeping stars) and of novae and supernovae explosions, which were called *kexing* (guest stars or visiting stars). So detailed were the records of the Chinese, Japanese, and Korean observations of the supernova event of AD 1054, for example, that modern astronomers were easily able to identify its present remains as the Crab Nebula in the constellation of Taurus, despite the fact that the event went virtually unobserved and unrecorded in Western Europe.

From some cultures, most notably those of the Mayas, Egypt, China, and the Islamic world, careful observations of the sky combined with centuries of relative social and political stability to make possible the discovery of much more subtle and long-term astronomical cycles. The Mayas, for example, were aware of the long-term reappearances of the planet Venus and built the planet's 584-day synodic period into their calendar. Both the Chinese and Islamic observers were aware of the fact that the lunar nodes, or the points on the celestial sphere where the moon's orbit crosses the ecliptic, drift in a westerly direction along the ecliptic at a rate of one complete revolution every 18.6 years and used this knowledge to predict the occurrences of both lunar and solar eclipses.

The Chinese and Islamic observers also recognized that the sun's equinox points drift in a westerly direction along the ecliptic at a rate of nearly 1° per year and made appropriate adjustments in their respective star catalogs and calendric systems in order to account for the protracted effect of this equinotical precession. Awareness of the shifting equinoxes may have also been the province of the Egyptians as well. A number of additions and reconstructions are found to exist in Egyptian temples and other structures which strongly suggest an architectural response to just such long-term changes in the positions of the equinoxes.

See also: ►Eclipses, ►Time, ►Celestial Sphere and Vault

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Astronomy of the Australian Aboriginal People

Roslynn D. Haynes

The Australian Aborigines were almost certainly the world's first astronomers. Their complex systems of knowledge and beliefs about the heavenly bodies have been handed down through song, dance, and ritual for some 40,000 years, predating by many millennia those of the Babylonians, the ancient Greeks, the Chinese, or the Incas. The legends which have survived, until very recently, within a virtually unchanged cultural context, show how natural phenomena, including celestial bodies and events, were assimilated by the Australian Aborigines into a holistic value system which was predicated on the close relationship of the individual with the whole natural world: It is significant, in this regard, that theirs was the only known culture with no myth of alienation from Nature, such as the expulsion from Eden of the Judeo-Christian tradition. On the contrary they believed that through their Great Ancestors of the Dreaming they, too, were continuing co-creators of the natural world. Hence they used their knowledge of the stars not only to predict and explain natural occurrences but also to provide celestial parallels with tribal experiences and behavioral codes.

The Aborigines' knowledge of the "crowded" southern sky was probably the most precise possible for people dependent on naked-eye astronomy. They made accurate observations, not only of first- and second-order stars, but also of the more inconspicuous fourth-magnitude stars. Pattern was apparently more important in recognition than brightness, for the Aborigines often identified a small cluster of relatively obscure stars while ignoring more conspicuous single stars in the vicinity. Thus the people of Groote Eylandt named as *Unwala* (the Crab) the small cluster of relatively insignificant (average magnitude 4.4) stars Sigma, Delta, Rho, Zeta and Eta Hydrae, while disregarding the adjacent bright stars Procyon (α Canis Minoris) and Regulus (α Leonis) (magnitude 0.36 and 1.35, respectively) which are not part of an obvious group. Members of the Boorong tribe of the Mallee District of Victoria limited their identification procedures to linear patterns of three or more stars. Unlike the familiar Greek designations, based on a join-the-dot pictorial image, the Aborigines identified a group of stars with the whole cast of characters in a story, the relationship being conceptual rather than visual. Color was also an important factor in the aboriginal designation of stars. The Aranda tribes of Central Australia distinguish red stars from white, blue, and yellow stars. They classify the bright star Antares (α Scorpii) as *tataka indora* (very red) while the stars of the V-shaped Hyades cluster are divided into a *tataka* (red) group and a *tjilkera* (white) group. The former are said to be the daughters of the conspicuously red star Aldebaran (α Tauri).

The Aborigines also differentiated between the nightly movement of the stars from east to west and the more gradual annual shift of the constellations. From this latter displacement they devised a complex seasonal calendar based on the location of constellations in the sky, particularly at sunrise or sunset. The Aranda and Luritja tribes around Hermannsburg in Central Australia knew that certain stars lying to the south, namely *Iritjinga* and the Pointers of the Southern Cross, are visible throughout the year, although their position in the sky varies. This amounts to a realization that stars within a certain distance of the South Celestial Pole never fall below the horizon.

Yet what the Aborigines did with their astronomical knowledge was fundamentally different from the procedures of Western science. Tribal Aborigines paid no attention to two of the most basic concepts of western science, numeracy and temporality; they made no measurements of space or time, nor did they engage in even the most elementary mathematical calculations. Their observations of the stars were conducted for essentially pragmatic reasons. Either they were an attempt to discover predictive correlations between the position of the stars and other natural events important to the survival of the tribe – the availability of specific foods or the onset of particular weather conditions, or they provided a system of moral guidance and education in tribal lore – a function regarded as equally necessary to the continuation of tribal identity.

As hunter – gatherers, dependent for their survival on a foreknowledge of environmental changes, the Aborigines noted the correlation between the movements and patterns of stars and changes in the weather or other events related to the seasonal supply of food. Thus the significance attributed to these sidereal occurrences varied with the diet and lifestyle of different tribes. On Groote Eylandt the appearance in the evening sky toward the end of April of Upsilon and Lambda Scorpii indicated that the wet season had ended and that the dry south-easterly wind or *marimariga* would begin to blow, causing changes in climate and animal behavior. At nearby Yirrkalla the appearance of Scorpio in the morning sky in early December heralded the arrival of the Malay fishermen who came in their canoes to collect trepang or *bêche de mer* which they sold to the Chinese. In winter, the most spectacular individual stars in the southern sky are Arcturus (α Bootis) and Vega (α Lyrae). When Arcturus could be seen in the eastern sky at sunrise, the Aborigines of Arnhem Land knew that it was time to harvest the spike-rush or *rakia*, a reed valuable for making fish traps and baskets for carrying food, and a local legend about Arcturus served as an annual reminder of this. On the other hand, amongst the *Boorong* tribe of the Mallee district of western Victoria, Arcturus was personified as *Marpeankurrk* the tribal hero who showed them where to find *bittur*, the pupa of the wood ant, a staple item of diet during August and September. The constellation Lyra represented the spirit of *Neilloan*, or the Mallee-hen who taught the tribe how to finds its eggs, an important source of food in October. Other notable events, like the ripening of tubers and bulbs and the appearance of migratory birds and animals, were correlated with specific positions of Orion, the Pleiades and the Southern Cross at different seasons of the year. For the Pitjantjatjara tribe in the Western Desert, the appearance of the Pleiades in the dawn sky in autumn was the sign that the annual dingo-breeding season had begun. Fertility ceremonies were performed for the dingoes, or native dogs, and some weeks later the tribe raided the lairs, culling and feasting on the young pups. The legends ensured that these nutritional associations were not forgotten and stressed their importance for the continuing survival of the race.

Equally important to the preservation of the tribe was its sense of identity, involving tribal beliefs orally transmitted across generations. These myths outlined the role of the Ancestors of the Dreaming in the scheme of the universe and the behavior appropriate to their descendants. Explanations of natural events which emphasized pattern, order, and laws, rather than unpredictable effects, reinforced the sense of an organic relationship between natural phenomena and social behavior. Many of these legends involved the constellations, so that the night sky provided a periodic reminder of the moral lessons enshrined in the myths.

Like all explanatory systems, including Western science, these legends represented attempts to understand, predict, and hence to obtain some control over the natural world. However, unlike the essentially analytical, materialistic, and particularizing approach of Western science, the underlying premise of all the aboriginal myths was a belief in the close spiritual unity of human beings, not only with other species, but also with inanimate objects. Astronomy was an integral part of the Aborigines' total philosophy about the natural world, so the legends emphasized the parallels between the personified heavenly bodies and their earthly counterparts, humanizing and integrating natural phenomena with tribal institutions and customs.

The meaning which a tribe attributed to the celestial bodies was conceptual rather than perceptual. It could not be understood by personal experience or by the intellect, but only through initiation into tribal lore which stressed the intimate, causal association between physical events and the human dramas of good and evil. Lessons about compassion, brotherhood, and respect for the land as Mother, the prohibition of incest and adultery, and taboos on killing or eating totemic animals were nightly reinforced by being enacted in the sky world which thereby established the universal validity of the tribe's ethical laws.

The many and diverse aboriginal myths associated with the heavenly bodies include stories about the Sun, the Moon, the Milky Way, the Magellanic Clouds, Mars, Venus, and the several constellations which form distinctive patterns in the southern sky – notably the Southern Cross and its pointers, the Pleiades, Orion's Belt, Scorpio, Gemini, and Aldebaran. The following are a representative selection of these myths.

In most of the Aboriginal creation stories, the Sun is the life-giving spirit. Amongst the Murray River tribes the origin of the Sun is linked to the tossing of a giant emu egg into the sky where it struck a heap of dry wood and burst into flame, bringing light to the hitherto dark world. Thereupon, the Great Spirit *Baiame*, seeing how much the world was improved by sunlight, decided to rekindle the woodpile each day.

In contrast to the ancient Greeks, the Amerind Indians and the Quechua Indians of Peru, all of whom designated the Sun as male and the Moon as female, whereas the Australian Aborigines represented the Sun as female and the Moon as male. In most areas, the Sun is regarded as a woman who daily awakes in her camp in the east and lights a fire to kindle the bark torch she will carry across the sky, thus providing the first light of dawn. She decorates herself with powder made from crushed red ochre, coloring the clouds red in the process. At evening she renews her powder in the western sky before beginning her long passage underground back to her camp in the east. It was probably this underground journey which was instrumental in the classification of the Sun as female, for her torch is thought to bring warmth and fertility to the interior of the Earth, causing the plants to grow. However, in Arnhem Land, where the Sun sets in the sea, she is thought to become a great fish, swimming under the Earth to return in the east next morning while the Moon becomes a fish, passing beneath the earth during the day.

The Moon, being male, is generally accorded greater status, and in many areas powers of death and fertility are accorded to him. An eclipse of the Sun is interpreted as indicating that the Moon Man is uniting with the Sun Woman. Several legends have evolved to account for the Moon's cycles. In coastal areas the correlation between the phases of the Moon and the tides was noted. In Arnhem Land and Groote Eylandt, where high tides occur when the new or full Moon sets at sunset or sunrise, respectively, and low tides when the moon is in the zenith at sunrise or sunset, the local Aborigines believe that the high tides, running into the Moon as it sets into the sea, make it fat and round. (Although the new Moon may appear thin, they deduce from the faint outline of the full circle that it too is round and full of water.) Conversely, when the tides are low, the water pours from the full Moon into the sea below and the moon consequently becomes thin.

In most areas the Moon was regarded as more mysterious, and hence more dangerous, than the Sun. Because of the association of the lunar cycle with the menstrual cycle, the Moon was linked with fertility and young girls were warned against gazing at the Moon unless they wished to become pregnant.

The Milky Way was regarded by the Aborigines as a river in the Sky World, the large bright stars being fish and the smaller stars water-lily bulbs. Central Australian tribes believed that the Milky Way divided the sky people into two tribes and thus it served as a perpetual reminder that a similar equitable division of lands should be observed between neighboring tribes. Various legends regarding taboo marriages, adultery, and reminders to celebrate tribal heroes, many of them involving a moral lesson, have evolved in different areas to account for the formation of the Milky Way and the dark region, known to Europeans as the "Coal Sack."

A Queensland version of the origin of the Milky Way associates it with *Priepriggie*, an Orpheus-like hero, as famed for his songs and dances as for his hunting. When he disappeared, his people tried unsuccessfully to perform his dance until they heard singing in the sky. Then the stars, hitherto randomly dispersed, arranged themselves to the rhythm of *Priepriggie's* song. Thus the Milky Way serves as a reminder that the tribal hero should be celebrated with traditional songs and dancing.

Because of its diagrammatic shape, the Southern Cross features in association with various characteristic objects in different areas. Around Caledon Bay on the east coast of Arnhem Land, it is taken to represent a stingray being pursued by a shark – the Pointers. On Groote Eylandt, where fish is the staple diet, the four stars of the Cross represent two brothers, the *Wanamoumitja* (Alpha and Beta Crucis), and their respective camp fires (Delta and Gamma Crucis) where they cook a large black fish (the Coal Sack) which they have caught in the Milky Way. The Pointers are their two friends, the *Meirindilja*, who have just returned from hunting. Desert tribes, on the other hand, see in the kite shape of the Cross the footprint of the wedge-tailed eagle *Waluwara* while the pointers represent his throwing stick and the Coal Sack his nest.

Venus, the Morning Star, was an important sign to the Aborigines, who arose at early dawn to hunt. It, too, was personified and frequently associated with death. Arnhem Land legends identify the home of the morning star, *Barnumbir*, as Bralgu, the Island of the Dead. Afraid of drowning, *Barnumbir* could be persuaded to light her friends across the sea at night only if she were held on a long string by two old women, who at dawn would pull her back to Bralgu and keep her during the day in a basket. Because of this connection, the morning star ceremony is important in the local rituals for the dead since a dead person's spirit is believed to be conducted by the star to *Bralgu.*

One of the most widespread Aboriginal myth cycles concerns the constellations of Orion and the Pleiades and these bear a striking similarity to the Greek story of the seven daughters of Atlas who, when pursued by Orion, flew into the sky as doves to form the constellation of the Pleiades. All identify them with a group of seven young women and nearly all portray them as fleeing from the amorous hunter Orion who, in some versions, is castrated as a punishment and warning to other potential wrongdoers. The whole cluster of Pleiades stories therefore forms part of a much larger group of myths of sexual conquest and submission.

Amongst the Pitjantjatjara tribe, the practical connection between the dingo-breeding season and the appearance of the Pleiades in the dawn sky in autumn is preserved in a local legend. The *Kungkarungkara* or ancestral women kept dingoes to protect them from a man *Njiru* (Orion), but he succeeded in raping one of the girls, the obscure Pleiad, who died. Even though the women assumed their totemic form of birds and flew into the sky to escape from him, he defies their dingoes and follows the women across the sky, armed with a spear (the stars of Orion's Belt) which has ritual phallic significance. Like the Greek Orion, *Njiru* was also a hunter, and pairs of smaller stars which arise near the constellation of Orion are said to represent his footsteps as he pursues the *Kungkarungkara.*

At Yirrkalla on the coast of Arnhem Land, the constellation of Orion is regarded as a group of fisherman arriving from the east in a canoe with a turtle they have caught, while the Pleiades represent their wives in another canoe with two large fish. As they approached the shore a heavy storm capsized the canoes, drowning the people. All the representative stars are visible in the sky during the wet season – a warning against the dangers of fishing when storms are imminent. In north-eastern Arnhem Land the story carries the added moral that the fishermen drowned as a punishment for catching catfish, forbidden to this tribe by totemic law.

Although relatively insignificant to the naked eye, the Large and Small Magellanic Clouds feature in many aboriginal legends as the camps of sky people. On Groote Eylandt they are believed to be the camps of an old couple, the *Jukara*, grown too feeble to catch their own food. Other star people catch fish and lily bulbs for them in the Milky Way and bring them to the *Jukara* to cook on their fires. The space between the Clouds is their cooking fire, while the bright star Achernar (Alpha Eridani, magnitude 0.49) represents their meal. This story suggests a celestial model of compassion for the aged. At Yirrkalla the Magellanic Clouds are said to be the homes of two sisters. During the middle of the dry season the elder sister (Large Cloud) leaves her younger sister (Small Cloud), but during the wet season she returns so that they can collect yams together. This story reflects the observed fact that at this latitude (12° S) only the Small Cloud is visible during most of the dry season (April to September), whereas both Magellanic Clouds can be seen during the wet season.

Meteors have been variously interpreted by different aboriginal tribes. In north-eastern Arnhem Land, because of their speed and unpredictability, they are believed to be spirit canoes carrying the souls of the dead to their spirit home in the sky. To the Tiwi tribe of Bathurst and Melville Islands, each is the single eye of the one-eyed spirit men, the *Papinjuwari*, who steal bodies and suck the blood of their victims, and their evil eyes are seen blazing as they streak across the sky looking for their prey. In other legends, meteors are associated with fire and linked to the waratah plant, *Telopea speciosissima*, a member of the Protea family, which is resistant to fire and whose brilliant red flowers seemed to the Aborigines like sparks from a fire. This was why, in the early years of white settlement, some Aborigines brought waratahs to the European blacksmiths: they identified the sparks from the anvil with the sparks from meteors and hence with the waratahs.

From this selection of star legends, it will be apparent that, with the possible exception of meteors (and even they can be regarded as recurrent events), the Aborigines' concern was not with extraordinary occurrences, but with the regular patterns of natural phenomena. The star legends served the purpose of integrating a potentially alien universe into the moral and social order of the tribe – by "humanizing" species and natural objects and ascribing to them behavior patterns and motivations which accorded with those of the tribal unit.

Such a philosophy serves a number of important social functions. In the first place it engenders a level of confidence about Man's place in the universe, not as a superior being but as an equal partner; in this it fulfils a role comparable to that of technology which also offers a level of some control over the environment. Secondly, this philosophy cultivates respect for the inanimate world as well as the animate since, through the indwelling power of the Ancesotrs, all creatures and things partake of the same spiritual identify as Man himself. Thirdly, the legends provide a justification for the customs, rites, and morality of the tribe, since these are reflected and enacted in the Sky-world.

The aboriginal myths are not fatalistic as astrology purports to be. Although they link certain natural events with a seasonal configuration of the sky, they make no deterministic predictions about individual lives; the moral values enshrined in the legends are held to be true for the *whole* tribe.

The most radical difference between the vitalistic beliefs which underlie these myths and the materialistic philosophy of western science concerns the relationship of the observer to the observed. In Newtonian science, the observer is assumed to be independent of, and distinct from, the object observed, which, in turn, is regarded as uninfluenced by the observer. Hence, the relationship between physical objects can be validly expressed in mathematical terms which remain true irrespective of the observer. The Aborigines, on the other hand, did not conceive of themselves as observers separated from an objectified Nature, but rather as an integral part of that Nature. The meaning of the celestial bodies, as of everything else in the environment, was neither self-evident nor independent of the observer; rather it depended on the degree of initiation into tribal lore which elucidated the links between tribal customs and natural phenomena. Without this knowledge the individual was disoriented and powerless in an alien universe.

See also: ►Environment and Nature of the Australian Aboriginal People

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Astronomy in China

Ho Peng Yoke

Chinese astronomy became a subject of long debate among historians and astronomers in the first half of the twentieth century. Some based their argument on the *Shujing* (Book of Documents) and concluded that Chinese star clerks had already made astronomical observations between 2000 and 3000 BCE. Richard Schlegel even asserted that they knew about the 28 lunar mansions as long ago as the year 1600 BCE. Others doubted the reliability of the records in the *Shujing* claiming that Chinese astronomy could not have originated earlier than 500 or 600 BCE. Some said that Chinese astronomy originated from India, others said from Arabia, and there were yet those who said that it was from Mesopotamia. Joseph Needham, for example, favors a Mesopotamian origin.

Recent archaeological studies carried out in China have thrown more light on early Chinese astronomy and enabled scholars to re-examine some of the old interpretations. Archaeologists have been hard at work during the last two decades to establish the Xia dynasty, which, according to tradition lasted from the twenty-first century BCE to the sixteenth century BCE, and which has until now been regarded as legendary. They have yet to recover written records of that period. Erlitou in Henan province, where bronze vessels dating back to the year 1700 BCE were recovered in 1971, is one of their important sites. Even the records in the *Shujing* have recently been re-examined by comparison with computed ancient astronomical phenomena.

In the oracle bone writings we can find records of eclipses, novae, and names of stars and some asterisms. The records indicate that the Yin people between the fourteenth and twelfth centuries BCE were already using a lunisolar calendar, where 1 year consisted of 12 moons or lunar months of either 29 or 30 days each, with an extra month known as the intercalary month added about every 3 years. From about the sixth century BCE until the use of the telescope for astronomical observations in Europe in the seventeenth century, Chinese star clerks kept the most consistent and continuous astronomical records on eclipses, comets, novae, sunspots, and aurora borealis in the whole world. Star catalogs were produced during the Warring States period (481–221 BCE) by Gan De, Shi Shen, and Wu Xian. Chinese astronomical records have found many applications in modern astronomy. One application is in the calculations of the period of Halley's comet. The Crab Nebula has been identified with the supernova observed in China in the year 1054. The first pulsar was discovered in 1967. It was found to be near a site where a "guest star" was recorded by the Chinese. A "guest star" in Chinese astronomy could refer to a supernova or nova, but it could also mean a comet or even a meteor, depending on the context. In this case it refers to a supernova or nova. As a result some astronomers made use of Chinese records in their attempts to discover other pulsars. Chinese records on sunspots have been used to determine sunspot cycles, and recently they were used in the study of the variation of the earth's period of rotation. There are many other applications for Chinese astronomical records, such as in a recent study of the Star of Bethlehem in the Bible.

There has been a prolonged dispute since the last century over the question of the origin of the 28 Chinese lunar mansions. These are 28 asterisms distributed along the ecliptic (the band of the zodiac through which the Sun apparently moves in its yearly course). The moon changes its position among the stars night after night, and appears successively in each of these asterisms, appearing from the earth as if it changes its lodging each night. Hence they were known as lunar mansions or lodges. Chinese astronomers also picked one of the stars in every lunar mansion as a reference point from which distances of other stars in its vicinity were measured. The stars used as reference points were called determinant stars. In ancient Hindu astronomy there were 27 *nakṣatras*, each of which had a principal star (*yogatara*). Nine of the *yogataras* are identical with the Chinese determinant stars. Some thought that the lunar mansions and the *nakṣatras* had a common origin, often with Sinologists and Indianists taking opposite sides. Before a conclusion was reached came a third contender, the *al-manāzil*, the moon-stations in Muslim astronomy. Then it was argued that Muslim astronomy was predated by Hindu astronomy. During the middle of the 20th century the most favored candidate was Mesopotamia, from which ancient Chinese astronomy and others were thought to be originated. This is the view favored by Joseph Needham. The argument against China's favor until then was that all the names of the 28 lunar mansions were not found earlier than the fourth century BCE. However, in the year 1978 the names of all the 28 lunar mansions were found inscribed on the lid of a lacquer casket of the early Warring States period, showing that the 28 lunar mansions were already there in China not later than the fifth century BCE. Chinese archaeological discoveries in the second half of this century and recent archaeological excavations carried out in India have also shown that both Chinese and Indian civilizations existed much earlier than they were thought. Whether the lunar mansions in Chinese astronomy were influenced by the Hindu *nakṣatras* or whether it was the other way round is an open question. Perhaps there was no influence between the two systems at all. The important thing in the study of history of science and civilization is to learn about mutual exchange of ideas among different cultures rather than to engage in futile disputes, claiming priorities and making scores in meaningless contests, in which there is no prize for the winner other than false pride.

The earliest existing Chinese documents on astronomy are two silk scrolls discovered in the Mawangdui tombs in Changsha, Hunan province in the year 1973. One of them, the *Wuxingzhan* (Astrology of the Five Planets) contains records of Jupiter, Saturn, and Venus, the accuracy of which suggested the use of the armillary sphere for measurement. These records were made between 246 and 177 BCE. The other, the *Xingxiangyunqitu* (Diagrams of Stellar Objects and Cloud-like Vapors of Various Shapes) illustrates different types of comets. Among the ancient astronomical instruments discovered by archaeologists are the bronze clepsydra from the tomb of Liu Sheng of the second century BCE and a bronze sundial of the Eastern Han period (25–220). The title of an early Chinese book on astronomy and mathematics, the *Zhoubi suanjing* (Mathematical Manual of Zhoubi), calls to mind either the Zhou dynasty or the circumference of a circle, and the vertical side of a vertical right-angled triangle. The book contains the so-called *Zhoubi* or *Gaitian* cosmological theory in which the heavens are imagined to cover a flat earth like a tilted umbrella, and shows paths for the sun at different seasons of the year. From the positions of the stars and planets mentioned in the text, Japanese scholars established a period between 575 and 450 BCE for the observations and inferred that the book was written within the same period. Christopher Cullen recently showed that the book could well be a work of the early first century.

During the second century Zhang Heng (78–139) constructed an armillary sphere as well as a seismograph for making astronomical observations and for detecting the direction of earthquakes. An armillary sphere consisted of a system of rings corresponding to the great circles of the celestial sphere and a sighting tube mounted in the center. With such an instrument Chinese astronomers could measure the positions of heavenly bodies. The mounting of the Chinese armillary sphere deserves special attention. As pointed out by Needham, it has always been equatorial unlike its counterpart in Europe which was ecliptical, but only changed to equatorial in modern telescopes. The new armillary sphere made by Zhang Heng resulted in more accurate observations and better star maps.

An important role of Chinese astronomy was calendrical calculation. The emperor regarded calendar making as one of his duties associated with the mandate that he received from Heaven. The Chinese calendar took into account the apparent cycle of the sun and the cycle of the moon, both of which, as we know, cannot be expressed in an exact number of days. The astronomer responsible for constructing a lunisolar calendar had to make accurate observations of the sun, the moon, and the planets, but however accurate his observations and his calculations, his calendar would sooner or later, in just a matter of decades, get out of step with observations. Hence throughout Chinese history no less than one hundred calendars had been constructed. Besides, sometimes there were also unofficial calendars adopted in certain regions in China. During the seventh century Indian calendar-making made its presence felt in China. We can read the names of a number of Indian astronomers and calendar experts who lived in Changan, the capital of Tang China.

In the early days of the Tang dynasty the calendar officially adopted was the *Lindeli* calendar constructed by the great early Tang astronomer, mathematician and diviner Li Chunfeng (602–670). By the early eighth century a new calendar became overdue. Eventually the old calendar was replaced by the *Dayanli* calendar constructed by the Tantric monk Yixing (683–727). Yixing's secular name was Zhang Sui. He is regarded as the most outstanding astronomer of his time for his recognition of the proper motion of the stars. In the year 721 the Tang emperor Xuanzong entrusted Yixing with the task of constructing a new calendar. To do this he constructed new astronomical instruments, including an armillary sphere moved round by wheels driven by water, and he also carried out a large scale research project to measure the length of the earth's meridian. He employed the method of difference, involving equations of the second degree, as well as the method of the remainder theorem in the *Suanzi suanjing* to calculate his new calendar.

From the late seventh century Indian Tantric monks had also come to reside in the Tang capital. Later Yixing made frequent contact with them and assisted them in the translations of some of their *sūtras* into Chinese. Yixing could have acquired from them some knowledge of astrology and mathematics, including the idea of a spherical earth and the sine table. There were then three clans of Indian calendar experts living in the Tang capital, namely the Siddhārtha clan, the Kumara clan and the Kaśyapa clan, of which the Siddhārtha clan was the most active and famous. At least two members of that clan had served as Directors of the Astronomical Bureau. The most distinguished member was Gautama Siddhārtha, who constructed an iron armillary sphere when he was director and translated the *Navagrāha* calendar into Chinese in the year 718. Most important of all, he compiled the *Da-Tang Kaiyuan zhanjing* (Prognostications Manual of the Kaiyuan Period of Tang Dynasty) between the years 718 and 726. The word *Navagrāha* means the "Nine Luminaries," namely the Sun, the Moon, Mercury, Venus, Mars, Jupiter, Saturn, and two imaginary planets *Rahu* and *Ketu.* Although this calendar was never adopted in China, it found its way from there to Korea, where it was used for a period of time.

During the Song dynasty (960–1279) astronomers made more accurate astronomical observations using new and larger armillary spheres. They constructed several such instruments, the most famous of which was that made by Su Song (1020–1101). It was an armillary sphere driven by a water-wheel using the principle of escapement. A full-scale study of Su Song's instrument is given in Joseph Needham's *Heavenly Clockwork.* Su Song's instrument was both an armillary sphere and a clock, but it was known only as an armillary sphere. Hence until it was pointed out by Needham, Price, and Wang Ling, nobody knew that the clock already existed in China when Matteo Ricci introduced the clock in the late sixteenth century.

Astronomy during the Mongol period (1271–1368) was closely connected with the name of Guo Shoujing (1231–1316), the last of the great traditional Chinese astronomers. The *Shoushili* calendar that he constructed was the most advanced and accurate calendar ever produced in traditional China. It was made possible by the precise instruments he built and the method of finite difference he used in his calculations. This was also the time when astronomers from the Arab world came to work in China. The Muslims were still active in the Astronomical Bureau when the Jesuits came toward the end of the sixteenth century. The Jesuits arrived at a time when Chinese astronomy was in a state of stagnation, when no one with the knowledge and skill of Guo Shoujing could be found. The Chinese learned pre-Copernican astronomy from them. Modern astronomy came to China only around the middle of the nineteenth century. It did not take long for Chinese astronomy to join the mainstream of modern astronomy. Just as Nakayama Shigeru said that the history of Japanese astronomy was the history of Chinese astronomy in Japan, Chinese astronomy has already become modern astronomy.

See also: ►Eclipses, ►Gan De, ►Lunar Mansions, ►Armillary Sphere, ►Li Chunfeng, ►Zhang Heng, ►Guo Shoujing, ►Calendars, ►Clocks and Watches

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Astronomy in Egypt

Gregg De Young

We have few written records dealing with the heavens, and those that we possess are derived from the Greek astronomical tradition and therefore are very late in Egyptian history. Thus, in order to assess the astronomical knowledge of ancient Egypt, we rely on such limited pieces of evidence as "diagonal calendars" that decorate some Middle Kingdom (ca. 2150–1780 BCE) coffins, orientation of tombs and pyramids relative to the cardinal compass points, and astronomical ceilings used in temple or tomb decorations.

Recent evidence from the area of Napta Playa indicates that observations of the heavens were already well developed during the predynastic period (prior to 3100 BCE) of Egyptian history. Here, an ordered array of stones grouped in a rough circle around a central stone are reminiscent of the artificial arrangement of megaliths at Stonehenge, although the Egyptian arrangement is much older.

One of the primary incentives for study of the heavens in ancient Egypt seems to have been to establish the cultic calendar on a firm basis. This cultic calendars growing out of less formal agricultural and ritualistic calendars, defined the beginning of the year with the heliacal rising of Sothis (modern Sirius). For administrative purposes, a civil calendar was superimposed upon the older luni-stellar cultic calendar. The determination of the year was not defined on astronomical evidence, however, but on counting off 365 days from the beginning of the year. Because the civil year contained exactly 365 days, it was typically out of step with the natural or solar year. The two coincided only every 1,460 astronomical years (the so-called Sothic cycle).

The civil year was divided into 36 "decans" of 10 days each, to which five epagomenal days were added. These "decans," represented in the "diagonal calendars", were associated with nightly timekeeping in temples for religious observance. Since it was essential to predict the coming of the dawn for temple rituals, each hour of the night was associated with one or more bright stars whose heliacal rising would signal the end of night. Since the sun moves slightly slower than the stars in its apparent circling of the earth, any chosen star will rise farther and farther in advance of the sun, so that it is an effective indicator of the dawn only for about 10 days, after which another decan star or stars will herald the coming sunrise.

The determination of cultic celebrations, however, continued to be based largely on lunar phenomena. In order to correlate the two calendars, the Egyptians used the observation that there are very nearly 309 lunar cycles in 25 civil years. In general, any two successive lunar months had 59 solar days, but every four years the last two months were given 60 days, a correction reminiscent of our leap year. This correlation allowed the priests to predict with fairly consistent accuracy where lunar festivals should fall within the civil calendar, obviating the necessity to observe the heavens in order to determine the time for a particular festival.

It has often been noted that pyramids, and especially the pyramids of the Giza plateau, as well as numerous tombs, seem to be aligned in accord with the cardinal compass directions. The precision of such alignments points to an astronomical determination of the cardinal directions, although we do not know precisely how this was done. The older hypothesis was that a level artificial horizon was constructed, against which the rising and setting points of a given star would be marked. Bisection of the angle between these two points, as measured from the center of the artificial horizon, determines true north. This technique, although possible, appears cumbersome. A relatively simpler method would have been to erect a gnomon perpendicular to the earth and construct around it a circle of arbitrary radius. Mark the two points at which the shadow of the gnomon touches this circle. The bisection of the angle formed between these two observations and the gnomon determines true north. We have, however, no surviving evidence to reveal which of these two procedures the ancient Egyptians used. (It is also fair to say that many temples and tombs are not so precisely oriented – many merely face the Nile, which flows roughly from south to north, without regard for local geographical variations.)

The scanty surviving evidence suggests that the Egyptian observer of the heavens used only the simplest of observational tools, and even these may not have been used extensively prior to the New Kingdom period (ca. 1550–1085 BCE). Nocturnal observations typically involved a *merkhet* (a palm rib notched at its wider end, used in conjunction with a plumb line) to determine the zenith transit of a celestial object. Daytime observations generally involved determination of solar altitude using length of shadows. These measurements were made using a horizontal graduated bar, with a small block perpendicular at one end to cast a shadow on the horizontal bar. Herodotus reports that the Egyptians knew sundials, but the surviving evidence favoring that view is extremely scanty. The shadow clock, however, does suffer from the same problems as the sundial. Both are constructed to divide the day into equal parts, although the inclination of the earth's axis creates unequal lengths of days throughout the year, complicating any attempt to regulate time through astronomical observations.

When astronomical observations were not possible, the Egyptians sometimes used a kind of water clock similar to a Greek clepsydra to determine hours. Here water is allowed to escape from a container of known volume through a small orifice at the base. The interior is graduated to show the lapse of time. The ancient Egyptians apparently did not appreciate that the rate of outflow is not constant. Here, too, we find that a considerable degree of inaccuracy or indeterminacy seems to have been routinely accepted.

Astronomical ceilings are among the most striking pieces of evidence concerning the ancient Egyptian's knowledge of the heavens. Central to these documents are a group of figures whose composition and orientation change very little with time. These are usually considered to represent the circumpolar constellations, although all attempts to match these figures with visible star groupings, apart from the foreleg (Big Dipper), have so far been unsuccessful. In addition to these groupings, there are often iconographic and inscriptional references to the naked-eye planets and to individual bright stars (most notably Sothis/Sirius). All of this indicates that the ancient Egyptians were careful observers of the night sky, although probably not overly concerned with reducing these observations to mathematical models of the kind found in Greece.

We know very little about practitioners of astronomy. Only in very rare instances do the funerary titles indicate someone who may have observed or studied the heavens for some specific purpose beyond personal curiosity. The evidence indicates, however, that there was a continuing effort to observe and describe celestial phenomena.

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Astronomy in Hawai'i

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There were two important tasks that drew on ancient Hawaiians' understanding of space and time. One was constructing a ritual calendar for determining the length of the day, week, month, and year; the other was navigating on the seas between island destinations.

The first, calendrics, was the responsibility of the priests, among whom were stargazers called *kilo hoku*, from *kilo* (to observe or to watch), and *hoku* (star). The same stargazers, however, observed more than stars. They knew the sun's motions and those of the moon and the planets, but the stars were the most challenging.

Let us look at this from the standpoint of the student who starts out in "class," which was a place set aside for men and boys to worship the gods. In a place where men only spoke with one another in the men's eating house, the *hale mua*, the "front" (*mua*) house in the compound of the household (*kulana kauhale*), a young boy began his training in these subjects. Since they were part of required religious training, he found himself within rock-walled enclosures, or temple (*heiau*) grounds set aside for men's worship, the *tabu pule* scheduled through seven nights, *na la kapu kauila*, totalling 56 nights in an eight-month period. The 240-day tabu period was followed by 120 days of the *makahiki* season during which taxes (*auhau*) were collected.

No one knows how astronomical subjects were taught, although some information has survived through stories and chants from the migration period of discovery and exploration, with wayfinding practice associated mainly with places visited in ancestral lands to the south. The sun's motion between the north and south and across the equator may have been the first fundamental horizon system to be learned, combined with the observations of stars nearest the rising and setting points of the sun in the morning and evening.

The sun's rising (*hiki*) gives the cardinal direction east its name: *hikina*. When above the horizon, it is *kau*, to be placed or to be hung, but it also means to set, as of the sun afloat westward, *kau lana ka la*. When the sun sets, it "enters" (*komo*) into the world below, so that cardinal direction west is called *komohana*, the "entering" place of the setting sun. When the sun has stopped on its northern journey, that point is called the sun "afloat," *kau lana ka la*. Its daily motion as it arches upward from its eastern azimuth or "pit" (*lua*) to local zenith (*nu'u*) and after noon "declines" ('*aui*) is called *ka'a, ka'a ka la ma lalo*, the sun moves down. When it crossed the equator, the sun was said to "trample" (*ke'ehi*) the "diaphragm" (*houpo*) of the god Kane (*ke'ehi i ka houpo o Kane*), the sun being the "eyeball" of Kane (*Kane 'onohi o ka la*). This is the basic compass, adding north for the right ('*akau*) and south for the left (*hema*) sides of the body.

The days were counted as nights of the moon, and there were two revolutions tracked, one synodic, and the other sidereal. Each "night" was clocked into quarters. The clock began at midnight, called *Kau*, or *Aumoe*, the latter meaning "time of sleep." Kau situates the clock on meridian, as at midnight and so also at noon, so the midday was also called Kau. When the sun was in the zenith (*nu'u*, *lolo*) it was called *kau ka la i ka lolo*, the "sun was over the brain (*lolo*)." This position of the sun, not only on meridian but in the zenith as well, took place twice in the year – once when the sun was going north, between May and June, and again when the sun was going south, between June and July. People today may call this "Lahaina noon," but generally the zenith sun appears at the southernmost part of the island of Hawai'i, about 19° north about May 15th (although the date is variable). All other "noons" when the sun is on meridian are called *awakea* after Sky Father, Wakea, whose name is synonymous with noon and the center of the celestial equator, called *Ka Piko o Wakea*, the "Navel of Wakea" (Sky Father). Piko means "center of the body," which has three such piko: one at the top of the skull in the soft spot, the fontanel; one at the navel, and one at the midpoint of the genital area in line with the piko in the middle of the skull. When one lies down, then the piko at the center of the horizontal body, called the '*opu*, is in contact with navel center of Mother Earth, *Ka Piko o ka Honua*. "The Navel of the Earth," or terrestrial equator, which extended beyond earth into the sky is *Ke Ala i Ka Piko o Wakea* (Path to the Navel of the Sky); *Ka Piko o Wakea* is the celestial equator.

The clock having thus two *Kau*, midnight and midday, is an indigenous concept of the "mean day," by which day and night are divided into equal parts. There were no hours, except the quartering for the night, commencing about sunset (i.e., 6:00 p.m.), called a "corner" (*kihi*), and the next "corner" at sunrise, *Kihi puka*; puka means "to emerge," as a celestial body, whether sun, moon, stars, or planets. Between the kihi corners were the *pili* quarters, meaning "close to," as in *pili 'aumoe*, about 9:00 o'clock at night, and *pili puka*, about 3:00 a.m., meaning "close to sunrise." From these data it is appears that the shape of the Hawaiian clock between the two Kihi is angular rather than circular, perhaps a rectangular shape. The day clock is spread out on both sides of noon (Kau, Awakea) by morning (*kakahiaka*), afternoon ('*auinala*, from '*aui*, "to decline," as of the sun), and evening (*ahiahi*). Day and night are *ao* (daylight) and *po* (night).

The moon was regarded as feminine, as passive light or a reflection of the goddess Hina, perceived as ruling the tides, as well as growing sea life on and around the living reef. Each night of the moon had a separate name through one synodic revolution of the moon, or that passage from the first crescent perceived in the west until it returned to that point again in 29.5–30 nights.

The new moon, or dark phase, was *Muku* (cut off or severed). Hina, the moon goddess, was thought to have gone into and through the Milky Way (*Ka Wai Ola a Kane*, "Living Waters of Kane"), in which her dying soul (*Mauli*) revived in the life-giving semen of the creator god. Her spirit was the last crescent waning moon (*Mauli*). On the night of Muku, Hina's spirit was in the Milky Way. After Hina comes through the *Wai Ola a Kane*, the first braid of her gray hair is seen at Hilo after sunset, low on the horizon, alive again. The waxing (*ho'onui*) moon begins at Hilo, moving south until first quarter at 'Ole, thus:

Muku	0	"cut-off"	New moon, dark phase
Hilo	1	"braid"	Moon in the west
Hoaka	2	"tusk" (moon shad ow, boar tusk)	
Ku-kahi	3	Ku-1 "cusp" (moon going south)	
Ku-lua	4	Ku-2	
Ku-kolu	5	Ku-3	
Ku-pau	6	Ku-end	
'Ole-ku-kahi	7	'Ole-1 "eye-tooth" (moon in the south)	
'Ole-ku-lua	8	'Ole-2	No planting nights
'Ole-ku-kolu	9	'Ole-3	Moon southeast
'Ole-pau	10	'Ole-end = one *anahulu* decan week of 10 days	

These ten "nights," or 10 days, were the first *anahulu* decan week of the month and year. In this circuit of 10 days the lighted part of the moon's crescent increased as the moon continued southward. This was followed by two more anahulu decan weeks of rounding (*poepoe*) of the moon when the lit portion lost its "cusps" (*Ole*, milk teeth) until the fully lit circle, after which it began to wane or "shrink" ('*emi*) back to the dark phase of new moon (Muku).

Huna	11	"hidden" as cusps of the moon
Mohalu	12	Shaula, in Scorpius
Hua	13	Jupiter = one-half sidereal lunation
Akua	14	God (moon in the east)
Hoku	15	Star (full moon)
Mahealani	16	16th moon (full moon)
Kulu	17	"drop" (waning moon)
La'aukukahi	18	"plant" 1 (moon going north)
La'aukulua	19	"plant" 2
La'aupau	20	"plant end" = two anahulu decan weeks
'Ole-ku-kahi	21	'Ole-1 (quarter moon, north)
'Ole-ku-lua	22	'Ole-2
'Ole-pau	23	'Ole-end
Kaloa-ku-kahi	24	Ka(na)loa 1"god of the sea" (fishing)
Kaloa-ku-lua	25	Ka(na)loa 2
Kaloa-pau	26	Ka(na)loa-end
Kane	27	Milky Way = one sidereal lunation
Lono	28	Lono (moon west of north)
Mauli	29	"spirit"
Muku	30	"cut-off" = three anahulu decan weeks =one synodic lunation

The ritual period of tabu days during eight months of the year was coordinated between synodic and sidereal lunations, zenith stars, and azimuths of sun and stars in the ecliptic. [The following is excerpted (and readjusted) from Johnson 2000.]

> The first ritual tabu period of the month, called a pule period, was imposed on the night of Hilo and raised on the morning of Kulua…
> This period of the Ku pule tabu amounted to 2 and 1/2 days, between Hilo, Hoaka, Kukahi, Kulua…
> During the poepoe rounding decan of the waxing moon, the tabu pule period was called the tabu of Hua, imposed on the night of Mohalu (12th night) and raised on the morning of Akua (14th night), i.e., from Mohalu, to Hua, and Akua. This added 1 and 1/2 more days to the 2 and 1/2 day Ku tabu before first-quarter moon…
> A tabu pule period was assigned to the god Ka(na) loa. Imposed for 1 and 1/2 days, it began on the night of 'Olepau and ended on the morning of Ka (na)loa-ku-lua, i.e., from 'Olepau to Kaloakukahi and Kaloakulua…
>
> After Kaloa-pau came the 27th night of Kane when began the tabu pule for this god on 1 and 1/2 days, from the night of Kane to the morning of Mauli, i.e., Kane, to Lono, and Mauli. While including the 28th night of god Lono, no tabu pule was set aside for the god Lono during the month.

(1) Tabu pule of Ku	2 1/2 nights	Hilo, Hoaka, Kukahi, Kulua
(2) Tabu pule of Hua	1 1/2 nights	Mohalu, Hua, Akua
(3) Tabu pule of Kanaloa	1 1/2 nights	Olepau, Kaloakukahi, and Kaloakulua
(4) Tabu pule of Kane	1 1/2 nights	Kane, Lono, Mauli

The tabu period was in force for 240 days and relaxed for 120 days, beginning in the month of October, or the last month of the summer (Kau) season. This anticipated the shift of prevailing winds from the southwest (Kona) and the beginning of the agricultural year, *makahiki*, in November when the Pleiades star cluster (*Makali'i*) was expected to rise above the eastern horizon in the evening, opposite the sun and after the new moon in November.

David Malo, native Hawaiian scholar at Lahainaluna Seminary in the mid-nineteenth century, said:

> The makahiki period began in Ikuwa, the last month of the period called Kau, and the month corresponding to October, and continued through the first three months of the period Hooilo, to wit: Welehu, Makalii and Kaelo, which corresponded with November, December, and January…
>
> There were eight months of the year in which both chiefs and commoners were wont to observe the ordinary religious ceremonies, three of them being the Hooilo months of Kaulua, Nana, and Welo, corresponding to February, March, and April; and five, the Kau months of Ikiiki, Kaaona, Hinaiaeleele, Hilinaehu, and Hilinama, which corresponded to May, June, July, August and September" (Malo 1951: 141).

The moon calendar was a coordination of synodic revolutions of the moon between Hilo and Muku of 29.5 to 30 days/nights of the month with sidereal lunations of 27.3 days/nights based on the transit of the meridian by a star, probably during quarter moon ('Ole nights) until the next transit.

What is the significance of the sidereal/synodic count in lunations of the moon's revolution around the earth and sun in one year? (1) The principle of the sidereal count is that, with respect to a star on the meridian, the moon's period of revolution around the earth is 27.3 days (Kane is the 27th night of the lunation). (2) The principle of the synodic count says that from its starting point at new moon, until it returns to that point, the moon revolves around the earth once every 29.5 days. Thus, (3) For every sidereal revolution of the moon around the earth in 27.3 days, the earth moves 1/13th of its orbit around the sun (with respect to a star on the meridian).

What was then the mode of intercalation to coordinate the sidereal with synodic lunations? We may only infer how that would have been done.

1. If we erase the 1/3rd fraction (Kane = 27 nights)
2. Then: 27 days × 13 months = 351 days = 1 sidereal year
3. We intercalate the fortnight (14 days) = 365 days = 1 tropic year
4. If we include the 1/3rd fraction, then: 13 sidereal months = 27.3 × 13 = 351.39 days
5. Intercalate 13.86 days = 365.25 days

This segment in *Kumulipo Mind* explored the relationship between the indigenous system and that borrowed from nineteenth century European calendrics after contact:

> This formula provided an iconography of time in the sacred structure of temples and ritual schedule to a numerology, such as 16 sidereal lunations is equivalent to 32 fortnights (13.5 days × 16) and 432 days, the significance of which has been explored in the discussion of the decan system and tropic (Johnson 2000: 111–112).
>
> Perhaps by pure chance the formula appears again in the Babylonian use of base 60 in the division of time connected to the earth's rotation on its axis such that 15 degrees equal one hour circle of the earth's rotation, thus:

1. 1 minute = 60 seconds
2. 60 minutes = 1 hour
3. 1 hour = 3,660 seconds
4. 24 hours = 1 day
5. 1 day = 1,440 minutes
6. 1 day = 86,400 seconds
7. 12 hours = 43,200 seconds
8. 6 hours = 21,600 seconds
9. 3 hours = 10,800 seconds
10. 11/2 hours = 5,400 seconds
11. 3/4 hour = 2,700 seconds
12. 3/8 hour = 1,350 seconds

By this may be comprehended that the basic determination is made that the "turning" (kahuli) of the earth on its axis, or because of its rotation, creates the meridian, called *kaupoku o ka hale*, the 'ridgepole of the house' (meaning the house of God, the heiau), cutting the night/day into two halves by which celestial bodies ascend to the zenith (nu'u) and transit by descent to the horizon.

The motion, however, is the earth rotating on its axis, which could not be seen except as a change.

> 'O ke au i kahuli, wela ka honua
> 'O ke au i kahuli, lole ka lani…
> In the time of turning over and around,
> The earth became hot; the sky changed"
> [Wa Akahi, Kumulipo].
>
> The passage of time is then measured by equalizing time on either side of the meridian, as between noon and midnight, or midnight to midnight, or noon to noon. The clock is geared to time elapsing between meridians, rather than between sunset and sunrise, or vice versa. The Hawaiians, like the Babylonians, had discovered the "mean day". By it they set their clock to keep track of the length of one day as from one midnight to the next.

The apparent movement of the sun was observed along the horizon between November and February as a slow period (actually, of the earth's orbit around the sun) and the fast sun between March and October. Perhaps the ancients had determined when the sun appeared to have crossed the celestial equator sometime in April and again in October, or the minor axis of the ecliptic, the major axis between January and July constituting the anomalistic, rather than the tropic year (i.e., the orbit of the earth around the sun).

This was essentially the story of demigod Maui lassoing the sun to make it go more slowly during the winter months by tying down all 16 legs of the sun to a *wiliwili* tree on the western slopes of Haleakala in east Maui. The sun's motion north and south between the solstices was perceived as the motion of a spider (*ke ala a ke ku'uku'u*) as it laid down a web of the celestial grid through which the stars are tracked in their fixed courses from east to west in the night sky.

Finally, as in classic cosmologies of the Mediterranean and Eurasian systems, the sky becomes a pictorialized storyboard conveying by imagery and metaphor the positions and movements of constellations as characters from the ancestral heroic traditions of the past, so that the sky is not filled with nameless lights. The following is part of a continuing quotation excerpted from *Kumulipo Mind*:

> The 'way of the spider' is known in Hawaii as the ecliptic, Ke-ala-a-ke-ku'uku'u 'pathway of the spider' (ku'uku'u, 'to let down, as a net') who is called Tukutuku-raho-nui (spider-of-large-scrotum) 'Great Spider', Tahitian (and Tuamotuan) tutelary deity of net-weaving in the Tahaki cycle. The pathway of this spider was shown on the navigation gourd (ipu makani) diagrammed by Kaneakaho'owaha, counselor to Kamehameha I, in old Hawaii. It had several markings: the celestial equator, Ka Piko o Wakea 'The Navel of Wakea (Sky Father)'; the ecliptic, Ke ala a ke Ku'uku'u 'The Path of the Spider', which was divided into four parts:

1. The limit of the sun's path in the north on the 15th or 16th day of the month Kaulua (June, for Gemini), the summer solstice, Ke Ala Polo-hiwa a Kane "The Black Shining road of Kane"
2. The limit of the sun's path in the south on the 15th or 16th day of the month Hilinama (December, unidentified), Ke Ala Polohiwa a Kanaloa "The Black Shining Road of Kanaloa"
3. The eastern quarter, Ke Ala'ula a Kane 'The Dawning of or the 'Bright (Red) Road of Kane'
4. The western quarter, Ke Ala Ma'awe'ula a Kanaloa 'The Red-Track (as of a spider's thread, from *awe*, strand, thread; '*awe*, tentacle) of Kanaloa'

> A line was drawn in by burning in (pyrogravure) between the North Star (Polaris) and the Southern Cross, indicating the meridian. From another tradition of the navigation gourd, according to Theodore Kelsey, the night sky was graphed, in the form of a net (koko) woven over the calabash of mesh squares, a grid numbering twenty-four to thirty-six spaces (maka), as of a net ('upena), called na maka o 'Alihi 'the eyes of 'Alihi. Below the rim of the gourd, securing the mesh to the rim, was a red cord of 'olona twine called the 'Alihi, corresponding to the name of Tahaki's loyal cousin and helper, Karihi, who assisted Tahaki in reaching the sky world (Kelsey, in Johnson and Mahelona 1975: 150–152).
>
> The Hawaiian navigation gourd net which bears the name of Karihi as the supporting red cord, 'alihi, and the 'eyes of Karihi', na maka o 'Alihi, is a parallel to the net of Tahaki fashioned by Tukutuku-raho-nui 'Great Spider' (Tahiti) whose path was outlined between the solstices and equinoxes on the ecliptic.

Tahaki's birth, like that of Maui, was in a West Polynesian home, and the place where Hema (Sema) was 'caught by the 'A'aia' was in Kahiki-west, or Viti, meaning in the direction of Fiji. In the Ulu genealogy, Kaha'i appears in the tenth generation after Maui.

In Hawaiian myth the spider's web as the shape of the spider in the sky is a form of the supernatural hero, Kana, son of Haka-lani-leo and Hina, chief and chiefess of Hilo, island of Hawaii. Kana was the grandson of Uli, the goddess, and Ku. Uli was the sister of the sky god Wakea and Manu'a (god of the underworld). The name Manu'a belongs to Samoa.

Kana is born supernaturally as a rope which was thrown into a pig pen and forgotten. He is the 12th son. The spirit of the cast-away baby visits the grand-mother Uli, and she recovers the neglected rope, putting it into a calabash of water where it grows 40 fathoms in 40 days, or one fathom a day, but no more than 400 fathoms.

In the meantime Kana's older brother, Niheu, who is only half as tall (five feet) as his ten brothers, is the only person able to lift the ten-fathom one-yard-long great *ulua* fish. Niheu tells his father he is unable to rescue his mother.

Kana is sought to help Hina because of his superb stretching powers, so Kana is sent by Uli to help Niheu rescue Hina from Keoloewa of Moloka'i. Meanwhile Keoloewa orders the turtles to raise the fortress, Ha'upu, on Moloka'i, higher. Niheu tries to climb it but is distracted by the plover who plucks five hairs from his head, whereupon Niheu falls, breaking his leg. (All of Niheu's strength is in his hair, which is never cut). So Kana employs his bodies to reach Haupu fortress:

> …Kana was very angry, for he knew that now they would have a great deal of trouble in rescuing their mother again. Kana turned over in the mats and having thus broken the ropes, stood up. The king saw that this man was taller than his fortress. As Haupu was slowly raised higher and higher, Kana

> stretched his body, first his human body, then his rope body, next his *convolvulus* (morning glory) vine body, his banana (cordage) body, and last his spider web body." (Fornander 1969: II: 16–18).

In a Kaua'i variant the motif of Kana's changing the hill by stamping (on) it with his foot (*ke kapua'i a Kana; kapua'i*, measuring foot; (vs.) *wawae*, "foot," as of the body) is repeated. The name of the hills raised by the turtles, both on Moloka'i and Kaua'i, is Haupu:

> Kana was afraid that it would reach too high, so he stretched himself up until his body was no larger than a spider's web. When he was tall enough, he put his foot on top of the mountain and crushed it down" [Another trait of his demigod is that he possessed two large, staring eyes].

In the tale of Kana the spider's web is the equivalent of the cord kept in a calabash of water. The cord measures out from the calabash, forming a 40–400 fathom rope. This may be interpreted again as the bailing gourd (*Hina-ke-ka*) filled with water and kept on the canoe.

The god of the golden plover, *kolea*, was Lono-kolea-moku, symbolized as a red stone in the heiau foundations at Cape Kumukahi, Puna, Hawaii. The rock was the first in a row of five stones, four of which were called "The Wives of Kumukahi," spaced around the cape and used to mark positions of the sun at its northern (*Hanakaulua* [Gemini]) and southern (*Kanono*, unidentified) limits.

The name Kumukahi (First Foundation) given to the easternmost point of land in the Hawaiian group is associated with the migration of Mo'ikeha from Tahiti. His younger brother, Kumukahi, got off the canoe near the place bearing his name, while Mo'ikeha continued northward. Several others jumped ship between Hawaii and Kaua'i, and Mo'ikeha pressed onward with his companion, La'amaomao, who had the wind calabash (*Ipu makani a La'amaomao*). La'amaomao would call the winds into the *ipu* when they were too strong for the canoe or summoned them forth out of the *ipu* when the sea was dead calm. Yet, when Mo'ikeha sent Kila, his youngest son, to Tahiti to get another son (or nephew), La'amaikahiki, La'amaomao was not in the returning crew doing all of the navigation for Kila.

About four to five centuries later, in the sixteenth to twentieth generation after Mo'ikeha, his mother, La'amaomao-wahine, bequeathed the wind calabash of La'amaomao to Ku-a-Paka'a:

> When La'amaomao finished talking, she opened the cover of a large gourd (ipu nui) and drew out a certain small gourd (ipu hokeo 'u'uku) which had been woven tightly with 'ie (Freycinetia) cord with a cover (po'i) on top.
>
> Then she turned to her son: "I give this gourd to you, as its name was your grandmother's name and mine also, and within it are her bones. When she was alive, all of the winds of this archipelago were her servants, beneath a marvelous power which she received, and she gathered all of the winds into this gourd, and they are still in this gourd until now, and their names were committed to her memory, those from Hawaii to Ka'ula, and when there was no wind, she would remove the cover and call the wind, and the wind would then blow, and when the cover was replaced the wind would cease, and this gourd was famous as the 'Wind Calabash of La'amaomao'." (Nakuina n.d).

The account of the wind calabash of La'amaomao finds a parallel in the Rarotongan tradition of the wind god, Raka-maomao, whereas in Samoa La'amaomao was a war god. In the tradition of Rata, the wizard Nganahoa combats the demons of the sea in a floating calabash called a "red gourd" ('*ue kura*) from which he divines their approach and continues to warn the doubting Rata. Nganahoa, a wizard who flies kites, applies to Rata to go with him on his voyaging canoe to find Vahieroa. Rata considers him useless and leaves without him, but Nganahoa follows him on a large gourd floating on the sea:

> At the time that the canoe sailed away there were only eleven men on board. The canoe sailed on until the land was out of sight, when the crew descried a large gourd floating on the surface of the sea. The crew threw Ngana'oa and his gourd overboard, and left him to his fate (as they thought). …The canoe proceeded on its voyage, and had sailed on for some distance when the crew noticed another gourd floating on the ocean; they at once cried out, 'There is our 'ue-kura floating on the sea.' Rata heard them and called out, 'Pick it up.' They did so, and when they opened it they were again confronted by the glistening eyes of Nganahoa" (Nakuina 1910).

Nganahoa in this form is the bailing calabash, like Hina-ke-ka. In the Tuamotus, Nganahoa is a star represented in Rarotonga as a character prominent in the Rata story. Like Tahaki (Kaha'i), Rata (Laka), grandson of Tahaki, goes on a voyage to find his father, Vahieroa (Wahieloa).

In Hawaii, Nganahoa is the name of the phallic rock on Moloka'i, Ka Ule o Nanahoa (Penis of Nanahoa). This ule was Ul or Uun "Aldebaran" (Hyades, in Taurus) in Micronesian star names. Aldebaran was one of the "four royal stars" or "Guardians of the Sky" in Persian astronomy, 5,000 years ago, when it marked the vernal equinox (Allen 1963: 383–385).

A peculiar attribute of Nganahoa in the Rarotongan version is that when the bailing calabash was brought aboard the canoe, all that was seen inside were the staring eyes of the wizard. In the Ipu-makani-a-La'amaomao carried by Mo'ikeha on his journey, La'amaomao was, apparently, not a body on the canoe, but rather, the bones of an ancestor in the calabash by which Mo'ikeha called the winds to come out when the ocean was dead calm, calling them back when the winds were too strong.

> Aldebaran (Nganahoa, Ka Ule o Nanahoa, Ul, Uun] in Taurus has been an ancient ancestor of star-worshipping wind-watchers on deserts as well as oceans. That the gourd was encased in basketry in Hawaii is clear in the case of the wind calabash of La'amaomao, but the Unu o Lono shrine, as the Ipu o Lono god image in the hale mua men's eating house, was suspended from a net (koko), reminiscent of the net ('upena) that went across the sky in the Kaha'i story.

Often ignored but present in the tradition of the Ipu o Lono is a small note, "This image had suspended from its neck a gourd, ipu, which was perforated to receive a wooden bail" (Malo 1950: 88). This means that the larger gourd of Lono, the *unu* (temple), also carried the *ka* bailing cup, gourd symbol of the goddes Hina-ke-ka, canoe-bailer form of the moon (goddess) (Johnson 1989: 50).

> The Ipu-makani-a-La'amaomao wind calabash is, in part, derived from the Malay word for 'compass', *mata angin*, 'eye of the wind' (*angin*). The standard Polynesian wind compass had eight 'eyes' (*maka*) or as many as thirty-two wind directions ('Aitutaki, Cook Islands). Hina-ke-ka, the bailing gourd, was not the wind compass (Ipu-makani-a-La'amaomao). It was a reflecting mirror or an instrument used as a plumb bob or water level. The Nganahoa calabash carried by Rata (Laka) was thrown out into the sea ahead of the canoe.

If Rigi was the Milky Way in the Caroline Islands (Micronesia) whose worm body became the "Eyes of the Pleiades" (Mata-riki, Makali'i) and was the companion (*hoa*) of Rigi, Aldebaran? After the Pleiades sets, Aldebaran is right behind it all of the time. When the Pleiades rise, Aldebaran is right behind them again. It was called "The Follower" (Al Dabaran), i.e., of the Pleiades, originally given to the entire group of the Hyades (Allen 1963: 383–384). This composed the letter *A* as the *alpha* in the alphabet derived from the head of the bull consisting of Aldebaran as the eye in the face and the other stars above the head constituting the horns. This eye was the Ule o Nanahoa (Nganahoa) in the wind calabash of La'amaomao (Hawai'i) that had helped Rata sail his canoe in the lands between Samoa, Tonga, and probably, Rarotonga where the tradition is prominently remembered as it is in Hawai'i.

The sky was a place to picture the characters and creatures in the heroic Polynesian past. The major figure was the culture hero and demigod Maui-ki'iki'i-a-Kalana whose position in the stars favored the constellations of Hercules, Ophiucus beneath, and Sagittarius in the ecliptic to the south. Available to Maui in that hour circle and the adjoining one is the constellation of Scorpius, with which the hero pulled up the land of Hawai'i as a giant fish. Scorpius is pictured as the fishhook that Maui used (Ka makau nui o Maui), three stars lying from east to west above the bright star and mid-shank of the hook, Antares, first magnitude star in the fishhook constellation as it curves around Shaula (Mohalu) to Leshaa in the barb. From the city of Honolulu this "hook" rises over the crater of Diamond Head to the southeast and drags over the sky until it sets to the west. Maui in Hercules sets before the hook ascends, 180° away on the eastern horizon, or a composition of Maui's three brothers, Maui-mua, Maui-roto, and Maui-pae, who are the three stars in the Belt of Orion stretched over 10° on either side of the equator. They are pictured as sitting in a canoe as they are helping Maui to pull together the fish that Maui caught and which drifted into separate parts. They were told not to look back, and as one of the three brothers does look back, the fish comes apart again into separate islands. Otherwise they are three men in a boat in a canoe house straddling the equator. Beside the Belt of Orion in the place of his sword, the ancient Hawaiians evidently saw the same shape of a weapon, calling it Na Kao, the javelins, i.e., the Belt and Sword of Orion, or perhaps they mistook it for Na Ka o Makali'i, the bailers (i.e., bailing gourds) of Makali'i (in the Pleiades).

Another interesting facet of Scorpius is that it lies within the swirling, twisting motion of a stream or pond of water, the Milky Way, as it courses or spirals across the sky during its own moving about. It will be seen stretched across the sky as a diagonal, from northeast to southwest, and only certain stars and constellations lie in the stream, called the Wai Ola a Kane, or living waters of Kane, the creator-god. In the same stream lies a reptile or shark called 'Ai-kanaka, whose wife is the moon, Hina-hanai-a-ka-malama. Through the year the lizard or reptile will jackknife across the overhead skies as the swirling stream moves until it is lying from northwest to southeast. Then it lies in two separate streams across the north and across the south, and then arches around the entire visible horizon before it slips off the edge of the world and comes back again, spiraling across the sky from northeast to southwest.

This is the galaxy, and the center around which it spirals is the galactic equator, and by it the ancient priesthood also told time. The motion of breaking up of the spiral was called *Kaha'i, Ha'iha'i, Ha'imoha'i*, for another hero of the migrations, Kaha'i, who went to the skies on a rainbow to look for his missing father, Hema. Only certain stars and constellations are found in the *Wai Ola*, pictured also as a coconut tree, with branches opening to the north and the roots growing to the south. Sirius lies outside this swirl, seeming to be alone and thus called, Lono-meha, "Lone Lono." Another star that seems to shine alone and brightly to the north is Arcturus in Bootes, called Hokule'a, meaning "clear star" or "star of gladness," according to the Polynesian Voyaging Society which named the canoe after Arcturus.

Otherwise, the Milky Way was called the "spine," *Kuamo'o*, in which the following were always found: Castor and Pollux in Gemini, called the "Twins"; Mahana Kaulua, or Na Mahoe, the twin in front, Castor, Mahoe Mua, and the twin behind, Pollux; Mahoe Hope; the Hyades, Kaomaaiku or Kanukuokapuahi; the Magellanic Clouds, "butterflies," Pulelehuakea, Pulelehuaeli; stars in Lyra, Keoea, Keho'oea, and Scorpius.

In the opposite pole, Canopus was called the solitary "Lord of Space," Ali'i-o-Kona-i-ka-lewa. It occupies the pole at one time, the star Achernar at another, and then there is the Southern Cross, rising on its side in the east, then coming upright, before tilting to the west and going out of sight. Some Hawaiians see a triggerfish, *Humu*, as the *humuhumu-nukunuku-a-pua'a*, or pig-snout fish in which the pig demigod, Kamapua'a, made his journeys by sea assuming the form of a triggerfish. The snout of the fish is pointed downward and the fin upward. Others knew the Southern Cross as a "cross" Hoku Ke'a, or a batfish, one of the skates or rayfish with wings outspread, tail upward, guilty for stealing the moon and hiding her, mother of culture hero Maui-ki'iki'i-a-kalana. So Maui retrieved Hina from the clutches of the batfish by waiting for the demon fish to close all of its eight eyes in sleep before he cut all of them out of the head of the monster. Another *humu* star, meaning, to be sewn or patched together, *humu*, is Humu, or Altair in Aquila, west of Maui-ki'iki'i-a-kalana. The pole star to the north, Polaris, is called Hokupa'a, "Fixed Star," but then all stars fixed in their tracks were called *na hoku pa'a* as against "wandering stars" or planets, the *hoku ae'a*, "wandering" or "vagabond" stars. The whole constellation of the Big Dipper was called "The Seven," Na Hiku.

Below the pole starting with Perseus is a line of stars that meets up with the asterism of the Pleiades in the head of the Bull, Taurus. These stars are called *a line*, i.e., Ka Lalani. Near the Pleiades, called "Little Eyes", Makali'i, are the Hyades, which are the opening of the fireplace, *Ka Nuku o Kapuahi*, recalling perhaps, as on the island of Mangaia in the Cook group, that a tribe of people suffered being cooked alive in an oven. Aldebaran in the eye of the Bull is called *Ka Oma Aiku*, meaning the adze of Aiku, one of the heroes of the migrations in the south, also known as Aukele-nui-Aiku, a navigator who found the home of Pele's sister in Ra'iatea and Borabora. The other "twins," Mahapili, are in Scorpius. The orbit of the stars was called the "circular road," *Ala Poai*. For the most part, so many star names retained in the nomenclature are unidentified, indicating the loss of much that the ancients had identified about the sky concerning the heroic past of their own wanderings, as they often called it, to go over the horizon ever receding.

See also: ►Stars in Arabic-Islamic Science

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Astronomy of the Hebrews

Y. Tzvi Langermann

The Hebrew astronomical tradition that shall be surveyed in this essay is that tradition recorded in the Hebrew alphabet dealing with the motions of the heavenly bodies and the structure of the heavens. These writings utilize principally the Hebrew language, but include texts in languages such as Aramaic and Arabic that can be written out in Hebrew script. Topics of specifically Jewish interest, such as calendar computations and doctrinal matters, occupy only a minor portion of this literature. For the most part, the Hebrew astronomical tradition differs little from contemporary writings belonging to the traditions with which Jews found themselves in immediate contact at any given age and place. To the extent that these other traditions may be classified as non-Western, the Hebrew tradition may be by and large considered such.

The earliest substantive materials are found in the *Talmud* and *Midrash*. Most of the discussions center upon the structure and physics of the heavens. Of particular interest are several notices of disagreement between Jewish and non-Jewish experts, for example, on the question of whether it is the star itself, or the spherical shell within which the star was thought to be embedded, which moves around the earth. In other words, we have clear evidence that even at this early date Jewish scholars identified themselves with particular conceptions of the heavens. *Pirqei di-Rebbe Eliezer, Baraitha di-Mazalot*, and *Baraitha di-Shmuel* are three post-Talmudic writings whose precise dating is problematic but which certainly precede the flowering of the sciences under the Abbasids. The latter two are the earliest texts which preserve any mathematical astronomy, e.g., a computational scheme for shadows. In addition, al-Khwārizmī's treatise on the Jewish calendar, which belongs to the Arabic tradition but is almost certainly based on Jewish sources, exhibits positional data for the epoch of the Temple. All of this indicates that a Hebrew tradition, drawing upon Indian, Hellenistic, and other sources, had developed by the eighth century.

Without doubt the years spanning the ninth through sixteenth centuries were the most fecund for the Hebrew tradition. During this period, which is more or less commensurate with what Western historians have long called the medieval age, interest in astronomy was especially stimulated in Arabic speaking lands from Spain to Iraq. Contemporary Jewish writings consist for the most part of exposés or translations of the fruits of Arab science. Dozens of works were written, surviving in hundreds of manuscripts; only a few can be surveyed here. Abraham bar Ḥiyya created a Hebrew astronomical vocabulary that endured side by side with that developed by the Tibbons, the famous family of translators of Arabic literature. Abraham ibn Ezra's astrological writings were immensely popular both in the Hebrew original and in Latin translation. Both Abrahams utilize more ancient sources that are no longer extant. Isaac Israeli's *Yesod ʿOlam* is a thorough analysis of all of the astronomical and historical questions connected with the Jewish calendar; his book, written in 1310 in a polished Hebrew style, may be considered the pinnacle of the Spanish Hebrew tradition. All the same, Hispano–Jewish authors continued to produce treatises in Hebrew and Judeo-Arabic through the end of the fifteenth century. For instance, the work of Abraham Zacuto, so important for the Portuguese explorers, appeared around the time of the expulsion of Jews from Spain.

Southern France, Italy, and Byzantium were the other major centers of astronomical activity during this period. Emmanuel ben Jacob, Jacob Anatoli, and Mordecai Comtino are, respectively, perhaps the most important representatives of the Hebrew tradition in those lands. In those areas in particular, Jews drew upon Latin, Romance, and other literatures, as well as Arabic materials.

The two outstanding philosophers of this period, Moses Maimonides and Levi Gersonides, participated strongly in the Hebrew astronomical tradition. Maimonides' wrote a small work on the calendar, and he included in his great law code, the *Mishneh Torah*, a detailed scheme for computing the first visibility of the lunar crescent. However, Maimonides' weightiest contribution is the very high value which he placed on the study of astronomy within the context of his religious philosophy, something which encouraged many Jews to acquaint themselves with, at the very least, non-technical resumés of astronomical knowledge.

Levi Gersonides was without doubt the most creative representative of the Hebrew tradition, indeed one of the greatest scientists of his epoch. He too developed his astronomical views within the framework of a finely tuned and very comprehensive religious philosophy. Levi was both an observer and a theoretician, and, most notable, one of the rare breed who attempted to fit his own original theory, which had to answer to certain philosophical constraints, to his own observations. Among his other major achievements, Levi invented the Jacob's staff, a simple but accurate instrument for measuring the angular distances between stars; studied the errors involved in instrumental measurements; and arrived at a much greater (and hence more realistic) value for the distances of the stars than those accepted by his contemporaries.

Jews living in Islamic lands, most especially the Yemen, continued to study the ancient and medieval texts well into the twentieth century. In those countries the Hebrew tradition was maintained chiefly through the copying of manuscripts, often transcriptions of Arabic texts into the Hebrew alphabet. In European countries the study of Latin texts in Hebrew translation seems to have accelerated in the fifteenth and sixteenth centuries. Some three Hebrew translations of Georg Peurbach's *Theorica* were executed, and several Hebrew commentaries were written, *inter alia* by Moses Isserles of Cracow and Moses Almosnino of Salonika, both of whom were leading rabbis of their times.

There is little in the Hebrew tradition that reflects the great advances associated with the European scientific revolution. Joseph Delmedigo, a widely traveled Cretan who studied under Galileo, published the only lengthy and detailed Hebrew exposition of the new science. Other publications, such as Tuviah Cohen's *Maaseh Tuvia* (Tuvia's Opus), present the new science in somewhat abbreviated form; and yet other writings, such as Solomon Maimon's exposé of Newton's work, remain in manuscript. The Hebrew tradition revived during the nineteenth century, particularly due to the efforts of the *maskilim*, advocates for widening the intellectual horizons of Judaism, who published Hebrew scientific texts in a number of fields. With the re-establishment in the State of Israel of a native Hebrew speaking population, and, no less importantly, institutions interested in teaching and writing about astronomy in the Hebrew language, the quantity and scope of the Hebrew tradition have dramatically increased.

See also: ►al-Khwārizmī, ►Abraham bar Ḥiyya, ►Abraham ibn Ezra, ►Levi ben Gerson, ►Abraham Zacu

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Astronomy in India

K. V. Sarma

Astronomy in India, as it was in other ancient civilizations, was interwoven with religion. While the different facets of nature, the shining of the sun, the waxing and waning of the moon, and the alternation of the seasons all excited curiosity and evoked wonder, religious practices conformed to astronomical timings following the seasons, equinoxes, solstices, new and full moons, specific times of the day and the like. In the Vedas, the earliest literature of the Hindus, mention of professions such as *Gaṇaka* (calculator) and *nakṣatra-darśa* (star-gazer), and the mention of a branch of knowledge called *nakṣatra-vidyā* (star science) are illustrative of the fascination that the celestial bodies exerted on the Vedic priests.

The Vedas and their vast ancillary literature are primarily works of a religious nature, and not textbooks on astronomy. Still, they inform about the astronomical knowledge, mainly empirical in nature and often mystic in expression, which Vedic Indians possessed and used in their religious life. One finds in the *Ṛgveda* intelligent speculations about the genesis of the universe from nonexistence, the configuration of the universe, the spherical self-supporting earth, and the year of 360 days divided into 12 equal parts of 30 days each with a periodical intercalary month. In the *Aitareya Brāhmaṇa*, we read of the moon's monthly elongation and the cause of day and night. Seasonal and yearly sacrificial sessions helped the priests to ascertain the days of the equinoxes and solstices. The shifting of the equinoxes made the Vedic priests correspondingly shift the year backward, in tune with the accumulated precession, though the rate thereof was not envisaged. The wish to commence sacrifices at the beginning of specific constellations necessitated the identification of the constellations as fitted on the zodiacal frame. They also noticed eclipses, and identified their causes empirically.

The computational components and work rules for times for Vedic rituals are to be found in the *Vedāṅga Jyotiṣa* (Vedic Astronomical Auxiliary), composed by Lagadha. On the basis of the astronomical configurations given in its epoch, the date of this text is ascertained to be in the twelfth century BCE. This work sets out such basic data as time measures, astronomical constants, tables, methodologies, and other matters related to the Vedic ritualistic calendar. It prescribes a 5-year lunisolar cycle (*yuga*) from an epoch when the sun and the moon were in conjunction on the zodiac at the beginning of the bright fortnight, at the commencement of the asterism Delphini (*Śraviṣṭhā*) of the (synodic month of) *Maghā*, and of the (solar month) *Tapas*, when the northward course of the sun began. The constants are contrived to be given in whole numbers for easy memorization. Accordingly, the *Vedāṅga Jyotiṣa* chose a unit of 1,830 civil days as its unit, which it divided into 5 years of 366 days each, the error of the additional 3/4 day in the year being rectified periodically. One thousand eight hundred and thirty days is equal to 62 synodic or lunar months of 29.5 days each, and 60 solar months. The two extra intercalary lunar months are dropped, one at the middle and the other at the end of the cycle, so that the two, the solar and lunar years, commenced together again, at the beginning of each cycle.

During the age that followed, a series of astronomical texts was written, mainly by 18 astronomers. Passages from some of these texts were quoted in later texts, and five of them were redacted by Varāhamihira (d. 587) in his *Pañcasiddhāntikā*. The texts of this age which are still available are the *Gargasaṃhitā*, *Parāśarasaṃhitā*, and the Jain texts *Sūryaprajñapti*, *Candraprajñapti*, and *Jambūdvīpa-prajñapti*. The astronomy contained in those is practically the same as that expounded in the *Vedāṅga Jyotiṣa* though with minor differences, including the shifting of the commencement of the year to earlier asterisms due to the precession of the equinoxes.

From about the beginning of the Christian era a number of texts were composed with the generic name *Siddhānta* (established tenet). The scope of these texts was wider, their outlook far-reaching, and their methodology rationalistic. Also, the science began to be studied for its own sake. The stellar zodiac was replaced with the 12-sign zodiac, and, besides the Sun and the Moon, the planets also began to be reckoned. Their rising and setting, motion in the zodiacal segments, direct and retrograde motion, times of first and last visibilities, the duration of their appearance and disappearance, and mutual occultation began to be computed. These and their synodic motion called *grahacāra* were elaborately recorded. Analyses of these recordings enabled the depiction of empirical formulae for computing their longitudes. While the use of the rule of three (*trai-rāśika*, direct proportion), continued fractions, and indeterminate equations helped computation, the use of trigonometry, both plane and spherical, and geometrical models enabled a realistic understanding of planetary motion, and developed rules, formulae, and tables. This resulted also in fairly accurate prediction of the eclipses and occultation of the celestial bodies. It is to be noted that in Indian astronomical parlance, the word *graha* signifies not only the planets Mars (*Kuja*), Mercury (*Budha*), Jupiter (*Guru*), Venus (*Śukra*), and Saturn (*Śani*), but also the Sun (*Ravi*, *Sūrya*), Moon (*Candra*), the ascending node (*Rāhu*), and the descending node (*Ketu*).

Yuga in Indian astronomy denotes a relatively large number of years during which a celestial body, starting from a specific point on its orbit, made a certain number of revolutions and returned to the same point at the end of the period. In the *siddhānta* texts the starting point is taken as the First point of Aries (*Meṣa-ādi*) (vernal equinox). Through extended observation over long periods, methods were formulated for ascertaining accurately the motion of the planets, as in the *Āryabhaṭīya*. Having obtained in this manner the sidereal periods of all the planets, their lowest common multiple was calculated backward to provide accommodation to the revolutions of the relevant celestial bodies. Thus the *Vedāṅga Jyotiṣa* used a 5-year *yuga* to accommodate only the sun and the moon. Later, the planets were included and the *Romakasiddhānta*, redacted by Varāhamihira, used a *yuga* of 2,850 lunisolar years, and the *Saurasiddhānta* used a *yuga* of 108,000 solar years. Āryabhaṭa (b. AD 476) formulated a *mahā-yuga* (grand cycle) of 4,320,000 years which was set to commence at the First point of Aries on Wednesday, at sunrise, at Laṅkā, which is a point on the terrestrial horizon of zero longitude, being the Greenwich meridian of Indian astronomy. He devised also a shorter *yuga*, called *Kali-yuga*, of 432,000 years, which commenced on Friday, February 18, 3102 BCE, where, however, the apogee and node were ahead by 90° and behind by 180°, respectively. Pursuing the same principle, other astronomers have devised *yugas* of different lengths, and still others have suggested zero corrections to the mean position of the planets at the beginning of the *yuga*.

Computing the longitude of a planet when the length of the *yuga* in terms of civil days, the *yuga* revolutions, and the time at which its longitude is required are given, reduces itself to the application of the rule of three, if the planetary orbits are perfect circles and the planetary motions uniform. Indian astronomers conceive their motion along elliptical orbits according to the epicyclic model or their own eccentric model. In the former, the planets are envisaged as moving along epicycles which move on the circumference of a circle, and in the latter, the planets are supposed to move along a circle whose center is not at the center of the earth, but on the circumference of a circle whose center is the center of the earth. Both models give the same result. Several sets of sine tables are also derived and several computational steps called *manda* and *śīghra* are enunciated to give the heliocentric positions in place of the geocentric.

When the true longitude of a planet at a particular point of time is to be found, the *ahargaṇa* (count of days) from the epoch up to the sunrise of the day in question is ascertained. To this is added the time elapsed from sunrise on the relevant day to the required point of time. Since the number of days in the *yuga* and the number of the relevant planetary revolutions (which are constants) are known, the revolutions up to the moment in question are calculated by the rule of three, and the completed revolutions discarded. The remainder would be the position of the mean planet at sunrise of the day in question at zero longitude (i.e., Laṅkā or Ujjain meridian). To get the correct longitude, four corrections are applied to the result obtained above. They are (1) *Deśāntara*, the difference in sunrise due to the difference in terrestrial longitude, (2) *Cara* (ascensional difference), due to the length of the day at the place, (3) *Bhujāntara*, the equation of time caused by the eccentricity of the earth's orbit, and (4) *Udayāntara*, the equation of time caused by the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course) with the celestial equator.

As a striking natural phenomenon, the eclipse had been taken note of and recorded in several early Indian texts. A solar eclipse was recorded in the *Ṛgveda*, where it describes how, when Svarbhānu (the dark planet *Rāhu* of later legends) hid the sun, sage Atri restored it, first as a black form, then as a silvery one, then as a reddish one, and finally in its original bright form. On account of the popular and religious significance associated with eclipses, their prediction assumed great importance in Indian astronomy. In the *Pañcasiddhāntikā*, details of the computation of the lunar eclipse were given in the *Vāsiṣṭha-Pauliśa* and *Saura Siddhāntas* with geometrical diagrammatic representation, and the solar eclipse in the *Pauliśa*, *Romaka*, and *Saura Siddhāntas*. The treatment in later *siddhāntas*, like those of Āryabhaṭa, Brahmagupta, Śrīpati and Bhāskara II, and also the *Sūryasiddhānta*, is accurate. A number of shorter texts also were written solely on the computation of eclipses, aiming at greater perfection.

The Vedas call the intrinsically dark moon *sūrya-raśmi* (sun's light), and thought that it was born anew every day in different configurations. Each of the 15 lunar days of the bright and the dark fortnights have high religious significance, and different Hindu rites and rituals are fixed on their basis.

From the early *siddhānta* age, computation of the moon's phases is referred to by the term *Candra-śṛṅga-unnati* (Elevation of the horns of the moon) and is computed elaborately. The first work to give this computation is the *Pauliśa Siddhānta*, which devotes an entire chapter to this subject. Most of the later *siddhāntas* also devote one chapter to the subject, adding corrections and evolving newer methods, and also giving graphical representations.

Still another topic which finds computational treatment in *siddhānta* texts is the conjunction of planets and stars. Two bodies are said to be in conjunction when their longitudes at any moment are equal. The conjunction of a planet with the sun is called *astamaya* (setting), with the moon is *samāgama* (meeting), and with another planet, it is *yuddha* (encounter). The conjunction of a planet with a star is similar, but with the difference that a star is considered a ray of light and has no *bimba* (orb) or motion. The computational methods followed are similar to those in the case of eclipses, with minor modifications. Full chapters are devoted in *siddhānta* texts to computing this phenomenon.

Although naked eye observations and the star-gazer (*nakṣatradarśa*) find frequent mention in Vedic literature, mechanical instruments are of a later origin. The earliest instruments used were the gnomon (*śaṅku*) for finding the cardinal directions, used in the *śulbasūtras*, and the clepsydra (*nāḍī-yantra*) for measuring time. The *Pañcasiddhāntikā* devotes one long chapter to "Graphical Methods and Astronomical Instruments." While Āryabhaṭa gives only the underlying principles in his *Āryabhaṭīya*, he has a long section of 31 verses on instruments in his *Āryabhaṭasiddhānta*. Almost all later *siddhāntas* have a full chapter on instruments, which include the armillary sphere, rotating wheels, and shadow, water, circle, semicircle, scissor, needle, cart, tube, umbrella, and plank instruments. Some of these are used for observation; others are for demonstration. After the advent of Muslim astronomy in India, the astrolabe became common and even Hinduized. A number of texts in Sanskrit also were written on the astrolabe, among which the *Yantrarāja* of Mahendra Sūri and *Yantracintāma* of Viśrāma are important. The pinnacle of this activity came with Sawai Jai Singh, ruler of Jaipur, who patronized a group of astronomers, built five huge observatories, in Delhi, Jaipur, Ujjain, Varanasi, and Mathura, and wrote the work *Yantrarāja-racanā* (Construction of Astrolabes).

Toward the early centuries of the Christian era, texts with the generic name *siddhānta* (tenet), in contrast to the earliest astronomical texts, were composed. These were mathematically based, rationalistic, and adumbrated by geometric models and diagrammatic representations of astronomical phenomena. While Varāhamihira selectively redacted in his *Pañcasiddhāntikā* five of the early *siddhāntas*, his elder contemporary, Āryabhaṭa (b. AD 499) produced a systematic *siddhānta* treatise entitled *Āryabhaṭīya*, in which he speaks also of the diurnal rotation of the earth. The work is divided into four sections, covering the following subjects: (1) planetary parameters and the sine table (*Gītikā-pāda*), (2) mathematics (*Gaṇitapāda*), (3) time reckoning and planetary positions (*Kālakriyā-pāda*), and (4) astronomical spherics (*Gola-pāda*). This *siddhānta*, which started the Āryabhaṭan school of astronomy, was followed by advanced astronomical treatises written by a great number of astronomers and was very popular in the south of India, where astronomers wrote a number of commentaries and secondary works based on it.

Brahmagupta (b. AD 598) started another school through his voluminous work *Brāhmasphuṭasiddhānta* in 20 chapters. This work shows Brahmagupta as an astute mathematician who made several new enunciations. He also wrote a work by the name of *Khaṇḍakhādyaka* in which he revised some of Āryabhaṭa's views. Among the things that he formulated might be mentioned a method for calculating the instantaneous motion of a planet, correct equations for parallax, and certain nuances related to the computation of eclipses. Brahmagupta's works are also significant for their having introduced Indian mathematics-based astronomy to the Arab world through his two works which were translated into Arabic in about AD 800.

Bhāskara I (ca. AD 628), who followed in Āryabhaṭa's tradition, wrote a detailed commentary on *Āryabhaṭīya* and two original treatises, the *Laghubhāskarīya* and the *Mahābhāskarīya*. Vaṭeśvara (b. AD 880) wrote his erudite work *Vaṭeśvarasiddhānta* in eight chapters, in which he devised precise methods for finding the parallax in longitude (*lambana*) directly, the motion of the equinoxes and the solstices, and the quadrant of the sun at any given time. He also wrote a work on spherics. Śrīpati, who came later (ca. AD 999), wrote an extensive work, the *Siddhāntaśekhara*, in 20 chapters, introducing several new enunciations, including the moon's second inequality.

The *Sūryasiddhānta*, the most popular work on astronomy in North India, is attributed to divine authorship but seems to have been composed about AD 800. It adopts the midnight epoch and certain elements from the old *Saurasiddhānta*, but differs from it in other respects. It promulgates its own division of time-cycle (*yuga*) and evinces some acquaintance with *Brāhamasphuṭasiddhānta*.

The *Siddhāntaśiromaṇi* of Bhāskara II (b. AD 1114) comprises four books: *Līlāvatī* dealing with mathematics, *Bījagaṇita* with algebra, *Gaṇitādhyāya* with practical astronomy, and *Golādhyāya* with theoretical astronomy. The author's gloss on the work which he calls *Vāsanā* (Fragrance) is not only explanatory, but also illustrative and highly instructive. Extremely popular and widely studied in North India, the work has been commented on by generations of scholars.

The *siddhānta* texts composed later, when Muslim astronomy had been introduced into India, bear its influence in the matter of parameters and models though the general set up remains the same. The more important among these are the *Siddhāntaśindhu* (1628) and *Siddhāntarāja* (1639) of Nityānanda, *Siddhāntasārvabhauma* (1646) of Munīśvara, *Siddhāntatattvaviveka* (1658) of Kamalākara, and the *Siddhāntasārakaustubha* (1732) of Samrāṭ Jagannātha.

In order to relieve the tedium in working with the very large numbers involved when the *mahāyuga* or *yuga* is taken as the epoch, a genre of texts called *karaṇas* was evolved which adopted a convenient contemporary date as the epoch. The mean longitudes of the planets at the new epoch were computed using the *siddhāntas* and revised by observation, and the resulting longitudes were used as zero corrections at the epoch for further computations. In order to make computations still easier, planetary mean motions were calculated for blocks of years or of days, and depicted in the form of tables. Each school of astronomy had a number of *karaṇa* texts, produced at different dates, and often exhibiting novel shortcuts and methodologies. While the North Indian texts had tables with numerals, South India, particularly Kerala, had its own traditions, and depicted the daily motions of the planets, sines of their equations, and other matters in the form of verses with meaningful words and sentences, employing the facile *kaṭapayādi* notation of numerals. The earliest *karaṇa* texts are the redactions by Varāhamihira in his *Pañcasiddhāntika* of the *Romaka*, *Pauliśa*, and *Saura Siddhāntas*, the epoch of all the three being 21st March, 505 AD.

Hindu religious life, which served as the incentive to the development of astronomy in India in its beginnings, has continued to be so even today for the orthodox Indian. The *pañcānga* (five-limbed) almanac, which is primarily a record of the *tithi* (lunar day), *vāra* (weekday), *nakṣatra* (asterism), *yoga* (sum of the solar and lunar longitudes), and *karaṇa* (half lunar day), can be said to direct and regulate the entire social and religious life of the orthodox Hindu. Though the primary elements of the almanac are identical throughout India, other matters like the sacred days, festivals, personal and community worship, fasts and feasts, social celebrations, customs, and conventions differ from region to region. These matters are also recorded in the almanacs of the respective regions. In order to bring about some uniformity in the matter, the Government of India appointed a Calendar Reform Committee in 1952 which made several recommendations, but conditions have not changed much.

In astronomy, as in other scientific disciplines, the Indian ethos had been to depict the formulae and procedures, but refrain from giving out the rationale, though much rationalistic work would have gone before formulation. This position is relieved by a few commentators, such as Mallāri in his commentary on the *Grahalāghava* of Gaṇeśa Daivajña and Śaṅkara Vāriyar in his commentaries on the *Līlāvatī* of Bhāskara II and the *Tantrasaṅgraha* of Nīlakaṇṭha Somayāji. It is also interesting that there are texts wholly devoted to setting out rationales, like the *Yuktibhāṣa* of Jyeṣṭhadeva. Even more interesting are texts like *Jyotirmīmāṁsā* (Investigations on Astronomical Theories) by Nīlakaṇṭha Somayāji, which open up a very instructive chapter of Indian astronomy.

See also: ►Eclipses, ►Gnomon, ►Clocks and Watches, ►Time, ►Astronomical Instruments, ►Observatories, ►Armillary Sphere, ►Algebra in India: *Bijagaṇita*, ►Precession of the Equinoxes

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Astronomy: Indian Astronomy in China

Yukio Ōhashi

Chinese astronomy and Indian astronomy were originally independent. Both of them already had developed when Indian astronomy was introduced into China along with Buddhism. The exact date of the introduction of Buddhism into China is not known, but it can be said that Buddhism was gradually introduced at the beginning of the Later Han (Eastern Han) dynasty (AD 25–220) or so. According to my study, the earliest information on Indian astronomy reached China at the time of the Later Han.

During the Sanguo (Three Kingdoms) period (AD 220–265), some Buddhist works, where information of Indian astronomy was included, were translated into Chinese. At the time of the Tang dynasty (AD 618–907), some detailed monographs of Indian astronomy and astrology were composed in China. There were some astronomers who were well versed in both Chinese and Indian astronomy. Yixing was one of them.

It is not known whether Chinese astronomy was introduced into pre-modern India or not.

Indian Astronomy in the Later Han Dynasty

At the time of the Former Han (Western Han) dynasty (206 BCE–AD 23), there was no apparent foreign influence on Chinese astronomy. As Buddhism was already known at the time of the Later Han dynasty, there was a possibility that certain aspects of Indian culture, including astronomy, were also introduced into China.

According to my research, some fragments of information about the Indian calendar reached China at the time of the Later Han dynasty (Ōhashi 1999). There are three reasons for my view:

1. When the Later Han *Sifen* calendar was compiled in AD 85, its first month was proposed to be large, although that was finally rejected. In the Chinese traditional calendar, the first month was small, because the first new moon occurs at the initial point of time, and the second new moon is included in the first day of the next month. To the contrary, the first month of the Indian traditional calendar was large, because the first new moon occurs at the initial point of time, and the second new moon is included in the last day of the same month. I suspect that the rejected proposal of the Later Han *Sifen* calendar might have been influenced by the Indian method.
2. The Later Han *Sifen* calendar has special days called *mori* and *mieri*, which did not exist in the Former Han dynasty. If 1 year is divided into 360 parts and 1 day is included within a part, the day is called *mori*. If the end of a day coincides with the boundaries of the parts, the day is called *mieri*. These days are of no use in Chinese traditional calendars, but they are similar to certain concepts of Indian traditional calendars, such as the method of intercalation in the *Arthaśāstra* (see the section on Yixing below; for details, see Ōhashi 2001).
3. In Chinese traditional calendars, midnight is considered the beginning of a day. However, when the date of the half moon and full moon was calculated in the Later Han *Sifen* calendar, daybreak was considered to be the beginning of a day. In Indian traditional calendars, sunrise is usually the beginning of a day. Therefore, the Chinese use of daybreak might have a connection with the Indian method.

From these three reasons, I suspect that certain information about the Indian calendar reached China.

However, the information must have been fragmental, and did not influence the Chinese calendar very much.

Indian Astronomy in Chinese Buddhist Texts

The *Madengqie-jing*

At the time of the Sanguo (Three Kingdoms) period (mid-third century AD), a Buddhist text called *Śārdūlakarṇa-avadāna* in Sanskrit was translated into Chinese by Zhu Lüyan and Zhi Qian as the *Madengqie-jing*. This is the first Chinese text where Indian astronomy and astrology are explicitly mentioned. This text explains lunar mansions and the astrology based on them at length and also mentions some calendrical information.

The astronomical system of the *Śārdūlakarṇa-avadāna* is similar to *Vedāṅga* astronomy, which is one of the six branches of auxiliary learning for the *Veda*. According to my research, *Vedāṅga* astronomy was produced in North India sometime between the sixth and the fourth centuries BCE (Ōhashi 1993). The description of astrology in the *Śārdūlakarṇa-avadāna* is also based on the Indian traditional system.

The original Sanskrit version of the *Śārdūlakarṇa-avadāna* has a description of the annual variation of the gnomon shadow, which is similar to that in *Vedāṅga* astronomy. The Chinese version, *Madengqie-jing*, also has a description of the annual variation of the gnomon shadow, but it is different from the Sanskrit original. Shinzō Shinjō, a pioneer of the study of the history of Eastern astronomy, pointed out that the description of the *Madengqie-jing* is based on the data around 43°N, and that the data might have been incorporated in Central Asia (Shinjō 1928: 217–218).

The *Śārdūlakarṇa-avadāna* was also translated into Chinese as the *Shetoujian-taizi ershiba-xiu jing* by Zhu Fahu at the time of Xi-Jin (Western Jin) dynasty (AD 265–316).

The *Daji-jing*

The *Daji-jing* (or *Dafangdeng-dajijing*) is a collection of *Mahāyāna* texts in Chinese. The *Yuecang-fen* (one text in the *Daji-jing*), which was translated by Narendrayaśa in AD 566, is the earliest Chinese text where zodiacal signs are mentioned.

The *Ricang-fen* (another text in the *Daji-jing*), which was translated by Narendrayaśa in AD 586, also mentions zodiacal signs. It is interesting to note that the annual variation of the length of daytime and that of the gnomon shadow, which are similar to those of the *Vedāṅga* astronomy, are mentioned there, but the position of the sun corresponding to their data is given with reference to zodiacal signs. This means that the system of *Vedāṅga* astronomy was still in use when Greek horoscopy reached India. *Vedāṅga* astronomy was widely used in India from sometime between the sixth and the fourth centuries BCE to sometime during the second and fourth centuries AD, and was mixed with the system of zodiacal signs which was introduced into India along with Greek horoscopy in the second or third century AD (Ōhashi 2002).

The *Ricang-fen* of the *Daji-jing* is, therefore, an important source for studying the history of Indian astronomy. It says that the length of daytime and nighttime is 15 *shi* (which corresponds to Indian *muhūrta* or 1/30 of a day) in the months of Scorpio and Taurus, and that daytime is 12 *shi* (minimum) and nighttime is 18 *shi* (maximum) in the month of Aquarius, and daytime is 18 *shi* and nighttime is 12 *shi* in the month of Leo. The length of daytime and nighttime changes linearly. The above-mentioned data look strange at first sight. The relationship between the length of daytime and nighttime and the sign of zodiac differs by one. For example, the above data tell that the vernal equinox occurs in the month of Taurus, and not in the month of Aries. The only possible explanation of this difference is that the data of the length of daytime and nighttime is for the beginning of the month, and the sign of the zodiac is for the end of the month. The linear function of the length of daytime and nighttime is the same in *Vedāṅga* astronomy. My studies reveal that this function is not the result of interpolation from the observational data around the solstices, but the result of extrapolation from the observational data around the equinoxes in North India. The *Ricang-fen* also gives the length of the midday gnomon shadow, which is basically the same as in *Vedāṅga* astronomy, which is also based on observational data from North India. Here, we can see that *Vedāṅga* astronomy was still widely used even after Greek horoscopy was introduced into India (Ōhashi 2002).

Indian Astronomy During the Tang Dynasty

The *Jiuzhi-li*

One system of Hindu Classical Astronomy was introduced into China. It was recorded in Chinese as the *Jiuzhi-li* (AD 718) of Qutan Xida, which is included in his (*Da-*)*Tang Kaiyuan-zhanjing*. The author, Qutan Xida (probably a Chinese transliteration of his Indian name Gotama Siddha), belonged to a family of Indian astronomers in China and was the director of the national observatory. In the title *Jiuzhi-li*, *jiuzhi* corresponds to the Sanskrit word *navagraha* ["nine planets", i.e. sun (Ravi or Sūrya), moon (Candra), five planets – Mars (Maṅgala), Mercury (Budha), Jupiter (Bṛhaspati or Guru), Venus (Śukra) and Saturn (Śani), Rāhu (ascending node of the lunar orbit) and Ketu (usually considered to be the descending node of the lunar orbit)]; *li* means calendar. This work explains the method for calculating the sun's longitude, the moon's longitude, and solar and lunar eclipses, etc. This text also contains a sine table. The work also says that Indian numerals are mentioned, but the actual shape of the figure has not come down in extant texts.

Kiyosi Yabuuti pointed out that some astronomical constants of the *Jiuzhi-li* are similar to the *Sūryasiddhānta*, which was summarized in the *Pañcasiddhāntikā* of Varāhamihira (sixth century AD). This is a text of the *Ārdharātrika* school of Classical Hindu Astronomy (Yabuuti 1944/1989, 1979; also see Yano 1979).

It is interesting to note that the traditional calendars of mainland Southeast Asia (except for Vietnam) and also the classical astronomy of Tibet are related to the *Ārdharātrika* school. It may be that the *Ārdharātrika* school was quite popular among Buddhists. The *Jiuzhi-li* has never been used as an official calendar in China, because the tradition of Chinese original astronomy was so strong.

Yixing

There was also a famous monk, astronomer Yixing (AD 683–727), who knew about Indian astronomy. For example, he mentioned the Indian zodiac in his *Dayan* calendar. However, he made his *Dayan* calendar in a Chinese traditional way. There is only one thing which I suspect shows Indian influence in his *Dayan* calendar. It is the change of the meaning of *mieri*.

Yixing explained the method to calculate the *mieri* as follows:

> If the *xiaoyu* (time in terms of 1/3040 day) of the mean new moon is less than *shuoxufen* (=1427), subtract the *xiaoyu* from the *tongfa* (=3040), and multiply the result by 30, and subtract the result from *miefa* (=91200). Divide the result by *shuoxufen*. The result is the number of days. Count the days from the mean new moon day and take the day after the resultant day. It is the *mieri*.

The meaning of this *mieri* is as follows. Let a synodic month be divided into 30 parts. Then, sometimes a part is included within a day. This kind of day is the *mieri* defined by Yixing. This *mieri* is similar to the "omitted *tithi*" in Indian calendars. In *Vedāṅga* astronomy, a *tithi* was a 1/30 part of a synodic month, where the equation of centre was not known. In Hindu Classical Astronomy, a *tithi* is a period of time during which the longitudinal difference of the sun and moon changes by 12°. If a *tithi* is included within a day, the *tithi* is called "omitted *tithi*". In Hindu traditional calendars, the name of a civil day is determined by the number of *tithi* at the beginning (sunrise) of the day. Therefore, the number of an omitted *tithi*, which does not include any sunrise, actually disappears from the calendar.

The significance of Yixing's definition is that when the sum of the *mori* (a day which is included within a segment of 1/360 of a tropical year) and *mieri* grows to 30, one intercalary month is produced. This way of thinking is similar to certain descriptions in Indian classics, such as the *Arthaśāstra*. A similar description is also found in a Chinese version of the Buddhist text *Lishi-apitan-lun*, translated by Zhendi at the middle of the sixth century AD.

I suspect that Yixing knew this Indian method, and changed the meaning of the *mieri* in order to make it meaningful in Indian calendrical context (Ōhashi 2001).

Other Texts in the Tang Dynasty

In addition to the above-mentioned texts, the *Suyao-jing* is also famous. In the title, *su* means lunar mansions, *yao* means planets and *jing* means canonical scripture. It is an astrological work which was compiled by Amoghavajra in the middle of the eight century AD. It is based on Indian horoscopic astrology.

There is also an astrological work with planetary ephemerides entitled *Qiyao-rangzaijue*, compiled by Jin Juzha, who is said to have been a Brahman priest from Western India, in the early ninth century or so. In the title, *qiyao* means seven planets, and *rangzaijue* means formulae to avoid disasters (caused by planets). This work is a kind of mixture of Indian astrology and Chinese astronomy. It includes the ephemerides of the five planets, Rāhu, Ketu and the sun. In Indian astronomy, Ketu usually means the descending node, or comets. However, Ketu in the *Qiyao-rangzaijue* is, according to Michio Yano's study, the apogee of the lunar orbit. This is a special feature of this work (Yano 1986).

We have seen some records of Indian astronomy in Chinese sources. We have to keep in mind that Indian influence on Chinese astronomy was very small. The tradition of Chinese original astronomy was very strong, and it seldom accepted foreign influence. However, we can find some exceptional influences in Chinese sources, and these exceptions draw attention to researchers.

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Astronomy in the Indo-Malay Archipelago

GENE AMMARELL

All societies have their own systems of knowledge through which they seek to understand the natural environment and their relationship to it. Thus we may be better able to understand a society by going beyond the categories of Western science and begin to consider the interrelationship of a society with its environment from the viewpoint of the members of that society. It is this attempt to understand how members of a society, themselves, conceive of their environment that has come to be known as ethnoecology (Casiño 1967). Ethnoastronomy, the subject of this article, may be seen as a branch of ethnoecology wherein the interrelationship of human populations with their celestial environment is the focus of interest.

The modern nation states of Indonesia and Malaysia have a combined population of approximately 260 million and encompass the homelands of well over 500 distinct ethno-linguistic groups whose cultures and languages form part of a common Austronesian heritage, a heritage they share with the majority of the peoples of the Philippines, Polynesia, and Micronesia, among others.[1] Inhabiting mountainsides, river valleys, and coastal plains and faced with a somewhat unpredictable tropical monsoon climate, the peoples of Island Southeast Asia have developed diverse systems of agriculture that include both inundated rice farming and the shifting cultivation of rice and other food crops. Spread across an archipelago of over 17,000 islands (at least 6,000 inhabited), they have also developed sophisticated systems of navigation. These indigenous agricultural and navigational practices have been informed by an astronomical tradition that is, at once, unique to this cultural area and richly diverse in its local variation. This article describes several of the many techniques of astronomical observation that are known to have been employed by the peoples of Indonesia and Malaysia to help regulate their agricultural cycles and navigate their ships.

[1] In addition, there are at least 100 Papuan languages spoken in the Indonesian province of West Papua on the western half of the island of New Guinea.

The Celestial Landscape

The passage of time is mirrored in all of nature: in the light and warmth of day and the dark and coolness of night, in the flowering of plants, in the mating and migratory behavior of animals, in the changes in weather, in the ebb and flood of the tides, and in the recurring cycles within cycles of the sun, moon, planets, and stars as they transit the celestial sphere. Of these cycles, perhaps the most obvious is the diurnal rising and setting of the sun, moon, planets, and stars, as well as the synodic or cyclic changes in the phase of the moon and in the time of day that it rises and sets. More subtle than these might be the annual changes in the sun and stars: the north–south shift in the path of the sun across the sky (including its rising and setting points and its relative distance above the horizon at noon) and the appearance, disappearance, and reappearance of familiar patterns of stars at various times of night. To the trained eye, nature is replete with signs of diurnal and seasonal change. As an integral part of the natural landscape, these recurring celestial phenomena have long provided farmers and sailors worldwide with dependable markers against which operations, agricultural as well as navigational, can be timed.

Likewise, orientation in space and the art of wayfinding have often relied upon knowledge of these same celestial phenomena, the English term "orient," itself, having been derived from the Latin for "rise" and later associated with the East as the direction in which the sun appears at dawn. Although the times that individual stars rise and set shift gradually throughout the year, as viewed from a given latitude, the azimuths at which a star rises and sets varies only slightly over a lifetime, thereby providing a reliable "star compass" by which to determine direction. So, too, the sun, moon, and planets rise and set generally east and west, depending upon their individual cycles, affording additional guides by that people are able to orient themselves on the land as well as on the sea.

Agricultural Time Keeping

Many traditional, sedentary desert and plains cultures have used the shift in the rising and/or setting points of the sun along the horizon to both mark important dates and seasons and to commemorate the passage of years.

Desert and plains environments are conducive to the development and use of these horizon-based solar calendars: a permanent location from which to make sightings, a series of permanent distant horizon markers, either natural or manufactured, and a clear view are all that is needed for such a calendar. England's Stonehenge and Wyoming's Big Horn Medicine Wheel provide striking examples. Such conditions, however, are not common across much insular Southeast Asia. Here the landscape may consist of anything from a nearby or distant mountain to, more often, nearby trees; the horizon is, therefore, a rather undependable device against which to sight and measure the rising and setting positions of the sun. But in cultivated areas of the region, even from swiddens located deep within the rainforest, one can usually find a field or home site from which much of the sky is visible.

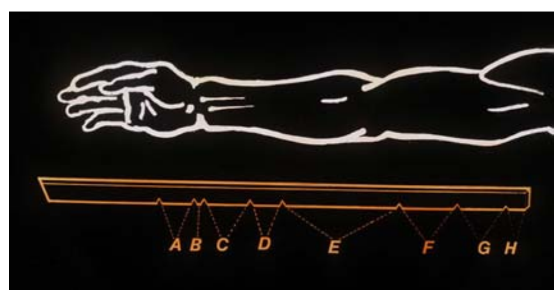
There are several types of observations of annually recurring celestial phenomena that can be made where permanent, distant horizon markers are not commonly available. These include cyclic changes in the phases of the moon, the annual changes in the apparitions of familiar groups of stars, and the annual changes in the altitude of the sun at noon. Here I present variations of these types of observations that we know have been practiced among traditional farmers of Indonesia. For the sake of clarity, they are grouped using Western astronomical categories as follows: solar gnomons, apparitions of stars at dawn and dusk, and lunar–solar and sidereal-lunar observations.

Solar Gnomons. Most often seen on sundials in western cultures, a solar gnomon is simply a vertical pole or other similar device that is used to cast a shadow. The altitude of the sun above the horizon varies not only through the day, however, but through the year as well. By measuring the relative length of this shadow each day at local solar noon, one can observe and more or less accurately measure the changing altitude of the sun above the horizon (or, reciprocally, from the zenith) through the year and, thereby, determine the approximate date.

Two distinct types of solar gnomons have been reported in the region. Both measure the altitude of the sun at local solar noon to determine the date. One type has been attributed to various groups of the Kenyah of the Apo Kayan of Kalimantan and may still be in use (Fig. 1).

It consists of a precisely measured (=span of maker's outstretched arms + span from tip of thumb to tip of first finger), permanently secured, plumbed, and decorated vertical hardwood pole (*tukar do*) and a neatly worked, flat measuring stick (*aso do*), marked with two sets of notches (Fig. 2). The first set corresponds to specific parts of the maker's arm and ornaments worn upon it, measured by laying the stick along the radial

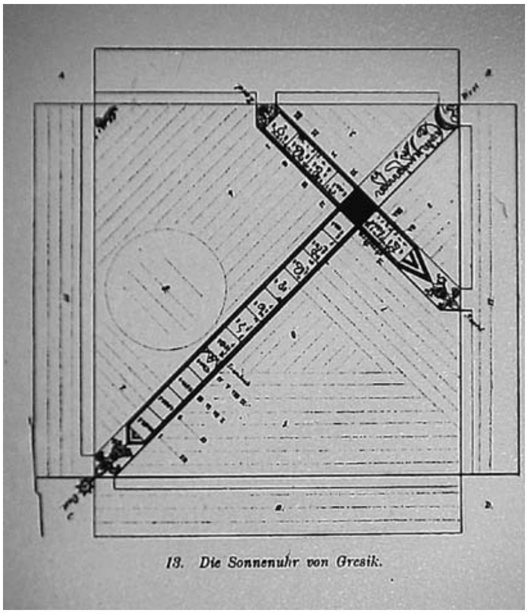
Astronomy in the Indo-Malay Archipelago. Fig. 1 Kenyah *tukar do* or solar gnomon (from Hose and McDougall 1912).



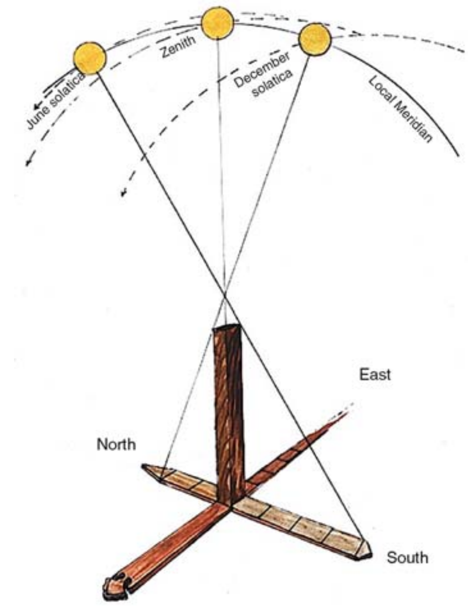
Astronomy in the Indo-Malay Archipelago. Fig. 2 Kenyah *aso do* or base of solar gnomon (adapted from Hose 1905).

side of the arm, the butt end against the inside of the armpit.

To mark the date, the measuring stick is placed at the base of the vertical pole, butt end against the pole and extending southward. This is done at the time of day that the shadows are shortest, local solar noon. On the day that the pole's noontime shadow is longest (the June solstice), a notch is carved on the other edge of the stick to mark the extent of the shadow made by the pole. This observation indicates that the agricultural season is at hand. From then on, the extent of the noonday shadow is recorded every 3 days as a record-keeping device. Dates, both favorable and unfavorable, for various operations in rice cultivation, such as clearing, burning, and planting, are determined by the length of the shadow relative to the marks on the stick



Astronomy in the Indo-Malay Archipelago. Fig. 3 The base of the *bencet* or solar gnomon showing the grid used to measure the length of the sun's shadow (Maass 1924).



Astronomy in the Indo-Malay Archipelago. Fig. 4 Javanese *bencet* and the annual motion of the sun (adapted from Aveni 1981).

that correspond to parts of the arm and to the marks made every 3 days (Hose 1905; Hose and McDougall 1912).

On Java a highly accurate gnomon, called a *bencet*, was in use from about AD 1600 until 1855 (Figs. 3 and 4) (Maass 1924; see also Ammarell 1996, 1998; Aveni 1981; van den Bosch 1980). A smaller, more portable device than that employed by the Kayan and Kenyah, the *bencet* divides the year into 12 unequal periods, called *mangsa*, two of which begin on the days of the zenith sun, when the sun casts no shadow at local solar noon, and another two of which begin on the two solstices, when the sun casts its longest mid-day shadows.

At the latitude of Central Java, 7° south, a unique condition exists which is reflected in the *bencet*. As the illustration shows, when, on the June solstice, the sun stands on the meridian (that is, at local solar noon) and to the north of the zenith, the shadow length, measured to the south of the base of the vertical pole, is precisely double the length of the shadow, measured to the north, which is cast when the sun, on the December solstice, stands on the meridian (at noon) south of the zenith. By simply halving the shorter segment and quartering the longer, the Javanese produced a calendar with 12 divisions, divisions that are spatially equal but which range in duration from 23 to 43 days. The 12 *mangsa* with their starting dates and numbers of days are shown on Table 1.

Apparitions of Stars at Dawn and Dusk. The second category of observational techniques regularly employed by traditional farmers of the region include all of those which involve apparitions of commonly recognized stars or groups of stars (which are herein referred to as "asterisms") at last gleam at dawn or first gleam at dusk.[2] Because of the earth's orbital motion about the sun, it can be observed that each star rises and sets approximately 4 min earlier each night. Similarly, each star appears to have moved about 1° west, when viewed at the same time, each night. As a result, around the time of its conjunction with the sun, any given star becomes lost in the sun's glare and is, therefore, not visible for approximately 1 month each year. It also means that the altitudes of stars above the horizon vary as a function of both the time of night and the day of the year, such that a certain star or group of stars, when observed at the same time each night (in this case near dusk or dawn) will appear at a given altitude above the eastern or western horizon on one and only one night of the year. Hence the use of any technique or device to measure the altitude of a star or group of stars as it

[2] I use the term "asterism" to refer to a commonly recognized patterned grouping of stars. While these groupings are often referred to generically as "constellations," I reserve the latter term to refer to the 88 bounded regions of the sky generally accepted by international scientific astronomers, these regions often named for asterisms found within their borders. Note, however, in Western starlore, there may be two or more asterisms within one constellation (e.g., the "Big Dipper" and the "Great Bear" in Ursa Majoris).

Astronomy in the Indo-Malay Archipelago. Table 1 The Pranatamangsa calendar (adapted from van den Bosch, p. 250)

Ordinal number	Name(s) of *Mangsa*	Duration (days)	First day(s) civil calendar
Ka – 1	*Kasa*	41	22 (21) June
Ka – 2	*Karo, Kalih*	23	2 (1) August
Ka – 3	*Katelu, Katiga*	24	25 (24) August
Ka – 4	*Kapat, Kasakawan*	25	18 (17) September
Ka – 5	*Kalima, Gangsal*	27	13 (12) October
Ka – 6	*Kanem*	43	9 (8) November
Ka – 7	*Kapitu*	43	22 (21) December
Ka – 8	*Kawolu*	26 (27)	3 (2) February
Ka – 9	*Kasanga*	25	1 March (ult. February)
Ka – 10	*Kasepuluh, Kasadasa*	24	26 (25) March
Ka – 11	*Desta*	23	19 (18) April
Ka – 12	*Sada*	41	12 (11) May

appears at first or last gleam can provide the observer with the approximate date.

I use the term "acronical" to refer to any stellar apparition that occurs at first gleam while "cosmical" is used to describe stars at last gleam. A subset of these, "heliacal" (Greek *helios*: "sun") apparitions of stars are those that occur just prior to and shortly after conjunction with the sun. The heliacal setting of a star or group of stars occurs on the date that the star or stars are last observed before conjunction, just above the western horizon at dusk. Likewise, the heliacal rising of a star or group of stars occurs on the date that the star or stars are first observed above the eastern horizon at dawn after several weeks' absence.

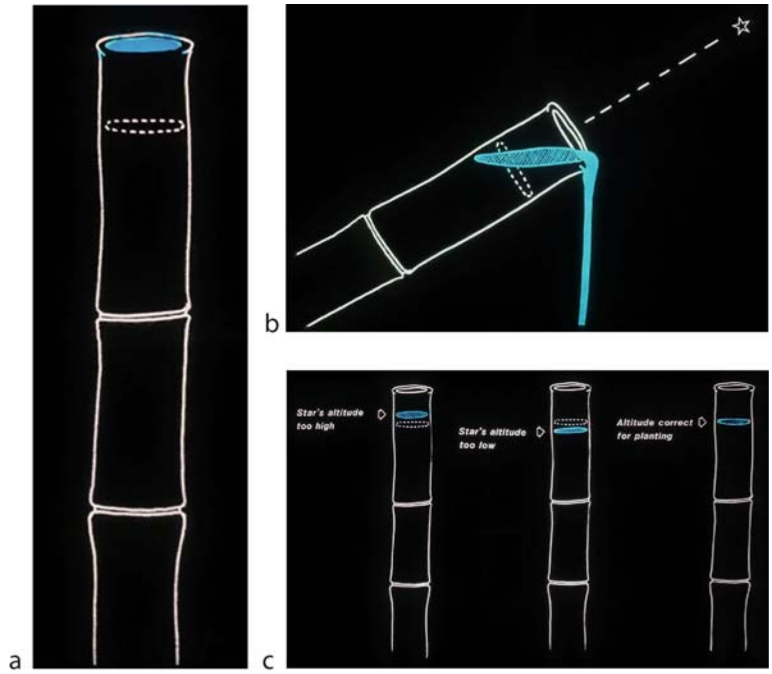
Just about 3 months after its heliacal rising, the star, now about 90° west of the sun, appears on the meridian at first gleam, an event that may be termed a "cosmical culmination" of the star. Two months later, the star is nearing opposition with the sun and undergoes an "acronical rising" in the east at first gleam. In less than 1 month, after opposition, the "cosmical setting" of the star is seen in the western sky. After two more months the star may be seen on the meridian at first gleam, accomplishing its "acronical culmination." Finally, about 3 months later, the star undergoes "heliacal setting" as the sun once again outshines it.

I would like to emphasize that these categories are taken from what is often referred to as the "exact science" of Western mathematical astronomy and are used here as a way of organizing and presenting this material to the Western scholar. The reader is cautioned that the actual observations made by indigenous farmers may not always be as precise as their assigned astronomical categories might imply. The demand for such precision varies greatly between and within cultures and with local environmental conditions. Here it would not be unusual to find a local farmer, for example, first noting the heliacal rising of the star cluster known in the West as the Pleiades at dawn several days or more after its mathematically calculated reappearance. Note that for convenience, I refer in this article to stars and asterisms by their accepted international scientific names. Where I know the name of a star or asterism in the indigenous language, I will note it as well.

The apparitions of stars at first and last gleam have been systematically observed by traditional cultures worldwide. From island Southeast Asia there are references in the literature, too numerous to describe in detail here, to the calendrical use at both dusk and dawn of the stars known internationally as the Pleiades, Orion and, to a lesser extent, Antares, Scorpius, and Crux (for more Indo-Malay examples, see Ammarell 1988, 1996; for examples from the Philippines, see Ambrosia, 1996). Culminations at both first and last gleam of the Pleiades, Orion, and Sirius are noted in the literature. Interestingly, the observation for calendrical purposes of such culminations seems to be unique to peoples of this culture area.

A small Dayak group related to the Kenyah–Kayan complex mentioned earlier practiced the first example in this category. Like their neighbors, they were swidden rice farmers. But unlike their neighbors who tracked the sun, they depended upon the stars to fix the date of planting. To do so, they nightly poured water into the end of a vertical piece of bamboo in which a line had been inscribed at a certain distance from the open end (Fig. 5a). The bamboo pole was then tilted until it pointed toward a certain star (unrecorded) at a certain time of night (also unrecorded), causing some of the water to pour out (Fig. 5b). It was then made vertical again and the level of the remaining water noted (Fig. 5c). When the level coincided with the mark, it was time to plant (Hose and McDougall 1912).

Near Yogyakarta, Central Java, a ritual practitioner was observed raising his hand toward the East in the direction of *bintang weluku* "plough stars" (Orionis) each day at dusk, rice seed in his open palm (Fig. 6).



Astronomy in the Indo-Malay Archipelago. Fig. 5 Bamboo device used by Kenyah–Kayan to measure the altitude of a star (adapted from Hose and McDougall 1912).

Astronomy in the Indo-Malay Archipelago. Fig. 6 Javanese ritual specialist holding rice in open palm at dusk, pointing toward the rising *bintang weluku* "plough stars" (Orionis).

On the night it reached the altitude such that kernels of rice rolled off his palm (angle of repose), it was time to sow seed in the nursery (van den Bosch 1980). Using a planetarium star projector, the author has determined the date of this event to be about 4 January (Ammarell 1996).

Lunar Calendars. Lunar calendars comprise the third category. These calendars are based upon the 29.5-day synodic period, usually measured from new moon to new moon and often subdivided by phase. Because there is not an even number of lunar months in a solar year and because agricultural cycles are, after all, tied to the solar year, simple lunar calendars alone are of little use in farming. But when they are somehow pegged to the solar year by reference to the apparent annual changes in the positions of the sun or stars or to other phenomena in nature that regularly recur on an annual basis, a lunar calendar can be of use to the farmer.

Indigenous lunar calendars fall into two general categories: lunar–solar and sidereal-lunar. Examples of the lunar–solar calendar include the Balinese ceremonial calendar, still in use, and the old Javanese *Saka* calendar, used from the eighth to the sixteenth centuries. Both are apparently of a common Hindu origin and are primarily lunar; both employ complex mathematical techniques to provide the intercalary days that periodically synchronize the lunar with the solar year (Covarrubias 1937; van den Bosch 1980).

A second type of lunar calendar, best described as sidereal-lunar, uses the apparitions at dusk and dawn of stars and asterisms as well as the appearance of other signs in nature (such as winds, birds and flowers) to determine which month is current. In these cases, it is only important to know which month it is for a few months each year (that is, during the agricultural season), thereby obviating the need for codified schemes for realigning the lunar with the solar/stellar year. Such "short" lunar calendars are found spread throughout the region (see Ammarell 1988). The Iban calendar provides a good example.

The Iban Calendar

Freeman (1970) describes the Iban as a riverine people practicing shifting agriculture in the vicinity of their longhouses, situated in low hills of Sarawak and West Kalimantan. The stars have played a central role in Iban mythology and agricultural practices. Several Iban stories tell how their knowledge of the stars was handed down to them by their deities and according to one village headman, "If there were no stars we Iban would be lost, not knowing when to plant; we live by the stars" (Freeman 1970:171). The Iban lunar calendar was annually adjusted to the cosmical apparitions of two groups of stars: the Pleiades and the three stars of Orion's belt.

The first observation was probably the most difficult. It was the reappearance of the Pleiades on the eastern horizon just before dawn after 2 month's absence from the night sky. This heliacal sighting, around 5 June of the civil calendar, informed the observer that the month, taken from new moon to new moon, that is current is, by convention, the fifth lunar month. It is during this month that two members of the longhouse went into the forest to seek favorable omens so that the land selected would yield a good crop. This may have taken from 2 days to a month, but once the omens appeared, they returned to the longhouse and work clearing the forest began. If it took so long for the omens to appear that Orion's belt rose before daybreak (heliacal rising around 25 June), the people had to "make every effort to regain lost time or the crop will be poor" (Freeman 1970:171). This reappearance of Orion at dawn occurred during the next or sixth lunar month, the time to begin clearing the land.

The remaining observations of the stars were more easily accomplished. They are all cosmical culminations, occurring "overhead" at last gleam, and could be seen to be approaching for several weeks. When the Pleiades underwent its cosmical culmination (3 September) and the stars of Orion's belt were about to do so (26–30 September), it was the eighth month and time to burn and plant. For good yields the burn should have occurred between the time that the two asterisms culminated at first gleam, usually when the two were in balance or equidistant from the meridian (16 September). Rice seed sown after the star Sirius had completed its cosmical culmination (October 15) would not have matured properly. It was okay for planting to carry into the tenth lunar month (October/November), but it had to be completed before the moon was full or the crop would fail. At this point the lunar calendar ended: only months five through ten were numbered and fixed while the remaining months varied according to how quickly the crop matured (e.g., *bulan mantun*, the "weeding month"). The lunar months from November to April were simply not numbered; it was difficult to see the stars during the rainy season and unimportant in any case.

Celestial Navigation

As we have just seen, the rice farmers of Indonesia have long noted correlations between celestial and terrestrial cycles and incorporated periodic changes in the sky into their agricultural calendars. Meanwhile, neighboring seafaring societies have used many of these same phenomena to orient themselves in both space and time for the purpose of navigation. Of these societies, the Bugis of South Sulawesi are perhaps the best known. Maintaining a tradition of seafaring and trade that spans at least four centuries, the Bugis are reputed to have established and periodically dominated strategic trade routes across Southeast Asia, stretching northeast from North Sumatra to Cambodia, north to Sulu and Ternate, and east to Aru and Timor. Their maritime prowess notwithstanding, Bugis systems of navigational knowledge and practice have only recently come under study (Ammarell 1995, 1999).

Bugis navigators still employ a system of dead reckoning that depends upon the knowledge of a variety of features of the natural environment to negotiate the seas in their tall ships. Although these features include land forms, sea marks, currents, tides, wave patterns and shapes, and the habits of birds and fish, navigators rely most heavily upon the prevailing wind directions, guide stars, waves, swells, and, increasingly, the magnetic compass.

Winds and Directions. The major wind patterns across island Southeast Asia are governed by the monsoons. In the Java and Flores Seas, from approximately May through October, winds from the east and southeast bring generally fair weather and steady breezes; from November through April, the west monsoon brings first calm air, then rain and squalls to the region. For the Bugis as well as a number of other regional ethnic groups whose languages share a common Austronesian heritage, these winds are of such fundamental importance that their names are synonymous with the local prevailing wind directions. Thus for the Bugis, both the monsoons and their prevailing directions in the vicinity of their homeland of South Sulawesi are: *bare'* "west" and *timo'* "east."[3]

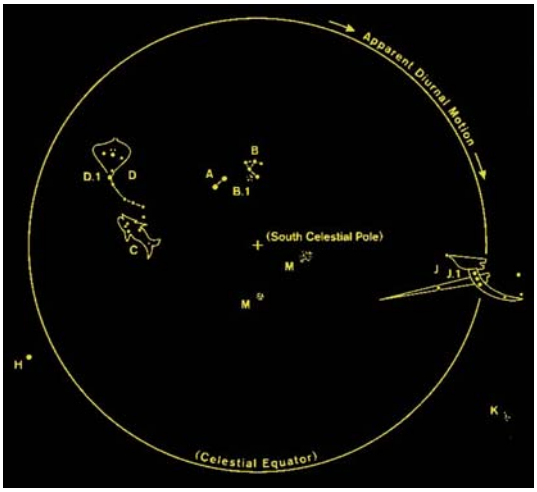
For the Bugis of the small coral islet of Balobaloang, located midway between Makassar on Sulawesi and

[3] For an exceptionally thorough historical and comparative discussion of concepts of orientation is several South Sulawesian languages, see Liebner (2005).

Bima on Sumbawa, trade routes are generally north and south across the Flores Sea. In principle, this allows them to take advantage of both easterly and westerly winds by reaching in either direction, although storms and heavy seas usually confined them, in the past, to port during the west monsoon. Formerly voyages were undertaken during the west monsoon only if the captain was hard pressed financially. Now, with motorization and larger ships, the voyaging season has been increasingly extended such that confinement to port is restricted to brief periods of severe weather, usually lasting no more than a week or two at a time.

Stars and Asterisms. Bugis navigators have long relied upon the stars and star patterns to set and maintain course. Although most sailors seem to know a few star patterns and their use, the navigators have been found to know many more. These star patterns, or asterisms, are known to rise, stand, and/or set above certain islands or ports when viewed from others and thereby pinpoint the direction of one's destination forming a "star compass." For example, in late July and early August *bintoéng balué* "Alpha&Beta Centauri" (Asterism A, Fig. 7) is known to make its nightly appearance at dusk in the direction of Bima as viewed from Balobaloang, that is, to the south.

As the night passes and a given asterism is no longer positioned over the point of destination, the navigator's thorough Gestalt-like familiarity with the sky allows him mentally to adjust to the new conditions: he can derive through visualization the points on the horizon at which the stars rise or set relative to wherever they currently appear. When a certain asterism simply is not visible, other associated but unnamed stars may be used to remind the navigator where the original asterism set or is about to rise or they may be used instead of the missing asterism. This, by the way, appears to be analogous to the "star path, the succession of rising or setting guiding stars down which one steers" described by Lewis for several cultures in Polynesia and Micronesia (1972:46–47). The stars identified by Bugis navigators are listed in Table 2 and illustrated in Figs. 7 and 8; those which are most relied upon will now be described.



Astronomy in the Indo-Malay Archipelago. Fig. 7 Bugis navigational stars: southern sky.

Perhaps the most frequently used asterism among the Bugis of Balobaloang is that *bintoéng balué*, mentioned above. These two bright stars are used to locate Balobaloang from Makassar and Bima from Makassar or Balobaloang. With regard to their rise/set points, navigators observe that they appear "in the south" at dusk during toward the middle of the east monsoon, the peak period for sailing; they further note that they rise "southeast" and set "southwest." Their brightness makes them visible even through clouds. The name *balué* is derived from *balu* that means "widow from death of the betrothed before marriage" with the affix *é* forming the definite article. Hence: "the one widowed before marriage." No graphical figure is attributed to this asterism.

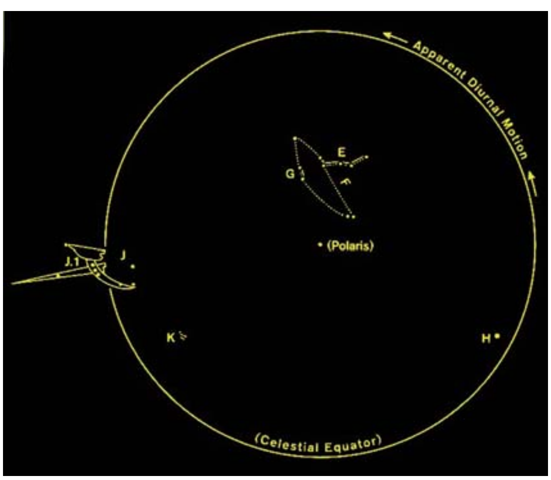
Just to the west of "Alpha&Beta Centauri" is *bintoéng bola képpang* (Crux), visualized as an "incomplete house of which one post is shorter than the other and, therefore, appears to be limping" (B in Fig. 7). Crux is used in conjunction with Alpha and Beta Centauri to navigate along southerly routes; like Alpha and Beta Centauri, it is known to set "southwest." Interestingly, it was emphasized that Crux is also used to help in predicting the weather. This asterism is located in the Milky Way that is known to the Bugis as *bintoéng nagaé* "the dragon," whose head is in the south and whose tail wraps all around the sky. As such, a bright haze of starlight surrounds Crux. On the eastern side of the house, however, there is a small dark patch totally devoid of light which is seen as a *bembé'* 'goat' (B.1 in Fig. 7). Between the squall clouds of the rainy season the goat in the sky may be seen standing, as goats are wont to do, outside the house trying to get in out of the rain. There are nights, however, when the goat is gone from the protection of the house. Hidden by haze, the missing goat portends a period of calm air and little rain.

In the northern sky the asterism that figures most prominently in Bugis navigation is known as *bintoéng kappala'é*, "the ship stars" in the international constellation of Ursa Majoris (two versions, E and F, in Fig. 8). The "ship" is used when traveling north and is known to rise "northeast" and sets "northwest" over Kalimantan from the port city of Makassar and from Balobaloang. Associations of this group of stars with the hull of a boat or ship appear to be common throughout the region.

Astronomy in the Indo-Malay Archipelago. Table 2 Bugis stars and asterisms familiar to navigators

Asterism	Bugis name[a]	English gloss	International designation
A	*bintoéng balué*	Widow-before-marriage	Alpha & Beta Centauri
B	*bintoéng bola képpang*	Incomplete house	Alpha–Delta, Mu Crucis
B.1	*bembé'*	Goat	Coal Sack Nebula in Crux
C	*bintoéng balé mangngiweng*	Shark	Scorpius (south)
D	*bintoéng lambarué*	Ray fish, skate	Scorpius (north)
D.1	(identified w/o name)	Lost Pleiad	Alpha Scorpii (Antares)
E	*bintoéng kappala'é*	Ship	Alpha–Eta Ursa Majoris
F	*bintoéng kappala'é*	Ship	Alpha–Eta Ursa Majoris; Beta, Gamma Ursa Minoris
G	*bintoéng balu Mandara'*	Mandar widow	Alpha, Beta Ursa Majoris
H	*bintoéng timo'* or *bintoéng timoro'* (Mak)[b]	Eastern star	Alpha Aquilae (Altair)
J	*pajjékoé* (Mak.)[b] or *bintoéng rakkalaé*	Plough stars	Alpha–Eta Orionis
J.1	*tanra tellué*	Sign of three	Delta, Epsilon, Zeta Orionis
K	*worong-porongngé bintoéng pitu*	Cluster seven stars	M45 in Taurus (Pleiades)
M	*tanra Bajoé*	Sign of the Bajau	Large and small magellanic clouds
[]	*wari-warié*	(No gloss)	Venus: morning
[]	*bintoéng bawi*	Pig star	Venus: evening
[]	*bintoéng nagaé*	Dragon stars	Milky way

[a]The Bugis term for "star(s)" is *bintoéng*; the suffix *é* may be translated as the definite article "the" in English.
[b]Although *timoro'* and *pajjékoé* are Makassar terms, they are more commonly used that the Bugis terms on Balobaloang.



Astronomy in the Indo-Malay Archipelago. Fig. 8 Bugis navigational stars: northern sky.

The two stars of *balu Mandara'* "widow of the Mandar" (G in Fig. 8) adjoin the "ship" and are likewise used to navigate northward. These two stars, Alpha and Beta Ursa Majoris, remind the Bugis of Alpha and Beta Centauri (thus the name *balu*), while "Mandar" recalls their northern seafaring neighbors.

Several asterisms and a planet are used for sailing east and west. They include: *timoro'* (Makassar) or *bintoéng timor'* (Bugis) "eastern star" (Altair; H in Fig. 8); *pajjékoé* (Makassar) or *bintoéng rakkalaé* (Bugis) "the plough stars" (Alpha–Eta Orionis; J in Figs. 7 and 8); *tanra tellué* "the sign of three" (Delta, Epsilon, Zeta Orionis; J.1 in Figs. 7 and 8); *wari-warié* [no gloss] or *bintoéng élé'* "morning star" (Venus in predawn sky); and *bintoéng bawi* "pig star" (Venus in evening sky), so named since it is believed that wild pigs will enter and destroy a garden or orchard when this object shines brightly in the west. Both the "pig star" and the "plough," by the way, speak to an agrarian lifestyle not practiced by Bugis seafarers but culturally shared with their kin who farm the lands of South Sulawesi as well as other islands of the archipelago. See Pelras (1987) for the astronomical knowledge of Bugis rice farmers.

Although the stars are useful guides, they are not always visible. Because it is possible to see landfall during the day, navigators appear to plan their voyages so as to maximize its usage. On a voyage from Balobaloang to Bima, the captain scheduled the departure for mid-afternoon allowing him to back-sight on Balobaloang and other islands of the atoll and observed the sun as it set in the west until dusk when Alpha and Beta Centauri appeared in the sky. There was, in fact, a period of about 30 min where both the receding island and the stars could be seen, providing a good opportunity to maintain course as attention was shifted from land forms to the stars.

Except during the height of the west monsoon, it is uncommon to experience extended periods of totally overcast skies. Should, however, the primary guiding asterism may be concealed by clouds, the navigator depends upon his knowledge of other asterisms or unnamed stars to fix his direction. If it is very cloudy, day or night, the navigator turns to wave directions and the magnetic compass to maintain course.

Although the more experienced navigators say that they could do without it and rely on wind, waves, and stars, the magnetic compass plays a central role in contemporary Bugis navigation and their presence should be of no surprise. Magnetic compasses, Liebner (2005) points out, have been used aboard the larger inter-island ships since the eighteenth century. On frequently sailed routes the helmsman knows from experience or from the navigator's instructions the proper compass bearing which will guide the boat toward its objective. At night under mostly clear skies, the helmsman points the ship's bow toward a succession of guide stars whose own azimuths change as the night passes. To compensate for this change, he checks the compass about once per hour, sometimes after several minutes of calling to a sleepy crew member for a flashlight or match by which to see it. On cloudy nights, when few or no stars are to be seen, the helmsman's job is much harder. Complicated by an often-unsteady helm, the helmsman is forced to check the compass every minute or so with a flashlight whose batteries are soon run down through constant use. By day the compass is generally observed more often regardless of the weather, although the sun, when low in the sky, is used as a reference.

Courses are committed to memory in terms of destinations and their required compass headings under various winds. That is, certain points of the compass are associated with certain destinations from various ports. For example, it is known that to sail from Balobaloang to Bima during the east monsoon, one must head due south, while during the west monsoon one heads south-southwest to southwest, depending on the strength of the wind and current. Likewise, to reach Makassar from the island during the east monsoon one travels somewhat east of north, while during the west monsoon a heading to the north-northwest is preferred. This difference, as navigators are quick to point out, takes into account drift from wind and currents, while true directions are also known. Practiced navigators have many of these bearings committed to memory and will refer to the experience of others as well as to charts and maps when they wish to travel to new or infrequent destinations.

On the author's initial voyage aboard a Bugis ship, the route traveled was well known to the seafarers of Balobaloang: Makassar to Bima via the island, a distance of about 212 nautical miles. Over the course of four days and five nights at sea without an auxiliary engine – and on later voyages after an engine had been installed – only occasionally were the helmsman or captain seen referring to the compass, and rarely at night or when in sight of land. When asked about this, both agreed that the compass could be used through the night, but to do so one would have to light the flashlight "so why not just use the stars?" Even if the compass were thrown overboard, we were assured the navigator could find his way.

Summary and Conclusion

This article has presented several examples of indigenous Indonesian calendrical and navigational systems and describes the celestial observations upon which they are based. It has also attempted to provide categories, drawn from international scientific astronomy, into which these observations may be placed.

With regard to the study of indigenous astronomical systems worldwide, there appear in regional agricultural calendars two types of celestial observations that may be unique to this cultural region. They are (1) observations of "cosmical" and "acronical" culminations – meridian transits at last and first gleam – of groups of stars and (2) observations of the lunar month for a limited number of months each year, creating discontinuous sidereal-lunar calendars. The use of stars by the Bugis navigators of South Sulawesi likewise appears represent a system that, along with its transformations used by Oceanic mariners, appears to be unique to the Austronesian world.

Implicit in the discussion of agricultural calendrical and navigation systems is the understanding that celestial observations do not stand alone. That is, many other environmental markers – changes in wind and weather and the appearances of flora and fauna also inform agricultural and navigational decision-making. It is suggested that by noting more carefully these and other signs in nature to which members of non-Western societies attend, we may gain a deeper appreciation of the true richness of human knowledge across cultures.

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Astronomy in the Islamic World

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From the ninth to the fifteenth century, Muslim scholars excelled in every branch of scientific knowledge; their contributions in astronomy and mathematics are particularly impressive. Even though there are an estimated 10,000 Islamic astronomical manuscripts and close to 1,000 Islamic astronomical instruments preserved in libraries and museums, and even if all of them were properly catalogued and indexed, the picture that we could reconstruct of Islamic astronomy, especially for the eighth, ninth, and tenth centuries, would still be quite deficient. Most of the available manuscripts and instruments date from the later period of Islamic astronomy, i.e., from the fifteenth to the nineteenth century, and although some of these are based or modeled on earlier works, many of the early works are extant in unique copies and others have been lost almost without trace; i.e., we know only of their titles. The thirteenth century Syrian scientific biographer Ibn al-Qifṭī relates that the eleventh century Egyptian astronomer Ibn al-Sanbadī heard that the manuscripts in the library in Cairo were being catalogued and so he went to have a look at the works relating to his field. He found 6,500 manuscripts relating to astronomy, mathematics, and philosophy. Not one of these survives amongst the 2,500 scientific manuscripts preserved in Cairo today.

The surviving manuscripts thus constitute but a small fraction of those that were actually copied; nevertheless they preserve a substantial part of the Islamic scientific heritage, certainly enough of it for us to judge its level of sophistication. Only in the past few decades has the scope of the activity and achievements of Muslim scientists become apparent, and the days are long past when they were regarded merely as transmitters of superior ancient knowledge to ignorant but eager Europeans. Islamic astronomy is to be viewed on its own terms. The fact that only a small part of the available material, mainly Greek and Indian material in Arabic garb, was indeed transmitted to Europe is to be viewed as an accident of Islamic history. There is no need to apologize for using the expression "Islamic astronomy." Within a few decades of the death of the Prophet Muḥammad in the year 632, the Muslims had established a commonwealth stretching from Spain to Central Asia and India. They brought with them their own folk astronomy, which was then mingled with local traditions, and they discovered the mathematical traditions of the Indians, Persians, and Greeks, which they mastered and adapted to their needs. Early Islamic astronomy was thus a pot-pourri of pre-Islamic Arabian starlore and Indian, Persian, and Hellenistic astronomy, but by the tenth century Islamic astronomy had acquired very distinctive characteristics of its own. Sabra (1987) labels this process "appropriation and naturalization."

Astronomy flourished in Islamic society on two different levels: folk astronomy, devoid of theory and based solely on what one could see in the sky, and mathematical astronomy, involving systematic observations and mathematical calculations and predictions. Folk astronomy was favored by the scholars of the sacred law (*fuqahā*ʾ), not least because of various religious obligations that demanded a basic knowledge of the subject; these legal scholars generally had no time (or need) for mathematical astronomy. That discipline was fostered by a select group of scholars, most of whose activities and pronouncements were, except in the case of astrological predictions, of little interest to society at large.

The astronomers also played their part in applying their discipline to certain aspects of Islamic religious practice. It was not Islam that encouraged the development of astronomy but the richness of Islamic society, a highly literate, tolerant, multiracial society with a predominant cultural language, Arabic: but neither did Islam, the religion, stand in the way of scientific progress. The Prophet had said: "Seek knowledge, even as far as China." To be sure, overzealous orthodox rulers occasionally pursued, killed, or otherwise attacked "scientists" or destroyed or burnt their libraries, but these were exceptions. The scholars of the religious law, who saw themselves as the representatives of Islam, generally ignored the pronouncements of the scientists, even on matters relating to religious practice. Astronomy was the most important of the Islamic sciences, as we can judge by the volume of the associated textual tradition, but a discussion of it in the broader context of the various branches of knowledge, which has been attempted several times elsewhere, is beyond the scope of this essay.

Arab Starlore

The Arabs of the Arabian peninsula before Islam possessed a simple yet developed astronomical folklore of a practical nature. This involved a knowledge of the risings and settings of the stars, associated in particular with the acronychal settings of groups of stars and simultaneous heliacal risings of others, which marked the beginning of periods called *nawʾ*, plural *anwāʾ*. These *anwāʾ* eventually became associated with the 28 lunar mansions, a concept apparently of Indian origin. A knowledge of the passage of the sun through the 12 signs of the zodiac, associated meteorological and agricultural phenomena, the phases of the moon, as well as simple time-reckoning using shadows by day and the lunar mansions by night, formed the basis of later Islamic folk astronomy.

More than 20 compilations on the pre-Islamic Arabian knowledge of celestial and meteorological phenomena as found in the earliest Arabic sources of folklore, poetry, and literature are known to have been compiled during the first four centuries of Islam. The best known is that of Ibn Qutayba, written in Baghdad about the year 860. Almanacs enumerating agricultural, meteorological, and astronomical events of significance to local farmers were also compiled; several examples of these survive from the medieval Islamic period, one such being for Cordoba in the year 961. The Yemen possessed a particularly rich tradition of folk astronomy, and numerous almanacs were compiled there.

Since the sun, moon, and stars are mentioned in the *Qurʾān*, an extensive literature dealing with what may well be labeled Islamic folk cosmology arose. This was inevitably unrelated to the more "scientific" Islamic tradition based first on Indian sources and then predominantly on Greek ones. Since it is also stated in the *Qurʾān* that man should use these celestial bodies to guide him, the scholars of the religious law occupied themselves with folk astronomy.

Persian and Indian Sources

The earliest astronomical texts in Arabic seem to have been written in Sind and Afghanistan, areas already conquered by the Muslims in the seventh century. Our knowledge of these early works is based entirely on citations from them in later works. They consisted of texts and tables and were labeled *zīj* after a Persian word meaning "cord" or "thread" and by extension "the warp of a fabric," which the tables vaguely resemble. The Sasanian *Shahriyārān Zīj* in the version of Yazdigird III was translated from Pahlavi into Arabic as the *Shāh Zīj*, and the astronomers of al-Manṣūr chose an auspicious moment to find his new capital Baghdad using probably an earlier Pahlavi version of this *zīj*. The various horoscopes computed by Māshāʾallāh (Baghdad, ca. 800) in his astrological world history are based on it.

Significant for the subsequent influence of Indian astronomy in the Islamic tradition was the arrival of an embassy sent to the court of the Caliph al-Manṣūr from Sind ca. 772. This embassy included an Indian well versed in astronomy and bearing a Sanskrit astronomical text apparently entitled the *Māhasiddhānta* and based partly on the *Brāhmasphuṭasiddhānta*. The Caliph ordered al-Fazārī to translate this text into Arabic with the help of the Indian. The resulting *Zīj al-Sindhind al-kabīr* was the basis of a series of *zījes* by such astronomers as al-Fazārī, Yaʿqūb ibn Ṭāriq, al-Khwārizmī, and others, all prepared in Iraq before the end of the tenth century. The *Sindhind* tradition flourished in Andalusia, mainly through the influence there of the *Zīj* of al-Khwārizmī (see below). As a result, the influence of Indian astronomy is attested from Morocco to England in the late Middle Ages.

Greek Sources

The *Almagest* of Ptolemy (Alexandria, ca. 125) was translated at least five times in the late eighth and ninth centuries. The first was a translation into Syriac and the others were into Arabic, the first two under al-Maʾmūn in the middle of the first half of the ninth century, and the other two (the second being an improvement of the first) towards the end of that century. All of these were still available in the twelfth century, when they were used by Ibn al-Ṣalāḥ for his critique of Ptolemy's star catalogue. The translations gave rise to a series of commentaries on the whole text or parts of it, many of them critical, and one, by Ibn al-Haytham (ca. 1025), actually entitled *al-Shukūk fī Baṭlamiyūs* (Doubts about Ptolemy). The most commonly used version in the later period was the recension of the late ninth century version by the polymath Naṣīr al-Dīn al-Ṭūsī in the mid-thirteenth century. Various other works by Ptolemy, notably the *Planetary Hypotheses* and the *Planisphaerium*, and other Greek works, including the short treatises by

Autolycos, Aristarchos, Hypsicles, and Theodosios, and works on the construction known as the analemma for reducing problems in three dimensions to a plane, were also translated into Arabic; most of these too were later edited by al-Ṭūsī. In this way Greek planetary models, uranometry, and mathematical methods came to the attention of the Muslims. Their redactions of the *Almagest* not only reformulated and paraphrased its contents, but also corrected, completed, criticized, and brought the contents up to date both theoretically and practically.

Theoretical Astronomy

The geometrical structure of the universe conceived by Muslim astronomers of the early Islamic period (ca. 800–1050) is more or less that expounded in Ptolemy's *Almagest*, with the system of eight spheres being regarded essentially as mathematical models. However, in Ptolemy's *Planetary Hypotheses* these models are already taken as representing physical reality; this text also became available in Arabic. Several early Muslim scholars wrote on the sizes and relative distances of the planets, and one who proposed a physical model for the universe was Ibn al-Haytham (fl. Cairo, ca. 1025). In order to separate the two motions of the eighth sphere, the motion of the fixed stars due to the precession of the equinoxes, and the motion of the fixed stars due to the apparent daily rotation, he proposed a ninth sphere to impress the apparent daily rotation on the others.

Of considerable historical interest are various Arabic treatises on the notion of the trepidation of the equinoxes. This theory, developed from Greek sources, found followers who believed that it corresponded better to the observed phenomena than a simple theory of uniform precession. The mathematical models proposed were complex and have only recently been studied properly (notably those of Pseudo-Thābit (date unknown) and Ibn al-Zarqāllu (Andalusia, ca. 1070), who seems to have relied on his predecessor Ṣāʿid al-Andalusī). The theory of trepidation continued to occupy certain Muslim scholars (in the late period mainly in the Maghrib), as it did European scholars well into the Renaissance.

Other significant Islamic modifications to Ptolemaic planetary models, devised to overcome the philosophical objections to the notion of an equant and the problem of the variation in lunar distance inherent in Ptolemy's lunar model, belong to the later period of Islamic astronomy. There were two main schools, one of which reached its fullest expression in Maragha in northwestern Iran in the thirteenth century (notably with al-Ṭūsī and his colleagues) and Damascus in the fourteenth (with Ibn al-Shāṭir), and the other developed in Andalusia in the late twelfth century (with al-Biṭrūjī). The latter tradition was doomed from the outset by a slavish adherence to (false) Aristotelian tenets and by mathematical incompetence. The former was based on sophisticated modifications to Ptolemy's models, partly inspired by new observations; Ptolemy himself would have been impressed by it, as have been modern investigators, for the tradition has been rediscovered and studied only in the latter half of this century. In the 1950s Kennedy discovered that the solar, lunar, and planetary models proposed by Ibn al-Shāṭir in his book *Nihāyat al-suʾl* (the Final Quest Concerning the Rectification of Principles) were different from those of Ptolemy; indeed they were mathematically identical to those of Copernicus some 150 years later. In this work Ibn al-Shāṭir laid down the details of what he considered to be a true theoretical formulation of a set of planetary models describing planetary motions, and actually intended as alternatives to the Ptolemaic models. He maintained the geocentric system, whereas Copernicus proposed a hypothesis, which he was unable to prove, that the sun was at the center of things. Nevertheless this important discovery raised the interesting question of whether Copernicus might have known of the works of the Damascene astronomer. Since the 1950s we have progressed to a new stage of inquiry: we now know that there was a succession of Muslim astronomers from the eleventh to the sixteenth century who concerned themselves with models different from those of Ptolemy, all designed to overcome what were seen as flaws in them. The question we may now ask is: was Copernicus influenced by any of these Muslim works? The answer is unsatisfactory, namely, that he must have been; definitive proof is, however, still lacking.

Mathematical Astronomy: The Tradition of the *Zījes*

The Islamic *zījes* constitute an important category of astronomical literature for the historian of science, by virtue of the diversity of the topics dealt with, and the information that can be obtained from the tables. Kennedy (1956) published a survey of about 125 Islamic *zījes*. We now know of close to 200, and material is available for a revised version of Kennedy's *zīj* survey. To be sure, many of these works are lost, and many of the extant ones are derived from other *zījes* by modification, borrowing, or outright plagiarism. Nevertheless, there are enough *zījes* available in manuscript form to reconstruct a reasonably accurate picture of Muslim activity in this field.

Most *zījes* consist of several hundred pages of text and tables; the treatment of the material presented may vary considerably from one *zīj* to another. The following topics are handled in a typical *zīj*:

1. Chronology
2. Trigonometry

3. Spherical astronomy
4. Solar, lunar, and planetary mean motions
5. Solar, lunar, and planetary equations
6. Lunar and planetary latitudes
7. Planetary stations
8. Parallax
9. Solar and lunar eclipses
10. Lunar and planetary visibility
11. Mathematical geography (lists of cities with geographical coordinates), determination of the direction of Mecca
12. Uranometry (tables of fixed stars with coordinates)
13. Mathematical astrology

As noted above, by the eighth century a number of Arabic *zījes* had been compiled in India and Afghanistan. These earliest examples, based on Indian and Sasanian works, are lost, as are the earliest examples compiled at Baghdad in the eighth century. With the *zījes* compiled in Baghdad and Damascus in the early ninth century under the patronage of the Caliph al-Maʾmūn, we are on somewhat firmer ground. These follow either the tradition of Ptolemy's *Almagest* and *Handy Tables* or the Indian tradition. Manuscripts exist of the *Mumtaḥan Zīj* of Yaḥyā ibn Abī Manṣūr and the Damascus *Zīj* of Ḥabash, each of which was based on essentially Ptolemaic theory rather than Indian. The *Zīj* of al-Khwārizmī, based mainly on the Persian and Indian traditions, has survived only in a Latin translation of an Andalusian recension. Amongst the most important and influential later works of this genre are: the *Ṣābīʾ Zīj* of al-Battānī of Raqqa, ca. 910; the *Ḥākimī Zīj* of Ibn Yūnus, compiled in Cairo at the end of the tenth century; the *zīj* called *al-Qānūn al-Masʿūdī* by al-Bīrunī, compiled in Ghazna about 1025; the *Zīj* of Ibn Isḥāq, compiled in Tunis, ca. 1195; the *I lkhānī Zīj* of Naṣīr al-Dīn al-Ṭūsī, prepared in Maragha in northwestern Persia in the mid-thirteenth century; and the *Sulṭānī Zīj* of Ulugh Beg from early fifteenth century Samarqand.

Although the *zījes* are amongst the most important sources for our knowledge of Islamic mathematical astronomy, it is important to observe that they generally contain extensive tables and explanatory text relating to mathematical astrology as well. Islamic astrological texts form an independent corpus of literature, mainly untouched by modern scholarship. Often highly sophisticated mathematical procedures are involved. It should also be pointed out that in spite of the fact that astrology was anathema to Muslim orthodoxy, it has always been (and still is) widely practiced in Islamic society.

All early Islamic astronomical tables have entries written in Arabic alphanumerical notation (*abjad*) and expressed sexagesimally, i.e., to base 60. A number written in letters equivalent to "23 30 17 seconds" (Ulugh Beg's value for the obliquity) stands for 23 + 30/60 + 17/3,600 degrees, i.e., 23°30′17″. In sexagesimal arithmetic, more so than in decimal arithmetic, it is useful to have a multiplication table at hand, and such tables, with 3,600 or even 216,000 entries, were available.

Already in the early ninth century Muslim astronomers had restyled the cumbersome Indian sine function using the Greek base 60 (which the Greeks had used for their even more cumbersome chord function). Likewise the Indian shadow functions, unknown in Greek astronomy, were adopted with different bases (12, 6, $6\frac{1}{2}$, and 7, and also 60, and occasionally 1). Most *zījes* contain tables of the sine and (co)tangent function for each whole, or half, or quarter degree of arc. Entries are generally given to three sexagesimal digits, corresponding roughly to five decimal digits. However, certain Muslim scholars compiled more extensive sets of trigonometric tables that were not included in *zījes*. In the early tenth century al-Samarqandī prepared a set of tables of the tangent function with entries to three sexagesimal digits for each minute of arc. Later in the same century Ibn Yūnus tabulated the sine function to five sexagesimal digits, equivalent to about nine decimal digits, for each minute of arc, also giving the differences for each second. He also tabulated the tangent function for each minute of arc, and the solar declination for each minute of solar longitude. His trigonometric tables were not sufficiently accurate to warrant this number of significant figures, and indeed over four centuries were to elapse before the compilation in Samarqand of the magnificent trigonometric tables in the *Sulṭānī Zīj* of Ulugh Beg, which display the values of the sine and tangent to five sexagesimal digits for each minute of argument and are generally accurate in the last digit.

Planetary Tables and Ephemerides

Given the Ptolemaic models and tables of the mean motion and equations of the sun, moon, and planets were available to Muslim astronomers in the *Almagest* and *Handy Tables*, or the corresponding tables based on Indian models that exemplify the *Sindhind* tradition, Muslim astronomers from the ninth to the sixteenth century sought to improve the numerical parameters on which these tables were based. Most of the leading Muslim astronomers of the early period made solar observations and computed new solar equation tables. Ibn Yūnus is the only astronomer from the first four centuries of Islam known to have compiled a new set of lunar equation tables. The majority of Islamic planetary equation tables are Ptolemaic, and where exceptions do occur, such as in the tables of Ibn al-Aʿlam and Ibn Yūnus for Mercury, we find that they are based on a Sasanian parameter rather than on any new observations.

Ptolemy used the same data as Hipparchus for his determination of the solar apogee and hence obtained the same result. The Muslims thus inherited the notion that the solar apogee is fixed with respect to the fixed stars (although the planetary apogees move with the motion of precession), and it is to their credit that their earliest observations established that the solar apogee had moved about 15° since the time of Hipparchus. Most early Muslim astronomers accepted the *Mumtaḥan* value of 1° in 66 Persian years (actually a parameter attested in earlier Persian sources) for both precession and the motion of the apogees. Ibn Yūnus possessed all the necessary data that could be used to demonstrate that the motion of the solar apogee is not the same as the motion due to precession, but he chose to use the same value for both, 1° in $70\frac{1}{4}$ Persian years, which happens to be remarkably close to the actual rate of precession. Al-Bīrūnī (Central Asia, ca. 1025) seems to have been the first to distinguish the proper motion of the solar apogee from the motion of precession (this discovery is sometimes erroneously attributed to al-Battānī). It was Ibn al-Zarqāllu (Andalusia, ca. 1070) who was the first to assign a numerical value to both motions, although he also subscribed to the theory of trepidation.

All Islamic *zījes* contained tables of mean motions and equations for computing solar, lunar, and planetary positions for a given time. Some of the equation tables are arranged in a form more convenient for the user (so that one simply has to enter the mean motions, and calculations are avoided). Auxiliary tables were sometimes available for generating ephemerides without the tedious computation of daily positions from mean-motion and equation tables. From the ninth to the nineteenth centuries Muslim astronomers compiled ephemerides displaying solar, lunar, and planetary positions of each day of the year, as well as information on the new moons and astrological predictions resulting from the position of the moon relative to the planets. Al-Bīrūnī described in detail how to compile ephemerides in his astronomical and astrological handbook *al-Tafhīm fī ṣināʿat al-tanjīm* (Instruction in the Art of Astrology). Manuscripts of ephemerides had a high rate of attrition since the tables could be dispensed with at the end of the year: the earliest complete extant examples are from fourteenth century Yemen, discovered in Cairo in the 1970s and still unpublished; on the other hand, literally hundreds of ephemerides survive from the late Ottoman period.

Stellar Coordinates and Uranography

Most *zījes* contain lists of stellar coordinates in either the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course) or the equatorial systems, or occasionally in both. A survey of the stellar coordinates in Islamic *zījes* would be a valuable contribution to the history of Islamic astronomy, and could help to determine the extent to which original observations were made by Muslim astronomers. An impressive amount of research on Arabic star names and their later influence in Europe has been conducted in the last few years by Paul Kunitzsch.

In his *Ṣuwar al-kawākib* (Book of Constellation Figures) the tenth century Shiraz astronomer al-Ṣūfī presented lists of stellar coordinates as well as illustrations of the constellation figures from the Hellenistic tradition and also information on the lunar mansions following the Arab tradition. Later Islamic works on uranography are mostly restricted to Persian and Turkish translations of al-Ṣūfī, although some astrological works also contain illustrations of the constellations that have recently attracted the attention of historians of Islamic art.

Spherical Astronomy and Spherical Trigonometry

Most *zījes* contain, in their introductory text, the solutions of the standard problems of spherical astronomy, such as, to give only one example, the determination of time from solar and stellar altitude. Rarely any explanation given of how the formulae outlined in words in the text were derived. There were two main traditions. In the first, the problems relating to the celestial sphere are reduced to geometric or trigonometric problems on a plane. The construction known as the analemma was a singularly powerful tool for solutions of this kind. In the second, the problems are solved by applications of rules of spherical trigonometry. Both techniques are ultimately of Greek origin, and Muslim scholars made substantial contributions to each.

There is some confusion about these contributions in the modern literature. It has been assumed by modern writers that when a medieval writer used a medieval formula that is mathematically equivalent to the modern formula derived by a specific rule of spherical trigonometry, the medieval scholar must have known the equivalent of the modern rule of spherical trigonometry. In fact, however, the medieval formula may have been derived without using spherical trigonometry at all. The first known Islamic treatise dealing with spherical trigonometry independently of astronomy is by the eleventh century Andalusian Ibn Muʿādh. The contributions to spherical astronomy by scholars such as Thābit ibn Qurra, al-Nayrīzī, Abu'l-Wafāʾ al-Būzajānī, al-Khujandī, Kūshyār ibn Labbān, al-Sijzī, and Abū Naṣr are outlined in the recently rediscovered *Maqālīd fī ʿilm al-hayʾa* (Keys to Astronomy) of al-Bīrūnī, also from the eleventh century.

Already in the work of Ḥabash in the mid-ninth century we find a Muslim astronomer at ease with both spherical trigonometrical methods and analemma constructions for solving problems of spherical astronomy. In the *Zījes* of scholars of the caliber of Ibn Yūnus and al-Bīrūnī we find various methods for solving each of the standard problems of medieval spherical astronomy.

The auxiliary trigonometric tables compiled by such scholars as Ḥabash, Abū Naṣr (Khwārizm, ca. 1000), and al-Khalīlī (Damascus, ca. 1360) for solving all of the problems of spherical astronomy for any latitude are a remarkable testimony to their mastery of the subject.

Observation Programs and Regional Schools of Astronomy: Al-Maʾmūn's Circle

In the early ninth century the Abbasid Caliph al-Maʾmūn patronized observations first in Baghdad and then in Damascus, gathering the best available astronomers to conduct observations of the sun and moon. Some of the results were incorporated into a *zīj* called *al-Mumtaḥan*, "tested," although the details of the activities at the two observation posts are somewhat confusing. The *Mumtaḥan Zīj* was apparently compiled in Baghdad by Yaḥyā ibn Abī Manṣūr, but upon his death, according to Ḥabash, the Caliph ordered his colleague Khālid al-Marwarrūdhī to prepare some new instruments and conduct a 1-year program of solar and lunar observations in Damascus in order to compile a new *zīj*. According to Ḥabash this was done, but no such *zīj* is otherwise known to have been prepared before Ḥabash's own *Damascus Zīj*. Also simultaneous observations of a lunar eclipse were conducted at Baghdad and Mecca, and the longitude difference used together with the newly measured latitudes of the two localities to find the *qibla* at Baghdad.

These observations, like later ones, were mainly directed towards determining the local latitude and current value of the obliquity, and towards deriving improved parameters for the Ptolemaic planetary models and more accurate star positions. The armillary sphere, the meridian quadrant, and the parallactic ruler were known to the Muslims from the *Almagest*, and they added new scales and other modifications, often building larger instruments even when smaller ones would have sufficed. Our knowledge of the instruments used by al-Maʾmūn's astronomers is meager. An armillary sphere used by Yaḥyā in Baghdad was said to display markings for each 10 min of arc, but even contemporary astronomers were not impressed by the precision of the results obtained using it. A mural quadrant made of marble with a radius of about 5 m was used in Damascus, as well as a vertical gnomon made of iron standing about 5 m high. Al-Maʾmūn also patronized measurements of the longitude difference between Baghdad and Mecca in order to establish the *qibla* at Baghdad properly, as well as measurements of the length of one degree of terrestrial latitude.

Other Observational Programs

Besides the officially sponsored observations conducted in Baghdad and Damascus in the early ninth century, there are numerous instances of other series of observations conducted in different parts of the Muslim world.

The two brothers called Banū Mūsā made observations in their own house in Baghdad and also in nearby Samarra about 30 years after the *Mumtaḥan* observations. They also arranged for simultaneous observations of a lunar eclipse in Samarra and Nishapur in order to determine the difference in longitude between the two cities. In view of their proficiency in mathematics, it is most unfortunate that neither of the two *zījes* compiled by them has survived.

Al-Battānī carried out observations during the period 887–918 in Raqqa in northern Syria. He appears to have financed his observational activity himself, and although we have no description of the site where he made his observations, the instruments mentioned in the *zīj* based on his observations include an armillary sphere and mural quadrant, as well as a parallactic ruler, an astrolabe, a gnomon, and a horizontal sundial.

The observational activities of the Baghdad family known as the Banū Amājūr were almost contemporaneous with those of al-Battānī in Raqqa. Father and two sons, and also a freed family slave, all made observations and each compiled a *zīj*, none of which survives. In the accounts of their eclipse observations recorded by Ibn Yūnus it appears that the place where they conducted their observations had some kind of a balcony fitted with slits for observation, but the details are obscure. A particularly interesting account of a solar eclipse in the year 928 that they observed by reflection in water includes a remark that the altitude of the sun was measured on an instrument marked for each third of a degree.

A large mural quadrant was erected at Rayy (near modern Tehran) about the year 950, but we have information only on its use to establish the local latitude and obliquity of the ecliptic. In Shiraz not long thereafter, al-Ṣūfī used an armillary sphere with a diameter of about 5 m to derive the same parameters and to "observe" equinoxes and solstices. Al-Ṣūfī is best known for his work on the fixed stars, but it seems that this was based more on "observation," looking at the heavens with the naked eye, than on "measurement," looking at the heavens with precision instruments and making estimates of positions. Another contemporary astronomer who conducted observations on which we have no information other than the main parameters of his *zīj* was Ibn al-Aʿlam.

In the late tenth century the distinguished mathematician and astronomer Abuʾl-Wafāʾ al-Būzajānī made observations in Baghdad. Most of these appear to have been directed towards the determination of the solar parameters, and the obliquity of the ecliptic and the latitude of Baghdad, although Abuʾl-Wafāʾ also collaborated with al-Bīrūnī in Khwārizm (modern Khiva in Turkmenistan) on the simultaneous observation of a lunar eclipse in the year 997. We have no information on the nature of the site where Abu'l-Wafāʾ made his observations, other than its location in a specific quarter of Baghdad.

Contemporaneous with the activity of Abu'l-Wafāʾ was the establishment in 988 of an observatory in the garden of the Baghdad residence of the Buwayhid ruler Sharaf al-Dawla. The organization of a building and program of observations was entrusted to Abū Sahl al-Qūhī, a mathematician of considerable standing. We know from contemporary historical records that a special building was erected for the observations, which in turn were witnessed by "judges, scientists and scholars of note, astronomers, and engineers." In view of the favorable conditions under which this observatory was established, and the competence of its director, it is somewhat surprising that the two recorded "observations" that were witnessed by so many dignitaries were the entry of the sun into Cancer and Libra in the year 988. Al-Bīrūnī describes the main instrument that was constructed as a hemisphere of radius 12.5 m on which the solar image was projected through an aperture at the center of the hemisphere. Activity at the observatory stopped in 989 with the death of Sharaf al-Dawla, so that the institution lasted not much more than a year.

In 994 Abū Maḥmūd al-Khujandī made a measurement of the obliquity using a meridian sextant of about 20 m radius. This instrument was erected in Rayy, but al-Khujandī confessed to al-Bīrūnī that it was so large that the center of the sextant had become displaced from its intended position.

The Egyptian astronomer Ibn Yūnus made a series of observations of eclipses, conjunctions, and occultations, as well as equinoctial and solstitial observations. We are extremely fortunate to have not only his reports of these observations, but also his citations of earlier observations of the same kind made by individuals such as Ḥabash and the Banū Amājūr. Ibn Yūnus' purposed in making these observations and recording them in the introduction to his *Zīj* is somewhat obscured by the fact that he does not list those observations or present those calculations with which he derived his new solar, lunar, and planetary parameters. Neither does he mention any locations for his observations other than his grandfather's house in Fustat and a nearby mosque in al-Qarāfa. The popular association of Ibn Yūnus with an observatory on the Muqaṭṭam Hills outside Cairo is, as Aydm Sayili has shown, a myth. Nevertheless, Ibn Yūnus mentions at least one instrument, probably a meridian ring, that was provided by the Fatimid Caliphs al-ʿAzīz and al-Ḥākim. In a later medieval Egyptian source Ibn Yūnus is reported to have received 100 dinars a day from al-Ḥākim, and it may be that such extremely high payments were made to Ibn Yūnus when he was making satisfactory astrological predictions for the Caliph. Al-Ḥākim made an abortive attempt to find an observatory in Cairo, but this was after the death of Ibn Yūnus in 1009. At some time during his reign there was an armillary sphere in Cairo with nine rings, each large enough that a man could ride through them on horseback.

The observations of al-Bīrūnī were conducted between 990 and ca. 1025 in several localities between Khwārizm and Kabul. His recorded observations include determinations of equinoxes and solstices, eclipses, and determinations of the obliquity and local latitude.

The corpus of tables known as the *Toledan Tables* was compiled in the eleventh century, based on observations directed by Ṣāʿid al-Andalusī and continued by Ibn al-Zarqāllu. Only the mean motion tables in this corpus of tables are original; most of the remains were lifted from the *zījes* of al-Khwārizmī and al-Battānī.

In the thirteenth century there was a substantial observational program at Maragha. The results are impressive only in so far as theoretical astronomy is concerned. Otherwise the trigonometric and planetary tables in the major production of the Maragha astronomers were modified or lifted in toto from earlier sources. This is not a happy outcome for a generously endowed observatory fitted with the latest observational instruments, known to us from texts. In the early fifteenth century the scene had moved to Samarqand in Central Asia: there, a group of astronomers, directed by the astronomer-prince Ulugh Beg, did impressive work. Only the 40-m meridian sextant survives from the observatory. These men produced a set of tables which it would be foolish to judge before they have been properly studied. The same is true for the short-lived observatory in Istanbul under the direction of Taqiʾl-Dīn (1577).

Regional Schools of Astronomy

After the tenth century they developed regional schools of astronomy in the Islamic world, with different interests and concentrations. They also had different authorities (for example, in the furthest East al-Bīrūnī and al-Ṭūsī, and in Egypt Ibn Yūnus). The main regions were Iraq, Iran and Central Asia, Muslim Spain, Egypt and Syria, the Yemen, the Maghrib, and later also the Ottoman lands. Only recently have the complex tradition of Muslim Spain (tenth to fourteenth centuries), the colorful tradition of Mamluk Egypt and Syria (thirteenth to early sixteenth centuries), the distinctive tradition of Rasulid Yemen (thirteenth to sixteenth centuries), and the staid tradition of the Maghrib (twelfth to nineteenth centuries) has been studied. The traditions of Ottoman Turkey and Mogul India are currently being researched.

Transmission to Europe

The Europeans learned of Islamic astronomy mainly through Spain, a region where, because of political problems and the difficulty of communications, the most up-to-date writings were not always available. This explains, for example, how it came to pass that the Europeans came across two major works of Muslim astronomers from the East, al-Khwārizmī and al-Battānī, at a time when these works were no longer widely used in the Islamic East. It also explains why so few Eastern Islamic works became known in Europe. None of the Eastern Islamic developments to Ptolemy's planetary theory was known in Andalusia or in medieval Europe. Al-Biṭrūjī's unhappy attempt to develop planetary models confused Europeans for several centuries; he must be worth reading, they naïvely thought, because he was trying to reconcile Ptolemy with Aristotle. As far as astronomical timekeeping was concerned, this does not seem to have been of much concern to the Muslims in Spain; hence nothing of consequence was transmitted.

On the other hand, some early Eastern Islamic contributions, later forgotten in the Islamic East, were transmitted to Spain and thence to Europe; they have been considered European developments because evidence to the contrary has seemed to be lacking. A good example is the horary quadrant with movable cursor (the so-called *quadrans vetus*), which was invented in Baghdad in the ninth century and (at least in the version with the cursor) virtually forgotten in the Islamic East thereafter; it came to be the favorite quadrant in medieval Europe. What, if any, astronomical knowledge was transmitted through Islamic Sicily remains a mystery, and nothing of consequence is known to have been learned about the subject by the Crusaders.

In the European Renaissance there was no access to the latest Islamic works. So the Europeans contented themselves with new editions of the ancient Greek works, with occasional, almost nostalgic, references to Albategnius (al-Battānī), Azarquiel (al-Zarqāllu), Alpetragius (al-Biṭrūjī), and the like. A few technical terms derived from the Arabic, such as alidade, azimuth, almucantar, nadir, saphea, and zenith, and a few star names such as Aldebaran, Algol, Al-tair, and Vega, survived. When the Europeans did come to learn of some of the major Islamic works and to try to come to terms with them it was as orientalists and historians of astronomy, for by this time the Islamic materials other than observation accounts were of historical rather than scientific interest. Thanks to orientalists like the Sédillots in Paris, works that had been completely unknown to Europeans and mainly forgotten by Muslims were published, translated, and analyzed. Islamic astronomy was highly respected by such scholars and others, like the historian of astronomy Delambre, who, innocent of Arabic, took the trouble to read what his colleagues had written about the subject. However, Islamic astronomy, indeed Islamic science in general, received a blow below the belt from Duhem, a physicist and philosopher ignorant of Arabic who simply ignored what scholars like the Sédillots had written. His thesis, that the Arabs were incapable of scientific thought and that whatever merits their science may have had were due to the intellectually superior Greeks, still has many followers, but only amongst those ignorant of the research of the past 150 years.

In the period after ca. 1500 Islamic astronomy declined. All of the problems had been solved, some many times over. Much of the innovative activity had led into a cul-de-sac, from which it would not emerge until modern times, thanks to investigations of manuscripts and instruments. Not that interest in astronomy died out. From Morocco to India the same old texts were copied and studied, recopied, and restudied, usually different texts in each of the main regions, but there was no new input or output of any consequence. Astronomy continued to be used as the handmaiden of astrology, and for the regulation of the calendar and the prayer times. Where there was innovation – such as, for example, in the remarkable device made in Isfahan ca. 1700 that correctly displays the direction and distance of Mecca for any locality – one must suspect the existence of an earlier tradition. However, the old traditions died hard, and Muslim astronomers for several centuries spent more time copying old treatises and tables than compiling new ones.

During the millennium beginning ca. 750 and especially in the period up to ca. 1050, although also in the period up to ca. 1500, Muslim astronomers did first-rate work, most of which was not known in medieval Europe at all. Those few Islamic works from the early period that were transmitted, notably the *zījes* of al-Khwārizmī and al-Battānī (especially through the *Toledan Tables*) and the banal summary of the *Almagest* by al-Farghānī, convey only an impression of classical astronomy in Arabic garb. However, they were in no way representative of contemporary Islamic astronomy in the East, and whilst the Europeans labored for centuries to come to terms with them, Muslim astronomers were making substantial contributions to their subject that have only been revealed by modern scholarship.

There is a wealth of material relating to this subject that remains untouched. Very few Islamic astronomical works have been published or have received the attention they merit. Three out of close to 200 Islamic *zījes* have been published in the optimum way (text, translation, and commentary). We have no published edition of the Arabic versions of the *Almagest* (except for the star catalogue), or of any Arabic recensions or commentaries. Many of the published Arabic scientific texts were printed in Hyderabad, most with no critical apparatus. Likewise most of the historically important Islamic astronomical instruments are still unpublished, although the catalogue currently in preparation in Frankfurt promises to make them better known.

In 1845 Sédillot, whose privilege it was to have access to the rich collection of Arabic and Persian scientific manuscripts in the Bibliothèque Nationale in Paris, wrote: "Each day brings some new discovery and illustrates the extreme importance of a thorough study of the manuscripts of the East." Sédillot also realized the importance of Islamic astronomical instruments. Given the vast number of manuscripts and instruments now available in libraries and museums elsewhere in Europe, the United States, and the Near East, and the rather small number of people currently working in this field, Sédillot's statement is no less true today than it was a century and a half ago.

See also: ►Astronomical Instruments in the Islamic World, ►Religion and Science in Islam, ►Stars in Islamic Science, ►Lunar Mansions in Islam, ►Ibn Qutayba, ►Time, ►*Zīj*, ►Māshāʾallāh, al-Khwārizmī, ►*Almagest*, ►al-Maʾmūn, Ibn al-Haytham, ►Naṣīr al-Dīn al-Ṭūsī, ►Precession of the Equinoxes, ►Ṣāʿid al-Andalusī, al-Zarqāllu, ►Maragha, al-Biṭrūjī, ►Astrology, ►Ulugh Beg, ►al-Bīrūnī, ►al-Battānī, ►al-Ṣūfī, ►Ibn Muʿādh, ►Observatories in Islam, ►Armillary Sphere, ►Qusṭā ibn Lūqā

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Astronomy in Japan: A Cultural History

Steven L. Renshaw, Saori Ihara

Japan's astronomical heritage, like so much of the culture's history, is one of enigma. Navigationally remote in ancient times and perhaps somewhat still socially remote amidst modern urbanization, it is easy for native and foreigner alike to perceive that there must be something unique and mysterious about what is "Japanese." Yet, this island country is a mixture of eastern and western imports, and the social, political, and pragmatic processes related to such importation have origins dating back at least two millennia. One who actually visits the country may be somewhat overwhelmed by a large number of temples, shrines, and other architectural landmarks, some dating back many centuries, all reflecting an interaction of native sociocultural systems with those derived from the Asian continent. The visitor may also be somewhat disappointed to find much of the nation's heritage engulfed by high-rise buildings and accompanying elements of industrialization, a factor which is also very much a part of modern Japan. Illumination from such industrialization is a thorn to every lover of the stars, from amateur to professional. Perhaps it is indeed the mixture of foreign imports with indigenous belief systems, a mixture more subtle than that of cultures such as the United States whose multiethnicity is so pronounced, that indeed proves to be the most unique aspect of Japan. In order to understand the deeper significance of Japan's heritage with the sky, one must often look beneath what appears on the surface.

For many in the West, astronomy in Japan is generally connected to Japanese names attached to comets, asteroids and supernova discovered by one of her many amateur astronomers, to astronauts accompanying NASA missions, to space probes launched from Tanegashima Island, or to the building of a huge telescope on Mauna Kea sporting the name of one of the most prominent asterisms of Japanese star lore, *Subaru*. A complete review of issues related to this heritage is far beyond the bounds of a single article. We will concentrate primarily on the cultural relations with the stars that have developed over the centuries in Japan. To provide an overview as well as a basis for understanding what astronomy means to this land, we will concern ourselves with (1) the development (or perhaps nondevelopment) of astronomy as a science in Japan, and (2) the significance of historical, social, and political purposes and their relation to star lore, mythology, and other aspects of cultural astronomy.

Astronomy as Science in Japan: Chinese and Western Influences

Many professional and amateur astronomers in Japan have asked, "Were ancient Japanese people not interested in the stars?" (see for example Yokoo 1997). Such a question reflects the fact that compared with Western traditions, it is quite difficult to find early star mythology and records of scientific or prescientific development that compare with many other ancient cultures. Though the exact date is uncertain, writing was introduced relatively late to the Japanese islands (the system was based on Chinese characters), and thus there is very little written record of ancient views of astronomy earlier than the seventh or eighth century.

In looking at Japan's development of astronomy, Aveni's (1989) allusion to a kind of ethnocentrism inherent in viewing *History of Astronomy* only through the eyes of the modern West and its evolved science is echoed in reverse. The Meiji Reformation (1867–1868) with a "deemphasis" of Buddhist traditions followed by post-World War II rejection of the most meaningful aspects of indigenous Japanese mythology left many in this country with a sense that there is and always has been little which can be considered original in astronomy emerging from Japan. On the other hand, the reader needs only to pick up any professional journal of astronomy to quickly find the names of Japanese authors who are conducting research in the science of astronomy using Western methodologies. Thus, to look at modern astronomy in Japan is not to look at any real cultural difference but instead to find an industrial country which is producing an increasing number of eminent scientists trained in Western methodologies. The importance of understanding cultural context relative to astronomical "knowledge" has been recently revived, and one cannot help but sense a certain "lack of self-esteem" among Japanese researchers who wish to pursue it.

In his *History of Japanese Astronomy*, Nakayama (1969) gives a very thorough account of the ways in which Chinese and later Western influences were imported into Japan throughout its history. Japanese astronomy was greatly conditioned and restricted by geographical, historical, and cultural barriers, and its early phases were dominated by Chinese influence and later by Western ideas. It is doubtful that any "scientific" expansion of Japanese astronomy occurred prior to close contact with China or with China via Korea. Further, while the primary purpose of calendrical study in both the West and in China was to develop precise means of time reckoning, calendar development in Japan generally focused on divination and securing the position of rulers rather than trying to develop precise theory, cosmology, or observation methods designed to explain the workings of the universe.

Nakayama's work is written in English and parallels the two-volume work on the *History of Astronomy* in Japan written in Japanese by the esteemed scientist and historian Watanabe (1986, 1987). A view of most Western discussions of the subject will lead the reader to conclude that little has changed in perception relative to Nakayama's assessment (see for example Sugimoto and Swain 1989; Pannekoek 1961; North 1995; Ronan 1996; Hashimoto 1997). While Aveni (1993) does emphasize more ethnographic and less ethnocentric viewpoints, he also tends to place Japan within the broader context of the "rich Chinese heritage," and does not really deal with Japan's cultural astronomical heritage.

When the English scholar, Chamberlain (1971), was assessing the general state of affairs in Japan in his *Japanese Things*, he indicated that even apart from any scientific originality, one would never find much creative lore composed in Japan relative to the stars. Viewing astronomy in Japan from only these perspectives, it is easy to get the impression that early and perhaps even later inhabitants of Japan never "looked up" were never inspired by much in the sky, patiently and/or eagerly waited for (or perhaps at times were even antagonistic toward) enlightenment from the Asian continent or later from the West, but nevertheless developed keen observational skills once such imports were implanted.

It is certainly true that almost everything which can be viewed as scientific astronomy was imported from the Asian continent or from the West in more modern times, and if only that side is viewed, discussion of the *History of Astronomy* in Japan can basically stop here. However, to discard the culture's relations with the sky by judging it only by its origination or development of scientific concepts dismisses what is perhaps one of the most unique case studies in how indigenous native beliefs (and accompanying views of the heavens) were integrated, seldom by forceful means (at least from the importer's side), with belief systems of other cultures (and their consequent views of the heavens). Such a pattern of coexistence has been paradoxical if not downright baffling to most Western eyes. By neglecting the socio-cultural side of Japanese history, one misses the complexity of the manner in which ancient Japanese (not only rulers, astrologers, and calendar scholars, but average farmers, fishermen, and other common citizens) incorporated astronomy into an extant system of belief and purpose, such providing culturally based reasons for the way astronomy did or did not develop in these islands.

Although we discuss many other examples of Japanese adaptation and development in the next section, it is worth noting particular historical events that we have explicated elsewhere (Renshaw and Ihara 1999). Consider the large influx of Chinese learning in the Asuka (late sixth to early eighth centuries AD) and Nara (710–784 AD) periods.[1] Certainly, palaces and Buddhist temples were being laid out using Chinese derived geomantic principles, and Chinese methods of calendar reckoning were adopted (Nakayama 1969). However, each aspect of Chinese learning that was incorporated had to find juxtaposition with a set of beliefs or purposes that sometimes stood in direct contradiction. Juxtaposing the descendancy of the emperor as a child of the sun goddess Amaterasu with the Chinese perception of imperial rule centered on the north celestial pole required some compromise. Buddhist temples aligned in North–South directions had to fit within a terrain that had Shinto shrines aligned in less celestial fashion but more along the flow of natural sites such as prominent sacred mountains, forests, waterfalls, or distinguished outcroppings of rocks. Apart from the necessary attendant "blessing" of a particular Shinto Deity on a Buddhist Temple, said deity often had a shrine built directly within the precincts of the temple grounds and was even given a form of "Buddhahood." Compromises also included such practices as substituting Shinto ritual objects for bones of the Buddha in the treasures buried beneath pagodas (see Matsumae 1993; Sonoda 1993; Brown 1993c).

The picture we see from reading Krupp's (1983, 1989) substantive accounts of temple layout and practice of seasonally based ritual in ancient Chinese capitals were only partially incorporated within the layouts and attendant rituals of ancient Japanese palaces and their imperial owners. Certainly, as will be seen in the review of social consciousness and purpose in the next section, rituals such as human sacrifice found no place in a belief system based on ritual purification and abhorrence of death. It is also significant to note that while China underwent several dynastic changes, some accompanied with revisions in cosmology and astronomical perception, Japan retained virtually one dynastic descendancy reaching well into the twentieth century, thus often seeing no need for "advances" taking place on the continent (Brown 1993a, c).

When cultural perspectives are included, it seems clear that the history of Japanese astronomy is not simply the history of Chinese astronomy or even, for better or worse, a direct mirror of such. While it may be impossible to distinguish anything as having been uniquely Japanese, cultural practices from earliest to modern times bear distinct marks of a social

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[1] An exhaustive account of these periods and the influence of continental imports is far beyond the scope of this article. The reader may find articles from Volume I of *The Cambridge History of Japan* series including Brown (1993a, b, c), Kidder (1993), Inoue (1993), Naoki (1993), Matsumae (1993), and Sonoda (1993) to be particularly relevant to a deeper understanding of these processes.

consciousness and purpose inherent in Japan's cultural development. Too, while Chinese astronomy may not have been given its due in modern scholarship, it is also evident that all Asian cultures cannot be "lumped together" with China in order to gain a full understanding of the relation of astronomy and culture in any particular one.

Socio-Political Purposes and Their Impact on Development and Adaptation of Star Lore and Mythology

Ruggles and Saunders (1993) ask, "What do people see when they look at the sky?" and further state that "the answer is as much a cultural as an astronomical one." Their perception is especially relevant to unraveling the enigma of Japan's heritage with the sky. A growing database of archaeological evidence, renewed postwar and nonreactive scholarship with regard to historical texts, and the development of interdisciplinary approaches reveal Japan as a culture that has always been guided by an indigenous social consciousness and for most of its history a rather consistent set of social and political purposes (Brown 1993a). Such was certainly a factor in how Japanese developed myth, legend, and lore related to the stars, and it is in this area that we can find the rich sources of cultural astronomy in Japan.[2]

The ancient sense of social consciousness and purpose may best be understood by using the analogy of a lake fed by two springs. The lake represents the historical and modern socio-cultural milieu of Japan, and the springs feeding it are the sources from which that milieu has been formed. The first and nearest spring is composed of a native social consciousness and a specific set of socio-political purposes that we detail later. The second spring (better viewed as many secondary springs) consists of the infusion of ideas, concepts, technologies, philosophies, and religions including a virtually continuous input from the Asian continent and in later centuries large contributions from the West.

It is important to realize that the primary spring has always been fed by the second. The flow may have been slow or even imperceptible at times, but it has always been there (Oguma 1995). On the other hand, this primary spring (regardless of its diverse historic origins) has always been deep and has formed an archetypal base through which everything must be filtered to become "Japanese." At least within the last 1,600–1,800 years, the secondary spring has probably never had a direct route to Japan's archetypal lake; such flow has almost always passed through the primary spring.

Brown (1993c), Kidder (1993), and Matsumae (1993) have provided a cogent paradigm through which Japanese social consciousness and attendant Shinto beliefs and practices may be understood as well as socio-political purposes that guided the early formation of Japan as a unified country. From this paradigm, three primary aspects of early Japanese consciousness emerge: "linealism," "vitalism," and "optimism." Linealism emphasizes ancestral descendancy with filial duty to parents, siblings, friends, nation, etc. Vitalism emphasizes life along with the abhorrence of anything that has to do with death and stresses ritualistic (not moralistic) purity. Optimism places emphasis on being concerned, not so much with the distant past or future, but rather with moving forward through seasons and cycles of life, regardless of circumstances. The socio-political purposes which played a role in Japan's early development as a nation may perhaps be best paraphrased as follows: (1) unification of often warring petty "kingdoms" (along with their local myth, legend, and lore) through (2) cooperative efforts of common people in various ways such as cultivating rice (using celestial signs and allegories for seasonal determination of planting and harvesting as well as agriculturally based festivals) in order to (3) establish a singular lineal order of imperial rule (resulting in perhaps one of the greatest national Japanese myths that of the sun goddess Amaterasu and her place as ancestral head of the imperial line).[3] It can easily be argued, given political developments of the twentieth century, that while some commodities have

[2] A good chronology in English of Japan's general history may be found in Torao and Brown's (1991) *Chronology of Japan*. The most exhaustive history of Japan in English is the recently released Cambridge series (Hall et al. 1993). For shorter and perhaps more approachable views of Japanese history written in English, the following may be of value: Sansom's (1974) prewar but still viable 3 – volume *A History of Japan* and his (1973) *Japan: A Short Cultural History*; Hall (1971) *Japan From Prehistory to Modern Times*; Mason and Caiger (1973) *A History of Japan*; and Morton (1995) *Japan: Its History and Culture*.

[3] From our earlier discussion, the reader should have a good idea of the kinds of conflicts many imported ideas created for early Japanese. Other brief examples will further clarify the point: while the infusion of Confucianism reinforced many aspects of "lineality," especially with regard to the development of bureaucratic governmental practices, the Confucian idea of a cyclical rise and fall of dynasties was never really accepted in Japan and stood directly against the idea of a singular imperial line. The fourth and fifth century infusions of Buddhism with beliefs, which emphasized a better life in death than in the present, directly contradicted the concept of vitalism and optimism. In addition, the Buddhistic idea of eventual decay as well as the Confucian idea of a "glorious past" were incongruent with virtually all aspects of Japanese consciousness and purpose.

changed and political power has not always been imperial based, these fundamental aspects of Japanese consciousness and purpose still form a prime keystone of the culture's psyche.[4]

One of the few writers in English to deal with Japan's cultural star lore and myth is Krupp (1991, 1997). Readers may be familiar with the several accounts he provides of the fundamental Japanese myth of Amaterasu and its relation to the Japanese political history. However, while this myth, itself closely tied with the political purpose of unification, is a prime example of lore that reflects Japanese sense of consciousness and purpose, there are many other aspects of Japanese traditions and bodies of star lore which show the complex relation between indigenous native belief, pragmatic social need and purpose, and the kinds of celestial ascription's that developed therefrom. Little of this material has found its way into English sources, and in the remainder of this article, we discuss some of many examples of relations between Japanese values and social purpose and the stars. Specifically, we will look at (1) values applied to particular star groupings such as Oyaninai Boshi, (2) cooperative efforts such as planting, harvesting and fishing reflected in star lore closely tied to such asterisms as Subaru and the belt stars of Orion, (3) ancient Japanese purposes as seen in star paintings of archaeological sites such as the tombs of Takamatsu Zuka and *Kitora Kofun*, (4) mixtures of Shinto belief and values seen in adaptations of continental legend and ritual such as that of the legend of Orihime and Kengyuu and its relation to the festival of Tanabata, and (5) the pre-eminent holiday of the year for Japanese, New Years Day, in which the values of linealism, vitalism, and optimism come together in a celestial greeting of new beginnings.

Oyaninai Boshi: Linealism, Vitalism, and Optimism in the Stars

There are a number of celestial symbols which concern various groupings of three stars; Oyaninai Boshi including Orion's belt stars (Nojiri 1973), three stars of the fifth moon station of the Azure Dragon of Spring which includes Alpha Scorpio flanked by Sigma and Tau, and three stars discerned in the constellation Aquila including Alpha flanked by Beta and Gamma Aquila (Uchida 1973).[5] All have to do with seeing the image of two parents standing or being supported on either side by their child in the middle. Such symbols of filial duty are numerous in Japanese star lore and reflect the strong sense of lineality later reinforced by Confucian ethics. Further, particular attention is placed on this value relative not only to parents but to friends as well. An example of a sense of Japanese identity is seen in Kenji Miyazawa's more modern "lore," *The Milky-Way Railroad* (Sigrist and Stroud trans. 1995).[6]

Another legend incorporating the aforementioned sense of Japanese consciousness includes the belt stars and M42 region of Orion. According to Uchida (1973), one day two sisters were walking down the road, the younger dutifully following her older sister and shouldering a tub of water. Being chased by an ogre, they found a rope leading to the heavens and began to climb. Though the sisters escaped the ogre, the younger sister sadly had her foot bitten off. These days, we see the bamboo pole (the three belt stars called Take no Fushi in this story) with which she continues to carry water as she follows her sister (the moon) around the sky. Her remaining foot (M42 region) peeks from the folds of her kimono. Western readers may find the end of this legend disturbing or even somewhat cruel. However, all the fundamental values of Japanese consciousness are found in this story: linealism in the form of filial duty, vitalism in strength and courage, and optimism in a will to "go on" within ones present condition to an immediate brighter future.

The anecdotal nature of such star lore and legend takes on a completely different meaning when viewed within the context of ancient Japanese social consciousness and purpose. Again, while it would be futile to argue that such lore developed independent of external sources, it is also clear that its Japanese development reflects a unique cultural identity.

Cooperative Activity: Pragmatic Signs in the Stars

As in many cultures, the three belt stars of Orion (called *Mitsu Boshi*), the Hyades (*Ame Furi Boshi* or Rain Stars), and the Pleiades (*Subaru*) played a prime role as symbols of fertility and time pieces relative to seasonal

[4] It is easy for the reader to get full insight into the significance of these ideas by reading the many excerpts of manuscripts from periods throughout Japan's history which are accompanied by commentary in the excellent *Sources of Japanese Tradition* compiled by Tsunoda et al. (1964). The sense of Shinto consciousness and its pervasiveness in modern Japanese life is also discussed by Shigemitsu (1996).

[5] Here and in later sections, we discuss the Chinese derived *Sei Shuku* or "moon stations" along with the animals of cardinal directions. Though used extensively in Japan from earliest Chinese infusions, a discussion of their complexity is more appropriate in a work on Chinese astronomy. The reader is urged to look at sources such as Needham (1959), Ho (1985), or Nivison (1989).

[6] *Douwa Shu; Ginga Tetsudou no Yoru*. (A Collection of Tales; Night of the Milky-Way Railroad) was originally started in 1924, adapted for some years, and finally published posthumously in 1951. It remains one of the most popular stories in Japan, loved by children and adults.

change, specifically planting and harvesting during the rice cultivation period (Hirose 1972; Uchida 1973; Nojiri 1973, 1982). Their earlier and later heliacal setting in Spring as well as heliacal and later rising in Fall encapsulate that season and in more ancient times provided symbols related to festivals such as Spring *Higan* and *Ura Bon*. Spring Higan is celebrated within a period of 7 days surrounding the Spring Equinox. At this time, as any casual observer in latitudes similar to Japan will note, the Pleiades, Hyades, and Orion, all begin to set earlier and earlier each evening. For early Japanese, this setting was allegorical to planting of rice seedlings (Subaru or the Pleiades appearing as united seedlings), the rainy season (Hyades or Ame Furi Boshi seen as rain stars), and cultivation (one of the earliest symbols seen in the three belt stars of Orion was that of *Karasuki* or plow). Ura Bon is celebrated in the Fall when ancestral *kami* (deity) visit and are sent on their way in thanks for bountiful harvests. In more ancient times, when this festival was celebrated on the lunar calendar based 14th–16th days of the 7th month (late August or early September in the Gregorian calendar), these three prominent star patterns were indeed seen to transit the zenith as the full moon set and dawn arrived, a signal that ancestral spirits had indeed departed for yet another "season" (Miyata 1996). The appearance of Subaru rising in the evening at this time of year seems to have had significance not only in its relation to the end of the rice harvest but to the coming of winter.

The mythology found in the *Kojiki* (Records of Ancient Matters; see Chamberlain trans. 1981; Philippi trans. 1968) and the *Nihongi* (Chronicles of Japan; see Aston trans. 1972) places much importance on the deity (sun goddess) Amaterasu, who "conquered" lesser deities (local states) and was considered the progenitor of the imperial line. Interestingly, one of the earliest and most significant aspects of Subaru was related to the myth of Amaterasu. Apparently taken from the phrase *mi Sumaru no Tama*, the name *Sumaru* was used to describe this asterism referring to the string of the august jewels known to have been hung on the *sakaki* tree while deities danced to lure Amaterasu from the cave (Nojiri 1973). Allegorically, just as the sun (Amaterasu) was seen to depart for the winter, jewels (Subaru or Sumaru) were seen to appear in the sky, jewels which could be seen throughout the winter months and serve as a reminder for early Japanese that at some time the sun would indeed return with her Spring warmth, and another planting season could begin.

Lore related to Subaru is extensive, but its prime importance can be seen in the fact that it not only played a role in what would become a central myth for unification of the country, but also a time piece for the pragmatic need of farmers and fishermen who played a role in such unification efforts. For common people, struggle for unification was of secondary importance. What was of prime concern was that they know good and bad times for planting, harvesting, or setting lines for fishing. While the three star patterns we have mentioned were of significance because of their heliacal rising and setting, the three belt stars of Orion, due to their prominence, apparent equal spacing, and perceived change in position as they traced their way across the winter sky, were of particular pragmatic use to early and later Japanese citizens.

When viewed in early evening, the perceived angle of the three belt stars seen rising in the East, moving across the sky, and setting in the West at different times of the year, provided the base for particularly interesting lore in which farmers used Orion as an agricultural symbol (Uchida 1973; Hara 1975; Nojiri 1988). The three belt stars are variously called *Awainya Boshi* (Millet Stars), *Komeinya Boshi* (Rice Stars), or *Awaine Boshi* (Millet and Rice Stars). All these names relate to seeing *Mitsu Boshi* as a fulcrum, balancing the yield of rice or millet crops as they move across the heavens. The star *Alnilam* (*Epsilon Ori*) is seen as the center of this fulcrum. *Mintaka*'s (*Delta Ori*) being higher or lower than the center indicates the yield of millet; *Almitak* (*Zeta Ori*) represents the yield of rice. In latitudes of Japan, *Mitsu Boshi* rises in an apparent vertical position. As the three stars move across the sky in the fall, they appear at an angle that gives rice a strong weight on the balance; this is the time to harvest rice and plant millet. As this constellation is seen setting in the West in late Spring, Zeta Ori begins to dip lower and lower; this is the time to harvest millet and plant rice.

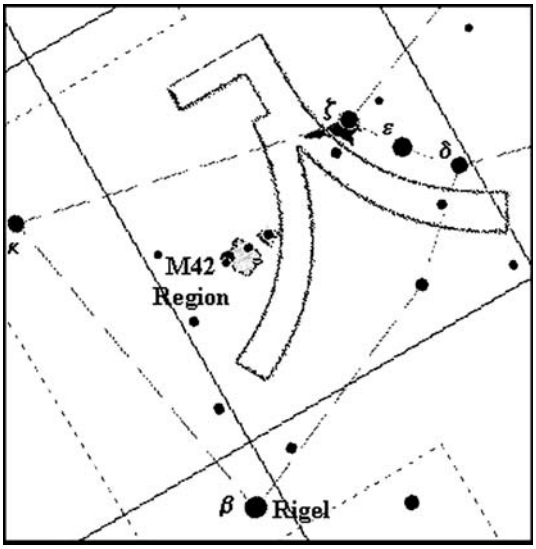
Especially in the cultivation of rice, several symbols of agriculture have been seen in the relation of the three belt stars to the M42 region. One of the oldest object references associated with this configuration uses the term *Karasuki* to describe the three belt stars as prongs of a plow with the M42 region being the handle used to pull it in the field. As mentioned earlier, this symbol is especially meaningful related to the evening appearance of the three stars in the time of early spring.

As a further example of adaptation of imports to suit unique and indigenous Japanese needs, it is interesting to look at some of the Chinese interpretations of star groupings such as Subaru or the three stars of Orion's belt and the differences in names applied by each culture. By the seventh century (perhaps earlier), the Chinese "cosmology" which gave rise to the concepts of 28 *Sei Shuku* or lunar stations encircling the celestial globe had found its place in Japan (Nakayama 1969; Watanabe 1987). The constellation of Orion contains two such *Sei Shuku*: the 20th which includes the small *Meissa* (*Lamda*, *Phi Ori*) and the 21st which embodies a much larger section of Orion and is most distinguished by the belt stars (*Mitsu Boshi*). Chinese characters were used by later Japanese writers to represent these configurations; however, the original Chinese term for the 21st *Sei Shuku* was simply *Shin* (three) while earliest records of Japanese nomenclature use *Karasuki* or plow (Ozaki et al. 1993; Shinmura 1994). Early Japanese gave little significance to the 20th station. Though continental influence can certainly not be dismissed as a major factor in Japan's agricultural development especially with regard to tools, it would appear that seeing this agricultural symbol in Orion may indeed have been in use before introduction of writing and other imports of more advanced Chinese culture into Japan.

Following massive infusions of culture from China and Korea, Japanese emperors practiced the custom of "plowing the first furrow" around the lunar New Year. However, Japanese lore associating the three stars with a plow seems to have preceded and perhaps only been augmented by the introduction of this Chinese based ritual.[7] "Astronomy" as practiced in China during Japan's early formation as a nation had depended for some time on somewhat more precise estimates of a lunar calendar for fixing dates (Nakayama 1969; Ho 1985). Because of its pragmatic use as an agricultural sign (though nonprecise), especially its prominent evening setting at what later was called Spring *Doyou* (the period of 18 days prior to the sectional term "Summer Begins," the official time for preparation to begin planting rice), *Karasuki* may have been original with early Japanese farmers. At any rate, its setting has certainly survived as a symbol of planting in most rice producing parts of Japan.

Another symbol for planting indeed reflects Chinese influence, and this is clearly seen in the incorporation of *Kanji* or Chinese characters. This symbol, again related to the setting of Orion in the West during the beginning of the rice cultivation season, was yet another reinforcement for use of the belt stars and M42 region as a sign for planting. Uchida (1973) indicates that Japanese in some agricultural areas see the Kanji for "entry" in the configuration and call it *Hoshi no Iri* (Entry of Stars). As fishermen saw stars set into the sea, Japanese farmers saw stars set into the western landscape. This symbol of Iri was merely another sign that it was time to plant (enter) rice seeds into the earth (Fig. 1).

Agricultural associations discussed so far have generally been related to the setting of *Mitsu Boshi* during early stages of annual rice cultivation. As mentioned, the rising of the three belt stars in the East was also an agricultural symbol and was allied with the end of the period of rice cultivation. Hara (1975) records



Astronomy in Japan: A Cultural History. Fig. 1 The *Kanji* for *Iri* or Entry superimposed on the belt stars and M42 region of Orion (computer graphic by Steven L. Renshaw).

that in many rice farming areas, the stars were called *Haza no Ma*, a term that refers to a three pole stand that is used in the field to dry rice. In the early phases of autumn, when Orion is no longer seen at sunset but rather rising earlier and earlier each night, farmers looked to the belt stars and saw them as a symbol that "only *Hasa* are left in the field," the harvest of rice being over.

While the combination of a lunar calendar and later adoption of a Gregorian calendar in post-Meiji era Japan led to more precise methods for determining times for planting and harvesting, many old farmers in rural agrarian areas still use methods that are centuries if not millennia old. According to Uchida (1973), the following timepiece is still recited in such areas: "When *Mitsu Boshi* are one fathom high, it's time to go to bed; when *Mitsu Boshi* are in the middle, it's the middle of winter; and when *Mitsu Boshi* lay, it's time to wake up." This refers to the vertical alignment of the three belt stars as they rise in early Fall, the angular position in the middle of the Southern sky in Winter, and the horizontal visual alignment in the West in Spring. These metaphors are related to, respectively, Fall harvest, Winter rest, and Spring planting.

Star lore related to fishing is somewhat more rare than that which is related to crop cultivation. It was primarily through cooperation of local farmers along with their local ancestral *kami* in the production of rice that early Japanese rulers were able to fulfill their purpose of unifying the country. Still, incorporating the legends of families of fishermen was an important part of this unification, and a mix of agrarian and fishing lore is found (see Nojiri 1982, 1987).

[7] See Krupp (1983, 1989) for a description in English of this and other cultivation related ceremonies that were practiced by the emperor in China. As they were recognized in Japan, some became part of the imperial ceremony, but many never found a place either because they did not fit within the imperial 'purposes' mentioned earlier or because they were in direct conflict with native *Shinto* belief (ritual sacrifice, for example).

In some fishing areas, the three belt stars are called *Kanatsuki*, which is a name given to a spear with three prongs used in fishing (Nojiri 1973; Uchida 1973). We can note some similarity in pronunciation of *Karasuki* (plow) and *Kanatsuki*. As a sign, *Kanatsuki* was used as a timepiece for favorable catches. When prospects for such seemed to be particularly good in the Fall, old fishermen were often heard to say "Let's wait for *Kanatsuki*" before going out for the evening's catch.

Perhaps one of the most significant relations to "fishing" found with *Mitsu Boshi* relates to their designation by some fishermen as Sumiyoshi Boshi. Sumiyoshi were the three deities mentioned in the *Kojiki* as being created from the ocean and being particularly favorable to seafarers (Nojiri 1988). Incorporation of these deities in the *Kojiki* and *Nihongi* was no doubt designed to find favorable reaction from the *be* or local families of fishermen. However, their use in legends which also included allusions to agricultural symbols make them a significant aspect of the way in which Japanese developed celestial allegories.

Obviously, ancient Japanese were not blankly "staring at their rice fields" while the heavens "revolved" overhead. Creative and pragmatic use of star patterns played a central role in the day to day life of common citizens. Using the example of the belt stars of Orion, we have briefly discussed some of the more significant associations used in cooperative activity.

Adaptation of Asian Cosmology for Power and Centrality: *Takamatsu Zuka* and *Kitora Kofun*

Some archaeological sites may provide cogent information relative to the early interaction of Japanese values and purpose with imported cosmology. One of the major archaeological discoveries was made in the early 1970s (Hirose 1972) in Asuka village, Nara prefecture. From an Edo Era painting showing this mound with a tall pine tree atop, this tomb was called *Takamatsu Zuka Kofun* (Tall Pine Burial Tomb) (Fig. 2).

Dating indicates that the tomb was built in the latter part of the seventh or early part of the eighth century. As was and is the case with most burials in China, Korea, and Japan, the tomb was aligned with celestial north. Paintings of animals related to the four cardinal directions were found on the walls, and careful inspection of the ceiling revealed a chart including the 28 *Sei Shuku* (lunar stations). Only a few scholars knew of the tomb's existence in the Edo era (1603–1867) and most believed it was that of the emperor Monmu (emperor from 697 to 707). Modern excavation revealed no inscription, and Monmu's tomb was later determined to be to the East. Similar tombs have been found in both China and Korea, and the construction period was also one in which scholars from Korea had been invited to the imperial court.

Astronomy in Japan: A Cultural History. Fig. 2 *Takamatsu Zuka Kofun* is aligned with celestial north. This view from due south shows the bamboo covered mound of the tomb. The doors are to chambers of relatively recent origin; inside are housed temperature maintenance and dehumidifying equipment used to protect the small tomb's delicate paintings. The tomb is not opened to the public (photo by Steven L. Renshaw).

What is significant about *Takamatsu Zuka Kofun* is the fact that it clearly shows the influence of Chinese and Korean cosmology on Japan in the Asuka Era (late sixth to early eighth centuries). In 1998, another such tomb, located about 1 km to the South of *Takamatsu Zuka Kofun* on Mount Abe and named *Kitora Kofun* (after the Kitaura area of Asuka village) was explored. The tomb was not actually entered but probed with subminiature cameras. Preliminary dating placed its construction within the same Asuka period as *Takamatsu Zuka Kofun*. While there are some remarkable similarities, there are also some anomalous differences in the paintings of the two tombs.

In *Kitora Kofun*, the paintings of the animals of cardinal directions appear to be in somewhat better condition than those of *Takamatsu Zuka Kofun* (in which some paintings appear to have been defaced in ancient times). The animals do seem to have been painted in a freer style than those that are found in the tomb to the north. There also appear to be more stars in the Kitora tomb paintings of the *Sei Shuku*. Unlike *Takamatsu Zuka Kofun*, the celestial equator and ecliptic as well as "the heavenly river" or Milky-Way appear distinct. Like *Takamatsu Zuka Kofun*, the tomb appears to have been plundered of any "treasure" it may have held. The south wall of *Takamatsu Zuka Kofun* was obliterated by entry in ancient times thus eliminating the painting of the Red Bird of Summer.

With regard to astronomical content, there are other significant differences. First, the paintings of *Sei Shuku* in *Kitora Kofun* appear to be based on Chinese/Korean charts of a much earlier period than that of *Takamatsu*

Zuka Kofun. Second, the point of the crossing of the ecliptic with the celestial equator can be seen in *Kitora Kofun* and appears to be near a point in Aries closer to Taurus and corresponding with a position several centuries earlier than the Asuka era or the tomb's construction (the vernal equinox was shifting into Pisces by the end of the seventh century). Third, since enough stars are seen in *Kitora Kofun* to determine just which ones could and could not be seen on the horizon, a relatively good estimate of observer latitude can be made. Fourth, the painting of the "White Tiger of the West" is reversed from that of *Takamatsu Zuka Kofun* and tombs with similar paintings found in China. In *Kitora Kofun*, the tiger is painted facing north. This point is especially interesting. When looking at the west wall of *Takamatsu Zuka Kofun* (note the photograph of the White Tiger in the Chinese tomb of similar dating in Krupp's *Echoes of the Ancient Skies* 1983: 112), the tiger is seen to face south, and this indeed corresponds with the placement of the figure of this animal among the stars. (Editor's note: see a detailed discussion of *Kitora Kofun* in this encyclopedia.)

These tombs provide us with a view of how Chinese/Korean astronomical thought found its way to Japan, and how such thought was incorporated into the social purposes of Japan's rulers. It seems evident that it is not the accuracy of the cosmology reflected in the tombs' paintings but rather the almost wholesale adoption of Chinese perceptions to further strengthen the centrality of imperial rule that was most important, especially in the case of *Kitora Kofun*. Japanese rulers wished to give themselves the same legitimacy that Chinese rulers had; incorporation of symbols and astronomical methods in order to accomplish this did not necessitate complete awareness of the underlying principles, but rather their mere presence. As mentioned earlier, such was the case with the introduction of Buddhism as well as other aspects of Chinese thinking. One can still see this kind of use of foreign import without substantive understanding in the almost playful use of foreign language in what sometimes appears to be gibberish in slogans and advertising of modern Japan. Use of foreign icons brings esteem, regardless of whether or not they are understood. Again, it must be stated that the central beliefs, ritual ceremonies, and social purposes of Japan appear to have remained and do remain somewhat constant regardless of import, such imports merely being incorporated within this larger "spring."

Adapting Chinese Lore to Native Beliefs and Purposes: Orihime, Kengyuu, and Tanabata

When we look at the adaptation of myth and legend imported from other cultures, we also find the obvious sense of indigenous Japanese values and socio-political purposes infused over time. Perhaps one of the best examples of this is the legend of Orihime and Kengyuu (Nojiri 1973). This story and associated festival were probably imported from China in the Heian Era (794–1185). The story involves the stars of Vega and Altair, and the reader should consult Krupp (1991) for an explanation of the story in its Chinese form. Essentially the same in character, there are some noticeable adaptations made based on the unique social and pragmatic needs of Japanese culture. In Japan, the star Vega is often called Orihime Boshi (Weaving Princess Star), and Altair is often called Kengyuu Boshi or Hiko Boshi (Puller of Cows Star). To give the reader one Japanese version of the legend, we will paraphrase Hara (1975).

One day, the emperor's daughter, Orihime, was sitting beside the Milky-Way. She had been weaving because her father, the emperor, "wished it" (he loved the beautiful clothes that she made). On this day, she was very sad because she realized that she had been so busy that she didn't have time to fall in love. Her father, Tentei, the ruler of the heavens, felt sorry for her and arranged a marriage with Kengyuu (who lived across the river, the Milky-Way). Their marriage was one of sweetness and happiness from the start; and everyday thereafter they grew happier and happier. But Tentei became very angry, because in spending so much time in her happy marriage, Orihime was neglecting her weaving. Tentei decided to separate the couple, so he placed them back in their original places, separated by the Milky-Way. On only one night of the year would he allow them to meet, the 7th day of the 7th month. Every year on that day, from the mouth of the river (the Milky-Way), the boatman (of the moon) comes to ferry Orihime over to her beloved Kengyuu. But if Orihime has not done her weaving to the best of her skills and ability, Tentei may make it rain. When it rains, the boatman will not come (because the river is flooded). However, in such a case, *Kasasagi* (a group of magpies) may still fly to the Milky-Way to make a bridge for Orihime to cross.

Related to this legend, ancient Japanese celebrated the festival of *Tanabata* on the 7th day of the 7th month each year (lunar calendar). The 7th day of the 7th month generally falls in August or September in the Gregorian calendar. At this time of year the constellations of Lyra and Aquila are prominent in the evening sky with their major stars (Vega and Altair) separated by the Milky-Way. The 7th day of the 7th month also finds a waxing crescent moon (boat) reaching its first quarter. If it is not raining, both *Orihime Boshi* (Vega) and *Kengyuu* (Altair) are quite conspicuous at the time of the *Tanabata* festival.

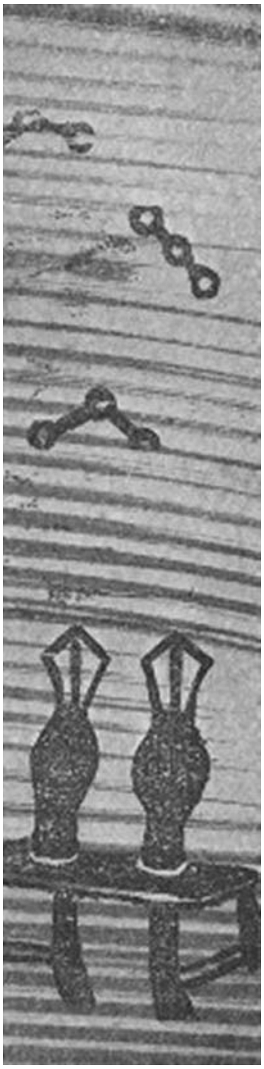
Tanabata may be translated as "weaving with the loom (*bata*) placed on the shelf (*tana*)," and the festival celebrates improvement of technical skill and ability. As in China, ancient Japanese added specific values to their wishes that Orihime hone her skills and work hard so that she could meet Kengyuu. In modern celebrations of *Tanabata*, people throughout Japan write wishes (generally for themselves or relatives) to the *kami* Orihime on colorful strips of paper. On the evening of Tanabata, they tie these paper wishes to freshly cut bamboo. Wishes may be for increased skills in work or school but may also be for anything that reflects a person's dreams and hopes for the future. Summer vegetables such as eggplant and cucumbers are prepared, and horse or cow figures made out of straw and water oats are decorated.

While the myth probably held seasonal significance in its Chinese origins, specifically the celebration of the end of the rainy season (reflected in a desire that it not rain), it found a variety of interpretations related to seasonality in its Japanese form. Particularly in relation to agricultural development in Japan, "wishes" related to celebrations of *Tanabata* ranged from desire for dry weather to desire for wet weather depending on the particular geographic region and whether a crop was to be planted or harvested at this time.

Following Shinto practice and ancient values, the concept of purification (generally including use of water) before the Bon festival (centered on the 15th day of the 7th month) was also added to the *Tanabata* festival. Before the legend was brought from China, a ritualistic festival had been held to welcome the water kami at this time of year; infusion of the legend of Orihime and Kengyuu added a motif of the ritual celebration of the marriage of a weaving lady and the water god (Okada and Akune 1993). In eastern parts of Japan, an associated ritual called Nebuta was celebrated. On the early morning of Tanabata, bamboo would be set afloat in the river, and people would brush their bodies with leaves from "silk" trees. By doing so, they were said to take their sleepiness (*nebuta*) away, another form of purification and preparation for Bon (Yoshinari 1996). The close relation of Tanabata to the indigenous Bon Festival has obviously led to a number of adaptations of the imported Chinese mythology. In short, one makes the coming of the Bon festival sacred by excluding impure spirits from the body at the first quarter moon, thus being pure for the coming of Bon at full moon. It is interesting that in some regions of Japan, *Tanabata* is accompanied by a taboo forbidding swimming or bathing in a river. Noting the relation with the celestial "river" or Milky-Way, the taboo is based on the idea that a *Kappa* or water deity resides in the river, and one should not make the pure water dirty by entering the water deity's home.

When it was first imported, *Tanabata* was celebrated only by imperial court officials. It was considered a graceful event, full of the simple elegance so associated with the Heian era of Japan. Lanterns were lighted, and poems were written on mulberry leaves still holding their dew (Nojiri 1973). Of course, as the custom spread to local areas, towns became covered with bamboo at *Tanabata*, and the festival took on more of the values inherent in Japanese consciousness and purpose (Fig. 3).

The process of adapting this imported legend and developing indigenous practices evolved in complex ways over the centuries, and we have touched on but a bit of this complexity. In modern times, the festival is generally celebrated on a solar July 7th, a date that is generally still within the rainy season. Sadly, the festival has lost much of its seasonal significance with modern industrialization. Of course, the vitalistic ethic of improved work and skill is still valued, regardless of



Astronomy in Japan: A Cultural History. Fig. 3 Decorated strip of *Tanabata* bamboo from the *Tottori* region of Japan. Note the representation of *Hiko Boshi* (Altair and two-flanked stars in Aquila) at the top and *Orihime Boshi* (Vega flanked by two stars in Lyra) near the middle (From Nojiri, Houei Nihon Seimei Jiten of Star Names in Japan, 1973, p. 60. Used with Kind permission of the publisher).

whether or not the day of celebration is attuned astronomically.

Prevalence of the Sun: Akemashite Omedetou Gozaimasu

No discussion of Japan's heritage with the sky can avoid the prime significance of the sun. Symbolism related to the sun is heavily incorporated in Japanese myth and is still seen in its flag. Being the most eastern of East Asian nations and indeed being seen as the land which the sun first greets in the morning, the phrase "land of the rising sun" developed special meaning for Japanese from ancient times. Along with the significance of Amaterasu as sun goddess, there are other ways in which the sun has become a central part of Japanese consciousness. The celebration of the New Year represents yet another way in which indigenous values are mixed with Chinese imports to provide a unique cultural perspective on the significance of vitalism and optimism.

While Christmas is celebrated in Japan to some degree, it is not considered a national holiday, and the attendant Western religious aspects of that day are certainly missing. New Year's Day is by far the more significant holiday. Before the Meiji Restoration, the New Year was celebrated according to the Chinese lunar calendar. In modern times, though the lunar calendar still has influence on scheduling of festivals and celebrations, the Gregorian calendar change is celebrated by most people as the "official" New Year.

In the days before the New Year begins, people busily prepare by cleaning house and cooking food to welcome the kami of new life. At this time, the Post Office is flooded by New Year's cards which each person sends to friends, relatives, and associates. Rail and air terminals are jammed with people trying to get back to their hometowns to spend the New Year's "night" and "daybreak" with family members.

Japanese express wishes for the New Year by saying "Akemashite Omedetou Gozaimasu." Only one Kanji (Chinese character) is found in this phrase (within the first word). This Kanji is a combination of the characters for sun and moon, and among other meanings, entails the sun and the moon getting together and becoming "bright." It represents "changing" and "opening," in a sense, "dawning" (Fig. 4).

In ancient lore (under the lunar calendar), the New Year was seen in relation to change in both the sun and moon as well as the symbol of their luminance. The meaning of the phrase "Akemashite Omedetou Gozaimasu" reflects the values of linealism, vitalism, and optimism. Perhaps it is expressed in English most appropriately as follows: "The year is changing; darkness gives way to light; new life begins; Congratulations!" Following tradition, many Japanese on New Year's morning brave the cold to find places with

Astronomy in Japan: A Cultural History. Fig. 4 The *Kanji* for *Ake*. Symbols for the sun and moon are placed together in this character to represent "bright" or "beginning" (computer graphic by Steven L. Renshaw).

unobstructed views of the Eastern Horizon and eagerly await the rising sun, the break of day, the symbol of new life. Incorporating the ideas of much ancient mythology, the sun is seen to be making its journey back to the North, and the Vernal Equinox is eagerly awaited.

As in other aspects of Japanese astronomy that we have discussed, Chinese imports and traditions were incorporated from early times. The New Year of 1996 was special in that it began another 12-year cycle of the Chinese calendar (based on positions of Jupiter with its 12-year orbit and consequent position about the ecliptic; Uchida 1981). The tradition of using Chinese based animal names for the 12 directions and associated years is popularly maintained in Japan. In 1996, things turned around once more to the direction of *ne* (mouse), the North, to the direction of the star Polaris, sometimes called *Ne no Hoshi* (mouse star) but also called *Shin Boshi*, the "Heart" star, the "soul of the Heavens." 1996 began the clockwise cycle again which from ancient Chinese geomancy means moving from N to NNE (1997, *ushi* or cow), to ENE (1998, *tora* or tiger), to E (1999, *u* or rabbit) and so forth.

The mixture of Chinese geomancy and symbolism with indigenous social values is clearly seen in the Japanese celebration of the New Year. Yet the quiet tolling of temple bells on New Year's Eve brings a certain calm and solitude unseen in most any other culture. It is in this very symbolic act that centuries of Japanese history and tradition, for better or worse, can be seen and truly appreciated.

Hopes for the Future Built on a Rich But Hidden Past

Most of Japan's recorded history reflects a culture continually influenced by imports, even when on the surface, the country appeared to be isolated. At the same time, a cultural consciousness combined with quite distinct social and political purposes has always been a source through which most any idea, foreign or domestic, had to be filtered.

Though we can still see much of the ancient heritage of Japanese astronomy in layouts, structures, mythology, and ethnographic lore, it is often difficult to find too many Japanese citizens aware of this sphere which incorporates a complex interaction of ancient values and purposes with celestial symbols. Feeling that the culture has adopted almost every modern concept that East or West has to offer, many Japanese themselves are unaware of the richness of their ethnoastronomic heritage. As in the West, many young Japanese are more likely to know the name of Pleiades rather than Subaru and associate the latter with an automobile company rather than the celestial symbol which meant so much to their ancestors. While Tanabata is still observed, and the legend of Orihime and Kengyuu still finds its way into modern songs and prose, few people are concerned about the festival's shift away from its seasonal association. In many ways, however, Japan's embracing of the West and virtual denigration of its past reflects a process which has been a part of the culture's way of handling infusion from its earliest times. Still, when the "face" is lifted, one still finds an enduring set of values and purposes that appear to predate written history.

Aveni (1989) alludes to the modern inclination to disassociate science from the social and historical context in which it was developed. He points out how such isolation lacks the notion of process or change and says that in a sense, we "seek ourselves in the tattered walls of others cultures." Aveni further mentions the danger of relying solely on written records and emphasizes using additional evidence in the form of archaeology and architectural icons to understand a nation's cultural astronomy. In taking a narrow view of astronomy as it developed into modern Western science, Aveni contends that we pursue what is interesting to us instead of what was important to the people we study.

The specific irony of Aveni's observations relative to the study of astronomy in Japan may rest in the view taken by many Japanese themselves. In a sense, the view is that we (Japanese) seek others' selves (Western science in particular) within the tattered walls of our own culture and come up sadly lacking. To further paraphrase, we (Japanese) tend to pursue what is of modern interest (to the West in particular) instead of what was actually important to our own ancestors throughout history. These perhaps enigmatic Japanese views are the result of a long and complex history involving interaction of native belief and consciousness with a perception that while unique, the native culture is somehow inferior to those imports it filters. Such lack of "cultural self-esteem" has led to a number of enigmatic events in Japanese history, not merely the denigration of its own astronomic heritage.

In looking at the overall influence of Japanese value, past and present, it may be worth noting that modern astronomical practice, while totally within the rubric of Western science, reflects a long heritage of curiosity combined with concern for future generations. A good example of this may be found in the diary of a young Kochi resident rediscovered in the 1980s. In 1664, while astronomers in Europe were trying to learn more about the motion and nature of comets, Matasaburou, a young boy of 12, began to observe what would later be known as Comet C/1664 W1. Encouraged by his teacher, Jian, he diligently observed the comet for over 4 months, wrote his impressions, and drew the changing shape of the comet in his diary. Despite the lack of astronomical knowledge, Matasaburou showed remarkable curiosity about the true nature of the *houki boshi* (brush star) and an abundant skepticism of the prevailing view among townspeople that the comet signaled doom. While his drawings do not have the flamboyance of those of Hevelius and others observing the comet in Europe, his diary shows every attempt to precisely plot the location and shape of the comet as it crossed the celestial sphere nightly. Matasaburou passed on to his own pupils the joy of discovery, and it is no doubt due to this that copies of his diary have survived the centuries. Such diligence is still seen in the work of amateur and professional astronomer alike. One cannot help but be reminded of the tireless efforts of professionals and amateurs who venture out on every clear night to observe and try to discover yet another celestial wonder.

Future astronomers, archaeoastronomers, and ethnoastronomers in Japan will no doubt come from an increasing number of young Japanese who have grown up in the intellectually free environment of modern Japan. Those not raised within the culture may find the door to Japan's astronomical past opening wider if there is a will to engage in exploration of consciousness and purpose still so evident beneath the surface of Japan's modern society. However, much work lies ahead in uncovering the vast richness of Japanese astronomy in history, and the future is probably most "optimistic" for those young Japanese scholars who find the riches of their heritage and culture inspiration and justification enough to seek knowledge about their nation's long pilgrimage with the sky.

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Astronomy in Mainland Southeast Asia

Yukio Ōhashi

Southeast Asia is divided into two parts, mainland Southeast Asia and insular Southeast Asia (also called the Indo-Malay Archipelago). Mainland Southeast Asia is further divided into two parts. One is Vietnam, where Chinese influence is greater than Indian influence, and the other includes Burma, Cambodia, Laos, and Thailand, where Indian influence is greater. The Malay Peninsula is a part of mainland Southeast Asia geographically, but is culturally closer to insular Southeast Asia.

Astronomy in Burma, Cambodia, Laos, Thailand, and Yunnan

Traditional Calendars in Burma, Cambodia, Laos, Thailand, and Yunnan[1]

The traditional calendars of Burma, Cambodia, Laos, and Thailand in Southeast Asia, and those of the Tai (or Dai in the Pinyin system of Chinese transliteration) people in Sipsong-panna (or Xishuang-banna in Pinyin) in the Yunnan province of China have similar characteristics. They are basically based on the Indian (Hindu) calendrical system, which is a luni-solar calendar, with certain simplifications. The Indian influence is seen, for example, in the fact that the length of a year used in most of these calendars is 365.25875 days. This is similar to the sidereal year (not tropical year) of the Ārdharātrika school, one of the schools of Hindu astronomy. Dikshit, an authority on Hindu astronomy in the second half of the nineteenth century, pointed out that the length of a year used in an astronomical work procured by a French envoy from the Ayutthaya dynasty of Siam (present Thailand) is the same as that of the *Sūrya-siddhānta* quoted in the *Pañca-siddhāntikā* of Varāhamihira (sixth century AD) (Dikshit 1981: 378). This *Sūrya-siddhānta* belongs to the Ārdharātrika school.

Besides the Indian influence, there is also Chinese influence in this area, notably the animal names of the 12-year cycle.

The main differences between Indian (Hindu) traditional astronomy and the calendars in mainland Southeast Asia (except for Vietnam) are as follows. (The traditional calendar of Vietnam is based on the Chinese system, which I shall discuss in the next section.)

1. In the Hindu traditional calendar, an intercalary month is inserted when two successive new moons occur during which the sun remains in the same zodiacal sign. In mainland Southeast Asian calendars, the 19-year cycle is usually used for intercalation during which seven intercalary months, which consist of 30 days, are inserted after the fixed month of a year. Actually, the 19-year cycle is not harmonious with the sidereal year which is used in Hindu and mainland Southeast Asian calendars, and I suspect that this 19-year cycle might have been introduced from China.
2. In the Hindu traditional calendar, one month is divided into 30 *tithi*s, which are the periods during which the longitudinal difference between the sun and moon changes by 12°, and the number of the *tithi* at the beginning of a day (usually sunrise) becomes the name of the day. So, the number of days in a month is automatically determined. In mainland Southeast Asian calendars, 29-day months and 30-day months are usually distributed alternately at definite months of a year, and 11 intercalary days are distributed in 57 years at the fixed month of a year. Actually this method is slightly inexact.

One thing may be added here. Among Tai (or Thai) people, lunar months are named by serial number, and there are some variations of this method. This method is similar to the Chinese method, but is absent in the Hindu traditional calendar. The method used by Dai people in Sipsong-panna in Yunnan province (in China) is quite similar to an ancient variation of a Chinese method.

I suggest the following tentative hypothesis. The 19-year cycle intercalation and the method of month reckoning using serial numbers were introduced from

[1] For the calendars in mainland Southeast Asia, except for Vietnam, see Eade 1989 and 1995. For the Burmese calendar, see Irwin 1909, Silva 1914, and Htoon-Chan 1918. For the Cambodian calendar, see Faraut 1910. For the Lao calendar, see Phetsarath 1940 and Dupertuis 1981. And also, for the Dai calendar in Yunnan in China, Zhang and Chen (1981) may be consulted. It may also be mentioned here that Casparis (1978) may be consulted for calendars in insular Southeast Asia.

China, and were modified after the introduction of the Indian calendar (Ārdharātrika school). (For details, see Ōhashi 2002.) It may also be mentioned here that the calendar used in the inscriptions of Champa, which was a kingdom that existed in present central and south Vietnam until the seventeenth century AD, was also based on the Indian calendar.

Controversy Regarding the Dai calendar in Yunnan, China

There was a controversy between Dong Yantang and Zhang Yong, both of whom are Chinese scholars, in the first half of the twentieth century regarding the origin of the Dai peoples' calendar in the Yunnan province of China. In 1938, Dong Yantang published a paper on the origin of the Dai calendar (Dong 1938). In this paper, Dong Yantang argued that the Dai calendar was based on the Qin calendar of ancient China.

In 1939, Zhang Yong wrote a paper on the Dai calendar (Zhang 1939). Zhang Yong criticized Dong Yantang's paper, and concluded that the Dai calendar was based on the Indian calendar. Zhang Yong pointed out some reasons. For example, the Dai calendar uses half months just like the Indian calendar, and the Dai calendar divides a year into three seasons just like the Indian calendar. These reasons are justified. Zhang Yong mentioned other reasons also, and tried to show that the Dai calendar was completely based on Indian calendar without Chinese influence.

I think that the Dai calendar is basically based on Indian calendars, but there may be some Chinese influence also, as I mentioned in the previous section.

Historical Development of the Traditional Calendars in Yunnan and Burma

According to Zhang Gongjin and Chen Jiujin (Zhang and Chen 1981), the texts entitled *Suding* and *Suliya* were followed by the Dai people for making calendars before AD 1931, but the text entitled *Xitan* has been followed since AD 1931 or so. Zhang and Chen also say that the *Suding* and *Suliya* do not follow the 19-year cycle of intercalation strictly, but the *Xitan* follows the 19-year cycle of intercalation. The calendrical luni-solar year of the *Xitan* practically keeps pace with the tropical year, although the solar new year's day is calculated by the sidereal year as before. I compared their astronomical constants with Indian constants, and found that the *Suding* and *Suliya* follow the Ārdharātrika school, while the *Xitan* follows the Saura school (Ōhashi 2002).

According to Irwin (1909), the *Makaranta* (there are two methods of epoch: AD 638 and AD 1436), which probably follows the "original *Surya Siddhanta*" (i.e., Ārdharātrika school), was followed in Burma originally. Afterwards the *Thandeikta* (epoch: AD 1738), which chiefly follows the "present *Surya Siddhanta*" (i.e., Saura school), was used. Irwin writes that the *Thandeikta* is said to have been composed in about AD 1738 or AD 1838, and that the present *Sūryasiddhānta* was introduced into Amarapura, Burma, in AD 1786, and translated into Burmese after about 50 years. Irwin also states that the 19-year cycle of intercalation was followed in the *Makaranta*, but was not strictly followed in the *Thandeikta*. We should note that the Burmese *Makaranta* is probably different from the well-known Indian Sanskrit astronomical table *Makarandasāraṇī* (AD 1478) of Makaranda, which follows the Saura school.

Here, the treatment of the 19-year cycle of intercalation is just the opposite of the Dai calendar (Yunnan, China) and Burmese calendar. More detail about the calendar reform in these regions should be investigated.

Traditional Astronomy and Modern Astronomy in Thailand

In the mid-fourteenth century AD, Lithai (King Ruang) of the Sukhothai dynasty wrote the *Traiphum* (Three Worlds) (Reynolds and Reynolds 1982). This is a celebrated text of traditional Thai cosmology, which is based on Buddhist cosmology. Some information about traditional astronomy and the calendar is also found there.

In 1685, King Narai of the Ayutthaya dynasty observed a lunar eclipse with a telescope with the Jesuits sent by the French King (See Tachard 1688/1981: 230–246, and Choisy 1993: 215). King Narai requested mathematicians from France, and planned to build observatories at Louvo (now Lop Buri) and Siam (now Ayutthaya). This event may be considered the beginning of modern astronomy in Thailand.

In 1687, a French envoy, Simon de la Loubère, visited the Ayutthaya dynasty and procured an astronomical work entitled *Souriat*. This work was later analysed by a celebrated astronomer, Jean Dominique Cassini (See Loubère 1693/1969: 64–67 and 186–199, and Bailly 1787: 3–30.). This is the earliest information of India-based astronomy reaching Europe. Dikshit pointed out that the length of a year used there is the same as that of the *Sūryasiddhānta* quoted in the *Pañcasiddhāntikā* of Varāhamihira (sixth century AD) (Dikshit 1981: 378).

In the nineteenth century, King Mongkut (Rama IV) (r. 1851–68) studied European astronomy as well as Thai traditional astronomy. He ordered his own observatory near Phetburi. He predicted the total solar eclipse of 1868. According to the *Dynastic Chronicle*, the King calculated the eclipse "by using the old astrological texts of Siamese and Mon, as well as many old American and English texts." According to Thongchai, the Mon text used by the King is the *Saram*, one of the two Mon treatises for planetary calculation known in Siam; the other text more conventionally used by astrologers at that time was *Suriyayat*. (See Thiphaakorawong, vol. 2 1966 of 1965–1974: 532–539, Cook 1992, and Thongchai 1994, chapter 2.) This was a symbolic event in the course of the introduction of modern astronomy into Thailand.

There are several inscriptions with calendrical data in Thailand, which are also important sources of Thai astronomy (Eade 1996). There was an independent kingdom, Lanna, in North Thailand from the end of the thirteenth century to the beginning of the twentieth century. The people of Lanna had their own astronomy, which was based on Indian astronomy. (See Soonthornthum 1998; for the Northern Thai calendar, see Davis 1976.)

Burmese Constellations

Burma has a special system of constellations, and there are three beautiful star maps drawn on the ceilings of corridors of the Kyauktawgyi Pagoda at Amarapura (near Mandalay, Burma) (Figs. 1a–d are the star maps photographed by the author in 1984).

King Pagan (r. 1846–1852) built the Kyauktawgyi Pagoda in 1847 on the model of the Ananda Temple at Pagan (U Lu Pe Win 1960: 5). There is a pioneer study of Burmese constellations by Francis Buchanan (1799) (also see Nishiyama 1997). Although Burmese constellations include Indian constellations, there are many Burmese unique constellations, which are very important for investigating the original Burmese contribution.

Astronomy in Vietnam

There are four main countries where Classical Chinese was used as the official language of traditional learning: China, Korea, Japan, and Vietnam. In this section, I will discuss some aspects of Vietnamese astronomy based on the sources I consulted. When a Vietnamese or East Asian person is referred to in this section, the surname is written first as is the custom in these regions, unless commented upon otherwise.

Previous Researches

In 1934, Mikami Yoshio, a pioneer of the study of the history of Eastern mathematics in Japan, wrote a paper on a mathematical work of Vietnam. This is a study of a Vietnamese mathematical work entitled *Chi-minh toan-phap*, written in classical Chinese, which was brought to Japan by Matsumoto Nobuhiro, an authority on Vietnamese study in Japan.

In 1940, Yung Chang (as transliterated in his own paper where Chang is the surname, or Zhang Yong in modern Pinyin transliteration) (1911–1939), a Chinese scholar, wrote a paper on the Vietnamese calendar. This is a pioneer study of the Vietnamese calendar, and I was much impressed by this work. In the 1960's, Huard and Durand wrote popular articles on the history of Vietnamese science (Huard and Durand 1961/1965; Durand and Huard 1964/1966). In 1964, Ho Peng-Yoke wrote a paper on the records of natural phenomena, including astronomical phenomena, recorded in a historical work of Vietnam. It is necessary to continue this kind of work, comparing the records with other East Asian records, and checking them with modern calculations.

In 1979, a monograph on the history of science in Vietnam was published in Vietnamese in Hanoi (Vien Su hoc 1979). This book includes 12 papers, including a paper on the history of Vietnamese mathematics written by Ta Ngoc Lien. As far as I know, this book is the most detailed work on the history of science and technology in Vietnam. In 1991, Han Qi, a Chinese scholar, wrote an overview of the history of astronomy and mathematics in Vietnam (Han 1991). [Ed. note: See Han Qi's article on Jesuits and Knowledge Exchange in China in this volume.]

In 1999, the ninth International Conference on the History of Science in East Asia was held at Singapore. In this conference, there was a session on "New Topics in the History of Science in East Asia-Preliminary Research on Vietnamese Scientific Tradition." In this session, Chu Tuyet Lan and Nguyen Xuan Dien from the Institute of Sino-Nom Studies, Hanoi, introduced Vietnamese works on science, medicine and technology (Nguyen 2002), and Alexei Volkov read a paper on the *Toan-phap dai-thanh* of Luong The Vinh, a Vietnamese mathematical work. I think that this conference marked a kind of breakthrough for the study of the history of Vietnamese astronomy and mathematics.

In 2000, I visited the Institute of Sino-Nom Studies in Hanoi, and consulted some Vietnamese astronomical works with the help of Ms. Chu Tuyet Lan and Mr. Nguyen Xuan Dien. When I visited Vietnam, I found a small book on 13 Vietnamese scientists, both premodern and modern, written in Vietnamese (Le 1999). This is a popular book for youths.

In 2002, Alexei Volkov published a paper on the *Toan-phap dai-thanh*. I think that this is a monumental paper on the history of mathematics in Vietnam. Also in 2002, a convenient bibliography of classical literature of Vietnam was published in Taiwan. Several astronomical and mathematical works are listed there (Liu, Wang, and Chen 2002, part 1: 452–459).

Vietnamese Astronomy

Rough History of Vietnamese Calendars

1. Acceptance of Chinese calendars, notably the *Shoushi* calendar

The *Yuanshi*, the official history of the Yuan dynasty of China, says that a Chinese calendar was given to the Vietnamese king (Tran dynasty) in 1265 (*Yuanshi*,

a

b

c


d

Astronomy in Mainland Southeast Asia. Fig. 1 Star maps drawn on the ceilings of corridors of the Kyauktawgyi Pagoda at Amarapura.

vol. 209, Annan, the second year of Zhiyuan). At that time, the *Shoushi* calendar, the celebrated calendar of the Yuan dynasty, had not been made, and the *Daming* calendar of the previous Jin dynasty was still used in China.

The *Dai-Viet su-ky toan-thu*, an official history of Vietnam written in Classical Chinese, says that the *Shoushi* calendar was given to a Vietnamese king (Tran dynasty) from the Chinese Emperor in 1324. (*Dai Viet Su Ky Toan Thu*: 220, vol.6, 42 b in the original block print). From the above sources, we can suppose that Chinese calendars were accepted in Vietnam until the early fourteenth century.

2. *Hiep-ky* calendar

The *Dai-Viet su-ky toan-thu* states that the *Shoushi* calendar was changed into the *Hiep-ky* calendar in 1339 (Tran dynasty) (*Dai-Viet su-ky toan-thu*: 229, vol. 7, 9 b-10 a in the original block print). This record possibly means that the name of the calendar was changed, and does not necessarily mean that the method of calculation was changed. The *Mingshi*, the official history of the Ming dynasty of China, says that the *Datong* calendar of China was given to the Vietnamese king (Tran dynasty) in 1369, the next year of the establishment of the Ming dynasty (*Mingshi*, vol. 321, Annan, the second year of Hongwu). It may be that the *Datong* calendar, which is a revised version of the *Shoushi* calendar, was accepted in Vietnam at that time.

3. *Thuan-thien* calendar

The *Dai-Viet su-ky toan-thu* tells that the *Hiep-ky* calendar was abolished, and the *Thuan-thien* calendar was adopted in 1401 (Ho dynasty) (*Dai-Viet su-ky toan-thu*: 267, (vol. 8, 39a in the original block print). The difference between these two calendars is not recorded.

4. Acceptance of the Chinese *Datong* calendar

Vietnam was directly ruled by the Ming dynasty of China from 1413 to 1428, and the *Datong* calendar must have been used. The Le dynasty was founded in 1428 in Vietnam, but there is no record that the calendar was changed.

The *Mingshi* states that the *Datong* calendar was given to the Mac, who ruled Vietnam for certain period, in 1540 (*Mingshi*, vol. 321, Annan, the 19th year of Jiajing). In 1829, Nguyen Huu-than wrote in his *Y-trai toan-phap nhat-dac-luc* that the *Datong* calendar had been used until the *Hiep-ky* calendar (Vietnamese adoption of the Chinese *Shixian* calendar) was adopted in 1813 (Zhang 1940: 34.).

5. *Hiep-ky* calendar (=*Shixian* calendar)

According to Nguyen Huu-than, as we have seen above, the *Shixian* calendar of the Qing dynasty of China was adopted in Vietnam as the *Hiep-ky* calendar in 1813 (Nguyen dynasty). This *Hiep-ky* calendar should not be confused with its previous namesake. Zhang Yong compared Vietnamese chronological tables with Chinese calendar, and pointed out that the *Shixian* calendar was actually used in Vietnam from 1813 to 1840.

6. Consideration of the longitudinal difference

Zhang Yong pointed out that the Vietnamese *Hiep-ky* calendar has differed from the Chinese *Shixian* calendar since 1841. This must be due to the consideration of the longitudinal difference between Vietnam and China.

Calendar Reformation Under Minh-manh

In order to reform the calendar, astronomical observations were made under the emperor Minh-manh (r. 1820–1840) of the Nguyen dynasty. There are some source materials about this reformation.

The *Dai-Nam hoi-dien su-le* (1855) is a comprehensive official record of the system of government of the Nguyen dynasty. It has a section on the Kham-thien-giam (National Astronomical Observatory). According to this section, it was declared in 1837 that the prime meridian for Vietnam passed through its capital (Hue), whose latitude was determined to be 16°22′30″, and longitude measured from the Western prime meridian to be 105° (*Dai-Nam hoi-dien su-le*, vol. 259, 13a–b). The actual position of Hue is 16°27′N, and 107°33′E (from Greenwich). So, the above-mentioned Western prime meridian must be Paris (2°20′E from Greenwich).

There is another interesting work entitled *Thien-van-khao* (Study of Astronomy), which is volume 1 of the *Su-hoc bi-khao* of Dang Van-phu. This text records longitude and latitude (from Hue) of several places determined in 1837. According to this text, the longitude seems to have been determined by the observation of lunar eclipses using local time. From the above sources, we know that Vietnamese astronomers made efforts to make the calendar more suitable for Vietnam.

Another interesting work is the *Quoc-trieu thien-van-chi*. This is a chronological compilation of the records of heavenly phenomena from 1569 to 1888.

The traditional astronomies in several regions of mainland Southeast Asia are very interesting, but their detailed study is our future task. Several original sources are still in manuscript form or extremely rare. Fortunately, some people are now going to study this subject, and I hope that more results can be reported in the near future.

In the case of Vietnamese astronomy, it is necessary to compare it with Chinese astronomy, and in the case of Burmese, Cambodian, Lao, and Thai astronomies, it is necessary to compare them with Indian astronomy. Thorough study of the regional differences and their relationships with regional cultures are needed. I hope some readers of this article contribute to this subject in the future.

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Astronomy in Mesoamerica

Martha J. Macri

Mesoamerica extends from northern central Mexico into Nicaragua. The region contains dozens of distinctive ethnic groups. Shared linguistic features, ceremonies, and mythic traditions show that these diverse peoples have been in intimate contact with one another for thousands of years. One of their shared intellectual achievements is their understanding of the cosmos. A long history of observing and recording astronomical phenomena has allowed them to establish amazingly precise measurements of the cycles of the earth, sun, moon, and the visible planets. Much of the indigenous knowledge in this region did not survive the initial years of violence and disease, which were followed by centuries of less dramatic, but equally destructive political and economic oppression. Nevertheless, among specialists in many contemporary indigenous communities (day-keepers, calendar priests, community scholars), fragments of the ancient knowledge are retained today. Further evidence comes from ethnographic and historical descriptions, measurements of ancient architectural features (site alignments and building plans), ritual books, and historical records of political events associated with astronomical phenomena.

Mesoamerican astronomy differs from that of Greece, Mesopotamia, China, and most of Egypt, in that it developed within the tropics (Aveni 1981). There, the stars of the night sky rise and fall in a more or less straight trajectory, while the stars of the northern sky trace circular patterns around the North Star. Also in the tropics, the annual solar cycle is measured, not just by the summer and winter solstices, but additionally, by the twice-annual passage of the solar zenith.

The set of twenty day names combined with the numbers from 1 to 13 (creating a 260 day calendar), and the year of 18 months of 20 days with five added days (resulting in a calendar of 365 days) were common throughout the region. The two calendars combine to form a cycle of 52 years, known to such linguistic groups as the Nahuatl, Maya, Mixe-Zoque, Zapotec, and Mixtec. These cultures shared ceremonies, mythic traditions, and a common system of knowledge that included the prediction of expected solar and lunar eclipses (Fig. 1), observation of the seasonal rising and setting of the Pleiades, and awareness of the periods of Venus, Mars, Jupiter, and Saturn. Dates of significant conjunctions of planets, the moon, bright stars, and constellations were recorded on carved stone monuments from at least as early as CE 156.

Astronomy in Mesoamerica. Fig. 1 Eclipse Glyph from the Dresden Codex. Photo taken by Ernst Förstemann in 1880. Courtesy of Dumbarton Oaks Research Library and Collection.

The movement of the sun, moon, stars, and planets seems to have been measured in part by observing the important points of rising or setting on the horizon and noting the alignment with hills, mountains, and buildings. Unusual shaped structures such as Building J at Monte Alban and the Caracol at Chichen Itza (Fig. 2) may have had astronomical observation as their primary function. The year sign found in Mixtec and Mexican codices was thought by some to represent an instrument used to measure the movement of the sun. Some modern Maya day keepers have calendar boards on which they mark the passing of days. The ancient peoples of Mesoamerica also produced mirrors, which may have been employed in observation, though such use has not been substantiated.

Astronomy in Mesoamerica. Fig. 2 The Caracol at Chichen Itza. Photo by author.

The degree of precision required to note astronomical phenomena varies greatly depending upon the event. Daily changes in the phases of the moon are easily observed. Solar events such as equinoxes and solstices are measurable within a range of several days. First perceptible movement of the outer planets (Mars, Jupiter, and Saturn) from stationary points (the location marking the change from forward to retrograde motion and vice versa) may not occur for a week or more. Some planetary conjunctions may be visually notable for weeks, but conjunctions involving the moon and the visible planets last for only a day or two and occur frequently. Heliacal risings and eclipses are measured by hours. An awareness of these variations is necessary to evaluate supposed records of such events.

Scattered throughout Mesoamerica are structures oriented so that solstices and equinoxes could be observed by persons stationed on their summits or sighting them through their doors. These include Group E at Uaxactun, buildings from the Puuc region in the northern Yucatan peninsula, the Templo Mayor in Mexico City, and Alta Vista near Zacatecas located directly on the Tropic of Cancer. Temple 22 at Copan, Honduras, the Governor's Palace at Uxmal, and the Caracol at Chichen Itza were built with architectural features marking the rising and setting points of Venus. At Yaxchilan summer ceremonial activities recorded in hieroglyphic texts on stelae and lintels coincided with the summer solstice.

Cycles composed of fractions of days were counted in multiples of the cycle in order to preserve whole numbers. For example, the lunar sidereal period (the time required for the moon to return to the same position against the background of the stars) were counted in sets of three. This cycle is observed today by the K'iche' Maya of Momostenango as an 82 day period equal to three sidereal periods of 27.3 days (Tedlock 1992). This same 82-day cycle, and multiples of it, were recorded by the Classic Period Maya in inscriptions at Palenque and Calakmul. The synodic period of the moon (the time required for the moon to return to the same position relative to the sun), 29.53 days, was frequently recorded in Classic Maya inscriptions in what is called the lunar series, part of the initial series dates that introduce a majority of Classic monumental texts. The lunar data recorded the number of days since the first visible crescent, the number of the current lunation within a set of six months, the name, or patron of the month, and whether the current month contained 29 or 30 days—another example of how the Maya dealt with fractions.

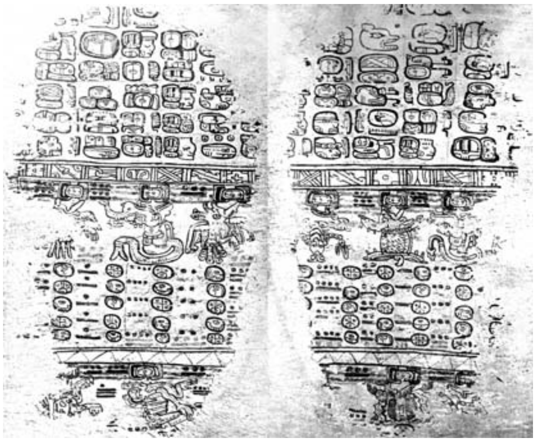
Although debated since the turn of the century, it now seems certain that the ancient Mesoamerican recognized 13 zodiacal constellations. Animals and other figures representing the constellations have been identified in the murals of Bonampak, in the sky band on Las Monjas at Chichen, in the Acanceh mural in Yucatan, in the three Maya fan-fold books, the Dresden, Paris, and Madrid codices (Fig. 3), and in the Mexican Borgia, Cospi, and Vaticanus codices, as well in as the colonial Florentine Codex by Sahagún.

The changing position of the Pleiades throughout the year continues to be important in Mesoamerica. Modern peoples tend to know the names of a few individual stars—undoubtedly, many were named in the past. Barbara and Dennis Tedlock, for example, have recorded that Alnitak, Rigel, and Saiph in the constellation Orion are known as the "three hearth stones" to modern K'iche'.

Today the K'iche' call the undivided segment of the Milky Way the "white road." The half of the Milky Way that contains the divided segment is referred to as the "road of the underworld." Linda Schele associates various ancient iconographic representations with the changing position of the Milky Way in the night sky. She suggests that when it crosses the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), it represents the place of creation, when it rims the horizon the portal to the underworld is then overhead, in its east–west direction it becomes the cosmic monster, and when it "sinks" from a horizontal to a vertical position relative to the ecliptic is depicted as a canoe.

Obsidian is thought to be the result of meteors hitting the earth. Throughout Mesoamerica, meteorites are called the excrement of the stars. Several Maya groups refer to meteorites as the cigar butts of the gods. As in the Old World, comets are generally considered bad omens. Both meteors and comets are illustrated repeatedly in the codices of central Mexico.

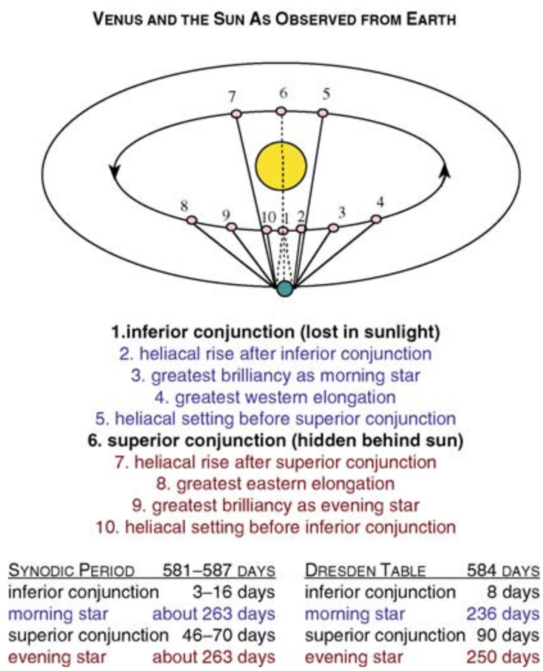
The planet Mercury has been associated with the Venus Almanac in the Dresden Codex, and with a passage in the Codex Fejérváry-Mayer of the Borgia group of codices. Mercury was in a line with Jupiter and Venus near the Pleiades in the western sky at



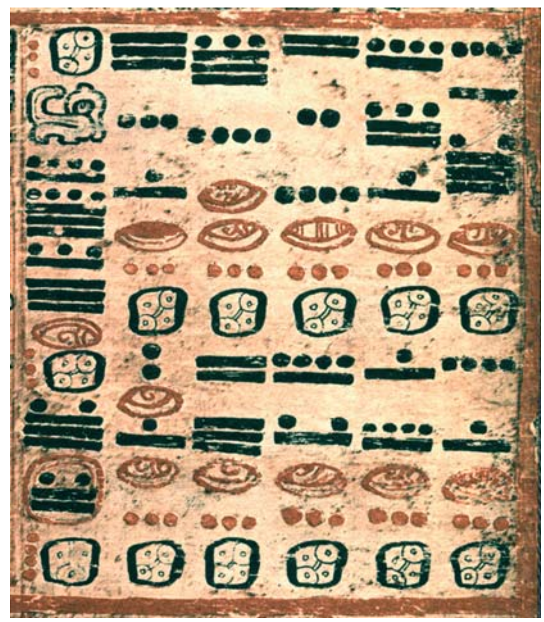
Astronomy in Mesoamerica. Fig. 3 Partial Zodiac from the Paris Codex. Photo by DeRosny in 1864. Courtesy of Dumbarton Oaks Research Library and Collection.

Astronomy in Mesoamerica. Fig. 4 Venus and Year Symbol at Chichen Itza. Photo by author.

Astronomy in Mesoamerica. Fig. 5 Venus Table, Dresden Codex, page 24, 49–53. Photo taken by Ernst Förstemann in 1880. Courtesy of Dumbarton Oaks Research Library and Collection.



Astronomy in Mesoamerica. Fig. 6 Diagram of the Synodic Cycle of Venus. Courtesy by author.



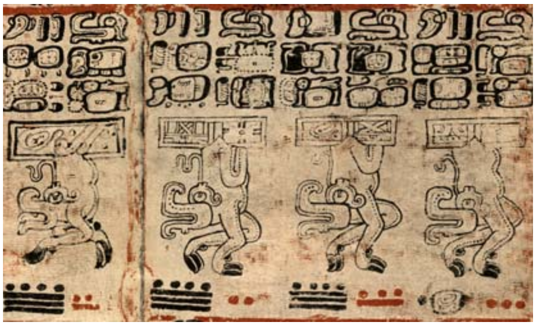
Astronomy in Mesoamerica. Fig. 7 Mars Table, Dresden Codex, page 43b. Photograph taken by Ernst Förstemann in 1880. Courtesy of Dumbarton Oaks Research Library and Collection.

twilight in CE 162, the Initial Series date on the Tuxtla Statuette. Twelve days later Mercury had reached maximum elongation and was heading downward toward the horizon, and Jupiter and Venus, still near the Pleiades, were less than 1.3° apart. If the 4 and 8 shown in the text of that inscription signify days, they may have recorded Mercury's maximum elongation.

Venus remains perhaps the most important planet throughout Mesoamerica (Fig. 4). Five sidereal periods are equivalent to eight of earth's solar years, a ratio shown by the five pages of calculations and images from the Dresden Codex (Fig. 5). Maximum elongation of Venus as evening and as morning star is recorded on the two Long Count dates on La Mojarra Stela 1 from Veracruz (CE 143 and CE 156). The Venus almanac in the Dresden Codex follows Venus through 65 synodical revolutions of 584 days. Heliacal rising after inferior conjunction is repeatedly recorded with war events in Maya texts from the Classic Period (Fig. 6).

The second date on La Mojarra Stela 1 is the day of the first rising of Mars in the east at sunset. At Palenque during the reign of Kan B'alam, a conjunction of Mars, Jupiter, Saturn, and the moon was recorded on CE July 19, 690. The Dresden Codex contains a 780-day Mars almanac. Page 43 shows calculations of multiples of the 780-day period (Fig. 7). The Maya depicted Mars as a hoofed beast suspended from the sky band (Fig. 8).

The two Long Count dates on the La Mojarra stela both record first stationary points of Jupiter. Conjunctions of Saturn and Jupiter of less than two degrees



Astronomy in Mesoamerica. Fig. 8 Mars Beast Suspended from Skyband in the Dresden Codex. Photograph taken by Ernst Förstemann in 1880. Courtesy of Dumbarton Oaks Research Library and Collection.

separation occur regularly at slightly less than 20 years (also only slightly less than a *k'atun* of 20 periods of 360 days). These conjunctions and attendant rituals are recorded at Palenque and Yaxchilan. Jupiter is specifically associated with several Maya rulers.

In ancient Mesoamerica astronomical knowledge was maintained by priest scholars an office distinct from political rulers. Astronomical knowledge was used, however, by political leaders to reinforce and to legitimize their authority. Written records include descriptions of the sky on dates that are significant because they are births or period endings. Dates for other events, such as accessions, wars, and heir designations, seem to have been chosen to coincide with planetary, lunar, and solar phenomena. A few dates seem to have been recorded specifically to commemorate an eclipse or some dramatic planetary conjunction.

In other parts of the world, the invention and spread of writing is associated with the necessity of keeping records of commercial transactions. In Mesoamerica, however, writing was stimulated by, if not invented for, the recording and prediction of astronomical phenomena. Even with the loss of literacy, astronomical knowledge has endured through oral traditions, and through persistent ceremonial practices.

Each of the sources listed below contains extensive bibliographies on Mesoamerican astronomy. Some websites provide introductory information, others, articles on specific findings. Web searches on Mesoamerican astronomy and related topics will yield a number sites showing that the desire to use the stars to understand current events did not die with the ancient sky watchers. Some of those sites also contain useful scientific information and informative charts and images.

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Astronomy in Native North America

E. C. Krupp

The astronomical activities and traditions of the American Indians north of Mexico were based upon practical observation of the sky but were not supported by a written language. For that reason, our knowledge of North American Indian astronomy relies upon the archaeological data, ethnohistoric reports from early encounters between Europeans and the indigenous peoples, and ethnographic information collected more recently by anthropologists. Although this material is distorted and incomplete, it enables us to outline the general character of North American Indian astronomy and to understand some of it in detail. All of these sources confirm that North American Indians farmed, hunted, and gathered by the sky. They developed calendric techniques to order the sacred and ordinary dimensions of their lives. They timed ceremonies by the sky. They extracted symbols from the sky. They told stories about the sky. Throughout all of the cultural territories, physical environments, and linguistic traditions of North America, celestial phenomena were incorporated into ritual, iconography, myth, shamanic activity, and worldview.

North American Indians were familiar, of course, with the fundamental cycle of day and night, the daytime path of the sun, and the unmoving pole of the night sky. Cardinal directions, which emerge from the daily rotation of the sky and the circular parade in which the stars march at night, were important to many groups. The moon's phases were monitored, and each monthly cycle was often associated with a seasonal change on earth. The seasonal shift of sunrise, sunset, and the sun's daily path was known. Solstices were recognized, and the rising and setting points of the summer and winter solstice sun sometimes established an alternate directional scheme. Seasonal appearances and disappearances of stars were noted. Constellations were contrived from conspicuous and useful stars. In the historic era, unusual events like eclipses, bright comets, fireballs, and meteor showers attracted notice and sometimes provoked ritual response. Planets were recognized by at least some groups, but explicit evidence of detailed indigenous knowledge of their cyclical behavior has not survived.

Like traditional peoples everywhere, the Indians of North America saw the sky as a realm of power. Access to that power required knowledge of the sky. They acquired that knowledge through careful observation and used that knowledge to order and stabilize their lives. This practical understanding of the sky – the sun, the moon, and the stars – is not the same thing as modern scientific astronomy, for it did not attempt to test and abandon metaphors of nature in the same way science does today. It did, however, help integrate human behavior with nature and consolidate social cohesion. Celestial objects were not just convenient metronomes. They were powerful, supernatural beings, and they revealed the basic structure – the fundamental order of the world. Because cosmic order is, in part, what is meant by the sacred, the Indians' interaction with the sky was an encounter with the sacred.

The earliest account of North American Indian astronomy was reported in 1524 by the Italian explorer Giovanni di Verrazano. He encountered the Narragansett Indians of Rhode Island and mentioned that their seeding and cultivation of legumes were guided by the moon and the rising of the Pleiades. The Pleiades comprise a distinctive cluster of stars. Its value as a signal of seasonal change was recognized throughout the continent. In California, for example, there is explicit evidence of Pleiades lore in all but 12 of the 58 native cultural territories. Those 12 actually correspond to a very small fraction of the entire area and population of the state, and their lack of Pleiades tradition is primarily due to linguistic and cultural extinction. Despite the extraordinary linguistic diversity represented by the 75 mutually unintelligible California Indian languages and 300 different dialects, names for the Pleiades, myths about the Pleiades, and seasonal references to the Pleiades are documented in all five major families of indigenous California languages.

Studies of North American Indian astronomy have emphasized the prehistoric Southwest and the historic Pueblos. This is due to the survival of prehistoric Pueblo architectural monuments and rock art and to the preservation of some information about historic Pueblo astronomical techniques and celestial lore in ethnological reports. Close to the end of the last century, Stephen described in detail the horizon calendar used by the Hopi Sun Chief to establish key dates in the ceremonial and agricultural cycles of the village of Walpi. More recently, historian of science McCluskey demonstrated that Hopi observations of the sun were accurate to 4 arcmin. This is, however, an average error, and it is difficult to do much better than 30 arcmin in any single horizon event. McCluskey verifed that the Hopi actually allowed themselves a few days' leeway in scheduling the winter solstice ceremony.

If Stephen had not seen the Sun Chief perform his duties, we would not know where his sunwatching station was located. Nothing marks the point out at the end of a mesa or on the roof of the highest house. Other references to North American horizon observatories suggest that many were just as subtly blended into the community landscape, and that makes the identification of prehistoric observatories a challenge. Symbolic astronomy was, however, often incorporated into monumental architecture and rock art. By analyzing alignments and iconography, it is sometimes possible to spot the hand of the ancient skywatcher. For example, Pueblo Bonito, an 800-room, five-story, D-shaped apartment-town in Chaco Canyon, New Mexico, makes good use of passive solar heating to stabilize room temperatures in summer and winter. It was completed in the twelfth century AD, and its east–west front wall is oriented cardinally with an accuracy of 8 arcmin. Such accuracy is achievable with simple surveying techniques that rely upon the unaided eye, but it is nevertheless respectable. In addition, archaeologist Jonathan Reyman interpreted corner windows in two rooms as winter solstice sunrise apertures.

The Anasazi built large subterranean community ceremonial chambers known as Great Kivas. Most of these, like Chaco Canyon's Casa Rinconada, possess cardinal orientation, and the plan of a Great Kiva is thought to mirror the Pueblo concept of the cosmos.

There are many pictographs and petroglyphs in Chaco Canyon, and the star and crescent on a panel near the Penasco Blanco ruin have been promoted by some as a representation of the AD 1054 Crab supernova explosion. Prehistoric Indians in the American Southwest very likely saw that spectacular event, but there is no way to verify that the Penasco Blanco pictographs are an eyewitness record of it. The supernova interpretation of star/crescent elements in Southwest rock art was first offered in 1955 as an explanation for two sites in northern Arizona. Since then, the number of reported star/crescent groupings has multiplied, but opinion on the supernova is divided. Reyman argues thoughtfully that the Penasco Blanco site is actually a sunwatcher's shrine and implies that the Crab supernova has nothing to do with these star/crescent designs. Even if they do depict the supernova rising with the waning crescent moon on the morning of 5 July 1054, they tell us nothing substantive about prehistoric Pueblo astronomy. In 1990, Robbins and Westmoreland revived the argument all over again with an analysis of numerical symbolism on prehistoric Mimbres ceramics. One of these has a rabbit in the shape of a crescent moon accompanied by a “star” with 23 rays. This detail is argued to be consistent with the Chinese historical account of the Crab supernova, for the Chinese reported it was visible in the daytime for 23 days.

A spiral petroglyph on Fajada Butte, the most conspicuous landmark in Chaco Canyon, interacts with “daggers” of midday sunlight at the solstices and the equinoxes. These light-and-shadow effects, first reported by Sofaer et al. received a great deal of international attention and inspired considerable controversy. Initially, the “Anasazi Sun Dagger” was interpreted as a “precise solar marker”, but it may be more correct to regard it as a symbolic seasonal display.

One of the best candidates for a sunwatcher’s observing platform is also located in Chaco Canyon, on an upper ledge on a rincon (a square-cut recess or hollow in a cliff) near Wijiji ruin. Rock art on the ledge includes elements as old as the Anasazi and as recent as the Navajo. A line-of-sight to the southeast coincides with a natural rock chimney on the other side of the rincon, and this feature dramatically marks the winter solstice sunrise.

Astronomer Zeilik has emphasized the importance of “anticipatory” observations of the solstices and other astronomical events. The Sun Chief must know ahead of time, with accuracy, when the solstice is due in order to mobilize the community for the ceremonial activity that culminates in the solstice. This is exactly what Walpi’s Sun Chief did, and Wijiji has the ability to deliver advance information and confirmation of the solstice. The site is interpreted, then, by extending significant information from the historic period back into the prehistoric context.

Astronomical components have been identified at many other sites in the Southwest, including Hovenweep, Yellow Jacket, Chimney Rock, Casa Grande, and Mesa Verde. Celestial rock art elements are present throughout the Southwest. Few of these involve accurate mapping of constellations, but several seem to invoke magical power attributed to the stars. Chamberlain has studied Navajo star ceilings in Canyon de Chelly and concluded that most of them are connected with symbolic protection or other celestial magic. Schaafsma interprets war and star imagery in the petroglyphs of New Mexico’s Galisteo Basin as part of a tradition of Southern Tewa celestial war magic.

Nine years after astronomer Hawkins rekindled interest in ancient and prehistoric astronomy in 1963, with his studies of solar and lunar astronomical alignments in Stonehenge, another astronomer, Eddy, identified celestial sightlines in the Bighorn Medicine Wheel, a North American antiquity *Time* magazine headlined as “Stonehenge USA.” The Bighorn Medicine Wheel is located at an elevation of 9,600 ft, above the timberline on Wyoming’s Medicine Mountain. It is a ring, 87 ft in diameter, drawn in small rocks. Originally, the Wheel had 27 or 28 spokes of stones that converged on the main cairn at the center. Five other cairns were constructed on the Wheel’s rim, and the one spoke that extends beyond the rim ends in its own cairn. The ring is actually a flattened circle. Its axis of symmetry coincides with the spoke that reaches from the outside cairn, southwest of the rim, to the cairn at the center. Eddy demonstrated that this line also continues to the northeast horizon and the point of summer solstice sunrise. He associated other lines between cairns with the sequential risings of three bright stars in the predawn sky in summer. Although the age of the Bighorn Medicine Wheel is uncertain, a radiocarbon date for a piece of wood retrieved from the central cairn associates it with the seventeenth century. Eddy thought that the Bighorn Medicine Wheel might have been used at that time by historic Plains Indians to make astronomical observations.

It seems likely, however, that the Bighorn Medicine Wheel is much older. It resembles other similar structures, especially in southern Canada, that are known to be thousands of years old. Who built the Bighorn Medicine Wheel and when it was built are still not known with certainty. There is reason to be skeptical about the practical value and validity of the stellar alignments, but the summer solstice sunrise line is congruent with the design. If the solstice alignment were part of the original plan, it may have had as much to do with vision quests and shamanic retreat as with calendric observation.

In the historic era, Plains Indians incorporated the sky into symbols and ritual. The well-known Sun Dance was intended to inspire prayer and visions through self-infliction of pain, fasting, and thirst. Gazing at the sun while suspended from a pole with ropes looped through the flesh of the chest was thought to purify and spiritually strengthen the participant. Although not all Plains tribes practiced this demanding regimen in the Sun Dance, acquisition of sacred power was a common theme. The enclosure in which the ceremony took place is called a Sun Dance Lodge, and it is sometimes built with 28 posts said to represent the days of the lunar month. Originally, the ritual was performed at the time of the summer full moon nearest to the time of the bison hunt.

Another Plains group, the Skidi band of the Pawnee, is known to have possessed a rich and detailed tradition of star lore. This knowledge has been reviewed and analyzed by Chamberlain in *When the Stars Came Down to Earth.* The Skidi Pawnee Morning Star sacrifice was timed by the movements of planets, especially Mars and Venus, and mythologically, the planets were key players in the Skidi Pawnee Creation myth.

In Nebraska, the Omaha devised a symbol of social cohesion and tribal stability out of the Sacred Pole that was erected ceremonially at tribal gatherings. Omaha myth and ritual allow us to deduce that the Sacred Pole was oriented on the north celestial pole. Its power was linked to the stabilizing character of the hub of the sky.

It is a curious fact that so much public interest in ancient North American Indian astronomy has been directed toward the prehistoric Southwest and the Bighorn Medicine Wheel. Although these sites are valid targets of study, they belong to relatively unpopulated parts of the continent. Even the well-documented traditions of the Plains Sun Dance, the Skidi Pawnee Morning Star Sacrifice, and polar axis symbolism of the Omaha Sacred Pole must be considered marginal traditions of North America.

The mainstream, on the other hand, belongs to the most populated zones of North America. To understand, then, the true character of North American Indian astronomy, it is necessary to look at the Mississippi Valley and California. Nowhere north of Mesoamerica had a comparable population density.

Unfortunately, we know relatively little about the astronomical traditions of the ancient Mississippi Valley. In 1961, however, archaeologist Wittry excavated a feature he called the Sun Circle at Cahokia, a great population center and powerhouse of regional trade in central Illinois between AD 700 and 1200. Cahokia is best known for its large mounds, some of which supported temples and residences. Others hosted burials. Monks Mound, the largest prehistoric earthen construction in the world, is the centerpiece of what was the Chicago of the prehistoric Midwest.

Originally, the Sun Circle was a 410-foot-diameter ring of 48 tall posts (perhaps 30 ft high), with a pole in the middle of the circle but offset apparently intentionally 5 ft from the true center. Three of the posts that once occupied the holes that now remain combined with the center pole to deliver alignments to the rising sun at summer solstice, winter solstice, and the equinoxes. Wittry believed that the Sun Circle's purpose was calendric. It is difficult to understand, however, why a complete ring of posts would be needed and why the posts were so tall. On the other hand, the intentional displacement of the central post makes the astronomical alignments possible.

Despite the ambiguity that persists with Cahokia's Sun Circle, archaeologist Fowler verified the ancient Cahokians' interest in cardinal directions. The city's limits were established by a particular type of earthen mound, and these mounds also defined the primary, and cardinal, axes of the site. In 1994, Fowler described another post circle on the main north–south axis of Cahokia. Its design, size, and astronomical potential mimic the Sun Circle.

The Incinerator Site, a smaller stockaded Mississippian village near Dayton, Ohio, included an arrangement of posts also thought to have astronomical meaning. The largest post, 2 ft in diameter, was located in a plaza, and it formed a line with a post inside a nearby building. This line pointed to the sunrise on April 24th and August 20th. Both dates potentially have agricultural significance. The April date could mark the end of the frost and the beginning of planting. The August date is linked to the Green Corn Ritual, performed in the historic era when the corn filled the husk but was not yet ripe. Cardinally oriented logs were kindled at this time into the New Fire, which also had solar associations.

European explorers encountered the descendants of the Mississippian mound builders in the southeast United States. The chief of the Natchez was known as the Great Sun. He claimed to be the brother of the sun and greeted the sun each morning, when it first appeared from the top of his residence mound. We also know the Natchez subdivided the daylight hours into four periods based upon the position of the sun. They measured the year in months based on the observed phases of the moon and named each lunation for an appropriate seasonal phenomenon.

In the Far West, before Columbus, California competed respectably with the Mississippi Valley for the distinction of being the most populous and densely populated zone north of Mesoamerica. Some indigenous astronomical traditions persisted in California until quite late, and valuable information was collected by ethnographers, especially Harrington. The revival of interest in California Indian astronomy was largely initiated by Hudson and Underhay, whose book, *Crystals in the Sky*, reconstructed the sky lore of southern California's Chumash Indians. Explicit references to horizon observations of the solstice sun and solstice rituals have been collected from the entire state. The moon's phases were counted, and the lunar months were named by most California groups. They recognized familiar patterns of stars, including the Big Dipper and the Belt of Orion. They named many other stars and used them as seasonal signals. They saw the Milky Way as a route to the sky followed by the souls of the deceased. Elaborate Milky Way ceremonialism is known among the Luiseño, who incorporated it into ritual initiation of the youth, mourning songs for the dead, sacred myth, and rock art.

California possesses many rock art sites and some of the most complex rock art in the world. Some of these sites have been associated with solstitial light-and-shadow events that interact with the rock art. Often, particularly at winter solstice, the light develops into a pointed, knifelike shape that pierces a carved or painted element. These effects appear to be symbolic, for they do not generally pinpoint the solstice with high accuracy. Rather, they "work" over a solstice "season" perhaps two to four weeks long. Although there is no explicit evidence that links solstice effects with California rock art, we do know the names of two Chumash shamans who went into the mountains at the time of winter solstice to paint on the rocks.

In detailed application, Native American astronomy was richly varied in North America, but its purpose and basic character were broadly the same throughout the continent. For that reason, we can rely upon Francisco Patencio, Chief of the Palm Springs Indians of southern California, for words that could apply to nearly all Indians:

> When the sun swung to the north and the moon showed quartered by day overhead, or west, they knew by the signs of the sun and the moon when the seeds of certain plants were ripe, and they got ready to go away and gather the harvest. Every plant that grew, the nesting time of all birds, the time of the young eagles, everything they learned by the signs of the sun and the moon. *Stories and Legends of the Palm Springs Indians* (Los Angeles: Times Mirror, 1943).

See also: ►Medicine Wheel, ►Time, ►Eclipses

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Astronomy in Sub-Saharan Africa

Keith Snedegar

At the turn of a new millennium the study of astronomical practices in precolonial African societies remains an open field. Major sources of evidence have yet to be fully scrutinized – astronomical texts in Arabic, Ge'ez, Hausa, Malagasy and Swahili, celestial iconography in the African arts, and perhaps most importantly, astronomical knowledge encoded in the vast reservoir of oral tradition. It should be no surprise that Muusa Galaal's groundbreaking monograph on Somali ethnoastronomy derives wholly from oral literature (Galaal 1992). As for the built environment, a few African architectural structures have been surveyed for astronomically meaningful features with interesting if not definitive results; further archaeoastronomical research would doubtless reveal more about the cosmologies behind African material culture. Nonetheless, scholars from various disciplines have already demonstrated that African time reckoning, divination systems, performance art and literature utilized the sky as a cultural resource. Jarita Holbrook of the University of Arizona is a leader of a new generation of scholars exploring African cultural astronomy (Holbrook 2004, 2005). At a popular level the documentary film *Cosmic Africa* (2003), featuring the South African astronomer Thebe Medupe, has done much to introduce the subject to wider audiences.

Sahara Region

Ancient astronomically aligned structures have been discovered in a megalithic complex in the southern Egyptian desert at Nabta, where nomadic pastoralists made their summer camps by a playa, or seasonal lake, between 6,500 and 5,300 years ago. The Nabta site probably served as a ceremonial center. It comprises several oval clusters of stones and isolated megaliths, and numerous tumuli containing cattle and sheep burials. The burials are analogous with ritual practices of modern African pastoralists who slaughter animals to mark socially important occasions. Archaeoastronomer McKim Malville used theodolite and GPS measurements to map the site. He found three lines of megaliths radiating from the largest structure. A nearby stone circle containing four sets of upright slabs, which may have been used to fix positions along the horizon, exhibits two line-of-sight "windows," along a north–south axis and at an azimuth of 62°; the rising mid-summer sun would have been visible through the second line of sight circa 6,000 years ago. Malville has theorized that the geometry of the standing stones reifies a conceptual system integrating death, water, seasonal fertility, and the motion of the sun (Malville et al. 1998). Presumably, the ancient Nabtans correlated solstice observations with the onset of summer monsoon rains. It is intriguing that the megaliths, located in the playa deposits, would have stood in the shallow lake water. The rising and falling water level marked against the stones could have been a powerful indicator of seasonality. With climatic change bringing hyperaridity and desertification to the Sahara region around 4,800 years ago, the seasonal occupation of Nabta came to an end. The Nabtan pastoralists may have migrated to the Nile Valley, contributing their practice of solar observation as well as their reverence for cattle to the cultural development of predynastic Egypt (Wendorf and Schild 2001).

While Nabta is the earliest Saharan site thought to have astronomical alignments, surveys of pre-Islamic tombs in the Tassili N'Ajjer region of Algeria and parts of southern Morroco have also indicated structural orientations suggestive of some calendrical purpose (Belmonte et al. 1999, 2002). In the historic period the nomadic Tuareg people have practiced celestial navigation in their travels across the great desert. When traveling north the Tuareg oriented themselves according to the mother camel constellation *Taləmt* (Ursa Major), and when traveling south they watched the gazelle stars *Ineren* (α and β Centauri). *Əmanar*, "The Guide" (Orion) and Tələzdak, the date palm (Scorpius) are other important asterisms in the Tuareg sky (Donaint 1975).

West Africa

By the first millennium AD the trade between West Africa and Mediterranean North Africa was functioning as an important mechanism for cultural exchange. The transmission of Islam to West Africa would engender formal academic traditions based on written texts in Arabic. From the fifteenth century onward a number of scholars in Timbuktu and other Islamic centers studied astronomy as an adjunct to the Quranic sciences. The corpus of Arabic scientific writings of West African provenance has yet to be analyzed in any detail, but a number of manuscripts preserve meteorological observations, particularly floodings of the Niger River, and details of solar and lunar calendars (Saad 1983). Rebstock (1990) located numerous mathematical, astronomical and astrological texts in Mauretania, 13 of them having to do with the Islamic calendar. Results of a study by the Al Furqan Foundation suggest that roughly one percent of Arabic manuscripts in West Africa contain astronomical material (Hunwick 1997). There are probably several hundred texts yet to be identified and analyzed. A Library of Congress exhibit of manuscripts from Timbuktu afforded a glimpse of this raw material, including tracts entitled *The Important Stars among the Multitude of the Heavens* and *The Rise and Setting of Auspicious Stars* (Library of Congress 2003).

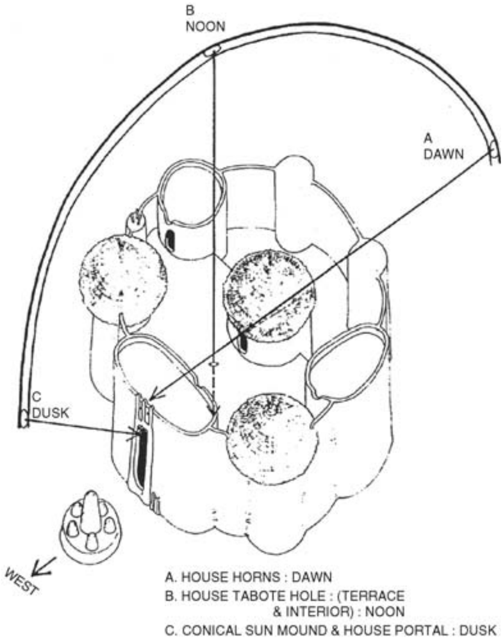
The existence of these texts indicates that at least some West African scholars engaged Arabic mathematical astronomy at rather advanced level. However, the reputed fascination of Aḥmad Bābā al-Tinbuki (1556–1627) and al-Ḥājj Muḥammad al-'Iraqi (fl. 1650) with esoteric astrology likely typifies the chief matter of interest. Many West African literati dabbled in celestial divination; others considered astrological prediction spiritually dangerous. The great Fulani scholar Muḥammad al-Wali (d.1688) wrote a diatribe against astrology and its practitioners. Ironically, his pupil Muḥammad ibn Muḥammad gained fame with an astrological opus, *al-Durr al-Manzūm* (Strung Pearls). It was not an original work. Its chief source was the *Secret Concerning the Dialogue with the Stars* of the Persian sage, Fakhr al-Dīn al-Rāzī (Ullmann 1972). The lack of any coherent school of astronomy or astrology in West Africa is perhaps attested by Muḥammad Bello of Sokoto, who recorded his observations of a bright comet in 1825. Several people asked him to explain the phenomenon so he wrote a treatise on it. Unable to find any scientific writings on comets, he was reduced to quoting theological opinions to assure his readers that the object did not signify the end of the world (Ogunbiyi 1991–1992) (Fig. 1).

The science of the stars did not remain solely in the Arabic language. Savants in the city of Kano translated Arabic star lore into Hausa. The anonymous pedagogical text, *Hisabi ʻAssawwakai*, gives an elementary account of Islamic astronomy, and is still circulating in northern Nigeria (Kani 1992). The Hausa took up astrology with enthusiasm, astrological verse becoming a prominent genre of vernacular literature. A Hausa poem attributed to Abdullah ibn Muḥammad describes the 28 *anwā'*, 12 signs of the Zodiac, and planetary rulership of parts of the sky, according to the foreign practice. Ibn Muḥammad apparently learned his astrological theory from the writings of Moroccan practitioners such as ʻAbd al-Hāqq, whose *Kitāb al-falak* (Book of the Planets), was widely read in Northern Nigeria. While the Ibn Muḥammad text largely retains Arabic terminology, other Hausa works apply indigenous epithets for the stars which were not derivations from the Arabic but reflect local tradition (Hiskett 1967, 1975).

Astronomy in Sub-Saharan Africa. Fig. 1 A page from *Kashf al-Ghummah fi Nafa al-Ummah* (The Important Stars Among the Multitude of the Heavens). Mamma Haidara Commemorative Library, Timbuktu, Mali (Library of Congress 2003).

As for the built environment in West Africa, studies by Drucker-Brown (1984) and Blier (1987) have shown that certain vernacular architectures perform a symbolic as well as a functional purpose; home design not only manages light and heat resources but incorporates visual metaphors of directional affiliation and spatial organization alluding to the sun's diurnal and annual motion. Among the Mamprusi of northern Ghana the *zonga* or entranceway of one's home faces west so that the rays of the setting sun are directed into an area where family elders sit. It is here where in the late afternoon the position of light falling onto a wall is judged as an indication of the agricultural seasons. Elaborating on this theme, the Batammaliba people of Togo and Benin believe that the home should be representative of the solar deity, Kuiye. When a house is constructed, the builders perform a ritual in hour of Kuiye. It occurs at local noon when the sun is on the meridian, the "center" of the sky, and involves the placement of cooked cereal on the *tabote* stone in the center of the homestead. The home itself is aligned on an east–west axis, with its portal and family shrines facing west. This allows the rays of the setting sun to strike the shrines of the family's deceased elders; it is believed that when such shrines are illuminated, Kuiye communicates with the ancestors about the affairs of living family members. Batammaliba granaries are also identified with Kuiye's domain, being divided into three sections, each associated with a different crop harvested in accordance with the three seasons delimited by tradition (Fig. 2).

Unfortunately, while West African astronomical traditions have not as a whole attracted much attention, an inordinate amount of publicity has surrounded exaggerated claims for an advanced state of knowledge on the part of the Dogon people of Mali. Based on their fieldwork conducted in the 1930s, Griaule and Dieterlen (1950, 1965) reported that the Dogon were aware of Sirius B, a small star invisible to the unaided eye. Such was the fuel for Temple (1975), among others, who claimed for the Dogon a heliocentric model of the solar system and independent knowledge of the satellites of Jupiter and the rings of Saturn. Thanks to television series such as "In Search of…" (1979) the Dogon have entered the popular imagination. Penetrating criticism by respected scientists and a field evaluation of Griaule's reportage, determining many elements, including the astronomical portions, to be either misconstrued or altogether unsupported by ethnographic evidence, have done little to stay the proliferation of misinformation on Dogon cosmology (Van Beek 1991).



Astronomy in Sub-Saharan Africa. Fig. 2 The sun's path and corresponding parts of a Batammaliba homestead (Blier 1987).

East Africa and Madagascar

By the shores of Lake Turkana a megalithic site designated Namoratunga II, comprising 19 basalt pillars and at least one grave marked by upright slabs, has been surveyed for possible astronomical alignments (Lynch and Robbins 1978). Although there is no proof positive that the Namoratunga stones were erected with an observational purpose in mind, they appear to be nonrandomly aligned in directions corresponding with the rising positions of seven conspicuous stars and asterisms – Bellatrix, Orion's Belt (δ, ε, ζ Orionis), Saiph, Sirius, the Pleiades, Aldebaran, and Triangulum – on the local horizon ca. 300 BCE. These stars may have served as calendrical markers for the ancient Cushitic people who erected Namoratunga. However, efforts to elucidate a cultural linkage between the purported Namoratunga tradition and calendrical practices of the Borana people in the historical period have met with doubtful results (Soper 1982; Doyle and Wilcox 1986). Most scholars have identified the Borana asterism *Lami* as the constellation Triangulum, but when Tablino (1994) asked Borana time-reckoning experts to identify *Lami* they invariably pointed out α and β Arietis. The Triangulum alignment at Namoratunga, at least, looks to be questionable.

Christian Ethiopia has a tradition of skywatching documented in manuscripts dated back to the Middle Ages. Neugebauer (1979, 1981) found that Ethiopian astronomical knowledge applied almost exclusively in religious contexts. The astronomical chapters of the Ethiopic *Book of Enoch* contain simple arithmetical schemes for the motion of the sun and moon. The origins of this treatment are obscure, but they are more likely to derive from the rudimentary astronomical traditions of Egyptian Judeo-Christian communities than from early Babylonian schemes. Other texts and Easter tables of the Ethiopian Church reflect the computus of Alexandrian Christianity. A thirteenth-century computus of Abu Shaker of Alexandria, for reckoning Easter and other movable feasts, is extant in a number of Ethiopic manuscripts dating from the sixteenth century. Ethiopian chronicles record comets, eclipses, and other astronomical events from the fifteenth century onward.

The folk astronomy of Islamic Somalia appears to be directly influenced by the practices of south Arabia. Nomadic Somali herders know Polaris as *Hhiddigo*, the Prayer Star; by noting its direction after establishing an evening camp, they can orient themselves toward Mecca for their five daily prayers. Somalis have also adopted the 7 day week, and the folk practice of *taawil*, or assigning a good or evil value to each day. The most telling indicator of Arabic influence, however, is the recognition of lunar stations (Arabic: *anwā'*), 28 stars or asterisms, noted for their risings and settings over the year. Although the camel and sheep herding peoples of Somali used the *anwā'* (called *god* in Somali dialects) as a framework for a seasonal calendar, they viewed lunar stations primarily as divinatory signifiers. It is still held by many Somalis that the Moon's passage through the stations releases favorable or unfavorable celestial influence. *Dirir* (Spica) which means "good omen" is the most important station, as it is believed to govern the summer rains. Traditional Somali weather experts judge the quantity of future rain when *Dirir* is in conjunction with the Moon; a majority consider the Moon and *Dirir* rising in conjunction to be an auspicious sign. However, if the Moon passes north of *Dirir* a drought is expected. A child born on the night of a conjunction is thought to possess *buruud*, the ability to inspire respect among the people. A *Dirir* child will also have good fortune in owning camels and horses. At all events, a considerable body of Somali proverbs, songs and folktales has grown around the import of lunar stations (Galaal 1992).

Peoples of the East African coast have for centuries engaged in long distance trade with the Middle East and South Asia. The fifteenth-century master seafarer Aḥmad ibn Mājid left behind an Arabic memoir on Indian Ocean navigation techniques which relied heavily on stellar observation. He noted that navigators of Mombasa, Sofala, and Madagascar sailed by the stars of Ursa Major, which they called *al-Hīrāb* (Tibbetts 1981). Swahili manuscripts at the University of Dar es Salaam also attest to celestial navigation on the part of East Africans. The Arabic element was considerable nonetheless: a majority of the 105 Swahili star names collected by Knappert (1993) are derived from Arabic, and Kiswahili lunar station vocabulary preserves the Arabic terminology essentially unaltered. Moreover, the adoption of Islam by Swahili-speaking peoples brought with it the Islamic lunar calendar and the practice of orienting mosques in the direction of Mecca. Nonetheless, the Swahili lived in an environment of parallel time-reckoning systems. The indigenous Bantu tradition of the Pleiades or *Kilimia* remained distinct from the *anwā'* system and continued to be used for the regulation of agricultural work. In Swahili the Pleiades are *Kilimia*, the Ploughing Stars. Referring to the *vuli* and *masika* monsoon periods, and their respective planting seasons, a proverb runs: "If the Ploughing Stars set in sunny weather they rise in rain, if they set in rain they rise in sunny weather." As viewed in the evenings from equatorial Africa the Pleiades disappear in the Sun's glare, they "set" about early May, reemerging in the morning sky just as June's *vuli* rains begin. Observed in the predawn sky *Kilimia* are seen to set at the end of the *masika* rains in November; when they are glimpsed rising in the evening twilight they herald a dry or "sunny" period. Alongside the Islamic lunar calendar Swahili-speaking peoples kept a 365-day year subdivided into 36 and a half "decades" of 10 days each. This solar year, which begins with the *Nairuzi* festival, appears to be of Persian origin (Gray 1955).

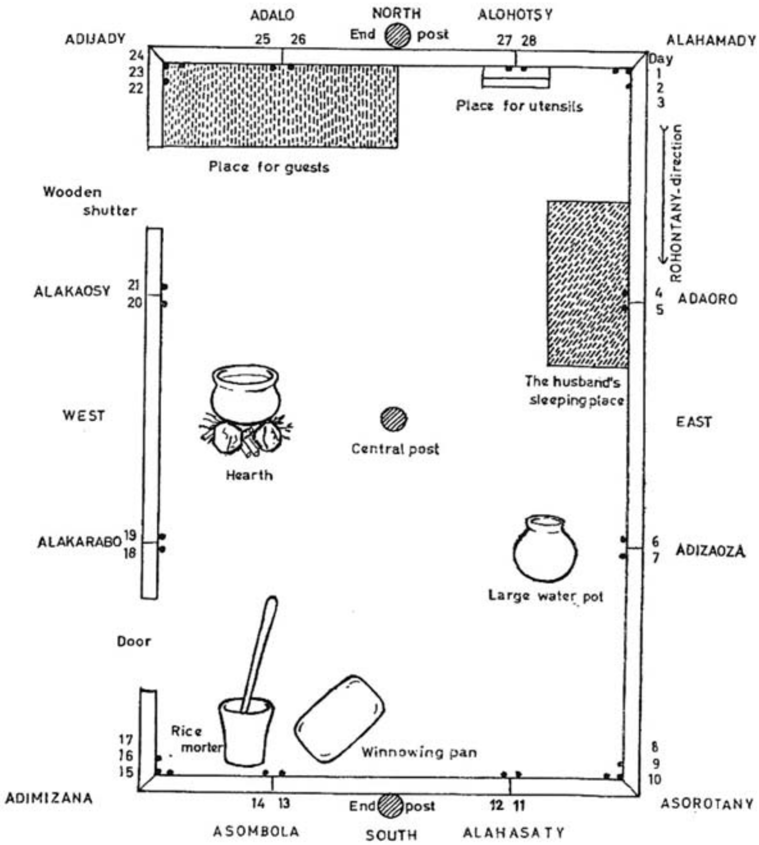
On the island of Madagascar the highly syncretic *Mpandandro* astrological system appears to integrate Arabic and South Asian practices with indigenous culture. Writing in a modified Arabic script, scholars among Antaimoro and Antambahaoka peoples of southeastern Madagascar compile *Sorabe*, or "great books" containing history, medicine, geomancy and astrology. Malagasy astrologers utilize lunar stations and assign favorable/unfavorable values to days within a 7-day week. The temporal scheme is represented spatially in the orientation and lay out of the traditional rectangular house (Verin and Rajaonarimanana 1991) (Fig. 3).

Central and Southern Africa

The African states centered on Great Zimbabwe and Mapungubwe between the twelfth and fifteenth centuries presumably developed temporal and spatial ideologies involving the sky. Even so, there is no conclusive evidence for intentional astronomical alignments at Great Zimbabwe, despite the recent conjectures of independent archaeologist Richard Wade (Campbell 2002). Other southern African sites have not been surveyed specifically for their archaeoastronomical potential, but the features of an Iron Age village called Ntsuanatsatsi are very suggestive. Situated a kilometer west of a prominent hill in the grassy highveld of the Orange Free State, South Africa, the stone-walled ruins face eastward. The place name, Ntsuatsatsatsi, attested to as early as the 1830s, means "sunrise" in the Sesotho language. For local Sotho clans the hill is reputed to have been where the first ancestors rose from the earth. In former times, Bafokeng chiefs held their councils on top of the ridge across from the hill. Their ability to gauge the annual motion of the sun by the sunrise locations on Ntsuanatsatsi hill may have contributed to the prominence of these early Sotho leaders (Maggs 1976).

The ritual initiation of adolescents into full membership of the community is an important aspect of African society. A "morning star," usually identified in the literature as the planet Venus, traditionally had strong associations with male rites of passage in Central and Southern Africa. The Mbunda people looked for an object they called *gongonosi*; the Tsonga of Mozambique used the cognate term *ngongomela* "towering in strength." Victor Turner noted the visibility of such a morning star on the last morning of the Ndembu ceremonies he witnessed; he further recorded that the initiation title of the third boy to be circumcised was *kaselantanda*, "he of the morning star" (Turner 1967). According to Junod (1927), Tsonga initiation schools were synchronized with the appearance of Venus in the morning sky during a winter month (June–September in the southern hemisphere). One of Junod's informants, the Tsonga elder Shinangana, chronicled a few of the schools in the last half of the nineteenth century: they occurred in 1862, 1873, 1881, 1887, and 1893. Venus was indeed a morning star in the first three years, but not in 1887 or 1893, although in the later year Jupiter was located in the morning sky and could have served as *ngongomela*. Hence, it would be rash to assert any correlation between periods of the morning visibility of Venus and the age-sets of Tsonga initiates. In a praise poem which inspired the young Nelson Mandela, Krune Mqayi sang of counting the years of manhood by the rising "Morning Star." For the Xhosa of South Africa this object was unquestionably the Pleiades, the dawn rising of which occurs late in June. It is said that the month of the Pleiades, *Eyesilimela*, symbolized new life; the coming-out ceremony of the *abakwtha* circumcision school was synchronized with the appearance of the star cluster (Snedegar 1997). The morning star, however imprecise its own identity, was recognized across central and southern Africa as a key identifier of the male child's passage into the daylight of adulthood.

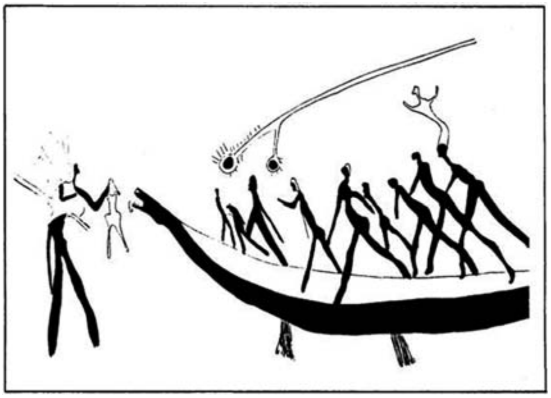
The night figures prominently in the cognitive universe of the Khoisan peoples, who articulate their knowledge in oral traditions which have been transmitted across generations. The evening campfire traditionally served as the venue for sky stories. Appropriately, many San groups recognize a "Fire Finisher" star whose



Astronomy in Sub-Saharan Africa. Fig. 3 Plan of a Malagasy house indicating directional associations with 12 months and 28 lunar stations (Ruud 1960).

position above the horizon indicates the time on cold winter nights. Fire Finisher is said to rise in the evening and set before dawn, about the time the night's fire has burned to embers. By all accounts, Fire Finisher is a brilliant star which seems to be alone in the sky. Three stars fit the profile and are in fact identified as Fire Finisher by different San groups: Antares (by the Nharo), Arcturus (!Xo), and Regulus (G/wi). Like Fire Finisher, all stars are associated with fire. In the Ju/'huoan dialect the act of stoking a fire, causing sparks to fly into the air, is described with the same words as a shooting star. One of the most famous myths concerns a girl of the "early race" who created the Milky Way by throwing ashes from her campfire into the sky. For many San, however, the Milky Way is the Backbone of the Night. There may be a connection with the moon. A nineteenth-century explanation of the Moon's waning phases claims that the Sun chases the Moon; as it catches up, the Sun slices away pieces of the Moon until nothing remains. But before the Moon is altogether devoured, it says, "Oh Sun! Leave for the children the backbone!" (Bleek and Lloyd 1911). Sirius is often identified as the Hip Star or Thigh Star. In her fieldwork, Marshall (1986) discovered that the !Kung San see Canopus and Capella as "horns of *tshxum*," an identity, perhaps a magical rain bull, centered on the Pleiades. Predawn observation of *tshxum* and its horns indicated the coming of spring rains.

In Khoisan mythology human ancestor spirits inhabit the night. They are accompanied by spirits of terrestrial animals including lions, elands, gemboks, hartebeests, steenboks, porcupines, hedgehogs, and giraffes. The starry sky becomes a great canvas for hunting stories, of which ≠Gao N!a, or G≠kao N!a'an, is often the leading man. According to a story collected by Marshall (1986), ≠Gao stood on the Large Magellanic Cloud one evening looking for game to hunt. He spotted three zebras, the three stars in Orion's Belt, and shot an arrow at the middle one. The arrow fell short; it is represented by the stars just south of the zebras. After his unsuccessful shot, ≠Gao decided to send the zebras down to earth for the San to hunt. Nineteenth-century Khoikhoi told a similar tale. Their rendition identified the hunter with the star Aldebaran, spurred on by his wives, the Pleiades. Having failed in his hunt, Aldebaran cannot return to his family, and is fixed in his place in the sky. Another story independently documented by Marshall and Biesele (1996), involves the sons of ≠Gao, !Xuma and Kha//'an,



Astronomy in Sub-Saharan Africa. Fig. 4 San rock painting of bolide-like object near Bethlehem, South Africa (Thackeray 1988).

identified with α and γ Crucis, who went out hunting an eland but themselves were pursued and killed by two lions "the keepers of the west," α and β Centauri. ≠Gao suspected the lions. He hid a pair of magic horns in a tree, and invited the lions to dance under its branches. The horns fell onto the celebrating lions, killing them. ≠Gao then resurrected his sons. Celestial players reenact the story on October evenings when the stars of Crux, representing the two boys, set or "die" on the southwestern horizon; they are followed by α and β Centauri, the lions tricked into death. As viewed from San locations in the Kalahari Desert, where Crux is not quite circumpolar, α and γ Crucis rise again later in the night; the boys are visually resurrected.

Meteors have an important place in Khoisan folklore. These "shooting stars" are interpreted in various ways, but they are generally considered to signify creatures having supernatural powers. Some say meteors are antlions falling to earth in search of food; for others they are porcupines or hedgehogs. Hence a porcupine-skin bag is called a star skin, and hedgehog fat is a chief ingredient for amulets worn in curing dances (Traill 1994). Through dance a shaman enters a trance state in which, it is believed, he is able to traverse the sky as a meteor, obtaining supernatural potency from the ancestors. Such potency is supposed to give him the mastery over disease as well as control of game animals and the spring rains. The meteoric trance experience is very probably illustrated in rock art. Although only a few rock art images suggestive of meteoric trance have been recorded, the territory in which these images have been found stretches from Zambia to Lesotho (Thackeray 1988). One extraordinary rock painting in South Africa portrays a shamanistic dance; a bolide-like object appears to zoom over the dancers' heads and burst into two fragments (Fig. 4).

See also: ►Namoratunga

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Astronomy in Tibet

YUKIO ŌHASHI

Tibetan astronomy is a living form of traditional astronomy, and is the basis of the Tibetan calendar which is used in Tibet and in Tibetan communities in India, and other places in the world.

There are four branches of Tibetan astronomical science (*rtsis*). The most important branch is *skar-rtsis* (star calculation) which is based on the *Kālacakra* astronomy of India. Another branch is *dbyaṅs-'char* which is based on Indian divination, *svarodaya.* Another is *nag-rtsis* (black calculation), based on Chinese astrology and natural philosophy, and the last branch is *rgya-rtsis* (Chinese calculation), based on the Shixian calendar of China.

Indo–Tibetan Astronomy

The Tibetan *Tripitaka* is a collection of Tibetan translations of Buddhist works, some of which include astronomical information. There is a Tibetan translation of the *Śārdūlakarṇa-avadāna*, which is a Buddhist work in which early Indian astronomy and astrology of the Vedāṅga period, the post-Vedic period before Greek influence, are mentioned. There is also a Tibetan translation of an early Indian astrological text ascribed to Sage Garga. Astronomical knowledge in these texts is from an early period, and not of *skar-rtsis.* The most important texts from an astronomical point of view are the Tibetan translation of the *Kālacakra-tantra* and its commentary, *Vimalaprabhā.*

Kālacakra-yāna Buddhism is the last stage of Esoteric Buddhism in India. Its most fundamental text is the *Kālacakra-tantra.* It is not known when and where it was composed. Some people say it was introduced into Tibet in AD 1027, and was introduced into India from Central Asia 60 years before. I believe that it was composed in the eleventh century, because the year 1027 is used as the beginning of the 60-year cycle (*bṛhaspaticakra*) in the text itself. I also believe that it was composed in India, because it adopts the Hindu system of astronomy without any apparent influence of Chinese or other astronomy.

According to the commentary *Vimalaprabhā*, there was the original text or *Mūla-tantra*, where the *Siddhānta* system of astronomy was explained, and the text on which it comments is the abridged text or *Laghu-tantra*, where the *Karaṇa* system of astronomy is explained. The *Mūla-tantra* is not extant, and it is difficult to say whether it actually existed as a whole or not, but some fragments are quoted in the *Vimalaprabhā.* The *Siddhānta* system of astronomy is called *grub-rtsis* in Tibetan, and the *Karaṇa* system is called *byed-rtsis.* In Tibetan astronomy, these two systems are basically the same, and only the length of a year and a month are different. In the *Siddhānta* system, one sidereal year = 365.270645 days and one synodic month = 29.530587 days. In the *Karaṇa* system, a sidereal year = 365.258675 days, while a synodic month = 29.530556 days.

In the Tibetan calendar, there are two intercalary months for 65 ordinary months. This is harmonious with the *Siddhānta* system, but not with the *Karaṇa* system. The *grub-rtsis* is usually followed now.

Since about the twelfth century, the *Kālacakra* calendar has been followed in Tibet. In the fourteenth century, a comprehensive treatise of *Kālacakra* astronomy entitled *mKhas-pa-dga'-byed* (AD 1326) was composed by an encyclopaedic scholar Bu-ston Rin-chen-grub (1290–1364). After Bu-ston, lHun-grub-rgya-mtsho wrote the *Pad-dkar-źal-luṅ* (AD 1447), and his system was developed as the Phug school. The most famous work of this school is the *Vaiḍūrya dkar-po* (AD 1683) written by Saṅs-rgyas-rgya-mtsho, who was the regent of the fifth Dalai Lama. Another famous work is the *Ñin-byed-snaṅ-ba* (AD 1714) of Dharmaśrī.

There is another school, mTshur-phu, whose fundamental text is the *Ñer-mkho-bum-bzan* (AD 1732) written by Karma Ṅes-legs-bstan-'dzin.

Let us use astronomical calculation in the *mKhas-pa-dga'-byed* as a case study. It is one of the earliest treatises of the *skar-rtsis* branch of Tibetan astronomy and will give a general idea of *skar-rtsis.* As *skar-rtsis* is based on *Kālacakra* astronomy, it is similar to Hindu astronomy. First, mean motions of the planets are calculated, and then the equation of the center and the epicyclic correction are applied. The operation of the equation of the center (Sanskrit: *manda-karman*) is called *dal-ba'i-las* in Tibetan, and the operation of the epicyclic correction (Sanskrit: *śīghra-karman*) is called *myur-ba'i-las.*

Three kinds of days are used. They are *ñin-źag* (Sanskrit: *sāvana-dina*), *tshes-źag* (Sanskrit: *tithi*), and *khyim-źag* (Sanskrit: *saura-dina*). A *ñin-źag* is a civil day measured from sunrise to sunrise. A mean *tshes-źag* is a 13th part of a synodic month. The equation of the center of the sun and moon are applied so as to make a *tshes-źag* correspond to the change of 12° of the longitudinal difference between the sun and moon. A mean *khyim-źag* is a 360th part of 1 year.

The ecliptic is divided into 12 *khyim* (Sanskrit: *rāśi*) or zodiacal signs, and also into 27 *rgyu-skar* (Sanskrit: *nakṣatra*) or lunar mansions. Each day as well as *rgyu-skar* is divided into 60 *chu-tshod* (Sanskrit: *nāḍī*). One *chu-tshod* is further divided into 60 *chu-sraṅ* (Sanskrit: *vināḍī*). One *chu-sraṅ* is divided into six *dbugs* (Sanskrit: *prāṇa*).

The mean motion of the sun and moon is calculated from the following simple formulae, which correspond to the *grub-rtsis* system:

Length of a *khyim-źag* = length of a *tshes-źag* × $\left(1+\frac{2}{65}\right)$

Length of a *tshes-źag* = length of a *ñin-źag* × $\left(1-\frac{1+\frac{1}{707}}{64}\right)$

The equation of the center of the sun is given for each zodiacal sign. Twelve zodiacal signs are divided into four quadrants. Then 6/135, 4/135, and 1/135 of the mean daily motion of the sun are subtracted from or added to the mean daily motion of the sun in each sign. The variables 6, 4, and 1 are called *dal-rkaṅ* (slow step). The ecliptic is divided into the first half (*rim-pa*) and the second half (*rim-min*). The first as well as the second half is further divided into the first part (*sṅa-rkaṅ*) and the second part (*phyi-rkaṅ*). So, one part consists of three signs. The first point of the first half is the apogee.

This *dal-rkaṅ* is, in fact, the difference between the mean motion and the true motion of the sun during one zodiacal sign's movement of the mean sun in terms of *chu-tshod.* Hence, the maximum equation is the total of the variables, that is 11 *chu-tshod* or 2°26′40″. The solar apogee is located at the first point of Cancer in this system.

One anomalistic month is roughly considered as 28 *tshes-źag*, and a correction is applied to the length of each *tshes-źag.* This correction is called *zla-ba'i-myur-rkaṅ* (fast step of the moon). The word *myur* (fast) shows that it was considered to be the epicyclic correction rather than the equation of center. Since the period of 28 *tshes-źag* is a little longer than the actual anomalistic month, a special correction is also applied so as to diminish the period of 28 *tshes-źag* at the rate of one *tshes-źag* per 3,780 *tshes-zag.* So, one anomalistic month becomes about 27.55459 civil days.

One anomalistic month is divided into four quadrants, each of which consists of seven *tshes-źag.* Then 5, 5, 5, 4, 3, 2, and 1 *chu-tshod* are added to or subtracted from the length of each *tshes-źag*. These values were probably originally meant to be the difference between the mean motion and the true motion of the moon during one *tshes-źag* in terms of *chu-tshod*. Since the time interval during which the moon moves the arc of one *chu-tshod* is about 1.01 *chu-tshod*, this was considered to be one *chu-tshod*, and the same value was used for the correction of the length of a *tshes-źag*. The maximum equation is the total of the variables, that is 25 *chu-tshod* or 5°23′20″.

Five planets are divided into *źi-ba'i-gza'* which corresponds to inner planets, and *drag-gza'* which corresponds to outer planets. The sidereal period (*dkyil-'khor*) of each planet is given as follows:

Mercury (*lhag-pa*): 87 days 58 *chu-tshod* 12 *chu-sraṅ*

Venus (*pa-saṅs*): 224 days 42 *chu-tshod*

Mars (*mig-dmar*): 687 days

Jupiter (*phur-bu*): 4332 days

Saturn (*spen-pa*): 10766 days

Just as in the case of the sun, *dal-rkaṅ* (slow step) for each zodiacal sign is given for each planet. The mean daily motion of each planet in the case of outer planets, or of the sun in the case of inner planets, is corrected as follows.

Corrected daily motion = $A \mp A(d/135)$, where A is the mean daily motion, and d is *dal-rkaṅ*. The value of *dal-rkaṅ* for each planet is:

Mars: 25, 18, and 7

Mercury: 10, 7, and 3

Jupiter: 11, 9, and 3

Venus: 5, 4, and 1

Saturn: 22, 15, and 6

The total of the value of *dal-rkaṅ* is the maximum equation in terms of *chu-tshod*. The maximum equation of each planet is:

Mars: 50 *chu-tshod* or 11°6′40″

Mercury: 20 *chu-tshod* or 4°26′40″

Jupiter: 23 *chu-tshod* or 5°6′40″

Venus: 10 *chu-tshod* or 2°13′20″

Saturn: 43 *chu-tshod* or 9°33′20″

The longitude of the apogee of each planet in this system is Mars: 126°40′, Mercury: 220°, Jupiter: 160°, Venus: 80°, and Saturn: 240°.

The "parameter of step" (*rkaṅ-'dzin*) is used to count steps of epicyclic correction. The period of 60 *chu-tshod*'s change of the "parameter of step" is considered one step. Sixty *chu-tshod* correspond to one lunar mansion, and there are 27 lunar mansions, so one cycle consists of 1,620 *chu-tshod*. One cycle is divided into two halves, and each consists of 14 steps. The 14 step of the first half and the first step of the second half consist of 30 *chu-tshod* only.

In the case of the outer planets, daily motion of the "parameter of step" is the mean daily motion of the sun minus the daily motion of the planet which has been corrected by its equation of center. In the case of the inner planets, the daily motion of the "parameter of step" is the daily motion of "parameter of fast step" (*myur-rkaṅ-'dzin*) minus the true daily motion of the sun. The "parameter of fast step" is, in fact, the daily motion of the planet's revolution, because it is defined as the quotient of 1,620 *chu-tshod* divided by the planet's sidereal period. The variable of the epicycle correction is given as *myur-rkaṅ* (fast step) for each step.

The method of the correction is as follows: let M be the true daily motion of the planet, D the daily motion of the planet in the case of an outer planet and the daily motion of the sun in the case of an inner planet, both of which have been corrected by the equation of center of the planet itself, K the daily motion of the "parameter of step," and m the *myur-rkaṅ*. Then, for the steps from the first step to the 13 step of the first half and from the second step to the 14 step of the second half, the following equation gives the true daily motion of the planet

$$M = D \pm K\frac{m}{60}.$$

For the 14 step of the first half and the first step of the second half, the following equation is used

$$M = D \pm K\frac{m}{30}.$$

The first half (*rim-pa*) as well as the second half (*rim-min*) are further divided into the first part (*sṅa-rkaṅ*) and the second part (*phyi-rkaṅ*). The correction is plus in the first part of the first half and the second part of the second half, and minus in the second part of the first half and the first part of the second half.

The values of *myur-rkaṅ* for each planet are shown in Table 1. The values are arranged for the first half. In the second half, the same value is used in reverse order.

Astronomy in Tibet. Table 1 The values of *myur-rkaṅ* for each planet

Planet	First part	Second part
Mars	24, 23, 23, 23, 21, 21, 18, 15, 11, and 3	11, 38, 80, and 53
Mercury	16, 16, 15, 14, 13, 11, 7, 5, and 0	4, 11, 20, 28, and 34
Jupiter	10, 10, 9, 8, 6, 6, 2, and 1	3, 6, 9, 11, 16, and 7
Venus	25, 25, 25, 24, 24, 22, 22, 18, 15, and 8	6, 30, 99, and 73
Saturn	6, 5, 5, 4, 4, 2, 2, and 0	2, 4, 5, 6, 8, and 3

The total of the value of *myur-rkaṅ* in one part is the maximum epicyclic correction in terms of *chu-tshod.* The maximum correction of each planet is:

Mars: 182 *chu-tshod* or 40°26′40″
Mercury: 97 *chu-tshod* or 21°33′20″
Jupiter: 52 *chu-tshod* or 11°33′20″
Venus: 208 *chu-tshod* or 46°13′20″
Saturn: 28 *chu-tshod* or 6°13′20″

In a paper written in 1986, I compared the astronomical constants used by Bu-ston with those of some schools of Hindu astronomy, and pointed out that they are close to those of the Ārdharātrika school of Hindu astronomy.

Sino–Tibetan Astronomical Science

The *nag-rtsis* is said to have been introduced into Tibet from China in the seventh century. It is based on Chinese astrology and natural philosophy. According to the *Zla-ba'i-'od-zer* (AD 1684) of Dharmaśrī, a popular work of *nag-rtsis*, the most fundamental elements of the *nag-rtsis* are as follows.

1. *Khams* (also called*'byuṅ-ba*), which are the five elements of Chinese natural philosophy: wood, fire, earth, metal, and water.
2. *Lo-'gros*, which are 12 animals used to name each year of a 12-year cycle: rat, ox, tiger, rabbit, dragon, snake, horse, sheep, monkey, bird, dog, and boar. This 12-year system is the Chinese system, which is widely used in East Asia. The combination of the *khams* and *lo-'gros* is used to name each year of a 60-year cycle. This is also the Chinese system.
3. *Sme-ba*, which is the Chinese "nine stars" used for astrological purposes.
4. *sPar-kha*, which is eight symbols of Chinese natural philosophy, of which the most fundamental text is the famous *Yijing* (I Ching, Book of Changes).
5. *Zla-ba*, which is 12 months for each of which 12 animals are attributed. The first month of spring is a tiger, and so on.
6. *Tshes*, which is the date of the month.
7. *Dus-tshod*, which is a 12th part of a day, for each of which 12 animals are attributed. The midnight is rat, and so on.
8. *gZa'*, which is eight planets: the sun, moon, five planets, and *rāhu*. The *rāhu* (dragon's head, or the ascending node of the lunar orbit) is not Chinese, but of Indian origin.
9. *sKar-ma*, which is the Chinese 28 lunar mansions or lodges.

The *rgya-rtsis* is based on the Tibetan version (AD 1725) of the Mongolian translation (AD 1711) of the Chinese astronomical work *Xiyang xinfa suanshu* (AD 1669) compiled in the Qing dynasty, which is the theoretical text on the Shixian calendar. The Shixian calendar is the last luni-solar calendar in China.

The traditional Tibetan calendar, which is based on the Phug school of *skar-rtsis*, is still used by Tibetan people. Also, several Tibetan astronomical texts are extant, and the process of astronomical calculation is explained in detail in these texts. More extensive study of Tibetan astronomy by historians of astronomy will be fruitful. In 1987, Chinese scholars Huang Mingxin and Chen Jiujin published a *skar-rtsis* text of epoch AD 1827, the *Rigs-ldan-sñiṅ-thig* of Phyag-mdzod gsuṅ-rab, with Chinese translation and astronomical commentary. This is a good introduction to Tibetan astronomy.

See also: ►Lunar Lodges, ►Mean Motion

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Atomism in Islamic Thought

Alnoor Dhanani

Atomism, the view that there are discrete irreducible elements of finite spatial or temporal space, played a significant role in Islamic intellectual history. It was upheld by most practitioners of the uniquely Islamic discipline of *kalām*. However, some practitioners of *kalām* (i.e., *mutakallimūn*) as well as all but one of the practitioners of *falsafa* (i.e., *falāsifa* – those engaged in the Neoplatonized Peripatetic philosophy of medieval Islam) were antiatomists. There was thus a lively debate between atomists and antiatomists, regarding not only matter theory, but also other areas of natural philosophy and cosmology, particularly theories of space, time, void, motion, and causality.

Kalām has no counterpart in the Western tradition. Even though primarily theological in orientation, it is not equivalent to theology. The subject matter of *kalām* includes not only theological topics, e.g., the nature and attributes of God, prophecy, and revelation, but also philosophical problems of cosmology, logic, anthropology, psychology, etc. The origins of *kalām* are obscure and a subject of debate. Suffice it to say that *kalām* arose in the mid-eighth century, and that during the later half of that century, questions about the nature and attributes of objects were being discussed. In their discussion of such questions among themselves and with others from the various religious and intellectual traditions of the Hellenized Near East, the *mutakallimūn* had access to views and theories propounded by the intellectual, doctrinal, and sectarian movements of Late Antiquity: Neoplatonism, Stoicism, Manicheanism, Dualism, Bārdaiṣānism, etc. Little is known about the *mutakallimūn*'s manner of access to these views. It was probably oral and through personal contact. Such a transmission is in sharp contrast with the large-scale translation of Greek philosophical and scientific texts during the late eighth and ninth centuries which gave rise to *falsafa*.

The *mutakallimūn* of the late eighth century held three theories of matter and its attributes. In the first, bodies are the only constituents of the world. All secondary qualities like sound, taste, color, etc. are thus corporeal. It follows that perceptible objects consist of several interpenetrating bodies. This view, whose origins are Stoic, was held by some Dualists. Its early *kalām* subscribers were Ḥishām ibn al-Ḥakam (d. ca. 795), and al-Aṣamm (d. 815). Later, the antiatomist Ibrāhīm ibn Sayyār al-Naẓẓām (d. 835–845) advocated it, albeit holding that motion was the sole accident.

In the second theory, unextended accidents are the only constituents of the world. Extended bodies result from a combination of accidents, namely, color, taste, hot/cold, rough/smooth. The origins of this view lie in Neoplatonism and Christian theology. Its *kalām* subscribers were Ḍirār ibn ʿAmr (d. 815), Ḥafṣ al-Fard (fl. 810), and Ḥusayn al-Najjār (d. ca. 835–845).

The third theory holds that accidents and bodies constitute the world, and that bodies are constituted from atoms. This view had its partisans among the Dualists and the Bārdaiṣānites. It was appropriated into *kalām* by Abū al-Hudhayl al-ʿAllāf (d. 841) of the Basrian Muʿtazilī school of *kalām*; the Baghdadī Muʿtazilī Bishr ibn al-Muʿtamir (d. 825–840); and Muʿammar ibn ʿAbbād al-Sulamī (d. 830). Towards the mid-ninth century, the atomic theory displaced its rivals to become the dominant physical theory of *kalām*. Atomism was upheld by the Ashʿarī *kalām* school formed in the tenth century in opposition to Muʿtazilīs, particularly regarding questions of man's free will and God's absolute power. However, atomism was attacked by the *falāsifa* who upheld Aristotelian arguments. In the eleventh century, the Basrian Muʿtazilī Abū al-Ḥusayn al-Baṣrī (d. 1044) embraced *falsafa* physical theory and abandoned atomism. Atomism declined further in the twelfth and later centuries with the growing influence of Ibn Sīnā's (d. 1037) philosophy. Even though atomism was never actually abandoned, it was no longer central to post-twelfth century *kalām*.

As none of the writings on physical theory of the eighth and ninth century *mutakallimūn* has survived, their theories must be reconstructed from extant fragments. The principal source has been the doxography, *Maqālāt al-islāmīyīn* (The Doctrines of Muslims) by the former Muʿtazilī and founder of Ashʿarī *kalām*, Abū al-Ḥasan al-Ashʿarī (d. 935). The following account of early atomism may be drawn: early *kalām* atomists distinguished between the atom (denoted by *jawhar* (atom), *juz'* (part), *al-juzʾalladhī lā yatajazzaʾ* (the indivisible part)) and the body. The body has length, breadth, and depth, while the atom lacks these dimensions (however al-Ṣāliḥī [fl. end of ninth/early tenth century] held that the atom was a body). Rather, they believed that dimensions are produced by combinations of atoms. Hence, a minimal length arises when two atoms combine (or, in the formulation of the *mutakallimūn*, a line is formed by the combination of two atoms). There were different views on the minimal number of atoms which constitute a body having length, breadth, and depth: Abū al-Hudhayl held that it was six; Muʿammar held that eight were required; and Abū al-Qāsim al-Balkhī (d. 931) held that four sufficed.

There are obvious parallels between *kalām* and Greek atomism regarding proofs for the existence of atoms, as well as terms which denote the atom. Yet the concept of dimensionless atoms combining to form bodies with dimension is unique to *kalām*. New light has been shed on this puzzling view, and on *kalām* physical theory in general, by the rediscovery of eleventh century sources. Of particular importance are the Basrian Muʿtazilī texts of Ibn Mattawayh and Abū Rashīd al-Nīsābūrī (both fl. first half of eleventh century), as well as Ashʿarī texts by Abū al-Maʿalī al-Juwaynī (d. 1085) and Ibn Fūrak (d. 1015). These sources reveal that, in his reformulation of *kalām*, the Basrian Muʿtazilī Abū Hāshim al-Jubbā'ī (d. 933) had redefined the atom as "that which occupies space (*mutaḥayyiz*)," a designation which was also applied to the body. From this designation, as well as arguments advanced in support of the theses that the atom has magnitude (*miṣāḥa*) and its shape resembles a cube, it is clear that the atom must somehow be extended (the Ashʿarī *mutakallim* Abū Bakr al-Fūrakī (d. 1085) states: the atom is the smallest of what is small with respect to volume). Paradoxically, these *mutakallimūn* insisted that despite its magnitude the atom lacked length, breadth, and depth. Like their earlier colleagues, they continued to hold that dimensions were produced by combinations of atoms. Moreover, they considered any difference between their view of the atom and the earlier view as marginal; it was partially conceptual but partially a result of the manner of expression.

These texts suggest the interpretation that a geometry of discrete space underlies *kalām* atomism (as in Epicurean atomism). In ancient and medieval thought, any distinction between geometrical and physical space was inconceivable. If physical space was continuous, then so was geometrical space. Likewise, discrete physical space meant discrete geometrical space. Hence, *kalām* formulations of "indivisible," "dimension," "magnitude," and "body" need to be analyzed within discrete geometry. Here, a point, which is defined as that which has no parts, is equivalent to the indivisible magnitude (i.e., atom). Next, a line, which is terminated by two end points, must consist of at least two indivisibles. It follows that two indivisibles constitute the least line and are the least to constitute the dimension of length. The *kalām* atom cannot, thus, have length, breadth, or depth, but it has magnitude for it is an indivisible of discrete (and not continuous) geometry. The combination of atoms to form linear dimensions is no longer problematical; unlike points of continuous geometry which lack both dimension and magnitude, atoms/indivisibles of discrete geometry have minimal magnitude yet lack dimension. Such atoms combine to form objects with larger magnitudes and dimension. In a discrete geometry whose indivisibles are square-shaped (as seen from a continuous geometry, for the *mutakallimūn* state that the atom *resembles* a square; having no dimensions it cannot be a square!), one may configure minimal bodies from four, six, or eight atoms.

In his critique of atomism, Aristotle argued that atomism entails indivisible parts of space, time, and motion. Accordingly, most eighth and ninth century atomist *mutakallimūn*, and many later *mutakallimūn* upheld the minimal parts of space, time, and motion. In the tenth century, Abū Hāshim al-Jubbā'ī abandoned the minimal parts of space (and consequently minimal parts of time and motion) in response to difficulties raised by antiatomists. His successors did not all adopt this view; some continued to say that space, time, motion, and matter were constituted out of indivisibles. We may also note that the atomist *mutakallimūn* upheld the existence of void spaces.

Atomism posed several conceptual and geometrical difficulties, some of which are traceable to Aristotelian arguments against atomism. It may be relevant to mention some Islamic contributions. One argument formulated by Abū al-Hudhayl, which is based on Zeno's dichotomy paradox, was the ant and sandal argument. Imagine an ant creeping over a sandal. In order to traverse the sandal, the ant must first traverse half the sandal; but to traverse half, the ant must first traverse half of this, and so on. Hence the traversal cannot commence unless the division terminates at an indivisible (i.e., atom). Abū al-Hudhayl's student, the antiatomist al-Naẓẓām, responded with his theory of leap (*ṭafra*), saying the ant does not traverse through all points on the path of traversal, but it traverses through some and leaps over others. Hence, al-Naẓẓām claimed, one may traverse from one location to another without traversing all intervening points. The theory of leaps played an important role in discussions of physical theory, if only to illustrate the absurdity of the actually infinite division of matter which was attributed to al-Naẓẓām. Al-Naẓẓām also formulated a clever argument against atomism. Imagine a rotating millstone. Since both an inner circle and the millstone's circumference must complete a rotation in equal time, when an inner circle is ten atoms in length, and the circumference is a hundred atoms, for each unit of space traversed by an atom on the inner circle, an atom on the circumference would have to traverse ten units. Explaining this, al-Naẓẓām resorted to his theory of leaps: when an atom on the inner circle moves one unit, an atom on the circumference moves one unit and leaps nine units. Abū al-Hudhayl, however, responded that the atom on the inner circle moves for one time unit and rests for nine units, while the atom on the circumference moves for all ten units. Al-Naẓẓām objected that this entails that particles of a solid body cannot adhere to each other but must be set loose to allow for such moments of motion and rest. Hence, a rotating solid body must disintegrate (*tafakkuk*) and its internal configuration of atoms be modified. The atomist *mutakallimūn*, unable to answer al-Naẓẓām's challenge, accepted the internal disintegration of a rotating body. However, they considered it to be analogous to a salt shaker where salt particles move freely within the confines of the shaker.

Why did the *mutakallimūn* embrace atomism? This question has puzzled researchers, particularly given the difficulties atomism raised. The thesis that atomism was theologically more acceptable than the continuously divisible matter theory of the *falāsifa* has been widely accepted. Continuous divisibility raises problems of infinity, and the *mutakallimūn* were mindful of the relationship between ending infinite regress in the argument for the temporal creation of the world and the argument for the divisibility of matter. Yet the question still remains as to why three theories of matter were considered theologically sound in early *kalām*, and why early atomists did not claim that their theory was, theologically, the most sound. The assertion that antiatomists were heretics is only found after the tenth century when atomism had triumphed. The question of the affinity of atomism to occasionalism has also been raised, but this needs to be reexamined in the light of new sources.

Atomism was also upheld by the famous physician and *faylasūf* Abū Bakr Muḥammad ibn Zakariyāʾ al-Rāzī (d. 925). However, surviving accounts are scanty. We only know that his atoms were extended (like Democritus' atoms). Atomism is part of al-Rāzī's cosmology of the five eternals: God, Soul, Space, Time, and Matter upheld by the Ṣābians of Ḥarrān. Some of al-Rāzī's views may derive from Irānshahrī (fl. late ninth century) about whom very little is known.

See also: ►Ibn Sīnā, al-Rāzī

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Ātreya

Guy Mazars

Ātreya or Punarvasu Ātreya was probably the physician of an ancient king of Gāndhāra. The name Ātreya implies that he was either a descendant or a disciple of Atri, a sage mentioned in the *Veda*. The date of Ātreya may be fixed before the grammarian Pāṇini (seventh century BCE) and after the *Atharvaveda* (1200 BCE), ca. 1000 BCE.

On the basis of his teachings, six of his disciples composed medical treatises. One of them, Agniveśa, wrote the *Agniveśatantra* or 'System of Agniveśa', which became known as the *Carakasaṃhitā* after its revision by Caraka. Another disciple, Bhela, wrote the *Bhelasaṃhitā*, which has fragmentarily been preserved in a single manuscript. Unfortunately, the text is mutilated and full of scribe's errors. Some scholars are of the opinion that the *Bhelasaṃhitā* may be older than the *Carakasaṃhitā*. The *Hārītasaṃhitā* is ascribed to a third disciple, also called *Ātreyasaṃhitā*. But the text that has come down to us is regarded as a relatively late work of an apocryphal nature, though parts of it might be old.

As to the treatises composed by the other three disciples of Ātreya, they have not been preserved. But quotations from their works occur in many commentaries. Two other Ātreya, Kṛṣṇātreya and Bhikṣu Ātreya, are mentioned in the *Carakasaṃhitā*. According to the *Mahābhārata*, the 'Great Epic of India', Kṛṣṇātreya was the founder of a medical school. There is mention of another Ātreya connected with the Buddhist University of Takṣaśilā. He was the teacher of a contemporary of Buddha (fifth century BCE), the famous surgeon Jīvaka to whom tradition attributes extraordinary operations.

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Aztec Science

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The name Aztec most commonly refers to a group of people who dominated the Valley of Mexico, and indeed much of central and southern Mexico, in the fifteenth and early sixteenth centuries. These people, who called themselves Mexica, settled their city of Tenochtitlan (today Mexico City) in the mid-1300s, in the midst of a large number of already-settled cities. The Mexica, as hunter and gatherer immigrants from the northern deserts, were latecomers to the Valley of Mexico and combined their nomadic-style culture with the ways of life of long-settled villagers and urban dwellers. In the fifteenth and early sixteenth centuries numerous different ethnic groups coexisted in the Valley of Mexico; these groups were politically organized in city–states and exhibited emblems of their specific cultural identities (such as patron gods, clothing styles, and distinctive dialects). Three of these groups, the Mexica of Tenochtitlan, the Acolhua of Texcoco, and the Tepaneca of Tlacopan, joined in a military alliance which conquered much of Mexico and created the Aztec empire.

Mexica society was hierarchical and highly specialized. In general, pronounced distinctions between nobles and commoners and between members of different ethnic groups also meant differences in access to certain scientific knowledge and specialized training. Noble boys were educated in priestly schools where the curriculum included literacy skills, astronomically based calendrics, and the learning of histories, orations, and songs. Some highly placed individuals, such as the sixteenth-century Acolhua king of Texcoco, Nezahualpilli, actively pursued scientific knowledge and were renowned as philosophers. This particular king spent endless nocturnal hours on his palace roof studying the movements of heavenly bodies, and consulted extensively with other learned individuals, undoubtedly priestly specialists. Medicinal knowledge and skills were in the hands of highly trained physicians, who appear in the documents as men or women skilled in herbal remedies and treatments of injuries and afflictions. Specific forms of scientific knowledge, embedded in industrial arts such as stone or feather-working, were generally the special province of defined ethnic groups, who passed on their craft from parent to child. Engineering and architecture (manifest, for instance, in the creation of buildings, dikes, and the development of elaborate irrigation works) would have required special training, perhaps in an apprentice-style setting. However, the documents are silent on this. Much knowledge of agronomics, as in genetic engineering of food crops, was probably developed by farmers themselves, who slowly but persistently developed increasingly productive strains of maize and other crops. While documentary evidence is scanty, it can be concluded that some scientific knowledge was developed and passed on in a formal, literary context while other knowledge (such as seed selection and midwifery) was maintained in a more informal "folk" realm.

The Mexica were the last of a long succession of complex states and civilizations in central Mexico. As such, they inherited many cultural traditions from prior civilizations, which included a great deal of scientific knowledge. Urban planning had a long history in Mesoamerica, and several cities in central Mexico display a consistency in their alignment since at least Teotihuacan times (ca. AD 1–750). While still a controversial subject, alignments of cities and specific structures within those cities were probably linked to astronomical phenomena. The Mexica were devout admirers of their predecessors the Toltecs (ca. AD 960–1160), to whom they attributed much of their scientific knowledge. This included medicine, geology and mining, astronomy and calendrics, architecture, and fine technical arts (especially featherworking, metal-working, and stoneworking). While the Mexica honored the Toltecs with these inventions, most of these skills and surely much of this knowledge clearly predated the rise of the Toltec civilization in central Mexico.

Mexica scientific knowledge was empirically based, but also closely linked to religious beliefs. To the Mexica and their neighbors, the natural and supernatural worlds shaded into one another, and their practical, scientific inquiries cannot be understood apart from their religious concepts and cultural symbolism. So empirical astronomy was intertwined with astrology; the involved system of calendrics was largely based on prolonged astronomical observations, but the calendars themselves were applied to ritual as well as practical ends. Medicine combined pragmatic remedies with shamanism, divination, and magical cures. Glyphic writing, sculpture, architecture, and the luxury crafts of stone-, feather-, and metal-working all relied on sophisticated and well-honed practical technologies; the resulting works served secular goals and/or displayed a complex religious symbolism. Animals and plants resided in the everyday, visible natural world, but also carried a heavy load of abstract meaning in the less tangible world of mythology and religious symbolism. To the Mexica and their neighbors, then, an empirical, scientific realm of understanding and inquiry was not readily separable from a more abstract, religious realm.

Mexica scientific concepts and knowledge are understood only imperfectly today, mainly due to the paucity of primary source materials on the subject. The ancient peoples of central Mexico, including the Mexica, maintained extensive libraries of pictorial books (codices), but virtually all of these were destroyed during or shortly after the Spanish conquest in 1521. Some of the information contained in these books was reconstructed following the Conquest and set down in written and/or pictorial form, usually under the supervision of Spanish friars. The most famous of these, and one which includes considerable information on astronomical knowledge, natural history, and medicinal practices is *Historia general de las cosas de Nueva España* [The General History of the Things of New Spain (Florentine Codex)], derived from native informants and compiled in the Narhuatl (Aztec) language by the Franciscan friar Bernardino de Sahagūn. Codices based on native glyphic writing traditions were also produced in early colonial times. Some of these contain interesting scientific details, such as images of plants and animals in place name glyphs and a star-gazing priest in the Codex Mendoza; or herbal remedies pictured and described in the Badianus Herbal. Also available, and providing variable enlightenment on native scientific concepts, are Spanish-language histories and descriptions of the Mexica and their neighbors by Spanish secular and religious officials. Among the most revealing of these are the natural histories of Francisco Hernández and Gonzalo Fernandez de Oviedo y Valdés, although the latter focuses primarily on areas to the south and east of the Aztec imperial domain. These post-Conquest sources blend native concepts and information with European understandings and conventions, and must be read in that light. Written sources are augmented by the material remains of the people themselves, discovered and interpreted archaeologically. The remains of structures provide clues to architectural and engineering skills; urban layouts suggest detailed understandings of the movements of celestial bodies; artifacts in metal, stone, and feathers (and the tools that produced them) reveal sophisticated industrial technologies; and ancient food remnants, such as corn cobs, demonstrate a steady enhancement of crop productivity through hybridization and selective breeding.

To illustrate the extent and goals of Mexica scientific inquiry, a closer look at astronomy, natural history, and medicine is presented below.

Cosmology, Astronomy, and Astrology

Like their forebears and contemporary neighbors, the Mexica were sophisticated observers of astronomical phenomena. Systematic celestial observations and studies were reportedly the domain of the elite. Imperial rulers such as Motecuhzoma (r. Mexica 1502–1520) had duties which included observing star groups in the night sky, as well as carefully following the morning star, Venus. Nezahualpilli, sixteenth-century ruler of neighboring Texcoco, could observe and record (and probably measure) the movements of celestial bodies from the roof of his royal palace. This “observatory” was structured so a man could just lie down and contemplate the night sky through small perforations through which were placed lances with cotton spheres atop. While this description of observing techniques is vague and not entirely clear, it does indicate that careful, rigorous, naked-eye techniques were employed to follow changes in the celestial realm. While rulers may have spent some of their nocturnal hours studying the heavens, this activity was more commonly performed by priests, who spent many waking hours at night. The Codex Mendoza shows one such priest engaged in observing the heavens for the purpose of marking the passage of time. Some temples may have served as “sighting stations” or observatories, from which pairs of crossed sticks could have been aligned to gain accurate lines-of-sight to celestial phenomena.

Lines-of-sight were also established between temples and recognizable points on the horizon, and between specific urban structures. The passage of the sun through the seasons could be readily charted in this fashion, with solstices and equinoxes especially marked. For instance, solar equinox sightings in Tenochtitlan were made from the Temple of Quetzalcoatl through an opening between the twin temples of the Great Temple. These various devices and techniques also allowed the ancient Mexicans to track the phases of the moon, record the arrangements of star groups (constellations), follow the movements of the Pleiades, calculate the rotation of Venus, and predict eclipses.

The Mexica conception of the universe and its heavenly bodies was a combination of scientific observations and ideological constructs. Celestial and terrestrial space was united in a hierarchical scheme, with 13 heavenly layers and nine layers of the underworld. Heavens and underworld were linked by earth, which was counted in each. The world above the earth combined visible phenomena with invisible gods and goddesses; for instance, the moon occupied the layer above the earth, followed by the clouds in the next tier, then the sun, Venus, and the Fire Sticks constellation (perhaps the belt and sword of Orion) in successive levels. It should be kept in mind that certain celestial bodies, especially the sun, moon, and Venus, were not only visible phenomena but were also accorded divine status. Heavenly layers also contained invisible deities, with the male/female creator god at the apex. This whole arrangement is quite different from the heliocentric (sun-centered) and geocentric (earth-centered) concepts developed in the Eastern Hemisphere.

The movements of the sun, stars, moon, and planets had important practical and ritual applications for the Mexica and their neighbors. They were especially concerned with the passage of time, and developed complex and accurate calendars. These included a calendar of 365 days (based on the sun's passage) and a ritual calendar of 260 days (of uncertain derivation). The former was especially used in seasonal agricultural planning, while the latter was the basis for divination and astrological determinations. Combined, these two calendars yielded a 52-year cycle which carried a heavy load of ritual and symbolism. To the Mexica, time was cyclical and repetitive, and much as the individual seasons and years came and went with marked similarity, so also did the 52-year "centuries." However, the fate-oriented Mexica also saw cycles in the creation and destruction of the universe; legends told of four prior worlds and their destructions, the Mexica living in the "fifth sun." A great deal of ritual and sacrifice was required of the central Mexicans to assure the continuance of this world, which could end at the closing of each 52-year unit. Thus a great deal of cultural interpretation was lent to the systematic visual astronomical observations of priests and rulers.

Similarly, ancient Mexicans frequently oriented entire cities along astronomical lines, especially 15–20 east of north. The basis for this common spatial arrangement is still unclear, although it may relate to the movements of the Pleiades. Still, in orienting their centers along consistent, meaningful lines, the earthly, sacred, and scientific were meshed into a single cultural realm.

Natural History and Ecology

Like the celestial bodies above the earth, the natural phenomena on and in the earth were viewed both scientifically and symbolically. In this close perceived link between natural and supernatural, the creatures of the earth performed a variety of functions in both visible and invisible cultural realms. Birds and beasts, for instance, were valued as providers of food, fur, and feathers, but were also frequent subjects of metaphors and players in myths and legends. However, the roles that creatures played in myths, the meanings they carried in the ritual calendar, or the messages they conveyed in metaphors were based on empirical observations of behavior, life cycles, and anatomy. For example, a human fugitive was likened to a fleet deer, the patting of tortillas compared to the flapping wings of a butterfly, and an eavesdropper described as the little mouse which inhabited every nook and cranny of a house. Close, systematic observations also led to an understanding of the transformations of the hummingbird, which seemingly died during nighttime or winter periods and came to life in the warmth of day or springtime.

Much of the study of wild creatures undoubtedly took place in the animals' natural habitat, so that, for instance, the wiley hunting techniques of the bobcat or the nesting of certain birds in "inaccessible places" are recorded. However, the Mexica also maintained a large zoo and aviary in the city of Tenochtitlan, and such a setting would have provided ample opportunity for observation and study. This was particularly significant for understanding birds and beasts from distant parts of the empire; these were especially valued for their fine feathers or precious pelts.

Habitats of various creatures were meticulously recorded, surely from direct attention to nature: the grey fox was a cave-dweller, the tadpole lived in fresh water among algae and waterlilies, the raccoon preferred forests and crags, and so on. The many parts of nature were understood as interconnected: the American Bittern's enthusiastic nighttime singing predicted heavy rains and abundant lacustrine fish; the Ruddy Duck's evening antics signaled rain at dawn; the song of another bird heralded the onset of frost.

Relationships among the various creatures themselves, including humans, were readily understood by the Mexica, whose hunter-gatherer experience was combined with knowledge acquired in agrarian and urban contexts. Human involvement in ecological dynamics at times had significant consequences. The Mexica were aware of the rarity of certain creatures, such as the wood ibis or certain serpents; indeed, they considered it a bad omen to catch the wood ibis, a cultural constraint which would have served to preserve this rare avian. In another example, the ruler Ahuitzotl (1486–1502) was reportedly responsible for bringing Great-tailed Grackles to Tenochtitlan from eastern lands and ordering their protection. However, these birds thrived to such an extent that they became an ecological burden and lost their popularity. In these contexts, the Mexica were active participants in the continuous ecological drama, engineering changes with often-unexpected consequences.

Medicine and Health

The Mexica were scientific and empirical in their discovery and use of medical cures for a large number of illnesses and injuries. The specialized doctor, or *ticitl*, used practical approaches to his/her profession, examining and diagnosing physical problems and prescribing appropriate cures. Physicians could call on a large pharmacopoeia derived from herbs, roots, animals, and minerals to relieve symptoms, heal injuries, and restore health. They were skilled in soothing burns, setting broken bones, and suturing lacerations, many of these latter injuries undoubtedly suffered in the frequent battles fought in this militaristic society.

Procedures could be multistaged and quite complicated. Broken bones, for instance, were first set, then splinted with poultices of specified ground roots or herbs. There was some variety in these usages, as the curative ground roots or herbs could be spread on the injury, drunk with pulque, or enjoyed in a bath. A bitten tongue was first subjected to a mixture of chile cooked with salt, followed by a more comforting application of bee or maguey honey. The Mexica considered at least 132 herbs to have curative properties, and these were applied to at least 40 ailments other than injuries. Curable ailments included nosebleed, pimples, headache, diarrhea, fatigue, coughs, chest pains, nausea, and many fevers and infections. Some infirmities could be served by a variety of cures – for instance, 45 different herbs could be used to relieve fevers and 18 could be applied to festered skin. On the other hand, some remedies had multiple uses – one herb, for instance, could reportedly slow bleeding, inhibit vomiting, relieve side and chest pains, and in general restore a person's strength.

Medicinal aids were often mixed into complex curative potions. Additionally, cures were at times combined with other types of remedies. One of the most popular of these was the sweatbath, often recommended as helpful in childbirth problems, skin festering, and traumas. Practical remedies were also at times joined with divinatory and magical cures; magic and divination were used in both diagnosis and curing of certain illnesses. The Mexica believed that some illnesses could have supernatural causes; these included soul loss and the intrusion of unpleasant supernatural substances.

In another vein, some illnesses required adherence to strict taboos: a patient with a fever was not to eat hot tortillas or chiles, and one with a head wound was to refrain from eating fish or meat. A preventative element is also evident in Mexica medicine. For instance, one designated herb was said to aid digestion and prevent fevers, a nursing mother could prevent diarrhea in her infant by shunning avocados, and stammering or lisping could be avoided by weaning children at a young age. Thus medicine and the maintenance of health in Mexica society were complex matters, relying on a blending of practical, scientific knowledge, and strong religious beliefs.

Applications of Mexica Science

What did the Mexica do with the vast amount of knowledge they and their forebears had acquired about the world around them? What was the purpose of the many systematic and rigorous studies they made of the heavens and the earth?

While some priests and rulers may have enjoyed the process of discovery for its own sake, it is clear that scientific knowledge among the Mexica was preeminently geared toward practical and religious applications. Long-term, rigorous observations of the heavens, and the recording of celestial movements, furnished the Mexica with temporal order. These scientific inquiries provided the basis for a sophisticated calendrical system, the ability to make appropriate seasonal preparations, and the capacity to predict and prepare for extraordinary and sometimes fearful events (such as eclipses).

The Mexica were hunter-gatherers long before they entered the Valley of Mexico and there adopted a well-developed agrarian lifestyle. Bolstered by both of these traditions, the Mexica were keen observers of nature and its processes. They understood the anatomy, behavior, life cycles, and ecology of wild plants and animals. They also had a sophisticated knowledge of cultigens, and drew on a long agrarian tradition of seed selection, agricultural technology, and even the ability to predict certain pertinent weather conditions from animal behavior. They applied this extensive and varied knowledge first and foremost to increase and protect their food supply. However, natural resources also enhanced their life conditions by providing fibers, furs, and feathers for clothing and adornment; building materials for domestic and godly shelter; and precious stones and metals for a show of status.

Nature also provided a wealth of medicinal cures, discovered, combined, and applied successfully by specialized physicians. Administering the proper remedy to the specific ailment undoubtedly required considerable experimentation, but unfortunately the documents are silent on this process.

We therefore have quite a bit of information on the Mexica's scientific results, but little understanding of their methods. Those methods, such as rigorous naked-eye astronomy, repeated observations of earthly phenomena, and centuries-long seed selection, yielded a significant body of sophisticated scientific knowledge, applied by the Mexica to cultural ends. The Mexica consistently linked the scientific realm to the religious and utilized empirical discoveries to enhance and embellish their everyday lives.

See also: ►City Planning, ►Agriculture, ►Architecture, ►Calendars, ►Astronomy, ►Medicine, ►Magic and Science, ►Religion and Science, ►Crops

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Bakhshālī Manuscript

Takao Hayashi

The Bakhshālī Manuscript is the name given to the oldest extant manuscript in Indian mathematics. It is so called because it was discovered by a peasant in 1881 at a small village called Bakhshālī, about 80 km northeast of Peshawar (now in Pakistan). It is preserved in the Bodleian Library at Oxford University.

The extant portion of the manuscript consists of 70 fragmentary leaves of birchbark. The original size of a leaf is estimated to be about 17 cm wide and 13.5 cm high. The original order of the leaves can only be conjectured on the bases of rather unsound criteria, such as the logical sequence of contents, the order of the leaves in which they reached A. F. R. Hoernle, who did the first research on the manuscript, physical appearance such as the size, shape, degree of damage, and knots, and the partially preserved serial numbers of mathematical rules (9–11, 13–29, and 50–58).

The script is the earlier type of the Śāradā script, which was in use in the northwestern part of India, namely in Kashmir and the neighboring districts, from the eighth to the twelfth centuries. G. R. Kaye, who succeeded Hoernle, has shown that the writing of the manuscript can be classified into at least two styles, one of which covers about one-fifth of the work. There is, however, no definitive reason to think that the present manuscript consists of two different works.

The information contained in the manuscript, the title of which is not known, is a loose compilation of mathematical rules and examples collected from different works. It consists of versified rules, examples, most of which are versified, and prose commentaries on the examples. A rule is followed by an example or examples, and under each one the commentary gives a "statement," "computation," and a "verification" or verifications. The statement is a tabular presentation of the numerical information given in the example, and the computation works out the problem by following, and often citing, the rule step by step.

Thus, the most typical pattern of exposition in the Bakhshālī Manuscript is:

1. Rule (*sūtra*)
2. Example (*udāharaṇa*)
   - Statement (*nyāsa*/*sthāpanā*)
   - Computation (*karaṇa*)
   - Verification(s) (*pratyaya*/*pratyānayana*)

A decimal place-value notation of numerals with zero (expressed by a dot) is employed in the Bakhshālī Manuscript. The terms for mathematical operations are often abbreviated, especially in tabular presentations of computations. Thus we have *yu* for *yuta* (increased), *gu* for *guṇa* or *guṇita* (multiplied), *bhā* for *bhājita* (divided) or *bhāgahāra* (divisor or division), *che* for *cheda* (divisor), and *mū* for *mūla* (square root). For subtraction, the Bakhshālī Manuscript puts the symbol, + (similar to the modern symbol for addition), next (right) to the number to be affected. It was originally the initial letter of the word *ṛṇa*, meaning a debt or a negative quantity in the Kuṣāṇa or the Gupta script (employed in the second to the sixth centuries). The same symbol is also used in an old anonymous commentary on Śrīdhara's *Pāṭīgaṇita*, which is uniquely written in the later type of the Śāradā script (after the thirteenth century). Most works on mathematics, on the other hand, put a dot above a negative number.

The problems treated in the extant portion of the Bakhshālī work involve five kinds of equations, namely (1) simple equations with one unknown (15 types of problems), (2) systems of linear equations with more than one unknown (14 types), (3) quadratic equations (two types, both of which involve an arithmetical progression), (4) indeterminate systems of linear equations (three types, including the so-called "Hundred Fowls Problem," in which somebody is to buy 100 fowls for 100 monetary units of several kinds), and (5) indeterminate equations of the second degree (two types: $\sqrt{x+a} = u$ and $\sqrt{x-b} = v$, where u and v are rational numbers; and $xy = ax + by$).

The rules of the Bakhshālī work may be classified as follows:

1. Fundamental operations, such as addition and subtraction of negative quantities, addition, multiplication, and division of fractions, reduction of measures, and a root-approximation formula,

$$\sqrt{a^2+r} \approx a + \frac{r}{2a} - \frac{(r/2a)^2}{2(a+r/2a)}.$$

2. General rules applicable to different kinds of problems: *regula falsi*, rule of inversion, rule of three, proportional distribution, and partial addition and subtraction.
3. Rules for purely numerical problems: simple equations with one unknown, systems of linear equations with more than one unknown, indeterminate equations, and period of an arithmetical progression.
4. Rules for problems of money: equations of properties, wages, earnings, donations, etc., consumption of income and savings, buying and selling, purchase in proportion, purchase of the same number of articles, price of a jewel, prices of living creatures, mutual exchange of commodities, installments, a sales tax paid both in cash and in kind, and a bill of exchange.
5. Rules for problems of travelers: equations of journeys, meeting of two travelers, and a chariot and horses.
6. Rules for problems of impurities of gold.
7. Rules for geometrical problems: volume of an irregular solid and proportionate division of a triangle.

All the rules of the first category, namely the fundamental operations, occur only as quotations in the computations of examples. Many of the other rules could belong to either *miśraka-vyavahāra* (on mixture) or *śreḍhī* (of series) in a book of *pāṭī* (algorithms) such as Śrīdhara's *Pāṭīgaṇita* and *Triśatikā* (eighth century), etc., but they have not been arranged according to the ordinary categories of *vyavahāra*.

We apparently owe the present manuscript to four types of persons: the authors of the original rules and examples, the compiler, the commentator, and the scribe. Possibly, however, the commentator was the compiler himself, and "the son of Chajaka" (his name is unknown), by whom the Bakhshālī Manuscript, or at least part of it, was "written," was the commentator, or one of the commentators. The colophon to the section that deals exclusively with the *trairāśika* (rule of three) reads:

> This has been written by the son of Chajaka, a brāhmaṇa and king of mathematicians, for the sake of Hasika, son of Vasiṣṭha, in order that it may be used (also) by his descendents.

Immediately before this statement occurs a fragmentary word *rtikāvati*, which is probably the same as the country of Mārtikāvata mentioned by Varāhamihira (ca. AD 550) among other localities of northwestern India such as Takṣaśilā (Taxila), Gandhāra, etc. (*Bṛhatsaṃhitā* 16.25). It may be the place where the Bakhshālī work was composed.

A style of exposition similar to that of the Bakhshālī work ("statement," etc.) is found in Bhāskara I's commentary (AD 629) on the second chapter called *gaṇita* (mathematics) of the *Āryabhaṭīya* (AD 499). Both Bhāskara I's commentary and the Bakhshālī work attach much importance to the verification; it became obsolete in later times. The unusual word *yāva* (*yāvakaraṇa* in Bhāskara I's commentary) meaning the square power, and the apparently contradictory meanings of the word *karaṇī*, the square number and the square root, occur in both works.

Bhāskara I does not use the symbol *yā* (the initial letter of *yāvattāvat* or "as much as") for unknown numbers in algebraic equations even when it is naturally expected, while he employs the original word *yāvattāvat* itself in the sense of unknown quantities (in his commentary on *Āryabhaṭīya* 2.30). This probably implies that he did not know the symbol. The symbol is, on the other hand, utilized once in the Bakhshālī work in order to reduce the conditions given in an example to a form to which the prescribed rule is easily applicable; after the reduction, the symbol is discarded and the rule is, so to speak, applied mechanically (fol. 54^{v}). This restricted usage of the symbol seems to indicate that the work belongs to a period when the symbol was already invented, but not very popular yet.

There has been quite a bit of dispute over the dates of the manuscript. Hoernle assigned the work to the third or the fourth century AD, Kaye to the twelfth century, Datta to "the early centuries of the Christian era," and Ayyangar and Pingree to the eighth or the ninth century. The above points suggest that the Bakhshālī work (commentary) was composed not much later than Bhāskara I (the seventh century).

See also: ►Zero, ►Śrīdhara, ►Bhāskara I

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Balkhī School of Arab Geographers

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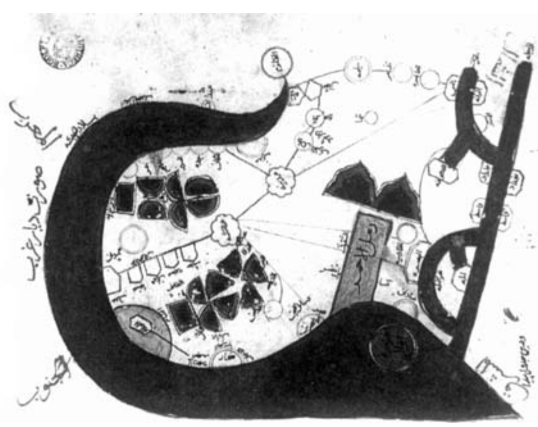
The Balkhī School refers to a group of four authors who recognize the fact that their geographic work is interlinked. It is also known to scholars as the Classical School of Arab Geography or the Islamatlas. Abū Zaid Aḥmad ibn Sahl al-Balkhī (d. 322/834), who wrote *Ṣuwar al-aqālīm*, is the earliest of them and presumably the originator. The other three authors are Abū Isḥāq Ibrāhīm ibn Muḥammad al-Iṣṭakhrī (ca. AD 950) (*Al-masālik wa'l-mamālik*), Muḥammad ibn Ḥawqal (d. between 350/861 and 360/972) (*Ṣūrat al-arḍ*) and Abu ᶜAbdallāh Muḥammad ibn Ahmad al-Muqaddasī (d. ca. 390/1000) (*Aḥsān al-taqāsim*).

Their work is based on a series of maps covering the Islamic Empire together with a text which consists mainly of notes on the maps. Many copies of these works survive; the earliest surviving manuscript being a version by Ibn Ḥawqal dated AH 479/AD 1086. This is the earliest Arabic manuscript to contain a map. Yet, copies of al-Iṣṭakhrī's book were still being produced as recently as the middle of the nineteenth century AD. There is so much material available that scholars have identified two separate editions 3ns of al- Iṣṭakhrī, three of Ibn Ḥawqal and two of al-Muqaddasī, although one of the versions of Ibn Ḥawqal does not contain maps. These different texts can be associated with similar sets of maps, and these maps can be compared and relationships established which enable us to trace the development of "Balkhī" cartography. The standard set of maps consists of a world map, two oceans (Indian and Mediterranean), four Roman provinces (i.e., areas which were originally Byzantine) and 14 Persian provinces (Fig. 1).

It is obvious that the maps are conceived as a set covering the Muslim Empire with reasonable detail, and there is no attempt to cover non-Islamic areas in the same way. It has been suggested that this policy of including only Islamic regions is deliberate. Each map is given a page or so of textual description, and each of these descriptions is planned in such a way that lists of routes, towns, mountains, rivers, etc., are given for each province. Thus they bear a certain resemblance to the work of Ibn Khurdādhbih, although the latter's work was not accompanied by maps nor did he limit himself only to the Dar al-Islam. There is a likelihood that the Balkhī School material and the work of Ibn Khurdādhbih are based on Persian (Sassanid) materials which survived the Islamicization of the Persian home areas.

The Balkhi maps cannot be connected together like the sectional maps of al-Idrīsī to form one large map of the known world. Al-Iṣṭakhrī and Ibn Ḥawqal show no interest in projection, scale, or mathematical geography and do not mention latitudes and longitudes at all. The only form of measurement given is that of days, journeys (*marḥala*). The maps are very geometrical in design. Lines are straight or arced, rivers are parallel lines, lakes often perfect circles. Towns can be circles, squares, four pointed stars or something similar. Stopping places on routes resemble small tents or caravanserais.

al-Muqaddasī's text is based on the same principles but is a considerable improvement over that of his predecessors. He also includes a section on astronomical geography and geodesy including a note on the Greek system of climates. Both Ibn Ḥawqal and al-Muqaddasī are more up-to-date and are more at home in Europe and North Africa, having a preference for the western part of the Empire rather than the Persian speaking areas. al-Muqaddasī's maps however have a closer affinity with those of al-Iṣṭakhrī, whereas we would expect,



Balkhī School of Arab Geographers. Fig. 1 Map of Arabia from al-Iṣṭakhrī's *Ṣuwar al-buldān*. From the from the nature of his text, something much more advanced. He has however a different selection of maps, there being no world map nor one of the Caspian Sea and a completely new map of the Arabian desert.

The works of these authors were reproduced continually throughout the centuries not only in Arabic but also in Persian or Turkish translation. Other writers occasionally borrow a selection of the maps or an individual map. Some of the later versions are very corrupt and hardly recognizable. A world map derived from this school appears regularly in the works of Ibn al-Wardī and often in texts of al-Qazwīnī's cosmography showing how popular these maps were in the Muslim world.

See also: ►al-Muqaddasī, ►Ibn Ḥawqal, ►Ibn Khurdadhbīh, ►al-Idrīsī, ►Maps and Mapmaking in the Islamic World, ►al-Qazwīnī.

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Bamboo

DAVID TURNBULL

Few other plants or materials have been so pleasing to the eye, have inspired so many artists, poets, and philosophers, or have contributed so materially to the development of civilization as have bamboos. Bamboo (*Arundinaria*) is a grass that grows with great rapidity in a wide range of climates with over 1,500 species around the world. It is both immensely strong and very light. It is easily worked with simple tools and is strikingly beautiful both in the economy of its natural form and in its finished state. Yet not only has its key role in the development of science and technology been largely overlooked by Western historians of science, but its contemporary uses tend to be contemptuously undervalued as simple and traditional. It was dismissed as "poor man's timber."

The reality is that bamboo has been one of the prime nutrients of Asian culture and may yet turn out to have a significant role to play in civilizations around the world. The applications and powers of bamboo are almost limitless from the purely aesthetic to merely practical. The earliest boats were made of bamboo. Through inspiring poetry, metaphysics, painting, and geometry while simultaneously being the material for its production, bamboo has both created and preserved knowledge, wisdom and art. Bamboo has not only sustained life by providing housing, food, and medicine, it has been used to make a profusion of tools and domestic and industrial essentials from baskets to scaffolding, cables, and steel reinforcing, from musical instruments to windmills, bridges, and airplanes.

It was a raw material for papermaking that bamboo made its greatest contribution in the past, while also having the capacity to revolutionize paper production in the future. Bamboo is a super producer yielding two to six times more cellulose per acre than pine and can be cropped annually, but its capacity to provide paper pulp has gone largely unrecognized outside India, China, Thailand, and Brazil. Fifty percent of the world's timber is used to make paper, while in India two-thirds of the paper is made from bamboo with more than 40 factories making 600,000 tons of paper annually. If this use of bamboo were extended worldwide, the saving of old growth forest currently used in wood chip production would be greatly reduced.

In Colombia and Costa Rica, bamboo, when coated with concrete in a form of lath and plaster construction, has proved to be a cheap and effective way of building earthquake-proof housing. Similar techniques are under development in the Philippines and Hawaii to use bamboo in cyclone-proof buildings. Bamboo has proved extremely effective in stabilizing soil and preventing erosion. As a "mop crop" it also has a great capacity to extract nitrates and phosphates from effluent. These characteristics make it an ideal plant for handling two of the world's most significant problems, soil degradation and water quality. It is the ultimate renewable resource and if it is employed in either or both these ways it can become a cheap and sustainable feed stock for making paper, houses, furniture, flooring, a profusion of decorative items as well as food and medicine.

However, it is in this transition from being virtually a free good to being a valued resource that potential problems lie. Demand is already exceeding supply in India, and while government economists in Delhi argue that bamboo can become a cash crop that will improve the lot of the poor, it is possible that the landless peasants will end up being unable to afford even poor man's timber. As Western civilization gradually overtakes the developing world, research on the more industrial uses has begun, and it is being widely used in making parquet flooring and laminated beams. It is to be hoped that, as it becomes a first world resource, it does not become just another opportunity for exploitation. If the developing economies leave the knowledge of its uses and the control of production in the hands of the local people, bamboo has the capacity to benefit all of us.

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Banū Mūsā

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The Banū Mūsā were three brothers, Muḥammad, Aḥmad, and al-Ḥasan, who were amongst the most important figures in the intellectual life of Baghdad in the ninth century. We do not know their dates of birth, but Muḥammad died in 873 and could hardly then have been less than 70-years old, because the youngest brother al-Ḥasan was already a brilliant geometrician in the reign of al-Maʾmūn (813–833). Their father, Mūsā ibn Shākir, was a noted astronomer and a close companion of al-Maʾmūn when the latter was residing at Marw in Khurasan before he became caliph. When Mūsā died, al-Maʾmūn became the guardian of his sons, who were given a good education in Baghdad, becoming skilled in geometry, mechanics, music, mathematics, and astronomy.

Under the successors of al-Maʾmūn, the brothers became rich and influential. They devoted much of their wealth and energy to the quest for the works of their predecessors, especially in Greek and Syriac, and sent missions to the lands of the Byzantine Empire to seek out manuscripts and bring them to Baghdad. Muḥammad is said to have made a journey to Byzantium in person. The brothers acted as sponsors to a group of scientists and translators, to whom they paid about 500 *dinars* a month. The most outstanding of these scholars were Thābit ibn Qurra and Hunayn ibn Isḥāq, who rendered numerous works, many of which would otherwise have been lost, from Greek and Syriac into Arabic. Muḥammad was on friendly terms with this group of scholars, particularly with Huṇayn, who translated and composed books at the request of his patron. The brothers therefore played a leading role in the transmission of Greek works into Arabic, and in the foundation of the long and important contribution of the Islamic world to the sciences. Some 20 works are attributed to the Banū Mūsā, of which three have survived. The best-known and most important of the brothers, books, which were largely the work of Aḥmad, is their *Kitāb al-ḥiyal* (Book of Ingenious Devices). The work comprises descriptions of some 100 small machines, including alternating fountains, self-filling and self-trimming lamps, and a clamshell grab. About 80 of the devices, however, are trick vessels of various kinds that exhibit an astonishing mastery of automatic controls. The inspiration for Aḥmad's work is undoubtedly to be found in the machine treatises of the Hellenistic writers, particularly the *Pneumatics* of Philo of Byzantium (mid-third century BCE) and the *Pneumatics* of Hero of Alexandria (fl. ca. AD 60). The *Kitāb al-ḥiyal*, although some of the devices in it come directly from Philo or Hero, goes well beyond its Greek predecessors, particularly in the use of small pressure variations and conical valves and other components in automatic controls. Indeed, the work of the Banū Mūsā in the variety and ingenuity of their control systems was unsurpassed until quite recent times. There may have been some didactic intention in their writing, but most of their constructions are quite trivial to our eyes. Nevertheless, many of the ideas, techniques, and components that they used were to be of considerable importance in the development of machine technology.

See also: ►Thābit ibn Qurra, ►Huṇayn ibn Ishāq, ►al-Maʾmūn

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Basketry in Ancient Egypt

Willeke Wendrich

The oldest basketry found in Egypt dates to the Neolithic period (ca. 5900–4000 BCE). In the Fayum Oasis, about 100 km (60 miles) southwest of Cairo, grain storage pits were excavated in the desert floor, lined with coarse straw basketry (Fig. 1).

First discovered in 1926 (Caton-Thompson and Gardner) and examined in detail for the first time in 2005 after recent excavations (Wendrich and Cappers 2005), these baskets represent a coiling technique. This entails a bundle of straw fastened into a coil with a number of stems pulled out of the straw bundle at regular intervals. This particular type of coiling went out of use and was replaced by a variation of the coiling technique, which existed simultaneously. This type of coiling makes use of different materials for the bundle and the winders (Fig. 2).

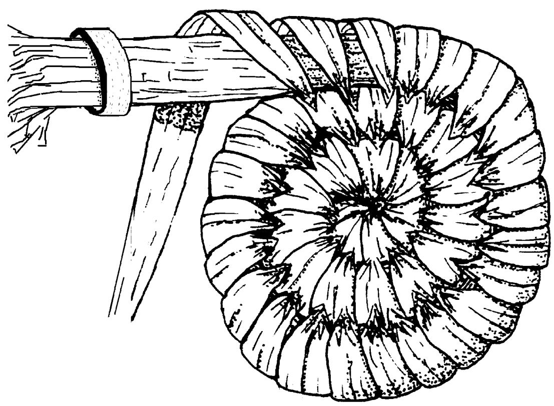
Near the Neolithic grain storage pits part of an extremely finely coiled basket was found, dated to about 4200 BCE, made of separate bundle and winder materials and decorated with darker winders along the rim (Fig. 3).

These two examples from the Egyptian Neolithic demonstrate that basketry technology was well advanced by that time and must have known a long period of development for which we have no other evidence.

The oldest and most frequently used techniques in ancient Egypt were coiling, twining and mat weaving. Coiling was used to produce sturdy baskets, varying in size from 3 to 60 cm in diameter. In Ancient Egypt wood was scarce. Basketry, therefore, had an important function, replacing cupboards as containers for clothing, food, and many other items. The tomb of Tutankhamun contained over 120 baskets (Reeves 1990: 204; Malek). Even coffins and sandals were made in the coiled technique.

Twining has been attested from the Predynastic period onward. The twining technique consisted of a (passive) warp and a weft of two active strands. These were twisted around the passive warp elements, and each other, in either S or Z orientation. The twining technique was extremely versatile, depending on the materials used and the distance between the weft and warp elements. Fig. 4 shows some of the variety.

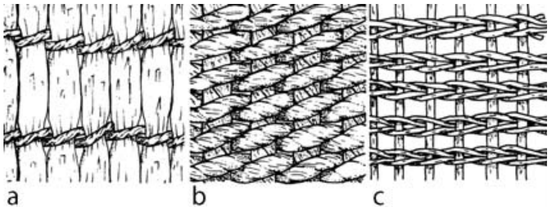
Matting was used widely as awnings, windbreaks and doors, but also as mattresses for sleeping and covers to wrap the dead. Egyptian architecture was characterized by many references to the use of mats in the original shrines and temples. The “drum” that was



Basketry in Ancient Egypt. Fig. 2 Coiling with separate bundle and winder materials. A bundle of grass is held into place by palm leaf winders.

Basketry in Ancient Egypt. Fig. 1 Neolithic grain storage pit lined with coarse coiled straw basketry, excavated in 2005. Photograph UCLA/RUG Fayum Project.

Basketry in Ancient Egypt. Fig. 3 The Fayum Neolithic produced very fine decorated coiled basketry. This 6,000 year old fragment was found only a few centimeters under the surface. Photograph UCLA/RUG Fayum Project.



Basketry in Ancient Egypt. Fig. 4 Three examples of the many variations used to produce twined basketry: (a) a mat made of bundles of grass, fastened into a fabric with widely spaced rows of twining; (b) a sturdy mat made of narrowly spaced twined string, and (c) a sieve grid made of open twined strips of palm leaf.

part of the so-called false door represented a rolled up mat, and decorative motifs on tomb and temple walls, such as pillars carved to resemble tied reed bundles, a stylized motif representing the tied off bundles of grass matting (the *kheker* motive) and other decorative patterns, also referred to mats. The Djoser complex in Sakkara, for instance, displayed many references to the perishable predecessors of its stone architecture (Lehner 1997: 84–93; Verner 2002: 108–140).

For mat weaving a simple horizontal ground loom was used, consisting of four wooden pegs in the ground, to which two crossbeams were tied. The warp was kept taut by tightening the strings tying the two beams to the ground pegs. A third beam, with evenly spaced holes, guaranteed the regular spacing of the warp string (in more delicate loom types this part would be called the *reed*). It had a double function, because by slamming the beam into the woven part of the mat, it also served as a beater, creating a tight weave. The mats were mostly made with a warp of grass string, spaced 3–4 cm apart, and a weft of single grass stems, or small bundles of grass. For sleeping mats the grass was laid in with the thicker base side of the stem, while the tip was left to stick out from the warp, forming a more comfortable thick fibrous pad underneath the mat. An early depiction of a mat weaver is found in the tomb of Khety in Beni Hassan and dates to the early Middle Kingdom (ca. 1900 BCE, see Fig. 5).

From approximately the fourth century BCE onward the plaiting technique became increasingly popular in Egypt. Sandals were no longer made of many parallel rows of coiling, but rather plaited with palm leaf. The equivalent of our flip-flop was plaited with eight strips of doam palm leaf, each approximately 4 cm wide. More elaborate sandals had several padded layers, of fine and coarse plaiting with different materials: coarse plaits from palm fiber for the outer sole, fine plaited palm leaf fabric for the inner sole. Fans were made of extremely fine plaited matting, using strands of palm leaf of only 2 mm wide. For both mats and baskets a completely new technique was introduced into Egypt,

Basketry in Ancient Egypt. Fig. 5 Tomb painting of a mat weaver (detail), dating to the Middle Kingdom (approximately 1600 BCE). From the tomb of Khety in Beni Hassan, Middle Egypt.

consisting of plaited strips sewn together to form a seemingly ongoing plaited fabric. Depending on the pattern, only twill strips plaited with a particular number of strands (9, 13, 17, 21, etc.) could be used, which created broad edges, with a particular orientation. The edges were pulled inside each other, thus completely hiding the sewing strand. The most commonly used materials for basketry changed slightly over time. In the prehistoric and Predynastic periods the materials attested are papyrus (*Cyperus papyrus*), the stems of the composite *Ceruana pratensis* and wheat or barley straw. In the Pharaonic period tall tough grasses (*Desmostachya bipinnata* and *Imperata cylindrica*) were used for twined and woven matting, as well as for the bundles of coiled basketry. The coils were fastened with winders of papyrus rind or doam palm leaf (*Hyphaene thebaica*). Date palm leaf (*Phoenix dactylifera*) occurred rarely in the Pharaonic period, but became widely used toward the Late Period and the Greco-Roman period, taking over the significance of both papyrus and doam palm leaf. This probably had an environmental reason; a slight climatic change caused the doam palm to retreat south and at present this species occurs only sparsely south of Luxor and is common only in Sudan. The date palm, on the other hand, was cultivated increasingly in all of Egypt. Similarly, papyrus plants, cultivated for writing material and basketry, withdrew to the south and at present do not occur in a natural habitat in Egypt.

The variety of ancient Egyptian basketry techniques, shapes, and materials reflect the widespread use and functionality of these objects. The tomb paintings and reliefs from all periods of Egyptian history corroborate the information from the archaeological material. Bearers of offerings were shown carrying baskets full of produce and goods, farmers were depicted sowing from twined baskets, loading the harvest in enormous carrying nets and carrying the threshed grain in baskets to the granaries. Perhaps the most telling was the fact that in many of the ostraka (pot sherds and lime stone chips used as scrap paper) from the village of Deir el Medina baskets (of grain) were listed as the standard size for paying wages.

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Baudhāyana

R. C. Gupta

India's most ancient written works are the four *Vedas*, namely *Ṛgveda, Yajur-veda, Sāma-veda*, and the *Atharva-veda*. There are different schools which are represented by various *Saṃhitās* or recensions of the *Vedas*. To assist their proper study, there are six *Vedāngas* (limbs or part of the *Veda)*, namely *Śikṣā* (phonetics), *Kalpa* (ritualistics). *Vyākaraṇa* (grammar), *Nirukta* (etymology), *Chandas* (prosody and metrics), and *Jyotiṣa* (astronomy, including mathematics and astrology). These auxiliary Vedic works (except the last) are written in *sūtra* or aphoristic style.

The *Kalpa Sūtras* deal with the rules and methods for performing Vedic rituals, sacrifices, and ceremonies, and are divided into three categories: *Śrauta, Gṛhya,* and *Dharma*. The *Śrauta Sūtras* are more specifically concerned with the sacrificial ritual and allied ecclesiastical matters. They often include tracts which give rules concerning the measurements and constructions of *agnis* (fireplaces), *citis* (mounds or altars), and *vedis* (sacrificial grounds). Such tracts are also found as separate works and are called *Śūlba Sūtras* or *Śulbas*. They are the oldest geometrical treatises which represent in coded form the much older and traditional Indian mathematics. The root *śulb* (or *śulv*) means "to measure" or "to mete out".

The names of about a dozen *Śulba Sūtras* are known. The oldest of them is the *Baudhāyana Śulba Sūtra*. It belongs to the *Taittirīya Samhitā* of the *Black Yajurveda* and is the 13 *Praśna* or chapter of the *Baudhāyana Śrauta Sūtra*. The title *Baudhāyana Śulba Sūtra* shows that its author or compiler was Baudhāyana, or perhaps more correctly, it belonged to the school of Baudhāyana. Other Vedic works bearing the same name are known. It is more proper to consider these works as belonging to the Baudhāyana school than to regard them as authored by the same person.

Here we are concerned with Baudhāyana the *śulbakāra* that is, the author of the *Baudhāyana Śūlba Sūtra*) or the *sulbavid* (expert in *sulba* mathematics and constructions). We do not know his biographical details. Georg Bühler believed that he hailed from the Andhra region, but a recent study by Ram Gopal shows that he probably came from northern India. His dates are also uncertain, being any time between 800 and 400 BCE. Taking into account the views of A. B. Keith, W. Caland, David Pingree, and Ram Gopal, he may be placed about 500 BCE or earlier. However, it must be noted that much of the material in *Baudhāyana Śulba Sūtra* is traditional and, thus, still older than its date of compilation and coding.

The *Baudhāyana Śulba Sūtra* is not only the earliest but also the most extensive among the *Śulbas*. The subject matter is presented in a systematic and logical manner. Of course, the language is somewhat archaic, and due to the aphoristic style, the rules are highly condensed. The *Baudhāyana Śulba Sūtra* was commented on by Dvārakānātha Yajva (ca. seventeenth century). His Sanskrit commentary called the *Śulbadīpīkā* was published more than a century ago by Thibaut (1848–1914) in his edition of the *Baudhāyana Śulba Sūtra*. A recent edition (Varanasi 1979) of the *Baudhāyana Śulba Sūtra* also contains the above commentary as well as another called *Bodhāyana śulbamīmāṁāṁsā*, which was written by Vyaṇkateśvara (or Veṅkateśvara) Dīkṣita who lived during the Vijaya-nagaram kingdom (ca. 1600).

The text of the *Baudhāyana Śulba Sūtra* is divided into three chapters which comprise a total of 272 passages or 519 aphorisms. The main subject is the measurement, construction, and transformation of various altars and fireplaces. The forms of the three obligatory *agnis* (whose tradition was older than even the *Ṛgveda*) were square, circle, and semicircle, but those of optional *citis* involved all sorts of plane figures, including the above three and also the rectangle, rhombus, triangle, trapezium, pentagon, and some complicated shapes.

Some mathematical topics covered in the *Baudhāyana Śulba Sūtra* are a fine approximation for the square root of two and the so-called Pythagorean theorem. In the latter, the sides of a right-angled triangle obey the rule $a^2 + b^2 = c^2$.

The *Baudhāyana Śulba Sūtra* also contains formulas for circling a square and squaring a circle, and provides rules for basic simple geometric constructions, such as drawing a perpendicular on a given line or drawing the right bisection of a line. Some other elementary plane figures such as the isosceles triangle, trapezium, and rhombus are also covered for construction.

The *Baudhāyana Śulba Sūtra* deals with the measurements and constructions of a large number of fire-altars (*Kāmya agnis*). These were needed as part of rituals performed to attain certain desired objects according to the religious beliefs of the Vedic people. It was essential that the shape, size, area, and orientation of the relevant altar be according to the prescribed instructions. Otherwise, there was a risk of divine wrath.

The standard forms of some of the optional altars were those which resembled certain birds. The most significant and perhaps the oldest of such altars was the *śyenaciti* (falcon-shaped altar). It was to be constructed when one desired heaven (after death) because "the falcon is the best flyer among the birds." The spatial dimensions, the number of bricks (of prescribed shapes and sizes), the number of layers, etc., are all given. It is interesting to note that the archaeological remains of this most striking and complicated *śyenaciti* reported to be built in Kausambi in the second century BCE, still survive.

Early Indian geometry developed because of the need for accurate altar constructions and transformations which often required quite advanced mathematical knowledge.

See also: ►Śulbasūtras

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Beads

Robert G. Bednarik

Of the Palaeolithic forms of possible symbolic products, beads and pendants seem to tell us the most about the cognition and technology of their users. First, there are the purely technological aspects. To make a bead one has to be able to drill through an object (or enlarge a natural perforation), thread a string through the hole and fasten the ends of the string, presumably by knots (Warner and Bednarik 1996). To persist with such a process of manufacture, one must have a mental construct of the end product, and a desire to acquire what is clearly a non-utilitarian artefact. While the bead is such an artefact, the string is not, being utilitarian. It is merely a means of permitting the bead to fulfil its non-utilitarian role. Hence this is a combination not only of diverse (composite) and interactive artefacts, but also a hierarchy of diverse concepts of relating to them. The primary imperative, presumably, is to display the bead to its best advantage; the secondary intent is to find a means of doing so. A piece of, say, ostrich eggshell can be worn on a string without first drilling a hole through it, so why bother with this additional work? It is through such considerations that beads are imbued with the potential of meaning and significance.

Whether they are sewn on apparel or worn on strings, beads and pendants have symbolic meanings that are far removed from the empiricism of the interpreting Western anthropologist. For instance, they may be protective, warding off evil spirits or spells, or they can be good luck charms. They can signify status (e.g. availability for marriage, political status, and state of mourning), and convey complex social, economic, emblemic, cultural, ideological, religious or ethnic meanings, or any subtle combinations of them. Their emic meanings can be public or private, but they may be difficult to convey to an alien researcher, and they could never be deduced reliably through archaeology.

Beads have no possible utilitarian function that is not attributable to purely symbolic purposes. Describing them as decorative, for instance, does not amount to any clarification, because it does not tell us why they are 'decorative'. All communicative functions of beads are culturally negotiated; the abstract values they communicate to the initiated beholder are crucial to their existence, yet for the early periods of humanity they are entirely inaccessible to the researcher. The outstanding technical perfection of some particularly early specimens has prompted the proposition that these objects expressed concepts of perfection and it has been demonstrated, via replicative experiments, that such perfection was achieved through a great investment of labour and carefully applied skills (Bednarik 1997). The intentionality of perfection as well as the various layers of intended cultural meanings of such objects would have been all impossible without the use of a 'reflective' communication system of a complexity that does not seem achievable without consciously modulated speech. Hence beads and pendants constitute key evidence in the quest to clarify the cognitive evolution of humans – not just because they demonstrate the use of symbolisms, but because they demand social, cultural and cognitive systems of an adequate sophistication to support the complex aggregate of mental abstractions without which such objects simply cannot exist. We have many other indicators of language use several hundred thousand years ago, during the Lower and Middle Palaeolithic (e.g. other forms of symbolism, or seafaring), but the use of beads and pendants during these earliest phases of human culture provides one of the most crucial forms of such evidence.

Middle and Lower Palaeolithic finds with both artificial and natural perforations are quite common, and many hundreds have been found since the mid-nineteenth century. They demonstrate considerable complexity of human cognition and social structures up to perhaps half a million years ago. The earliest mention of possible beads of the Lower Palaeolithic relates to the first Palaeolithic tools ever reported, from the very type-site of the Acheulian (Boucher de Perthes 1846). Prestwich (1859: 52), who recognized the authenticity of the St Acheul stone tools Jacques Boucher de Perthes had been collecting for many years, noted that the holes in some of the *Porosphaera globularis* beads he himself collected at French sites had been artificially enlarged. Similarly, many of the 200 Acheulian beads Smith (1894: 272–276) discovered at Bedford, England, showed artificial enlargement of the natural orifice. These, too, were of *Porosphaera globularis* fossil casts, but Smith was not aware of the earlier French finds. His opinion that the globular fossils had been used as beads was confirmed by Keeley (1980: 164) who examined some of the Bedford specimens. However, these important finds remained largely ignored until Bednarik, interested in resolving the issue of the earliest beads, conducted a detailed microscopic study of 325 *Porosphaera globularis* specimens held in the Pitt Rivers Museum at Oxford University (Bednarik 2005). They had all been collected before the early twentieth century, most in England, some in France. In focusing on the best-provenanced part of the collection, the Acheulian finds from the Biddenham quarry at Bedford, he found that many specimens bore distinctive artificial flaking around the narrow end of the natural central tunnel. Moreover, many were observed to bear distinctive wear facets around both tunnel openings, which leaves no doubt about their use as beads. They must have been permanently arranged with their tunnels in alignment to acquire this wear – in other words, they must have been on a string and worn in that way for considerable periods, often for years (Fig. 1).

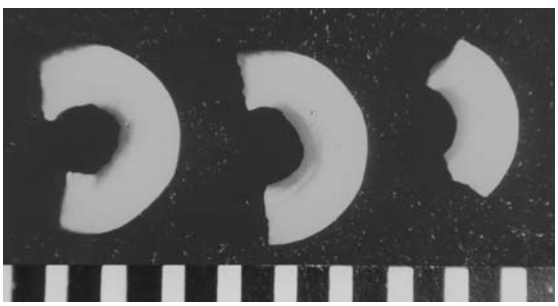
Circular, disc-like fossil casts have also been found at Acheulian sites, such as the crinoid columnar segments (*Millericrinus* sp.) from Gesher Benot Ya'aqov, Israel (Goren-Inbar et al. 1991), and in France columnar crinoid segments from a site on the Loire and from Soissons, near Aisne, Picardie (Bednarik 2005). Several disc beads made from ostrich eggshell have been excavated from substantial Acheulian layers in Libya (Bednarik 1997). They are from the El Greifa site complex at Wadi el Adjal, near Ubari. The site is located on what was a peninsula of the huge Fezzan Lake in the Pleistocene, which then occupied a large part of southwestern Libya. The U/Th isotopes of the calcareous sediments dated the ostrich eggshell beads from the Late Acheulian of El Greifa site E as being in the order of 200,000-years old. The near-perfect rounded circumference and central perforation of these beads demonstrate that hominins of the Acheulian possessed the technology of working this fragile medium with confidence and skill. These perfectly

Beads. Fig. 1 Some of the Acheulian stone beads from Bedford, England (photo by author).

made artefacts also imply the existence of the social structures necessary to provide an ideological context for the production and use of body 'decoration' (Fig. 2).

Among the earliest objects with human-made perforations we know of are the two perforated pendants from the Repolust Cave in Styria, Austria. One is a wolf incisor, very expertly drilled near its root; the second is a flaked bone point, roughly triangular and perforated near one corner (Bednarik 1997). Both objects have received little attention since they were first reported (Mottl 1951). They were excavated with a lithic industry variously described as Levalloisian, Tayacian and Clactonian, which is in fact an undifferentiated Lower Palaeolithic assemblage, clearly free of Mousterian elements. There is no reliable dating evidence available, the currently favoured age estimate of around 300,000 years is based on the accompanying faunal remains, especially the phylogeny of the bear remains (Fig. 3).

In addition to these Lower Palaeolithic beads from three continents, there are numerous perforated objects also from the Middle Palaeolithic, and many of them may have served as beads or pendants. The Micoquian has yielded an artificially perforated wolf metapodium



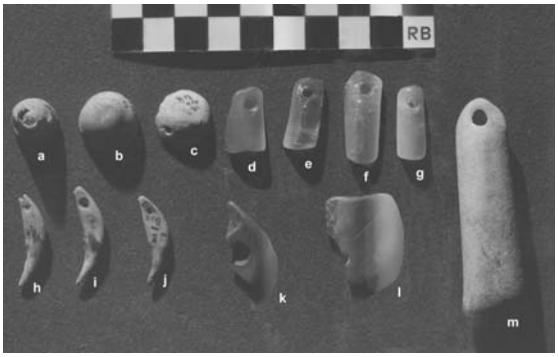
Beads. Fig. 2 The technical perfection of ostrich eggshell beads, such as the El Greifa specimens, illustrates the cultural complexity of the Acheulian period (photo by author).

Beads. Fig. 3 Perforated wolf incisor, Repolust Cave, Austria, probably of the Lower Palaeolithic (photo by author).

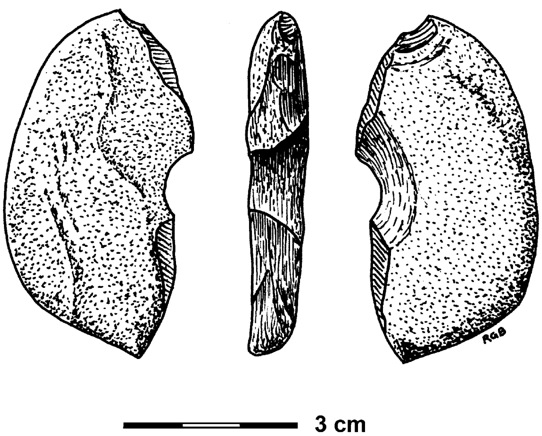
as well as a wolf vertebra from the Bocksteinschmiede, Germany (Marshack 1991; Narr 1951), while the Micoquian of Prolom 2, Crimea, produced no less than 111 perforated animal phalanges, besides four engraved palaeoart objects (Stepanchuk 1993). The Mousterian of France has yielded a partly perforated fox canine and a perforated reindeer phalange from La Quina (Marshack 1991; Martin 1907–1910), another perforated bone fragment from Pech de l'Azé (Bordes 1969), and a probable crinoid[1] fossil from Fontmaure (van der Made 2002). Two perforated canines from Bacho Kiro, Bulgaria, too, are of the Middle Palaeolithic (Marshack 1991). The Middle Stone Age of Blombos Cave, South Africa, produced 41 perforated snail shells that are about 75,000-years old. Two slightly older perforated seashells come from Border Cave, also in South Africa (Beaumont et al. 1992), as does a centrally perforated ostrich eggshell fragment from the same site, about 76,000-years old (Grün and Beaumont 2001). Other African finds of the general period are a perforated shell from Oued Djebanna, Algeria; four deliberately drilled quartzite flakes from Debenath, Nigeria; and a bone pendant from Grotte Zouhra, Morocco (McBrearty and Brooks 2000). Towards the end of this technological phase, beads and pendants became increasingly common, and materials of stone began to be drilled, first appearing in Russia and China. Thirteen such specimens from the lower occupation layer of Kostenki 17, found below a volcanic horizon thought to be about 40,000-years old (from the Campanian Ignimbrite eruption in Italy), include not only polar fox canines (Fig. 4) and gastropod shells with perforations, but also stone and fossil cast objects (Bednarik 1995). From an intermediate Middle to Upper Palaeolithic site in China, wenhua Shiyu, comes a broken stone pendant (Bednarik and Yuzhu 1991; Fig. 5). The oldest beads found in Australia, from Mandu Mandu Creek rockshelter, are about 32,000-years old and of a stone tool industry of Middle Palaeolithic technology (Morse 1993).

With the advent of the Upper Palaeolithic in Eurasia, beads became more numerous in various regions. This includes specimens made by the Neanderthals of the Châtelperronian of the French Upper Palaeolithic, among them again a crinoid fossil segment (Leroi-Gourhan 1965; Fig. 6). Just three graves at the Russian site Sungir' – with a stone tool technology that is transitional between Middle and Upper Palaeolithic implement types, the Streletsian – contained more beads than have been found in the entire Pleistocene sites of the rest of the world (Bednarik 1995). They yielded 13,113 small ivory beads and over 250 perforated canine teeth

[1] A crinoid is a type of primitive marine invertebrate animal (echinoderm) with a cup-shaped body and five feathery radiating arms.



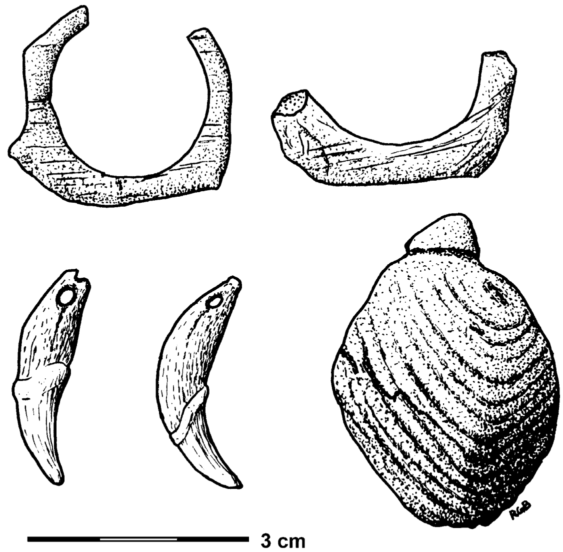
Beads. Fig. 4 Beads and pendants from Kostenki 17, Russia, >40,000-years old. (a–c) are snail shells; (d–g) are silicified, semi-translucent fossils; (h–j) are fox canines; and (k–m) are stone pendants (photo by author).



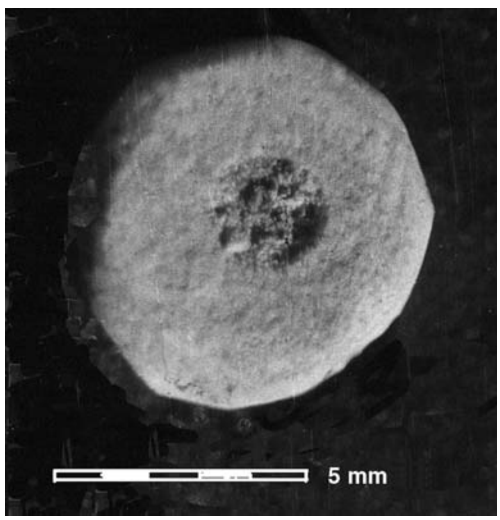
Beads. Fig. 5 Fragment of drilled stone pendant, about 28,000-years old, from wenhua Shiyu, China (drawn by author).

of the polar fox. By this time, perhaps 28,000 years ago, the art of bead making had reached an extraordinary level, in which the results of thousands of hours of labour were lavished on just three burials. In India we have only a few specimens from the entire Palaeolithic: two from Bhimbetka, south of Bhopal, and three from Patne, Maharashtra (Fig. 7). Two of the latter are not perforated, although one is centrally scored (Bednarik 1997). Other Asian regions producing ostrich eggshell beads include Siberia (Krasnyi Yar, Trans-Baykal), Inner Mongolia (Hutouliang) and the Gobi desert in northern China and Mongolia. The ostrich, now extinct in Asia, was widely distributed to the end of the Pleistocene, occurring in the Arabian Peninsula until well into historical times.

Both southern and northern Africa have yielded countless finds of worked ostrich eggshell (Baur-Röger 1987, 1988; Camps-Fabrer 1962, 1966, 1975; Cziesla 1986; Goodwin 1929; Marmier and Trecolle 1979;



Beads. Fig. 6 Two ivory ring fragments, two perforated animal canines and a fossil shell with an artificial groove for attachment, made by Neanderthals. Grotte du Renne, Arcy-sur-Cure, France (drawn by author).



Beads. Fig. 7 Ostrich eggshell bead, early Upper Palaeolithic, from Bhimbetka, Madhya Pradesh, India (photo by author).

Marshall 1976; Sandelowsky 1971; Woodhouse 1997). In the far north of Africa the Capsian, belonging already to the first half of the Holocene, yielded not only numerous figurative and non-figurative engravings on ostrich eggshell fragments, but also beads of snail shells, teeth and small stones, besides those of ostrich eggshell. The southern African sites providing such finds date from the Middle Stone Age right up to recent periods. Ostrich eggshell beads from Bushman Shelter near Ohrigstad, Transvaal, have been suggested to date from somewhere between 12,000 and

47,000 years ago. Beads of this material span a vast age spectrum, still occurring in recent periods in southern Africa. For instance, they are found in the Smithfield B, a tool complex of the subcontinent's interior regions of the fourteenth to seventeenth centuries AD. Indeed, ostrich eggshell beads are among the most enduring symbolic artefacts in human history. Much the same can be said about other forms of beads. For instance, a publication about Palestinian jewellery of the most recent ethnographic past features a photograph of a bead described as a 'fossilized sea urchin' (Helmecke 1990: Pl. 13f), depicting in fact a crinoid fossil cast that closely resembles the crinoids recovered from the Acheulian site Gesher Benot Ya'aqov in the same region, on the River Jordan (Goren-Inbar et al. 1991). Although separated by hundreds of millennia in time, the same materials were used for the same class of symbolic artefacts over an enormous time span – a poignant reminder that in terms of their humanness, our distant ancestors were a great deal closer to us than many archaeologists are willing to concede.

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Ben Cao Gang Mu

Liao Yuqun

The application of herbal, mineral, animal, and man-made substances in medical therapy has been recorded in China since antiquity. These pharmaceutical compilations are called *Ben Cao*.

In the Ming dynasty, a masterpiece, *Ben Cao Gang Mu* (Compendium of Materia Medica), was published in AD 1590. In China, as well as in other parts of the world, this work is the best known and most respected description of traditional pharmaceutics. The value of this enormous achievement, written by one person, goes far beyond the scope of a pharmaceutical-medical drug work. In fact, it constitutes an extensive encyclopedia of knowledge concerning nature and the technology required for the medicinal use of nature.

The compilation of *Ben Cao Gang Mu* was based on the *Zheng Lei Ben Cao* (Classified Materia Medica, compiled at the end of the eleventh century AD). Li Shizhen, the author, took from it 1,479 drugs. He supplemented these with 39 drugs that had been included in the drug compendia of the Jin Yuan period, as well as with 374 drugs that he himself described for the first time, so that the *Ben Cao Gang Mu* contained a total of 1,892 drugs. This number is confirmed by the table of contents; the actual number should be 1,898. To continue the statistics: the number of drug illustrations is 1,160 and that of the recorded prescriptions is 1,196, of which Li Shizhen collected or newly compiled 161 himself.

The entire work was divided into two chapters of illustrations and another 52 chapters containing the texts. The first four text chapters are of a general nature; chapters five through 52 contain the monographs. The total number of drugs was divided into 16 groups, and then 60 subgroups. Thus, for example, the group of herbs was divided into the subgroups of mountain herbs, aromatic herbs, swamp herbs, poisonous herbs, convolvulous herbs, water herbs, stone herbs, moss and lichen herbs, and finally, various herbs.

For each drug the following ten items were discussed. As they were used only when the information was necessary, not all are contained in each monograph:

1. Information concerning a previously false classification of the drug
2. Information on secondary names of the drug, including the sources of these names
3. Collected explanations
4. The pharmaceutical-technological preparation of the drug
5. Explanation of doubtful points
6. Correction of mistakes
7. Information on the thermo-influence and taste of the drug
8. Enumeration of the main indications of the drug
9. Explanations concerning the effects of the drug
10. Enumeration of prescriptions in which the drug is used

As for the author, Li Shizhen was born into a medical practitioner's family. When he was unable to pass the official career exams after three attempts, he was determined to devote himself to the study of medicine. Through 30 years' clinical practice and learning from many experts, he, after innumerable hardships, completed the manuscript in 1578, but the first edition was not finished until after his death.

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Bhāskara I

Agathe Keller

Bhāskara I was a 7th century astronomer, probably from the region that is between the border of modern day Mahārashtra, Gujarat, and Madhya Pradesh in India.

He wrote two treatises in the line of Āryabhaṭa I's astronomy, the *Mahābhāskarīya* (Shukla 1960) and the *Laghubhāskarīya* (Shukla 1963). Bhāskara did not just restate in an explicit way Āryabhaṭa I's astronomy; he also provided explanations and interpretations of this astronomer's reasoning. Bhāskara I is also the author of a commentary on the *Āryabhaṭīya* (see the entry on Āryabhaṭa). This is the oldest known Sanskrit commentary on this treatise. It is also the oldest known commentary for the whole mathematical and astronomical tradition in Sanskrit. The commentary is called the *Āryabhaṭīyabhāṣya* (Shukla 1976; Keller 2006). Bhāskara I himself dates the writing of this text to 628 AD. He is thus a contemporary of Brahmagupta.

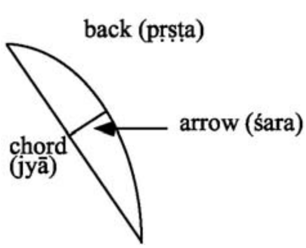
This commentary, not being written in compact *sūtra* verses, can help us reconstruct what astronomy and mathematics were for a 7th century astronomer. It gives us precious insights into how mathematical and astronomical concepts were derived and discussed. Bhāskara, for instance, discusses the relation of mathematics to astronomy, giving several definitions of mathematics in the opening part of his commentary. His idea of *gaṇita* (computation, mathematics) seems to be quite malleable and open. Indeed, if the discipline called *gaṇita* is understood as a set of procedures, general (*samānya*) or specified (*viśeṣa*), then it encompasses astronomy (*jyotiṣa*). But it can also be seen as a set of specialized subjects. In this case, it is quite separate from astronomy. Bhāskara provides us with different proposals as to how one can classify the subjects related to mathematics. He thus states for the first time the classification of mathematics into eight *vyavahāra*s, which were used after him in arithmetical texts (see the entry on arithmetic in India). He also alludes to equations (*bija*) as a way of classifying mathematical subjects, an idea that had a certain posterity in the algebraic tradition in India (see the entry on algebra in India). For Bhāskara I all computations belonged both to arithmetic (*rāśigaṇita*) and to geometry (*kṣetragaṇita*). Thus series (*średdhi*) are seen as both sums of numbers (belonging thus to arithmetic) and piles of objects (belonging thus to geometry).

Bhāskara's commentary also testifies to how astronomy and mathematics were practiced in those times. For instance, Bhāskara gives details on the constructions of gnomons (sundials), describing various shapes, styles and schools for this instrument. He also sometimes explains how a mathematician (*gaṇaka*) uses a working surface (probably just the bare ground or a slate) on which numbers are disposed and diagrams drawn. These were then used when solving problems, which involve moving quantities, or seeing a proof in a drawn figure (Keller 2005).

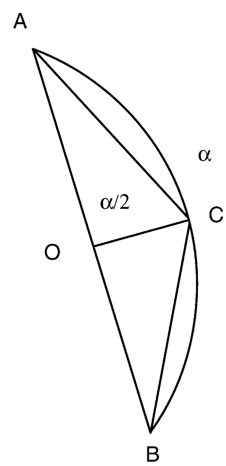
Bhāskara's commentary on the *Āryabhaṭīya* is an important landmark in understanding the beginning of sine trigonometry. His work shows us that the fundamental diagram of sine trigonometry is a bow field (*dhanuḥkṣetra*). A bow field is composed of a back (*pṛṣṭha*), a chord (*jyā*) and an arrow (*śara*). This is illustrated in Fig. 1.

By the time Bhāskara wrote his commentary, it was fairly common to consider something that can be a bit confusing at first, the half-chord of the half-arc. That is, in Fig. 2, the segment AO is the half-chord of $a/2$, and not the half-chord of a. This segment is what we call the sine of arc $a/2$, when in a circle of radius 1. In Bhāskara's mathematics, however, circles are seldom with a unit radius, and so he deals in fact with R sines, e.g., R times the sine. This segment is called *ardhajyā* (lit. half-chord), but slowly as it became a technical term in itself, the word half (*ardha*) was sometimes dropped, until the segment itself was called *jyā*. The innovation constituted by the sine over the chord becomes clear if we look at Fig. 2 again. Indeed, by using this segment, computations using the Pythagorean theorem become possible enabling one to derive lengths of segments quite easily. To explain how to derive tables of sine differences, Bhāskara prescribed the construction of a diagram, which is shown in Fig. 3 (Hayashi, Yano 1991). It can be seen as an ancestor of our trigonometric circle.

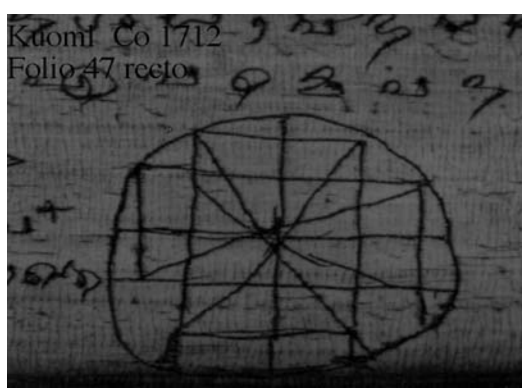
As a mathematician, Bhāskara did not restrict himself to trigonometry but provided his insights on a great range of subjects. For instance he gave a detailed version of different problems solved by a pulverizer (e.g., a method to solve Pell equations, Bag 1979), all sorts of variations on the Pythagorean theorem, reflections on the concept of quadratic irrationals (Chemla, Keller 2002 and Datta 1980), and many others (Rao 2006). As a scholar, he often staged intellectual debates and took positions on them, thus letting us have a feel for the oppositions existing between different schools of mathematicians and authors that existed at the time, something that Brahmagupta's work also testifies to.



Bhāskara I. Fig. 1 A bow field. Drawing by the author.



Bhāskara I. Fig. 2 The half-chord of the half-arc. Drawing by the author.



Bhāskara I. Fig. 3 Bhāskara's diagram for deriving sines.

Bhāskara's legacy has been especially felt in Kerala. If you judge the popularity of an author as being measured by the number of commentaries it has given rise to, we can note that in Kerala, his works were commented upon by Govindasvāmin (ca. 825), Śaṅkaranārāyaṇa (ca. 869) and Parameśvara (ca. 1430). After first being confused with his namesake Bhāskara II by early 19th century scholars (Datta 1930), his work was slowly brought to light in the early twentieth century (Datta and Singh 1938). Finally K. S. Shukla took the time to edit his texts and translate his treatises in the 1960s and 1970s.

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Bhāskara II

R. C. Gupta

Undoubtedly, the greatest name in the history of ancient and medieval Indian astronomy and mathematics is that of Bhāskarācārya (b. AD 1114). His *Līlāvatī* is the most popular book of traditional Indian mathematics. He is usually designated as Bhāskara II in order to differentiate him from his earlier namesake who flourished in the early part of the seventh century.

According to Bhāskara's own statement towards the end of his *Golādhyāya,* he was born in Śaka AD 1036 or AD 1114. He also adds that he came from Vijjaḍaviḍa near the Sahya mountain. This place is usually identified with the modern Bijapur in Mysore. S.B. Dikshit is of the opinion that Bhāskara's original home was Pāṭaṇa (in Khandesh), where a relevant inscription was discovered by Bhau Daji in 1865. According to the inscription, Manoratha, Maheśvara, Lakṣmīdhara, and Caṇgadeva were the names of the grandfather, father, son, and grandson, respectively, of Bhāskara. Caṇgadeva was the chief astronomer in the court of the king Siṅghaṇa and had established in AD 1207 a *maṭha* (residential institution) for the study of the works of his grandfather. Bhāskara's father, Maheśvara, was also his teacher.

Bhāskara's *Līlāvatī* (The Beautiful) is a standard work of Hindu mathematics. It belongs to the class of works called *pāṭī* or *pāṭīgaṇita*; that is, elementary mathematics covering arithmetic, algebra, geometry, and mensuration. Its popularity is shown by the fact that it is still used as a textbook in the Sanskrit medium institutions throughout India. It provides the basic mathematics necessary for the study of almost all practical problems, including astronomy. The subject matter is presented through rules and examples in the form of about 270 verses which can be easily remembered. There is a story that the author named the work to console his daughter Līlāvatī, who could not be married due to some unfortunate circumstances; but the truth of the story cannot be ascertained. Bhāskara addressed the problems to a charming female Līlāvatī, who, according to some scholars was his wife (and not his daughter).

The great popularity of *Līlāvatī* is illustrated by the large number of commentaries written on it since it was composed about AD 1150. Some of the Sanskrit commentators were: Parameśvara (about 1430), Ganeśa (1545), Munīśvara (about 1635), and Rāmakṛṣṇa (1687). Only a few of these have been published. Gaḍeśa's gives a good exposition of the text with a demonstration of the rules. However, the best traditional commentary is the *Kriyākramakarī* (ca. 1534), which is a joint work of Śaṅkara Vāriyar and Mahiṣamaṅgala Nārāyaṇa (who completed it after the demise of Śaṅkara).

There are a number of commentaries and versions in regional Indian languages. Quite a few modern scholars have edited, commented on, and translated *Līlāvatī*. At least three Persian translations are known, the earliest being by Abū al-Fayḍ Fayḍī (AD 1587). The English translation by Colebrooke (1817) was based on the original Sanskrit text and commentaries.

Bhāskara's *Bījagaṇita* (Algebra) is a standard treatise on Hindu algebra. It served as a textbook for Sanskrit medium courses in higher mathematics. In it the author included an exposition of the subject based on earlier works. Among the sources named were the algebraic works of Śrīdhara and Padmanābha. Besides operations with various types of numbers (positive, negative, zero, and surds), it deals with algebraic, simultaneous, and indeterminate equations. There is a separate chapter on the Indian cyclic method called *cakravāla*. He attributes the method to earlier teachers but does not specify any name. Due to the difficult nature of some of the topics, the *Bījagaṇita* was not as popular as the *Līlāvatī.*

Bhāskara's *Siddhānta-śiromaṇi* (AD 1150) is an equally standard textbook on Hindu astronomy. It has two sections: *Grahaṇita* (Planetary Mathematics) and the *Golādhyāya* (Spherics). Often these two sections appear as independent works. There is a lucid commentary on the whole work by the author himself. It is called *Mitākṣarā* or *Vāsanābhaṣya*. Other commentators include Lakṣmīdāsa, Nṛsiṁha, Munīśvara (1638/1645), and Rāmakṛṣṇa. The 14th chapter of the *Golādhyāya* is the *Jyotpatti*, which may be regarded as a small tract on Hindu trigonometry.

Usually it is customary to regard Līlāvatī, Bījagaṇita, Grahaṇita, and the Golādhyāya as the four parts of the *Siddhānta Siromaṇi* which make it a comprehensive treatise of Bhāskarācārya's Hindu mathematical sciences. His two other works are the *Karaṇa-kutūhala* (whose epoch is 1183), a handbook of astronomy, and a commentary on Lalla's *Śiṣyadhīvṛddhida-tantra* (eighth century AD). Some other works have also been attributed to him, but his authorship of *Bījopanaya* is questionable.

Bhāskara introduced a simple concept of arithmetical infinity through what he calls a *khahara*, which is defined by a positive quantity divided by zero, e.g., 3/0. His arithmetical and algebraic works are full of recreational problems to provide interesting pedagogical examples.

Perhaps the most important part of Bhāskara's *Algebra* is his exposition of the Indian cyclic method. We now know that the method was already known to Jayadeva (eleventh century AD or earlier). A modern expert, the late Selenius, praised it by remarking that "no European performance in the whole field of algebra at a time much later than Bhāskara II, nay nearly up to our times, equaled the marvelous complexity and ingenuity of cakravāla method." Fermat proposed the equation $61x^2 + 1 = y^2$ in 1657 to Frénicle as a challenge problem. However, by applying the above method, Bhāskara had already solved the problem five centuries earlier. Bhāskara's solution (which he got just in a few lines) in its smallest integers was $x = 226{,}153{,}980$, $y = 1{,}766{,}319{,}049$.

The feat was possible not only due to the technique but also because of a well-developed symbolic notation. Colebrook remarks

> Had an earlier translation of Hindu mathematical treatises been made and given to the public, especially to the early mathematicians in Europe, the progress of mathematics would have been much more rapid, since algebraic symbolism would have reached its perfection long before the days of Descartes, Pascal, and Newton.

Another gem from Bhāskara's *Algebra* is a very short proof of the so-called Pythagorean theorem.

The geometrical portion of *Līlavatī* covers mensuration regarding triangles, quadrilaterals, circles, and spheres. A special rule gives the numerical lengths of the sides of regular polygons (from three to nine sides) in a circle of radius 60,000. The last chapter entitled *Aṅka-pāśa* is devoted to combinatorics.

Bhāskara's *Jyopatti* contains many trigonometrical novelties which appear in India first in this tract.

Although an equivalent of the differential calculus formula

$$\Delta \sin \theta = \cos \theta \, \Delta\theta$$

already appeared in Munñjla's *Laghumānasa* (AD 932), Bhāskara II gave its geometrical demonstration. He knew that when a variable attains an extremum, its differential vanishes. A crude method of infinitesimal integration is implied in his derivation of the formula for the surface of a sphere. This he gave in the *Vāsanābhāsya* on the *Golādhyāya* (Chap. III).

Bhāskara's *Siddhānta-śiromaṇi* is one of the most celebrated works of Hindu astronomy. It is a comprehensive work of *Brahma-pakṣa*. He praised Brahmagupta, who belonged to the same school, but his own astronomical work became more famous.

Although based on the works of predecessors, rather than on any fresh astronomical observations, the *Siddhānta-śiromaṇi* served as an excellent textbook. Systematic presentation of the subject matter, lucidity of style, and simple rationales of the formulas made it quite popular. It also contained some improved methods and new examples. For instance, he gave a very ingenious method of finding the altitude of the Sun in any desired direction in his *Golādhyāya* (III, 46). His professional expertise and all-round knowledge made him a truly great and revered *ācārya* (professor) of Hindu astronomy and mathematics for generations.

See also: ►Algebra in India, ►Mathematics in India, ►Geometry in India, ►Parameśvara, ►Munīśvara, ►Trigonometry in India, ►Combinatorics, ►Muñjāla

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Bian Que

Liao Yuqun

Bian Que, one of the most famous medical men in ancient China, lived during the time of the Zhou dynasty, between 500 and 600 BCE. He was good at various subjects in medicine and skilled in diagnosis and treatment, especially in pulse-taking and acupuncture.

Sima Qian (about 145–96 BCE), a well-known historian, wrote a biography of Bian Que in his work *Shi Ji* (Historical Record). In it, he discussed Bian Que's practicing medicine, wandering from town to town and effecting miraculous cures, even bringing the dying back to life. In the end Bian Que was killed by a jealous commissioner of the Imperial Academy of Medicine. Sima Qian says: "Bian Que expounded medicine as the guiding principle of (medical) technique; the later generations followed it and could not change any more." He was regarded as the founder of traditional Chinese medicine, but according to the historical materials in the biography, Bian Que lived and flourished for hundreds of years. That is because its author confused him with another famous medical man, Qin Yueren. Probably Qin Yueren was a follower of Bian Que's teachings.

In the earliest bibliography, *Qi Lue*, written in the first century BCE, Bian Que was assumed to be the author of some medical works such as *Bian Que Nei Jing* (The Internal Classic of Bian Que) and *Bian Que Wai Jing* (The External Classic of Bian Que). Although all of them have been lost, the contents can be partly found in other extant medical works, which reflect what he contributed to traditional Chinese medicine.

Bian Que said that the blood and *qi* (vital energy) move along the channels of the body, making 50 circuits per day. Some medical historians consider this the first intimation of the circulatory system of the blood; others are more skeptical. This view was constructed on the principle of cyclicism, a very common mode of thought for the Chinese.

It was he, too, who founded the extremely complicated old Chinese system of pulse-taking, according to which a doctor was supposed to be able to diagnose an illness solely by the condition of the pulse. It was not just a question of whether the beat was strong or weak, regular or uneven. Pulses could also be distinguished as "sounding like a sickle, first exuberant then dying away"; "flowing along quietly like flying hair or feathers"; "beating deep and strong like a thrown stone"; "sounding delicate like the string of an instrument"; or "slipping along like a fish or a piece of wood on the waves". From the above selection of possible pulse beats, it is easy to see with what extraordinarily sharpened sensitivity the Chinese doctor examined his patient. Bian Que also discussed how to diagnose illness by the condition of the complexion. For example, a yellow complexion and nails were an indication of jaundice; red dealt with the heart; and white was always due to the lungs.

As for therapy, Bian Que used the traditional techniques such as acupuncture, moxibustion, and drugs to cure various diseases. We do not know who invented those treatments; however, all of them were improved owing to Bian Que's practice and teaching. Indeed, these are still followed in clinical practice and diagnosis today.

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Bitumen in China

Hans Ulrich Vogel

Reports of bitumen seepages and production concentrate on four provinces: northern Shaanxi and eastern Gansu from the Han period onward, Sichuan from the Ming onward, and Xinjiang which has records of bitumen seepages during the periods of the Northern Dynasties (386–581), the Tang, and the Qing. In addition, during the Ming and Qing periods, minor production sites existed in Guangdong, Taiwan, Zhejiang, Anhui, and Liaoning (Liaodung).

The earliest record of bitumen seepages refers to northern Shaanxi that is the oil fields of Yanchang and Yongping of today. The *Hanshu*, first century AD, states that in Gaonu district (modern-day Yan'an) "there is the Wei River; it can burn." This statement is elucidated by later sources, which say that on the water of the Wei River "fat" (*fei*) is floating which can burn and which can be taken for greasing cart axles or as fuel for lamps.

Sources from the Song onward provide more details on the locations of Shaanxi petroleum seepages and production methods. In his famous account of about 1070 on using petroleum carbon for ink, Shen Gua (1031–1095) mentions the production of "stone oil" (*shiyou*) in the two prefectures Fu and Yan and of "stone juice" (*shiye*) in Yanchuan. He wrote that stone oil grew in the sand and stones of the waterfront, was mixed with spring water, and, with a view to ink manufacture, was produced inexhaustibly within the earth, in contrast to the limited supply of pine wood. In spring, local people collected it with pheasant tail brushes and put it into pots. The method of collection described by Shen Gua is similar to that described in Agricola's *De re metallica* of the mid-sixteenth century.

Song and Yuan sources report that near Yan'an bitumen was used to make so-called "stone candles" (*shizhu*). Lu You (1125–1210) says in his *Laoxuean biji* of 1190 that they are solid like stone and give a very bright light. Moreover, "they also gutter like wax [candles]. Their smoke, however, is thick and may fumigate and defile curtains and clothes. This is why people in the western [part of the empire] do not esteem them." The stone cave supplying the raw material for the production of the stone candles was, however, closed in 1270 by government order.

Perhaps the first notion of a well intentionally dug for getting bitumen can be found in the *Da Yuan da yitongzhi*, the comprehensive administrative and geographical description of the Yuan period:

> South of Yanchang district, at Yinghe, there is a stone oil well which has been cut open. Its oil can burn and also cures itches and ringworms of the six domestic animals. Annually, 110 *jin* [pounds] are handed in. Moreover, in Yongping village, 80 *li* north-west of Yanchuan district, there is another well, which annually procures 400 *jin*. They are handed over to the [Shaanxi] Route (*lu*).

As in many other cases, the output of oil seepages was low. The record also shows that the government was heavily interested in this resource, probably because of its importance for warfare.

The use of bitumen in warfare from the Yumen oil field in western Gansu is reported by an eighth-century source, stating that, in 578, the Emperor Wu of the Northern Zhou, when being besieged by the Turks at Jinquan, took this "fat" and set it afire, thus burning the enemies' assault weapons. When brought into contact with water, it burnt even more, with the result that Jinquan was saved.

With the development of deep drilling, Sichuan became an important producer of bitumen, being a by-product of the search for brine and, later, natural gas. Sixteenth-century accounts report that the sources of the fire wells of Jiading and Qianwei are all "oily." Because of its odor, locals call the stone oil "realgar oil" (*xionghuangyou*) and "sulfur oil" (*liuhuangyou*). It was thought that the sources and veins of stone fat, realgar, and sulfur were interconnected. Officials filled bamboo tubes with oil and ignited it for lighting the way. Moreover, special iron lamps were constructed which fitted the use of bitumen as fuel. An indigenous terminology developed which was based on the colors of bitumen. White bitumen was called "rice-soup oil" (*mitangyou*), green "green-bean oil" (*lüdouyou*), yellow "gardenia-nut oil" (*zhiziyou*), and black "black-lacquer oil" (*moqiyou*). Petroleum occurred at depths of 180–220 m, ca. 360 m, and 950–990 m, and there were experts who knew exactly to which depths the hoisting buckets should be sent to have them filled with petroleum exclusively.

The most important application of bitumen in crude and distilled form was certainly in the military field, where it was used for incendiary weapons. The sources do not inform us about details of the processing and distilling methods, but this may be due to the fact that these were treated as military secrets. The second most important use of bitumen was for lighting purposes, for which numerous references, particularly for regions near bitumen seepages or wells, can be found. In Sichuan, bitumen appears to have served sometimes as fuel for the evaporation of brine. Bituminous products were also used for greasing cart axles and the bearings of water power trip-hammers, manufacturing ink, sealing leather wine sacks, covering floors, and tempering iron.

Moreover, bitumen was often applied for medical, pharmaceutical, and alchemical purposes. For instance, Li Shizhen's *Bencao gangmu*, published in 1596, states that it is smeared on ulcers, ringworms, worms, and scabies, and is used for drugs which heal flesh wounds caused by iron arrows. A source of the seventh century tells us that when swallowing the bitumen of Jiuzi in Xinjiang, fallen out teeth and hair can be induced to grow again. Later sources are less sanguine about internal application and sometimes stress that bitumen is poisonous.

Although, in China, bitumen seepages and deposits were discovered and used from an early period onward, the overall economic, technical, and scientific role of bitumen remained small and did not extend much beyond the limits of the small number of production areas. The only exemption was in the military field, where testimonies of fire and flame throwers using distilled petroleum are numerous. The revolutionary impact of the Drake Well in mid-nineteenth century Pennsylvania was not due to the depth reached in deep drilling, but to the fact that beforehand a thorough scientific investigation of the properties, refining methods, and possible applications of petroleum had taken place. It was this combination of scientific investigation, technical achievement, establishment of production plants, and creation of a huge demand that was responsible for the rise of the petroleum industry in the West.

See also: ►Salt (China), ►Tribology (China), ►*Bencao gangmu*

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Bone Technology in Africa

ALICE M. CHOYKE

Particular cellular structures in the hard tissues of animals provide potential raw materials for manufacturing tools and ornaments. Mammalian bones and teeth provide the bulk of the raw material not only because of their form but also because they were available in the refuse derived from the consumption of meat. Egg and mollusk shell (gastropods and bivalves) were also modified. It is possible that, like ivory in later periods, they might have been sought after for the sake of the shell raw material itself. In parallel, since osseous tissues come from living animals which often had important symbolic significance to the humans exploiting them, their bones may also have had a variety of special significances in traditional tool manufacture. At the beginning, bones were used rather than modified in regular ways, but quite early on humans used a variety of techniques (cutting, scraping, abrasion, and drilling) to produce standardized objects. Until the Late Bronze Age in the second millennium BC, flaked stone tools, rough stone surfaces, and polishing materials were used to manufacture quite sophisticated objects.

As it was the cradle of humankind, it is not surprising that Africa was the scene of the earliest bone working in the world and some of the latest as well, representing almost two million years of transforming the hard tissues of animals into tools and ornaments. Furthermore, African bone technology is also distinguished by the use of two special raw materials: ivory and ostrich eggshell. As elsewhere, however, animal bone lay at the heart of technological processes while antler, a staple material in Europe, was unknown. Shells, riverine or marine, were used as ornaments almost everywhere across the continent and from remarkably early times in the Middle Stone Age to the present.

Outside Africa, until quite recently, the earliest, securely dated worked bones, small split-based projectile points, came from the Central European Szeleta culture at around 35,000 BP, representing the earliest securely dated manufactured objects in Europe, coeval apparently with the arrival of anatomically modern humans in Europe. Worked wooden artifacts from the sites of Clacton and Lehringen as well as three wooden spears found at the 400,000-year old site of Schoeningen in Germany, however, show that Middle Pleistocene European hominids used wood. *Homo erectus* craftspeople could scrape and shave wood so handily that working bone should have presented few problems. There are also examples from this early time period in Europe of large mammalian phalanges, deer antler and diaphysis shaft fragments being used as retouchers for making stone tools. There is even one example from Italy of bifacial tools flaked from an elephant long bone (d'Errico and Backwell 2001; d'Errico 2003).

Some of the chronological and spatial gaps in the distribution of these early bone objects from Europe and Africa revolve around the survival of bone on archaeological sites. Very ancient sites are rare everywhere in the world. Furthermore, and importantly, preservation of organic, osseous materials was dependent on the way those objects were used, where they were discarded, and the natural conditions prevailing in those places. Acidic soils destroy bone while root action and animal gnawing can also modify surfaces and shapes. Osseous materials of any kind, compared with stone, will begin to erode and break apart when exposed for more than a month or two in the open air. Thus, both cultural behavior with regard to tool use, location(s) of that use, and traditions of discarding worked bone after they broke compound natural conditions to affect what objects can be found by excavating archaeologists. Bone tools have not often been systematically researched, perhaps because their study also requires such an intimate knowledge of the biology of the bones they derive from.

The Taphonomy[1] of Worked Osseous Materials

What particularly makes any discussion of African bone tool technologies a challenge is the size of the continent, especially relative to the amount of published research which has gone on there. This research has been quite localized in time and space. On the one hand, lands along the great Nile, from Nubia to Egypt have been intensively studied. However, the very grandeur of Egyptian civilization has meant that researchers have concentrated on the grand places, the palaces, temples, and burial monuments and emphasized ceramics and exquisite, special finds. Predynastic settlement has only recently begun to be investigated and even there the bone finds are rarely published in detail. Much less is known of the later prehistory and history of bone technology in the enormous territory of North Africa, best known archaeologically for the great Roman and Medieval Islamic cities whose ruins dot the shores of the continent.

On the other hand, because humankind is infinitely fascinated with its beginnings a great deal of attention has been paid to early hominid sites in South Africa, the Rift Valley and Congo. Over 50 years ago, Raymond Dart, the physical anthropologist famous for his discovery of the baby Australopithecine skull from Taung in South Africa (Dart 1925), later interpreted some of the bone finds from the South African site of Makapansgat as being among the first "natural" tools used by these early hominid populations (Dart 1949, 1962). Since then there has been debate concerning whether these artifacts were modified or simply used by these early hominids or were the result of nonhuman taphonomic processes such as erosion. However, such tools were never found, or rather they were not evident to the people working on these ancient sites and so the idea was rejected. It was almost inevitable, given the relatively well-funded research on early human sites, regularly ongoing in Africa, that new finds would emerge to revive Dart's ideas and even greatly expand them.

The First Humanly Modified Bones in the World—Termite Extraction Tools

Three of the most famous early hominid sites in the world, Swartkrans (Members 1-3, ca. 1.8–1.0 Mya) Sterkfontein (Member 5, 2.0–1.7 Mya), and Drimolen (2.0–1.5 Mya) are located in South Africa. These sites contain the first evidence for the systematic modification and use of long bone shaft fragments and horncores (the boney core within bovid horn sheaths) for tools (d'Errico and Backwell 2001, 2003). These 68 tools were originally interpreted through microscopic analysis as tools for digging up tubers and working skins (Brain and Shipman 1993). The bones from these three sites were later reexamined using a multidisciplinary approach that compared wear patterns on pseudobone tools created by known natural processes with the patterns on experimentally used bone tools and with the traces of wear found on the original objects (Backwell and d'Errico 2005; d'Errico and Backwell 2003).

It was immediately clear that the wear on the artifacts matched that neither on pseudotools nor on artifacts used for digging tubers or preparing hides. Wear traces on the working ends of tools used experimentally to excavate termite mounds most closely fit the wear traces found on these archaeological objects (Backwell and d'Errico 2001). The bones used as raw material all show signs of weathering prior to use in that they have weathered breakage patterns as opposed to spiral fractures. In addition, compared to other bone fragments found at these sites the 68 modified bone objects stand out as a group since they are made from longer, broader bone fragments showing that they were intentionally selected by these early hominids. The researchers were able to find robust horncores with tips that had been reshaped by grinding.

The presence of such relatively sophisticated shaping suggests that even at this early date, modern human behavior was beginning to emerge, together with

[1] Taphonomy is the study of the conditions and processes by which organisms become fossilized or are preserved.

the ability to preplan objects according to culturally determined patterns. Although the technology used was far less complex than the completely shaped bone tools found at Middle Stone Age sites such as Blombos cave in southwestern South Africa or regularly encountered in materials from the Late Stone Age to the present day, there is still evidence that the location and direction of the facets produced on the tips represent planned behavior. The makers and users of these termite extraction tools, probably the robust australopithecine, *Paranthropus robustus*, seem to have had a clear understanding of the relationship between the shape of the tip and how the tools were going to be used (D'Errico 2003; D'Errico et al. 2003). Such complex thinking was always previously associated with anatomically modern humans. The discovery and recognition of these tools have forced scientists dealing with human evolution to change their ideas about what defines modern human behavior.

The earliest specimens of anatomically modern *Homo sapiens* come conclusively from Africa at Omo Kibish in Ethiopia dating to 185,000 BP and Herto in Ethiopia dating to 165,000 BP. However, evidence for planned sophisticated tool making, especially complex techniques for modifying osseous materials for tools and ornaments or even symbolic expression, only appears, at the earliest, 50,000 years later. Students of the development of modern cognitive thought divide into two schools on this issue. One school, led by the scholar Richard Klein (2002), proposes a revolution in mental capabilities beginning around 40,000 years ago in Europe and some 5,000 to 10,000 years earlier in Africa. This can be seen for example, in the presence of ostrich shell disk beads at the site of Enkapune Ya Muto in Kenya dated to 45,000–50,000 BP. A smaller but growing group of researchers lead by Brooks and Henshilwood have argued that technological complexity developed slowly in a piecemeal way along with what may be called modern human behavior (McBrearty and Brooks 2000). Proofs of this development may be found in the single-row barbed harpoons from Katanda in the Congo, which have been controversially dated to 90,000 BP (Brooks and Smith 1987), and more securely in the well-dated finds from Blombos Cave dated to 77,000 BP.

Katanda and the Harpoon in Africa

Barbed harpoons have a special place in the history of bone technology of Africa (Yellen 1998), demonstrating continuity in their basic form if not in their actual use. At Middle Stone Age Katanda, single-row barbed harpoons were found with remains of giant Nile carp. New dates seem to reconfirm that Katanda was a very early site (McBeaty and Brooks 2000). The harpoons were dated using thermoluminesence techniques, and there is still debate whether the deposits where the harpoons and fish remains lay can be accurately dated using this method. It has also been suggested that the harpoons themselves may have been washed onto this terrace from later sites. The debate will probably only be resolved if more sites from this early date are found. The manufacturing technique used to produce the Katanda harpoons (D'Errico et al. 2003) was quite different from the technique worked out for the harpoons found at the Later Stone Age lakeshore site of Ishango in Zaire. Ishango is securely dated to around 25,000 BP (Brooks and Smith 1987). The bone harpoons found there have been interpreted as signs of a fishing industry (Van Noten 1982; Brooks and Smith 1987).

It no longer seems quite so unreasonable that objects of such sophistication could have been produced so early in the history of modern *Homo sapiens*. Such single- and double-row barbed objects have also been found widely distributed across Africa on sites younger than 10,000 BP (for example, Camps 1974, Camps-Fabrer 1961, Haaland 1992; Petite-Maire et al. 1983). Although the earliest harpoons from Katanda and Ishango in Central Africa are interpreted as having been used in fishing, there is ample ethnographic evidence showing that such barbed objects can also be used for hunting land mammals, especially in bush land where the prey may not be visible. Mesolithic (Haaland 1992) midden deposits at a lacustrian site from northern Mali dating to ca. 6900 BP contained 200 beautifully carved single- and double-row harpoons as well as fish hooks, long pins and a carved crocodile bone (Petite-Maire et al. 1983).

Single-row harpoons were found at the Sudanese site of Esh Shaheinab in the Nile Valley as well as another late single-sided harpoon made from elephant ivory (Choyke 1990) from the Middle Bronze Age site of Kerma (ca. 3500 BP), the capital of the Nubian Kingdom of Kush located on the Upper Nile in Sudan. Other, single-row barbed harpoons were discovered at two pre-Iron Age settlements (ca. 3000 BP) at Gajiganna on Lake Chad (Breurig et al. 1996). Later evidence, from a burial at the site of Daima I (around 2500 BP), also on the shore of Lake Chad, shows a double-row alternating barbed harpoon having been used as a weapon against humans (Connah 1981). All these complex, fine objects were produced using a variety of techniques depending on the time period and local traditions. Whether used for fish, hunting land mammals or as weapons in human conflict all such objects required a disproportionate amount of time to produce, beyond what would have been practically necessary. Thus, their form has other social implications related to display and identity within and between groups of people.

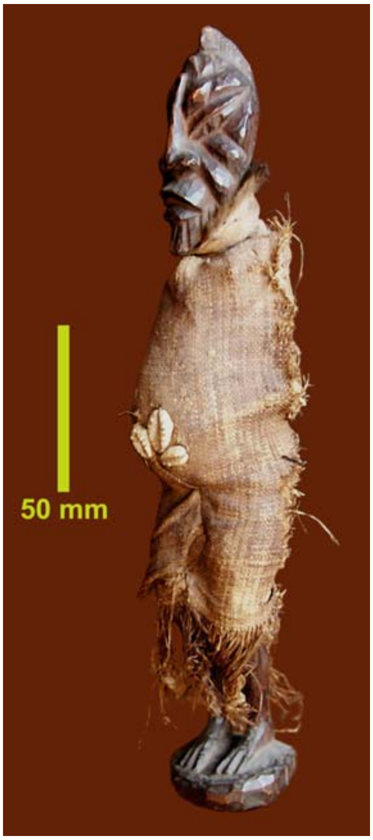
Ornamentation and Symbolic Reasoning

The well-published Middle Stone Age cave shelter of Blombos overlooking the Indian Ocean is securely dated by thermoluminesence to ca. 77,000 BP. It is notable for the 40 standardized bone tools found there including the three finely crafted spearheads and three projectile points. These points were formed by scraping and then polished to give them "added value" possibly in exchanges designed to facilitate relationships between neighboring groups of people. Other bone points at the same site were used in leather working (Hensilwood et al. 2003; D'Errico 2003:192). However, the site is also remarkable for a ruminant mandible fragment with 11 incisions grooved on it with a flint point (D'Errico et al. 2001). Together with pieces of ochre that were ground flat and incised with patterns this represents evidence of symbolic thinking.

Even more sophisticated symbolic thinking is evidenced by the much later incised long bone handle or rod dated to ca. 25,000 from Ishango Cave in Zaire. These repetitive regular groups of notches have been interpreted as representing some kind of mathematical thought (D'Errico 2003) or as a record of regular events, perhaps associated with female cycles such as menstruation (Brooks and Smith 1987). This question will probably never really be resolved.

Blombos cave excavations also revealed 19 tiny bivalve shells of *Nassurius kraussianus*, which had been artificially drilled, as evidenced by wear facets around the edges of the holes (D'Errico 2005). Engraved ostrich shell found at the site of Diepkopf on South Africa's Western Cape dates to 60,000 BP while ostrich shell beads dated to 70,000 BP came to light at Loiyangalani in Tanzania. Again, it has been argued that such sophisticated objects were designed not only for personal adornment but also for exchange, a social lubricant for acquiring social partners (Yellen and Brooks 1995, D'Errico 2003). Fish vertebrae drilled to be made into beads have been reported from Mesolithic sites in Central Sudan (Haaland 1992).

Beads made of bone and mollusk and bivalves and, in particular, ostrich shell, continue to be made even today. (Figs. 1 and 2) everywhere on the continent (Vialou and Vialou 1981; Breurig et al. 1996; Camps 1974; Camps-Fabrer 1966; Connah 1981; Choyke 1990; Van Noten 1982, Petit-Maire et al. 1983). Ostrich shell beads and engraved shells appear regularly on Neolithic sites across North Africa. Cowrie shells, often with their dorsal sides cut off so they lay flat on clothing or on the neck, were certainly used in North Africa by the Neolithic period. Since their form resembles the human vulva it is usually suggested that these shell beads are connected with fertility. In ancient Egypt, there are depictions of women wearing cowrie shells. As in many other places around the world, they



Bone Technology in Africa. Fig. 1

are often imitated in other raw materials like gold, bronze, and bone. All these kinds of bone and shell beads represent a technological tradition of fantastic antiquity which seems to grow sharply in complexity and become widespread about 6000–7000 years ago, in North Africa at least, with a variety of incised bones, decorative pins, and a variety of ornamental shapes produced in bone and shell. The Neolithic period in Africa also saw the advent of special tools and ornaments made from human teeth, long bones, and even crania—surely all with special, socially deeply embedded symbolic significance (Camps-Fabrer 1966).

The Use of Ivory

Although drilled and suspended animals' teeth, and in particular canine teeth, are found around the world, the earliest use of ivory still seems to have been at Olduvai Gorge in Tanzania, as reported by Mary Leakey in the Olduvai volume. This material has not been studied as it is difficult to differentiate true and pseudotools made on teeth, but Mary Leakey described them as tools. However, with the extinction of mammoths, African elephant and hippopotamus ivory use became restricted

Bone Technology in Africa. Fig. 2

Bone Technology in Africa. Fig. 3

to Africa and the Near East, certainly from the fifth millennium onwards, only reappearing in Celtic continental Europe at the end of the Iron Age and with the coming of the Romans.

In Africa, ivory was traded from Central Africa to the Nile Valley to make prestige goods and beautiful ornaments at least from the predynastic Middle Bronze Age (second millennium BCE). There is now evidence of this trade in the Iron Age from Botswana (Reid and Segobye 2000). Ivory as a raw material was exported out from Europe through Egypt around the Mediterranean. Roman sites in provincial Europe frequently have objects made from ivory, manufactured elsewhere in the empire.

Manufacturing of ivory seems to have become common rather late compared to other raw materials. From the Kushite site of Kerma comes a hippo ivory harpoon as well as elaborately carved inlays from elephant ivory (Choyke 1990). Dynastic Egypt sees an explosion in the use of ivory as decoration for furniture and as beads, buttons, and statuettes, perhaps related to the widespread use of metal in bone and ivory industrial manufacturing. This tradition of ivory working continued into medieval times (for example in Ghana, Stahl and Stahl 2004) and until recently in sub-Saharan Africa (Figs. 3 and 4).

Bone Tool Production in Later Prehistory

By the Neolithic period, bone working had developed into a multitude of variable industries using different combinations of techniques. Each group had their own standardized way of making tools and these were best made into pointed tools like awls and projectile points. Use was frequently made of ruminant metapodium bones, which can be grooved down the median line with a pointed flaked stone tool and then easily split. Using one of the epipheseal ends as a handle the diaphysis was sharpened through some combination of scraping with a flaked stone tool or abrasion with a rough-textured stone. This is an ancient technique, even preserved in a ritual form as a burial offering in the cemetery at Kerma where two new and identical mirror-image sheep metapodial awls from two different bones were deposited with the deceased (Choyke 1990). Awls were used in leather-working and coiled basket working. Stone tools were the tools of choice in bone working until the end of the second millennium BCE in Egypt when metal tools took over. Stone tools, however, were still important at Kasteelberg, an Iron Age site in South Africa where a combination of hammering off the epiphyseal ends, grooving, splitting, and fine grinding and polishing were used to create beautiful bone projectile points or link-shafts for arrows. These objects have parallels with objects used until recently by

Bone Technology in Africa. Fig. 4

San Bushmen (Smith and Poggenpoel 1988). Simple bone awls based on the spiral fracture of long bones were also common at Kasteelberg as elsewhere across Africa and the world. Otherwise, there are broad tendencies for bone to continue to be made into objects with beveled edges used as wedges, scrapers, and burnishers, especially for leather working and ceramic production.

It would be impossible here to go into all the different ways bone, ivory, ostrich-egg shell, and mollusk shell have been used in the last 6000 years in Africa. There is a general tendency for bone objects to be made for increasingly special purposes. Often they were made to be parts of composite objects as fittings, handles, closures, and ornaments. Hopefully, as archaeological work continues in Africa it will be possible to present a more integrated picture of the way this ancient technology developed there.

See also: ►Ishango Bone, ►Fishing in the Stone Age, ►Beads, ►Stone Tools

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Brahmagupta

R. C. Gupta

"Brahmagupta holds a remarkable place in the history of Eastern civilization." (Sachau 1971). Bhāskara II described Brahmagupta as *Gaṇakacakracūdāmani*, jewel among the circle of mathematicians.

Brahmagupta was born in AD 598 according to his own statement: "… when 550 years of the Śaka era had elapsed, Brahmagupta, son of Jisṇu, at the age of 30, composed the *Brāhmasphuṭasiddhānta* for the pleasure of good mathematicians and astronomers." Thus he was 30 years old in Śaka 550 or AD 628 when he wrote the *Brāhmasphuṭasiddhānta*. That he was still active in old age is clear from the title epoch of AD 665 used in another of his works called *Khaṇḍa-khādyaka*. Pṛthūdaka Svāmin, an ancient commentator on Brahmagupta, calls him Bhillamālācārya, which shows that he came from Bhillamāla. This place has been identified with the modern village Bhinmal near Mount Abu close to the Rajasthan–Gujarat border.

We have no knowledge of Brahmagupta's teachers, or of his education, but we know he studied the five traditional *Siddhāntas* on Indian astronomy. His sources also included the works of Āryabhaṭa I, Lāṭadeva, Pradyumna, Varāhamihira, Siṃha, Śrīṣeṇa, Vijayanandin, and Viṣṇucandra. He was, however, quite critical of most of these authors.

The *Brāhmasphuṭasiddhānta* is Brahmagupta's most important work. It is a standard treatise on ancient Indian astronomy, containing 24 chapters and a total of 1,008 verses in *āryā* meter. The *Brāhmasphuṭasiddhānta* claimed to be an improvement over the ancient work of the *Brahmapakṣa*, which did not yield accurate results. Brahmagupta used a great deal of originality in his revision. He examined and criticized the views of his predecessors, especially Āryabhaṭa I, and devoted two chapters to mathematics. There have been many commentators on this work. The earliest known was Balabhadra (eighth century AD), but his commentary is not extant.

Chapter 7 is on *Gaṇita* (Mathematics). It deals with elementary arithmetic, algebra, and geometry. The subject is presented under 28 topics of logistics (arithmetical operations) and determinations, including problems related to mixtures, plane figures, shadows, series, piles, and excavations. He wrote in a concise and understandable style, whether dealing with simple mathematics or complex geometry. In the treatment of surds, Brahamagupta is remarkably modern in outlook. The *Brāhmasphuṭasiddhānta* includes formulas for the rationalization of the denominator, as well as a marvelous piece of pure mathematics in the rule for the extraction of the square root of a surd. Still more remarkable algebraic contributions are contained in a chapter entitled *Kuṭṭaka*, which is a traditional name for indeterminate analysis of the first degree. The second order indeterminate equation

$$Nx^2 + c = y^2 \qquad (1)$$

is called *varga-prakṛti* (square nature). An important step towards the integral solutions of such equations is what is called Brahmagupta's Lemma in the history of mathematics. In modern symbology the Lemma is as follows:

> If (α, β) is a solution of (1) with $c = k$, and (α', β') is its solution with $c = k'$, then $(\alpha\beta' \pm \alpha'\beta, \beta\beta' \pm N\alpha\alpha')$ will be its solution with $c = kk'$.

This lemma not only helps in finding any number of solutions from just one solution, but it also helps in solving the most popular case of $c = 1$, provided we know a solution for $c = -1$, or ± 2 or ± 4.

In geometry, Brahamagupta's achievements were equally praiseworthy. He wrote a fine symmetric formula for the area of a cyclic quadrilateral, which appeared for the first time in the history of mathematics. Even more important are his expressions for the diagonals of a cyclic quadrilateral.

Brahmagupta's name has been immortalized by yet another achievement. A "Brahmaguptan quadrilateral" is a cyclic quadrilateral whose sides and diagonals are integral (or rational) and whose diagonals intersect orthogonally. He gave a simple rule for forming such figures in the *Brāhmasphuṭasiddhānta* (Chap. 7, verse 38): If a, b, c and α, β, γ are the sides (integral or rational) of two right-angled triangles (c and γ being hypotenuses), then $\alpha\gamma, b\gamma, c\alpha,$ and $c\beta$ are the required sides of a Brahamaguptan quadrilateral.

Prior to Brahmagupta, the usual method for computing the functional value intermediary between tabulated values was that of linear interpolation, which was based on the rule of proportions. He was the first to give second order interpolation formulas for equal as well as unequal tabulated argumental intervals. Mathematically, his rule is equivalent to the modern Newton–Stirling interpolation formula up to the second order.

The *Khaṇḍa-khādyaka* is a practical manual of Indian astronomy of the *Karaṇa* category. The author claims that it gives results useful in everyday life, birth, marriage, etc. quickly and simply, and is written for the benefit of students. The work consists of two parts called the *Pūrva* and the *Uttara*. The former comprises the first nine chapters and expounds the midnight system. The latter six chapters provide corrections and additions. This work has been studied by a great number of commentators, from Lalla in the eighth century to Āmarāja in the twelfth. It was translated into Arabic first by al-Fazārī (eighth century) and then by al-Bīrūnī.

Brahmagupta's genius made use of mathematics (traditional as well as that which he developed) in providing better astronomical methods. He used the theory of quadratic equations to solve problems in astronomy. He knew the sine and cosine rule of trigonometry for both plane and spherical triangles. He supplied standard tables of sines and versed sines.

The historian of science George Sarton called him "one of the greatest scientists of his race and the greatest of his time."

See also: ►Geometry in India, ►Arithmetic in India: Pāṭīgaṇita, ►Algebra in India: Bījagaṇita, ►Astronomy in India

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Bread in Africa

Diane Lyons, A. Catherine D'andrea

Bread is a dietary staple in north and northeastern Africa and is an important food for some Saharan and East African groups. African breads are baked, steamed, and sometimes fried to produce pancakes, flat breads, loaves or cakes using ovens, griddles, and moulds. Technical choice is associated with the baking properties of bread ingredients and should not be considered evolutionary stages.

B

Wheat and barley are Near Eastern cereals that were introduced into northeastern Africa in ancient times. Only Near Eastern cereals contain gluten, an elastic protein formed when their flours are mixed with liquid to produce dough. If yeast is added and ferments, it produces carbon dioxide gas which becomes trapped in the dough's elastic structure causing it to rise. Sourdough leavening is common in Africa and is produced with residue left in dough mixing containers or by adding dough saved from a previous batch. However, barley and many varieties of wheat (e.g., emmer wheat and at least one wild ancestor of wheat) form gluten with poor leavening capacities. These cereal flours still produce viscous dough suitable for shaping by hand, a prerequisite for baking on oven floors and walls. Light airy bread was possible only after bread wheat, a variety with superior leavening capabilities, was developed in southwest Asia probably during the fourth millennium BCE. Well-risen loaves are expensive because they require longer baking times, use more fuel and are only made for special occasions or commercially.

African cereals (sorghum, millets, teff) and other indigenous plants do not contain gluten and their flours are made into fermented batter or thick porridge and baked on griddles or in shallow earth depressions. Only sorghum flours will form dough suitable for baking in ovens.

Bread in Africa. Fig. 1 Place names mentioned in the text. Map by Kees de Ridder.

Early History

Bread baking often leaves little material evidence to track its antiquity. 18,000 years ago at Kubbaniya in Egypt, wild plants were made into a fine mush possibly to feed young children (Hillman 1989). Pot boiling was unknown at this time and plants may have been ground and baked in shallow earth depressions similar to those of the Tuareg (see later) (Close 1995). Ash bread is also common with nomadic people and leaves no evidence. Hunter-gatherers in southern Africa make “cakes” from ground corms of the iris family baked in hearth embers (Deacon 1984: 258), and nomadic pastoralists in northern Ethiopia make unleavened wheat bread by inserting a hot stone into small lumps of dough that are baked near the fire (Dufton 1970: 219–220).

Ancient Egypt

Emmer wheat and hulled barley were grown in the Nile Valley since the sixth millennium BCE (Murray 2000) and were used to make bread and beer in Dynastic Egypt. Bread baking practices are known from tomb paintings, miniature models of kitchens and bakeries, statuettes, texts, excavations of bakeries, oven installations, analyses of preserved bread loaves, and experimental studies (Samuel 2000). Caution is required in interpreting artistic renderings as “photographic” records, as images were intended for elite burials and likely do not provide details of the range of bread-baking practices. Most evidence indicates that grain was pounded in a mortar, ground into flour on a saddle quern (a simple stone mill used for grinding grain by hand), sieved through baskets, and then mixed with water or milk and sometimes dates, honey, eggs, butter, coriander, sesame seeds, or fruit (Samuel 2000; Wilson 1988). Bread may have been leavened, but this process is not required for bread making and chemical studies of preserved bread indicate that many were not fermented (Samuel 2000).

During the Old Kingdom (2686–2160 BCE) emmer wheat and barley flours were baked into bread in large conical molds called *bedja*. *Bedja* were stacked and preheated, filled with dough or batter, covered, set into depressions in the bakery floor, and banked with hot embers (Lehner 1997). Bread was also baked as hand-formed loaves in hearth ash, on griddles or preheated ceramic dishes. Small cylinder ovens about 30 cm high were heated with fuel fed through a door at the base. The top was covered and bread was baked on a shelf a third of the way up the interior (Wilson 1988). During Middle Kingdom times (2055–1650 BCE), bread was hand-formed, made in tall cylinder moulds, and baked on griddles or on open hearths (Samuel 2000: 565).

During the New Kingdom (1550–1069 BCE) emmer wheat predominated and bread was baked in tannur-type ovens that became the main domestic and temple bread-baking technology (Samuel 1999). Tannur first appear in southwest Asia in the late fourth millennium BCE (Van de Mieroop 1997: 156) and consist of a clay cylinder, sometimes set into a bench, with wood, cattle dung, or other fuel fed through an opening at the bottom. Dough is inserted through the top and is

Bread in Africa. Fig. 2 Dome oven. Photo by Cathy D'Andrea.

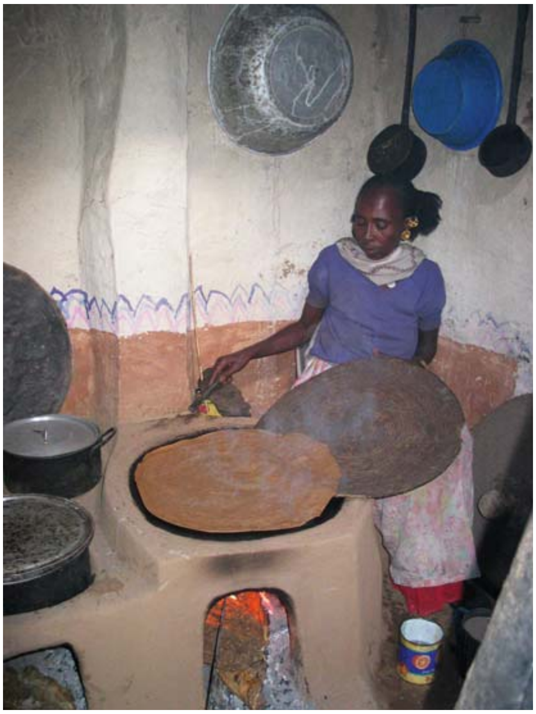
Bread in Africa. Fig. 3 "Sunny bread". Photo by Cathy D'Andrea.

pressed onto the hot interior walls to bake, although platters for large loaves may also have been baked in these ovens (Samuel 2000: 568). Long conical moulds were used for ritual purposes in the New Kingdom (Samuel 2000: 567) and a variety of hand-formed bread shapes were baked inside large commercial domed ovens. Some ovens were so large that the baker was held by his feet as he reached inside to position dough and retrieve baked bread (Wilson 1988: 55).

Major changes in bread making occurred during Greco-Roman times (332 BCE–AD 395) when free threshing wheat (durum and bread wheat) replaced emmer, and the saddle quern was replaced by the rotary quern (Samuel 2000). Small dome-shaped ovens are used to bake "sunny bread" (bread leavened in the sun) today near Luxor (Figs. 2 and 3).

Horn of Africa

The northern highlands of Ethiopia and Eritrea provide the only conditions for growing wheat in tropical Africa. Bread was a dietary staple by Aksumite times (300 BCE to AD 800) when huge quantities of bread were taxed from rural households (Kobischanov 1979). No definite bread ovens are known from the highlands,



Bread in Africa. Fig. 4 *Enjera* baking on *m'ogogo.* Photo by Diane Lyons.

but clay griddle fragments, dated to 500 BCE and similar to those used in domestic kitchens today, were found near Lake Tana along with the earliest evidence for tef, barley and emmer wheat in the region (Dombrowski 1971).

In northern Ethiopia and Eritrea, clay griddles (60 cm in diameter) called *mogogo* (Tigrinya) or *metad* (Amharic) are set atop a firebox made of upright, clay-covered stone slabs with an opening to the front for feeding fuel of cattle dung and small branches. In the central and southern highlands griddles are balanced on three stones set over a fire. Griddles are lightly lubricated with crushed oily seeds and dome-shaped lids are used to steam the bread (Lyons and D'Andrea 2003). *Enjera* or *taita*, spongy pancake bread made of teff, wheat, barley, and sorghum flours, is served with all meals (Fig. 4). Several varieties of slightly leavened and unleavened flat breads are made in the highlands and are differentiated by their thickness, ingredients and length of fermentation. In southwestern and central Ethiopia, similar pancakes and flatbreads are prepared from the fermented pseudostem of ensete (Smeds 1955: 24).

Somalian bread is similar to Ethiopian *enjera* but is made with sorghum flour batter poured onto a well-oiled griddle. Sweet *enjera*, and bread made with eggs are also produced. Thick sorghum dough is baked into flat bread on an oiled pan and Swahili sorghum bread is also consumed (see later) (Abdullahi 2001).

Bread in Africa. Fig. 5 *Kissra* baking. Photo by Catherine D'Andrea.

Sudan

Sudanese pancake bread called *kissra* is a staple made with fermented sorghum or finger millet batter on ceramic (now more commonly metal) griddles called *doka* heated atop three stone hearths (Dirar 1993: 171). At least 11 different types of Sudanese sorghum or sorghum-based breads are produced. Sudanese *doka* are similar to Ethiopian griddles, but were developed later *circa* AD 600 (Adams 1977; Shinnie and Shinnie 1978: 107). (Fig. 5). In Eastern Sudan thick sorghum porridge is baked into small flat bread called *hadib,* on the inner preheated walls of earthenware pots or metal petrol cans (Dirar 1993: 220).

Northern Africa

Wheat and barley have been grown in northern Africa since the mid- first millennium BCE, and sorghum and pearl millet were introduced into Libya during the early Islamic period (Pelling 2003). In the High Atlas Mountains of Morocco today, bread flours are made of wheat, barley, maize, millet and sometimes acorn (Balfet 1975; Bruneton 1975). Women make ovens (*afarnu*) by piling small stones 50 cm high and 80 cm diameter at the base and then coating the pile with thick clay (Bruneton 1975). After the clay dries, holes are cut at the top and base and the stones are carefully removed. The top opening draws a draft and fuel is fed through the bottom opening. Oven floors consist of flat stones resting on rock salt to retain heat. Once the oven is heated coals are swept to the side and dough is placed on the oven floor.

Different bread varieties include leavened wheaten bread for feast days and barley flour loaves for daily fare. Fast breads are baked from leavened dough in the embers or unleavened dough is baked on a hot stone plate or pottery sherd balanced on two stones over a fire (Bruneton 1975). Dough can be flavored with herbs, oil, garlic, onions, dill, sesame and aniseed (Balfet 1975; Bruneton 1975). Small domestic dome-shaped bread ovens are replacing traditional technologies in Morocco (Peña et al 2003).

In large villages in Tunisia leavened bread is made in commercial tannur-type ovens, and griddlecakes (*kesra*) are baked in a dish or on a metal plate. Griddle bread and pancake are sometimes stuffed with vegetables, meat and fruit, or a spicy sauce (Balfet 1975).

Sahara

Wheaten bread is common in the diet of the northern Tuareg and is baked in hearth ash, on a metal baking sheet or on the sides of an inverted metal pot heated over the fire (Nicholaisen 1963). However, millet flour is made into batter and baked in a preheated shallow depression in the ground. Fine sand and hot coals or a small fire is set over the top to bake the batter through (Gast, Marceau, and Adrian 1965; Nicholaisen 1963). The finished bread is washed, broken into pieces in a bowl, served with liquid butter and eaten with spoons. Some bread is made with millet flour, berry juice and special plants as a medicine for women. The flour is mixed with water into a solid "cake" and is baked like other millet bread (Nicholaisen 1963). Nomads in Sudan and Egypt use similar but larger earth "ovens", sometimes with floors of heated pebbles or pot sherds, to bake sorghum or millet flour bread (Dirar 1993: 218; Hobbs 1989).

East African Coast

Ovens called *mofa* occur in ninth century AD houses at Shanga on the Kenyan coast. *Mofa* were also used on some Arab dhows (Horton 1996: 46, 353). At Shanga, *mofa* consist of clay bowls set in floors that were possibly used to both bake bread and boil liquids (see Horton 1996: Plate 21). At the nearby site of Manda, *mofa* were made of clay cylinders with no base. These cylinders were approximately 40 cm in diameter and were constructed inside a pit (Chittick 1984: 153). The cylinder was then surrounded with soil and a fire was lit inside to heat the walls. Sorghum or millet flour dough was baked on the hot interior walls and such cakes were described by twelfth century Chinese traders as dietary staples (Horton 1996: 353). Horton (personal communication 2005) has observed that *mofa* are concentrated in northern coastal sites where sorghum is consumed and are much less common on southern coastal sites where rice is eaten. Although *mofa* are similar to tannur, Horton suggests that the technology is simple and could be a local invention.

West Africa

Bread was possibly made at Jenne-Jeno, Mali 2000 years ago from pearl millet and sorghum flours using earth depressions like those of the Tuareg (McIntosh 1995: 159–160). Medieval Arabic travelers observed bread made with unspecified tubers and millets in the eastern Sahara, Jenne, and Gao. These were consumed either as luxury items or cheap traveler's fare (Lewicki 1974: 46–47, 80), but baking technologies are not described. Today round clay griddles with four to six small bowls are used to fry fermented batter of pearl-millet flour into small cakes called *masa* or *marsa* in Ghana (Apentiik 1997) and Mali. Guinea millet is also made into fritters and cakes in northwestern Guinea (National Research Council 1996: 237).

Contemporary Issues

A recent advance in bread making technology is the introduction of electric mills that relieve women from the burden of grinding flour. Of considerable concern is the rapidly growing demand for Western white wheaten bread in Africa's urban centres. Methods are being developed to produce leavened bread with African cereals. Such projects are intended to protect African crop production and reduce reliance on imported wheat (National Research Council 1996).

See also: ►Ethnobotany in Ethiopia

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Mark Lehner's excavations of bakeries at Giza, Egypt (various websites)

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Brewing in Africa

JOHN W. ARTHUR

Beer in Africa has been an important food staple since the Old Kingdom of Egypt (5400–5500 BP), from the site of Hierakonopolis (Geller 1992; Maksoud et al. 1994) and the New Kingdom of Egypt (1550–1070 BCE), to workmen's village sites at Amarna and Deir el-Medina (Samuel 1996). In many cultures of Africa, beer provides a substantial part of the diet, with one-eighth to one-third of grain crops being processed and consumed as beer (Platt 1964). Beer socially binds people together and serves to reinforce social hospitality, usually without aggressive behavior or addiction (Mandelbaum 1965). African societies use beer to indicate wealth and status, as a commodity of reciprocity, hospitality, and communality, as a payment of tribute to leaders, and as a vital food for the redistribution of wealth (Arthur 2003). In some cases, colonialism has dramatically changed the structure of beer and its ties to society. This paper reviews the importance of beer in Africa based on a number of ethnographic case studies.

Beer Production

The production of beer in Africa is usually under the domain of women. It requires a considerable amount of time-consuming labor. In most societies, producing beer is a multistep process. For the Mabaso women of South Africa or the Maale of southern Ethiopia, beer production can range from 5 to 12 days (Donham 1999: 153–155; Reusch 1988: 24). First, women let the grain sprout in a damp pot to produce a malt and then mix it with additional grains, and grind on a stone for hours. They bring large quantities of water from up to a mile away to mix with the ground grain and then boil the malt and flour in large pots. After boiling the mixture, women ferment the beer in large gourds or ceramic vessels. In Tanzania, the Haya make a beer using a combination of bananas and sorghum (Carlson 1990). They use ripe bananas because of their high sugar content, which assists in the fermentation process. The bananas are mashed with the help of dried grass, and then water is added in equal proportion to the banana liquid. After the water is added, dried sorghum is mixed into the water and banana solution and left to ferment for 24 h. In Ethiopia, the Gamo produce beer by two different methods (Arthur 2000). The highland Gamo produce beer by boiling water in a large ceramic cooking jar and then pouring the water over the wheat and barley flour and stirring it in a large serving bowl, where it is left to cool. It is then poured into a beer jar to ferment for 4 days. The second way to produce beer, which occurs in the lowland areas, is to combine and boil water and flour and then store this mixture in large beer jars for fermentation (Arthur 2000, 2002, 2003). In the majority of societies, women produce the beer, but once they produce it, it is used by many segments of society.

The Social Consumption of Beer

In Africa beer is consumed every day as a food product and beer also plays an essential role in the establishment of social obligations. The importance of communal consumption is one of the reasons people process their grains into beer rather than bread (Dietler 1990). Beer is often considered a food, rather than a beverage, and the consumption of beer adds considerably to their daily calories (Gardiner 1836: 266; Green 1999: 414; Haggblade 1992: 395; Karp 1980: 85; Moore and Vaughan 1994: 192; Richards 1939: 80; Saul 1981: 746–747). Beer may contribute to increasing caloric intake, but its symbolic role may be more important than its nutritional role. However, de Garine (1996: 215) argues that beer "may be richer in vitamins PP and

B-12, phosphorous and calcium than sorghum porridge, but it contains only half the calories, one-quarter of the proteins and no glucids" (Adrian and Sayerse 1954: 136; Pele and Le Berre 1966). For example, among the Koma of northern Cameroon, sorghum beer provides one-third the total energy consumed in a year and bonds age-sets and establishes a hierarchy between each one (de Garine 1996: 210). Among the Tiriki people of Kenya, beer is offered to visitors as a sign of friendship (Sangree 1962: 11), and the Baganda of Uganda use beer as a way to bond two men socially (Robbins 1979: 371). Beer acts as a social lubricant when the Tiriki and the Iteso people of Kenya men sit around communal beer pots everyday to discuss social issues, disputes, and tell stories (Karp 1980; Sangree 1962). The Haya of northwest Tanzania pay respect to fathers by offering them a gourd of banana beer, which must be done before others can be served (Carlson 1990). In addition, the Haya will offer a sacrifice of a gourd of beer to a father at the ancestral altar. The Kofyar of northern Nigeria conduct all aspects of their daily life around beer (Netting 1964). The Kofyar use beer as an award and as a punishment against not taking part in work parties, verbal or physical violence, disrespect of a clan member, or minor theft.

Beer as a Motivating Ingredient

In order to gather a work party, beer is essential; without beer, it is impossible to bring people together to cooperate on the task at hand. Work feasts are a type of commensal politics (Dietler 2001; Dietler and Herbich 2001), where people organize to work on a specific project and in return receive beer for their labor. Beer in work parties provides a social alliance between the work party sponsor and the people involved in the work party. Beer changes the context of the group, by becoming the "social focus" for all of the work party members, but also for people associated with the party members (Donham 1999: 155). Among the Konso of southern Ethiopia, the quality and quantity of beer is a motivational force in gathering people for a work party (Watson 1998: 148). If a person produces a high quality beer in sufficient quantities, then they can expect a range of 20–50 people to help them in the fields. There are a number of different types of Konso work parties, which involve fixed or volunteer groups, costing the sponsor approximately 50–150 Ethiopian birr (US $7.00–$21.00) depending on the size of the work party. Feasts also accompany work parties, as in Southern Africa, where leaders and wealthier commoners organize large work parties and then provide an abundance of beer (Crush 1992). The Pondo of South Africa rate their beer feasts higher than meat feasts, because beer makes the work seem more like a party (Hunter 1979: 89–90). Among the Kofyar of Nigeria, beer is the primary means for repaying voluntary labor to hoe and harvest agricultural fields and for building corrals and houses (Netting 1964). These examples demonstrate that beer is a motivating force for labor and beer also has a role to play in the formation of the elite.

The Social Hierarchy of Beer

The payment of tribute with beer indicates its economic and political importance. Although beer in Haya society is a secular refreshment, it has symbolic value since when Haya men make banana beer they must be sexually abstinent while brewing the beer (Carlson 1990: 298, 303–304). When the Haya produce beer, it is their obligation to pay their leader four or more gallons of banana beer. Beer, along with livestock, barkcloth, and iron products, are presented to leaders as tribute. They present the leader with special gourds of beer that have wrappings of banana fiber covering the gourds which are tied with twigs and leaves from a plant that symbolizes purity and strength. As with the offering of beer to the deceased father, the Haya king also offers a sacrifice to his ancestral altar for the welfare and fertility of his kingdom.

The Chagga leaders of Tanzania opened their houses and gave generous supplies of beer, which fulfilled their redistributive obligations and supported the warriors, who would fight on their behalf (Dietler 1990: 370–371; Gutmann 1926: 346). The Chagga leaders would collect this beer through either a tax that the people were happy to pay so that they might socialize with the leader or through a work party in which people would help cultivate his millet crop, which was used to make a beer feast. A sign of a good Buganda leader is the redistribution to the people in the form of "beer, meat, and politeness" (Mair 1934: 183). As with the Chagga, the Buganda leaders obtain their beer through a tribute system and beer also is used to settle disputes as fines (Robbins 1979: 371). Thus, the payment of beer forms a social, economic, and political reciprocal bond between commoners and leaders.

Brewing beer in association with slaughtering cattle among the Koma of Cameroon also provides a means to improve an individual's status (de Garine 1996: 208–210). The cattle dance ceremony celebrates the hard work and good qualities of a man's wife as being a good mother to their children. The ceremony in her honor is a redistribution feast that increases the husband's social status by distributing meat and beer to their kin and religious leaders. Once the husband has hosted up to seven ceremonies his status increases because he is knowledgeable about the secret rituals and places and can drink beer from his own pot without sharing.

Beer is associated with the wealthy, high-caste Gamo households (Arthur 2003). The political and religious aspects of Gamo life are under the authority of the *mala* caste. The production and consumption of beer occur at all political and religious ceremonies such as at initiation feasts for ritual-sacrificers (*halakas*), weddings, and at ceremonies celebrating saints' days. The *mala* ritual-sacrificers must demonstrate their generosity through beer feasts. The wealthiest *mala* are "caught" by the other *mala* members to become ritual-sacrificers (*halaka*) (Halperin and Olmstead 1976). If the people choose a person to become a ritual-sacrificer, his duties are to perform animal and beer sacrifices in which he prays for the health and fertility of his people, crops, and animals. Gamo ritual-sacrificers are always men, who must be circumcised, married, wealthy, and morally respected (Sperber 1975: 215). However, to become a ritual-sacrificer, a person has to perform two beer feasts (*perso oosha*), which include producing enough beer for the people who reside in his political region (*dere*) (Freeman 1997). This ritual-sacrificer must have enough farmland to provide for producing large amounts of beer and other types of high-status foods. This redistribution of wealth cannot be refused by the chosen ritual-sacrificer (Sperber 1975). He must organize two different feasts, one at his house and the other in the area of community gatherings (Freeman 1997). At both feasts, the participants must wait to start drinking until the *halaka*-to-be and the elder-sacrificer pour beer on the ground as an offering for the spirits. Each redistribution feast can comprise up to 300 people and requires 800 kg of wheat for beer production (Halperin and Olmstead 1976).

Thus, beer in African cultures is more than just a beverage; it is a critical component to the social, economic, and political structure of society (Carlson 1990; Netting 1964; Robbins 1979; Sangree 1962). People spend a considerable amount of their labor and time processing their crops into beer rather than bread because of the value of beer in establishing alliances. Beer binds these different groups together by providing a means of establishing reciprocity in the form of labor and social and economic coalitions. Furthermore, the importance of beer in the form of symbolic respect to the living and to ancestors exemplifies its significant role for the well being of societies (Arthur 2003).

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Buddhism and Science

Somparn Promta

Buddhism is normally viewed as an atheist religion. Modern interpretations of the Buddhist teachings made by Buddhist scholars in Southeast Asia seem to bring Buddhism close to what is called 'science' in the modern world. That is, Buddhism is explored as a religion teaching that human life, the world, and the universe are the *Dhamma*, a Pali word containing complicated meanings. According to Buddhadasa, the most famous Thai Buddhist thinker, the Dhamma has four meanings (1) natural things, (2) natural laws, (3) human obligations to follow natural laws, and (4) the fruits gained from following the laws of nature. So human life, the world, and the universe, according to Buddhism, are natural things in themselves and they follow the certain laws of nature.

In Buddhist perspective, natural things and natural laws are not created by God or any other supernatural power. They exist naturally, meaning that the concept of creation is not necessary. However, Buddhism does not stress the philosophical arguments concerning the origin of the universe. The view of Buddhism on natural things and natural laws is practical in a sense that knowing what is the world *as we see now* should lead to a happy life. It should be noted that Buddhism believes that religious practice is closely connected to the laws of nature, so the learning of religious teachings in Buddhist perspective is learning the laws of nature.

In Buddhist texts, five laws of nature are mentioned (1) physical law, (2) biological law, (3) psychic law, (4) *kammic* law, and (5) moral law. The first two laws are believed by Buddhist scholars to be the same laws explored in physics, chemistry, and biology in modern Western science. Psychic laws could be partly compared to what are called psychological laws in Western psychology. However, there are some special contents in the Buddhist psychic laws not found in Western psychology. An example of these is the cultivation of the mind through meditation. Kammic laws are the laws concerning human actions. Buddhism believes that what we are is directly the result of what we do. We are born as a free entity to choose our future freely. Philosophically speaking, Buddhism believes that we are born with a free will. In this sense, we are solely responsible for whatever we have done. *Kamma* or *Karma* in Buddhist teaching, an action with intention and carrying moral value, is a secret power, like the field in physics, which dominates our life. Good Kamma determines a good life; bad Kamma determines a bad life. Moral laws are the laws that govern any events that cannot be classified under the first four laws. For example, Buddhism believes that the unjust or immoral structure of society is a bad thing. It is bad according to moral law. It is possible that individuals in society act well according to the law of Kamma, but they are good people in a bad society. The Buddha is well known as arguing against the caste system in ancient India. For him, it is possible that people of each class act well according to their class duties, but caste is still a bad thing, judging from moral law.

Looking through the Buddhist five laws of nature, we can see that the belief in nature is wider than the belief in nature found in science. In Western science, the laws of nature as found in physics, chemistry, and biology have nothing to do with social justice, fair distribution, or the violation of human rights. Science within this tradition has become something containing a narrow meaning. Science never questions how we can gain a happy life or a just society. Typical scientists seem to think that such a question should be considered outside the scientific community. It should be part of political science or political philosophy. The above tendency leads to the separation between 'knowledge' and 'value', and between 'nature' and 'human convention'. The Buddhist conception of natural laws does not make the same separation. For Buddhism, physical and biological laws are the beginning laws of nature to be explored. They are looked on as a means leading to some things more valuable.

Between human life and the physical world, Buddhism thinks the former is of more importance. However, as our life can never be separated from the world, the study of the physical world is accepted by Buddhism to be of some value as far as it is undertaken in balance with the study of human life. Furthermore, the study of the physical world must not be run separately from the study of society. If we are allowed to call the activities of exploring nature through the Buddhist five laws 'Buddhist science', what follows is that Buddhist science stresses the balance between three things: human life, society, and physical world.

The confrontation between modern science and Buddhism in the Buddhist countries such as Thailand seems to be best understood in the light of the Buddhist conception of nature as said above. In Thailand, where Theravada Buddhism plays the role of a national religion, the sale of GM food is allowed by law under the condition that the products must be declared to contain GM ingredients. Buddhism in Thailand does not raise moral questions about this, while Islam seems to doubt it. The recent study of the opinions of Buddhists concerning the issues of human cloning and stem cell research in Thailand declares that the Buddhists, compared to Christians and Muslims, can more easily accept human cloning and the use of stem cell for medical purposes if it is proved safe. This phenomenon can be understood if we are reminded that Buddhism is a religion free from religious dogmas. Like science, Buddhism believes in the natural creation of things. For Buddhism, anything allowed to happen in the world is 'natural'. So, Buddhists do not view human cloning as unnatural. On the contrary, it is 'natural' in a sense that it is allowed by the second law of the five laws. However, it should not be understood that Buddhism has nothing to question about these issues. These arguments essentially stem from the conception of balance between the five laws. Human cloning and stem cell research are viewed as activities run within the second law. So, it is not isolated from other laws.

Finally, Buddhist scientists in Buddhist countries like Thailand seem to feel that Buddhism and science are friendly. This feeling possibly stems from the picture of Buddhism in their minds. Buddhism as taught in the university classroom shares a lot with science. In chapters of high school Buddhism textbooks, the way the Buddha searches for knowledge is usually described in terms of scientific enquiries. The Buddha says that he did not create the truths he found after the process of study. They were naturally given. Anyone, according to the Buddhist perspective, can be a Buddha. The term 'Buddha' means the one who is enlightened. Enlightenment is nothing but the realization of natural laws. Knowledge in the Buddhist view is in the end the same thing as morality. We can easily find the balance between knowledge and value in Buddhist science.

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Building Construction

Norbert E. Wilhelm

It is difficult to talk about the differences in Western and non-Western building technologies, as many approaches used today in this field were also used in western countries in the past. Some, such as mud technology, are currently being revived in Europe. A more appropriate expression might be indigenous or traditional technology.

Some basic approaches, such as the construction of walls out of stonemasonry, mud or branches plastered with mud can be found in many places in the world. It is not surprising that there is not so much basic difference, as the construction materials had to be found in the surroundings. What is amazing is to explore which quality or intelligence is presented in the specific adaptation to the climate and in resistance to disasters.

Traditional Construction Technologies are Still of Great Value

The fact that we now use other technologies does not mean that traditional knowledge was primitive.

Dealing with local material is more ecological, and these old technologies have no recycling problem.

Traditional technologies went through a long process of evolution, so they are in most cases the very best solution, taking into account what basic materials were available at any given place and time. They are well adapted to the local climate and are rather safe with regard to recurring local hazards. However this is only to the extent that was possible with the available materials and knowledge. The typical empirical way of improving the design could respond only to events with a reasonably short recurring period.

Modern technology has to an extent not yet proved its durability. We face problems, like corrosion in prestressed concrete bridges, whereas stone arch bridges survived for centuries without even regular maintenance or repairs. None of the modern bridges in steel or reinforced concrete would ever have such durability.

Many of these old building technologies still have a potential for improvements, if modern materials and knowledge could be added in a sensible way.

Today traditional building technology is for the poor; it is often the only one they can afford and handle. Unfortunately this gives it a bad image. It has become the technology of the lowest classes, seen as being primitive, in spite of all its values and potential.

Some famous architects have discovered the value of traditions and have gotten inspiration from local buildings. Considerable literature about vernacular architecture has emerged, praising the so-called *genius loci* (sense of place). An excellent collection which shows how people live is Oliver's *Dwellings* (2003). Unfortunately most literature looks purely at the architectural aspects, so that the engineering experience and the intelligent use of materials including their ecological aspects and their climatic adaptations is left out. This is what this article will concentrate on. One should not see the *genius loci* as something mystical; it is an experience that is presented by traditional buildings and it is important to document the technology in better detail, so that it does not get lost with the death of the last craftsmen.

Tradition Goes with Esthetics

Transport of nonlocal material was too expensive; this led to a rather great uniformity in a specific region. And as buildings and other constructions are unengineered, there is also not much variation in the structure. As a result, traditional buildings are rather uniform. The limitations given today by town planning regulations with regard to the size and often with the specification of certain exterior materials were more or less imposed by the limited resources for the old construction methods.

Limiting the variations of the buildings has a great esthetic advantage. Total uniformity is boring; too many differences in aspects and the missing of a common idea make the built environment chaotic. This is not surprising; all building was based on the variations of plants, landscape and textures of the available materials. The grain of a piece of wood never is uniform, but it follows a certain law, a certain pattern. No piece looks like the other, yet we still can say what type of wood it is. A landscape has its character, and a forest has its own appearance and mixture of trees. No person looks exactly like someone else. We are used to such variations generated by certain mechanisms and we appreciate them.

You can analyze this hypothesis when you visit a medieval town in Europe or if you walk through an old Indian city like the historic part of Ahmedabad, or an oasis in the desert. There are prevalent materials and variations of the design, based on traditions, limitations of the structural system and on what the owner could afford. Such an appearance corresponds to the older people's experience with their surroundings, and we find it pleasant. A similar homogeneity is difficult to achieve in today's architecture: normally, styles vary too much or completely new quarters or towns are too uniform.

Valuable Experience Is Conserved in Traditional Buildings

Our modern design work is to a very large extent based on mathematical models and calculations, which give reasonably reliable results for the dimensions and make nearly every shape possible. The old builders did not have such comfortable design tools. They were lucky if they could cope with the geometrical questions in the case of more complicated buildings. The construction of the building with regard to structural problems and in order to provide an optimal climate under the given conditions and restrictions was based on experience. That means testing at the scale of 1:1 at the real building. However, throughout history, traditional technologies were perfected bit by bit. The choice of material was limited to what could be found locally. So stones, mud, wood, and leaves are prevalent in construction technologies.

A limited range of materials is easier to handle in an improvement process. The results we can see today are quite intelligent and efficient. They represent the experience of hundreds or sometimes even thousands of years. For example in earthquakes, sometimes traditional buildings behave very well and are most efficiently designed, as one will see further below. What is not surprising, but really remarkable, is the climatic adaptation. If you follow the design criteria for comfort in a certain region, you end up normally with the traditional building layout and detailing (Koenigsberger 1973; Lippsmeier 1969).

However, there are several problems with traditional construction. As it is not based on theoretical models, average craftsmen and engineers do not really know why it works. So one has to follow the old rules, which get more and more lost. Only a few bright people brought the methods forward in the past. All the others were only followers.

The Major Construction Elements

There are many similarities between traditional construction technologies in non-Western countries and historical constructions in Europe. Either there was an exchange over wide distances in early times or the availability of material dictated similar solutions. Most likely both were true. However some tropical areas had their own specific solutions, manly dictated by the different climate and available materials.

Walls

Walls, the most important construction elements, are mainly of the following types:

a. Wattle and daub. The basic structure consists of wooden posts, normally directly put into the ground or in a simple foundation. In some regions the ends of the posts to be placed in the earth were slightly burnt until they developed a charcoal surface; that made them a bit more resistant to rot. A grid of smaller branches or bamboo, normally bound together by plant fibers, filled the space between the posts. The infill could also be of stronger horizontal branches and vertical hatch or wooden weaving. This wooden core was covered on both sides with mud. Sometimes fibers like short cut straw were added (Figs. 1 and 2).

This wall type is probably used the most in the world. The method of infill is also used for the typical European timber framework. One can achieve a very smooth surface if the last layer is reworked over and over without letting it dry until all shrinkage gaps are filled.

b. Mud formed in situ. Here the mud is mixed with water until it becomes workable. This is often done with the help of an ox walking in the mud. Then the mud pieces are placed one over the other while still wet and made smooth.

Building Construction. Fig. 1 Wattle and daub wall.

c. Sun dried mud bricks. After forming and drying bricks of wet mud, they are joined together with mud mortar.

d. Rammed earth. Here only slightly moistened and rather sandy soil is rammed in forms of varying sizes in layers. High buildings up to five storeys are built with this method. Well-known examples are the houses in Sanah, Yemen and the famous mosque in Mopti, Mali. In Europe large and high buildings still exist, made of rammed earth; it used to be a widespread method in Southern France.

In Afghanistan, one of the historical school buildings has a mixed wall construction, where the faces of the walls are made of mud bricks and the core of the walls is filled with rammed earth. Corners are made of burnt bricks in mud mortar. This two storey building in the center of Kabul is more than 100 years old and the walls are still sound (Figs. 3–5).

More about mud technologies (as well as their further development with lime or cement stabilizers)

Building Construction. Fig. 2 Wattle and daub wall old German house, now used for exhibitions (photo by the author).

Building Construction. Fig. 3 School building in rammed earth in Kabul, Afghanistan (photo by the author).

Building Construction. Fig. 4 Old castle near Kabul Afghanistan (with rammed earth) (photo by the author).

Building Construction. Fig. 5 Detail of the rammed earth blocks (photo by the author).

can be found in Doat (1991), Minke (1999), and Niemeyer (1946).

e. Typical for many tropical hot and humid areas (where day and night temperatures vary only slightly) are light and easily ventilating walls. There the users can benefit from the slightest breeze. These walls are mostly made entirely of bamboo, but one can also find grass or palm leaves as cladding. Even entire structures of strong grass like reed existed where this grows close to swampy areas, for example in the Marshs (North of Basra) in Iraq (Thesinger 1967). They are bound together as in Thor Heyerdahl's famous boat Ra and can form quite sizable arch structures (Fig. 6).
f. A structurally interesting system concerns Chinese temples and other important historical buildings, where wooden columns (with infill or free standing) carry the roof. Such freestanding columns get their horizontal stiffness against wind mainly due to a high load from the roof. The horizontal load from the wind is related to the height of the structure, and adding vertical loads can increase the horizontal resistance. This is exactly the case, as the tiles of these Chinese roofs are embedded in a thick layer of special mortar. From below it looks like a full wooden roof. Leaving the mortar out would seriously harm the structural integrity. Unfortunately this strategy does not work in the case of earthquakes, as there the horizontal forces are related to the mass. So adding more weight in the roof does not help; old pagodas collapsed during earthquakes.

Building Construction. Fig. 6 Thor Heyerdahl's boat (exhibition in Tenerife, Spain). Similar technology is used in the swamps of Iraq for buildings (photo by the author).

Slabs

Slabs and flat roofs are normally supported by wooden beams with different infill materials. The major ones are:

a. Stones, which are then covered with mortar or mud. In this case, the beams have to be rather close together. Larger crossbeams can often support small secondary beams. This construction is rather typical for the east African coast with its Arabic influence.
b. Mud, reinforced by wooden branches. The construction usually starts with a mat (bamboo or similar), which prevents the mud from falling down. The branches, being fully embedded in the mud, act as a reinforcement, so that the distance between the beams can be larger upto about 45–60 cm (1.5–2 ft) (Fig. 7).
c. In Rajasthan, India, ceilings and roofs are made in stone-producing regions by placing a stronger stone as a beam and stone plates between those beams.

Roof Structures

In addition to slab roofs one can find the following basic roof structures:

Building Construction. Fig. 7 Roof structure (Dubai) beams, mats, and mud as topping (photo by the author).

Building Construction. Fig. 8 Support of a roof in China (photo by the author).

a. Wooden beam structures, where besides, the purlin[1] and rafter construction, we can mention some interesting other types. (1) In traditional Chinese roofs, the main load-bearing element consists of wooden beams arranged one on top of the other with small spaces in between. The top beams get shorter to follow the form of the gable. This makes larger spans possible without doing complicated latticework, although at the expense of more timber consumption (Fig. 8). (2) Some communities in Gujarat, India built conical roofs with small beams without intermediate support, which act like shells (see case study). Others build a wooden dome on a square house using strong branches (Figs. 9 and 10). (3) In Eastern Africa large roofs were built using tree type support systems. Now one can find this efficient system being revived in beach resorts at the Mombassa coast (Fig. 11).

[1] A purlin or purline is a piece of timber laid horizontally on the principal rafters of a roof to support the common rafters on which the roof covering is laid mostly using battens.

Building Construction. Fig. 9 Simple *Bungha* roof from the inside (photo by the author).

Building Construction. Fig. 10 A simple roof structure out of branches (Gujarat, India) (photo by the author).

b. Domes and vaults are often used in desert architecture. Most are made of mud bricks, as they have sufficient strength. The main problem in a dome and vault construction is to counterbalance the horizontal thrust. Heavy and sometimes inclined walls do this. If stones are used for domes, a good overlapping can take a lot of the horizontal tension. This is the case in many old mosques and temples (Fig. 12). Tension belts, which would be the best technical and scientific response to the problem, are not used to my knowledge. For vaults, only horizontal tension beams lead to an improvement. They can be found for example in old Ottoman buildings in the Balkans,

Building Construction. Fig. 11 Roof structure with tree-type supports (Beach Resort in Kenya) (photo by the author).

Building Construction. Fig. 12 Dome (Jumma Mosque, Ahmedabad). Ring forces balanced by overlapping; joints open where there is a little overlapping (photo by the author).

where wooden beams carry an intermediate floor under the vault. Removing such a floor with its beams could lead to collapse; even a replacement not respecting the invisible anchoring detail could have this effect. Interesting information on how to build domes and vaults without shuttering can be found in Doat (1991) and Minke (1999).

The above example as well as the Chinese roof (that stabilizes the wall columns by its weight) demonstrates how dangerous it could be to change traditional construction. One has either to follow the tradition strictly or one must fully understand how it works.

Roofing Material

Roofing material for waterproofing varies a lot.

a. Slab roofs (which are prevalent in dry climates) have mud layers for waterproofing. In some cases they are covered with an additional layer of bricks or clay floor tiles laid to slope. This makes their use as roof terraces more convenient. Normally they are only a mixture of mud and chaff. This cover is in some rare cases also used for sloped roofs.
b. Suitable leaves or grasses are very common covers for sloped roofs. There is the well-known thatch roof using various types of local grasses, some of them are more and some are less resistant. Palm branches are prepared by folding them in half, so that the stalk is one side and the whole piece can be bound to the substructure. This type of roof is called *macuti* in Eastern Africa. The pieces are laid with overlapping shingles. Rounder growing palm leaves are simply overlapped. All these roofs provide good ventilation and heat insulation which make the houses comfortable. However every three years or so thatch type roofing needs to be replaced, which is costly for the owners, and good material gets scarce in some regions.
c. Burnt clay tiles were common in some areas of India and for all official buildings in China, where they are normally glazed. As mentioned, in China, tiles are laid on top of a wooden structure in mortar. In India traditional country tiles were made of short conical pipes that were cut into halves. They are like all traditional tiles laid one on the bottom as a channel and one on top to cover the gap between the two bottom tiles. A more recent type has a U-section as a tapered channel and is laid in the same manner. People who could afford put several layers on the roof for better heat protection. The small gaps in such tiled roofs ensure good ventilation. Predominantly a layer of split bamboo supports the tiles. It is safer than the one batten per tile as we know it. In case an earthquake or high wind moves the tiles, they cannot fall down and cause harm. In some regions of India, one can also find such tiles laid in mud on simple thatched roofs (Figs. 13 and 14).

Building Construction. Fig. 13 Country tile roof (Gujarat, India). Split bamboo placed close together serves as battens (photo by the author).

Building Construction. Fig. 14 Country tile roof from inside (photo by the author).

Building Construction. Fig. 15 Roof with a stone slab (Rajasthan, India) (photo by the author).

d. Domes and vaults get a finishing by lime plaster. To make this watertight, the sand used must have different grains and some organic material added in order to increase the elasticity.
e. Regions with suitable stone plates have sloped roofs with overlapping stone slabs. (Fig. 15).

Earthquake Resistance

In many non-Western regions, earthquakes are a major natural hazard and all buildings are built to resist their forces.

It is not the earthquake that kills; it is the collapsing building. Traditional constructions have a remarkable earthquake resistance. Problems start when the traditional way of construction is modified. Craftspeople who execute the works cannot really design for earthquake resistance once traditional design is given up. The strength and the proper dimension of a structure were developed by experience, and this is also reflected in the features that may make a structure more earthquake resistant, even if they are not recognized as structural elements. Even builders might not know why there are certain elements, which users normally consider decoration, which often play a vital role in the buildings' strength.

An earthquake's actions can in a simplified way be understood as horizontal forces acting on the structure. They are more or less proportional to the mass of the structure concerned and are expressed as percentage of the gravity acceleration.

Various strategies deal with earthquake safety. Basically one can have (a) buildings that do not harm people when they collapse; (b) a construction that is light where earthquakes do not induce large forces; and (c) buildings can be strengthened in various ways to withstand earthquakes. Often a combination of those measures is used. One can also have a rather elastic and flexible structure, which reacts by deformation, but that is not the case in traditional buildings.

Traditional Japanese houses consist only of a light wooden structure and a sort of paper filling for the walls. As the structure is light, an earthquake will not introduce many forces and if it collapses, the walls are not seriously hurting users. This is an intelligent construction using strategies (a) and (b).

All types of thatched roofs (real thatch and covers from palm or banana leaves) always supported by a wooden structure, follow the same strategy. They are light and will not cause harm when the roof collapses. Even roof tiles did not result in serious injuries when falling down during earthquakes (or cyclones). As mentioned, in India, there were many pieces of split bamboo lying so close together that tiles could not fall through. However, when modern roof tiles were introduced, this feature was given up, as those new tiles only match well with single straight battens as support. Central Europe, where the design of modern tiles comes from, has not got serious earthquake problems, and there is always a ceiling under the roof. Introducing the same technology in earthquake-prone areas like northern India, where people normally cannot afford a cladding under the roof, was probably not a good idea. In the great Gujarat earthquake in 2001, falling tiles injured people, but practically nobody was killed. The death toll came mainly from collapsing slabs or slab roofs, especially when their supports failed.

To make the building itself resistant to prevailing earthquakes, following strategy (c) can be achieved in various ways. Rather resistant are wooden structures, filled with either woven mats or similar (which is the usual construction in the real tropics (see climatic adaptation), or with mud (mostly a wattle and daub type, see wall materials). Some latticework or diagonals increase the horizontal resistance. However, often the traditional joints are a weak point.

You often find this type of approach for the first floor of two storey houses. It has a long tradition in Muslim construction and can still be seen in old Turkish towns as well as in Kabul, Afghanistan. The first floor weight is more essential to the structure, as it contributes more to the internal forces, so it is wise to make it light.

A good way to reinforce masonry buildings against earthquake actions is to use horizontal bands with good tension strength. This is the recommended method for one and two storey buildings in many modern earthquake-related building design standards. Today, the bands are normally made of reinforced concrete. You will find similar bands in Turkey and in the Himalayan region of India etc., where houses are constructed of stones. These bands are however made of wood, a material that is relatively cheap and has good tension strength. There you find one piece of wood on either side of the wall, often interconnected in a form of a ladder by smaller batten type pieces. It looks and acts very similar to modern steel reinforcement in concrete beams. In the Himalayan region, people most likely discovered independently from the Arabic-influenced regions the positive effect of wooden beams in case of earthquakes. You can find buildings, mainly with dry masonry, which have wooden beams incorporated. They look very nice and can be considered as traditional decoration, but basically, they are reinforced against earthquakes.

Wattle and daub walls have also a rather high-tension strength, as the basic structure consists of wood. In addition, the walls are light and do not attract high horizontal forces.

Another way to increase the strength of a structure is to give it a suitable form. If you fold a piece of paper, the load bearing capacity becomes much greater compared to a flat piece. Round forms are very resistant and this is used in certain types of buildings. In Gujarat, India such a house type, called *bungha*, withstood the last heavy earthquake amazingly well (see the case study below).

A very simple and basic approach to make a wall itself earthquake resistant is to make it thicker. Assuming that the wall is sufficiently monolithic, one can assume that the resultant of the horizontal earthquake forces acts in the center of gravity of the wall, for a prismatic object that is the middle of the height. If the wall is wide enough in relation to the height, it cannot turn over. This is why huts (with light thatched roofs) and low stonewalls have no problems in earthquakes, even if they are only built with mud mortar. More effective are tapered walls with a wide base in the form of a retention wall or dam. This approach can still be found in earthquake-prone areas (Fig. 16).

In general, as one could see, traditional buildings were amazingly well adapted to earthquake hazards and this within a rather limited range of available local materials. Many problems started, when traditions were given up and westernized construction was imitated without designing the buildings for the prevalent hazards.

Building Construction. Fig. 16 Mud wall in a tapered form to withstand horizontal earthquake forces (Gujarat, India) (photo by the author).

Climatic Adaptation

For a good adaptation to the climate, the construction of a house plays a major role. Together with the architecture (Koenigsberger 1973; Lippsmeier 1969; Wilhelm 2000), which should deal with orientation, shadowing, openings, and spatial arrangements, the temperature and the air movement and the type of material used and its dimension also influence major components of comfort.

In desert conditions, thick and heavy walls provide a good phasing (time shifting of the temperature curve between outside and inside the building) and damping of the temperature. Mud and rubble stonewalls in the range of 30–45 cm (1–1.5 ft) as used in traditional constructions in such regions have a phasing of 12 h or so. This is how people can benefit from cool nights during the daytime. In the night they sleep outside or ventilate the room, if it is too hot from the heat stored during the day. A straw rich mud plaster normally increases the insulation and contributes to the damping effect. So the peak temperatures inside are lower than outside and closer to the average. In the desert environment, the rooms stays within comfortable conditions, whereas a prefabricated concrete building with thin elements as required for structural safety becomes too hot (Fathi 1986).

Building Construction. Fig. 17 Wind catcher tower (Dubai) (photo by the author).

In tropical conditions, light walls are traditional, which makes it possible to benefit from the slightest change of temperature. Weavings also let the air though, so that the users get more comfort through the air movement. All traditional houses in hot climates have openings near the roof or a roof that let the air pass through. In thatched or palm leaf roof covers this advantage is combined with good insulation properties so that the heat is kept out.

Ventilation can be further increased, if the floor is penetrable and put on stilts. Houses on the South East Asian islands with bamboo floors follow this strategy. A further improvement of the ventilation can come through a chimney effect. Raised gables in Bali, chimney-type additions on the center of the roof, wind towers in Arabia and holes on the top of domes are such devices (Fig. 17).

Example 1: Traditional Bunghas in the Semidesert of Kutch, Gujarat, and India

Probably the oldest types of houses in the semidesert of Kutch are called *bunghas*. They look very much like the well-known African round huts. They were considered rather backward and primitive type of construction. The big surprise was their amazingly good performance during the high magnitude earthquake in January 2001, where nearly 20,000 people died in the region.

Practically none of these buildings collapsed, except for those that were rotten, as the wooden roof structure and the walls had been weakened by termite attacks. Looking closer into the quality of the bunghas, one finds a very good adaptation to the desert climate with hot days and cool nights.

Building Construction. Fig. 18 Decorated *Bungha* (Gujarat, India) (photo by the author).

Building Construction. Fig. 19 Grain storage made of fiber-reinforced mud (Kutch, Gujarat, India) (photo by the author).

The bunghas are round structures, standing on platforms for better protection from the rain, which weakens the mud walls, as there are heavy rains from time to time. Several bunghas are placed together on this platform, forming the home of a large family. The houses with mud plaster are often nicely decorated and have furniture made of fiber-reinforced mud with a lot of decorations. The walls are in many cases made of wet mud pieces put in layers. In some cases sun dried mud bricks are used, fixed together with mud mortar (Figs. 18 and 19).

Another wall type consists of random rubble stone masonry, again fixed together with mud mortar. The fourth wall type found in some areas is the wattle and daub construction.

The wall thickness varies with the material. Wattle and daub is normally about 15 cm. This is the thickness that results from the material used and it is rather appropriate to provide a reasonable insulation and damping to cope with the high temperature differences between days and nights. The filling with branches, together with the mud layers on both sides, has rather good thermal properties. However from the point of view of building physics, a slightly thicker wall would be desirable.

The pure mud walls are about 30 cm thick, which ideally corresponds to the damping and insulation requirements. Mud mortar rubble stonewalls are generally 45 cm or 1.5 ft, which again corresponds ideally to the thermal requirements. The round form gives the walls a great stability, which explains the good performance of the bungha during the earthquake. The conical roofs are made of wooden rafters and covered with thatch. To interconnect the rafters, small branches or the core of palm leaves are used in small bunches that can easily be bent into horizontal rings. From the top, such a roof structure looks like a spider's web: the rafters go in a radial form from the center to the wall and their interconnections form concentric rings.

Many communities use a king post in the center of the room. They put a heavy beam on top of the wall about 1.80 m high, on which the king post ends. These people are sure that the king post is necessary, but other communities manage without it. They use a corner piece for each rafter to transmit the horizontal thrust of the conical roof to the walls that are acting as a tension ring. This interesting innovation takes longer to spread to the other communities living in the same region where bunghas are built (Figs. 20 and 21).

The roof cover is made of thatch, which has good insulation properties and at the same time lets air pass through and provides a good insulation for the buildings. Together with the good insulation and storage capacity of the walls the house is kept cool during the day and it is also comfortable in the cold nights in winter, which can reach zero degrees. Users are well aware of this and they call it a built-in air conditioning system. However they would like some improvements like better flooring and longer lasting roof materials.

Building Construction. Fig. 20 Old *Bungha* roof (Kutch, Gujarat, India). Large roof without king post and excellent decoration (photo by the author).

Building Construction. Fig. 21 Detail: corner element in a *Bungha* roof (photo by the author).

Example 2: The Afghan City House

Afghanistan has a harsh climate (hot summers, relatively cold winters and nights) and in addition there are earthquake hazards. Traditional housing is well adapted to those conditions. Whereas in villages, single storey mud or stone houses are prevalent, cities like Kabul have a long tradition of two storey buildings.

The plinth is built in random rubble stone dry masonry. This keeps the moisture from the soil out of the walls. In western technology the damp proof courses were only introduced in the beginning of the last century, normally as bitumen felt layers.

The ground flooring is laid on top of the so-called fox's dens. This is a system of ducts, which ventilate the space under the floor and is in some cases used as a heating system similar to the Roman holocausts (hollow floors and in some cases wall ducts, where fire was made for heating). Transverse main ducts connect both exterior plinth walls, so that the air can pass through. From this main duct secondary ducts run in a perpendicular direction. Then a layer of mud follows which carries the flooring, which is either made of brick or only mud. This construction keeps the floor dry. The ground floor walls are made of sun-dried mud bricks with a wall thickness of at least 30 cm (12 in.).

This corresponds ideally to the climatic requirements, as this wall has a high storage capacity and a phasing of up to 12 h. This room is cool on summer days (as it preserves the night temperature condition). A wooden framework with an infill of sun dried mud bricks forms the upper floor walls. These upper walls are only about 12 cm (5 in.) thick and have large windows. So the rooms in the upper floors pick up the outside conditions much faster, and one can choose the most comfortable room. The light walls, together with the wooden framework and a sort of batten as bracing against horizontal forces, make the building rather earthquake resistant.

The floor and the roof slab have wooden beams as load bearing structures at 45–60 cm apart (1.5–2 ft). As described earlier, there is a reinforced mud layer across the beams. To get the roof watertight, a layer of mud mixed with hacked straw is applied, which needs to be replaced every few years.

Some houses of this type are reported to be 200 years old and the technology is still used today. Those and more modern examples show the potential of mud houses.

Improving the traditional construction systems would be a real benefit for the poor, who mostly have only their labor to invest.

See also: ►Architecture in Japan, ►Islamic Architecture

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Cakravala Method

S. Raghavan

Let us consider the equations (i) $3x = 6$ and (ii) $5y = 2$ in the two variables x, y. We recognize at once the (integer) solution $x = 2$ for equation (i) and further note that there can be no y in the set **N**: = {1, 2, 3,...} of natural numbers which satisfies equation (ii), since the constant term 2 on the right-hand side of equation (ii) is not an integral *multiple* of (i.e., is not divisible by) the coefficient 5 of the variable y therein. Leaving these two simple examples of linear equations in a single variable, let us take up the following linear equation involving two variables x and y:

$$px - qy = m \qquad (1)$$

where the coefficients p, q and the constant term m belong to the ring **Z** of the usual integers....–3, –2, –1, 0, 1, 2, 3, ... Clearly, for (1) to have a solution $x = a$, $y = b$ with a, b in **Z**, it is necessary that any common divisor t of p and q (i.e. any t in **Z** dividing both p and q) must be a divisor of m as well. Thus the greatest common divisor (g.c.d. in brief) d of p and q denoted as (p, q) in symbols must also divide m. Now, a well-known algorithm of Euclid's for finding (in finitely many steps) the g.c.d. of any two given integers p, q enables us to write their g.c.d. d in the form $d = pa + qb$ with suitable a, b in **Z**, and we are led to the solution for (1) in integers $x = am/d$, $y = -bm/d$. We should not fail to mention that an alternative approach to solving (1) is to expand the rational number q/p (for $p \neq 0$) as a simple continued fraction. For example, if $p = 3$, $q = 11$ in (1), then $q/p = 11/3$ has the continued fraction expansion $(3{+}1)/(1{+}1/2)$ whose "penultimate convergent" $(3{+}1)/(1 = 4/1)$ solves this special case of (1) with $x = 4$, $y = 1$.

Solving linear equations such as (1) in 2 variables or in more variables often opens the door to cracking interesting puzzles or even settling serious problems! A clear description of the method of solving (1) is available in *Āryabhaṭīya*, a Sanskrit text of the (fifth or) sixth century AD. (According to Ian Pearce (2002), the mathematical part of *Āryabhaṭīya* covers arithmetic, algebra, plane trigonometry and spherical trigonometry and also contains continued fractions.) As observed by André Weil, this is also "the first ever explicit description" of the general solution in integers for (1) from anywhere, except China. In subsequent Sanskrit treatises, this method came to be known as the *kuttaka* (pulveriser) method, but it might not be fair to attribute the same with authority to Greek mathematicians granting the familiarity of Indian astronomers with developments in Greek mathematics until then. It is interesting to learn from Weil how, in utter disregard or (possible) ignorance of the remarkable application of the *kuttaka* in India and of the connection with the seventh book of Euclid's *Elementa*, Bachet ventured to insert (in the second edition of his book *Problèmes plaisants et délectables*) a strong claim to the *kuttaka* method as his own. Before attempting to say anything about the *cakravāla* method, let us see how the *kuttaka* method is applied.

Equation (1) can be rewritten as an (equivalent) "congruence" relation modulo the integer q, namely as $px \equiv m(\text{mod } q)$; we might recall here the customary notation, for a, b, c in **Z**, that $a \equiv b(\text{mod } c)$ exactly when c divides $a - b$. Whenever d, the g.c.d. of p and q divides m, we can find, by Euclid's algorithm, an integer x such that $px - m$ (equals qy and hence) is divisible by q, i.e., $px \equiv m \ (\text{mod } q)$. The *kuttaka* precisely enables one to find the form of the general solution of this congruence (whenever (p, q) divides m). Take, by way of an example, the congruence $3x \equiv 1$ (mod 7). Since the g.c.d. (3, 7) equals 1, the congruence is indeed solvable. Now $3 \times (-2) = -6 \equiv 1(\text{mod } 7)$ and so, on multiplying both sides of the congruence by –2, we get $-6x \equiv -2$ (mod 7) which is the same as $x \equiv 5$ (mod 7). The *kuttaka* thus tells us that any integer of the form $7n + 5$ for arbitrary n in **Z** satisfies the congruence $3x \equiv 1(\text{mod } 7)$.

From linear equations in x and y, let us move on to (much more non-trivial) equations of degree 2 in two variables, e.g. $x^2 - Ny^2 = 1$ for N in **N**. If $N = M^2$ with $M \in \mathbf{Z}$, the solution in integers x, y of this equation can be immediately found by factorising the left hand side and rewriting the equation as $(x + My)(x - My) = 1$ and hence as $(x + My) = (x - My) = \pm 1$. However, if $N = 2$ or any square-free integer (i.e. not divisible by the square of any prime number), then one could ask for all integers y such that $Ny^2 + 1$ is the square of an integer and, in other words, ask for solutions in integers x, y of

$$x^2 - Ny^2 = 1 \quad (2)$$

which indeed looks harder and is known as Pell's equation (ever since Euler attached Pell's name to it *by* mistake!).

For a while, let the square-free integer $N > 1$ be kept fixed in our general discussion and let, for any given integer m, the given triple $(x, y; m)$ stands for a solution in integers x, y of the more general diophantine equation

$$x^2 - Ny^2 = m \quad (3)$$

We can clearly identify, for any $t \neq 0$ in **Z**, the triple $(tx, ty; t^2m)$ with $(x, y; m)$.

Under the heading *Vargaprakrti*, (3) was investigated by the Indian mathematician Brahmagupta (seventh century AD) who used his *bhavana* rule to get non-trivial solutions for (2) in integers for several cases of N (and, in particular, for $N = 92$ or 83, solutions given by $(1151)^2 - 92 \times (120)^2 = 1$, $(82)^2 - 83 \times 9^2 = 1$. The *bhavana* (composition) rule gives, for two given triples $(x, y; m)$ and $(z, t; n)$, their product (or composite) $(x, y; m)(z, t; n)$ by the formula

$$(x, y; m)(z, t; n) := (xz \pm Nyt, xt \pm yz; mn) \quad (4)$$

Written in expanded form, this leads us to the composition formula

$$(x^2 - Ny^2)(z^2 - Nt^2) = (xz \pm Nyt)^2 - N(xt \pm yz)^2 \quad (5)$$

expressing, in modern parlance, the multiplicative property of the norm form $x^2 - Ny^2$ in two variables x and y.

The square-free integer N associated with the triple $(x, y; m)$ for (3) was referred to as the *gunaka* (or *prakrti)* and the integer m therein as *ksepa* (additive). Brahmagupta knew how composition of a triple $(x, y; m)$ with a triple $(p, q; 1)$ with the same *gunaka* N leads to a triple $(x', y'; m)$, while the product $(x, y; m)$ $(x, y; m)$ is again a triple $((x^2 + Ny^2)/m, 2xy/m; 1)$ provided $(x^2 + Ny^2)/m$ and $2xy/m$ are both in **Z**. For $m = -1$ or ± 2, composition of $(p, q; m)$ with itself leads to $(p^2 + Nq^2, 2pq; 1)$ or $((p^2 + Nq^2)/2, pq; 1)$, respectively. While the composition formula (5) occurs explicitly in Brahmagupta's work, special cases of the same for $N = 3$, $z = 5$, $t = 3$ may have been applied by Archimedes to obtain approximations to $\sqrt{3}$ by rational numbers, according to Weil.

We now give an example to see how the *bhavana* rule helps in solving (2). Let us take Brahmagupta's investigation of the case $N = 83$ itself. The natural number "closest" to the *vargamoola* (square root) $\sqrt{83}$ of 83 is 9 and the relation $9^2 - 83 \times 1^2 = -2$ is the same as the triple $(9, 1; -2)$ corresponding to the value 83 for N. Composing this triple with itself according to *bhavana* as in (4), we note that $((9 \times 9) + (83 \times 1 \times 1))^2 - 83((9 \times 1) + (9 \times 1))^2 = 4$, giving the "square" of $(9,1; -2)$ as $(164, 18; 4)$. On division throughout by 4, the last-mentioned triple leads exactly to $(82, 9; 1)$ which is a solution (as discovered by Brahmagupta) for (2) with $N = 83$. In H. T. Colebrook's book, *Algebra with Arithmetic and Mensuration, from the Sanscrit of Brahmegupta and Bháscara*, one can find an entire section dealing with Brahmagupta's investigations on *Vargaprakrti.* Brahmagupta could find extremely accurate values for $\sqrt{N}$ using his solutions for (2). According to Ian G. Pearce (2002), "this contribution is of huge interest as it is essentially the same method rediscovered and used by Newton and Raphson around 1690, which is known as the Newton–Raphson iterative method".

Despite Brahmagupta's admirable results, the general solution of (2) is still not at hand! The brilliant *cakravāla* (cyclic) method for the general solution of (2) has been located in the work of Bhaskara much later, around the twelfth century. Almost the same description of the *cakravāla* is provided in a commentary written around the eleventh century by "an otherwise unknown author" Jayadeva, leaving it open (for anyone) to identify the real inventor of the *cakravāla*. We shall now give a brief description of the method and an illustrative example.

The idea of the method is to start from a triple $(p_0, q_0; m_0)$ with "small" m_0 and use the *bhavana* to get a triple $(p_1, q_1; m_1)$ with m_1 "small" again and eventually, in finitely many steps, hit upon a triple $(u, v; r)$ with $r = 1$, -1, ± 2; for $r = 1$, (2) is solved with $x = u$, $y = v$ but in the three remaining cases of r, composition of $(u, v; r)$ with itself yields a solution for (2) as explained earlier (noting that the *gunaka* N is kept fixed all the while). For the triple $(p_0, q_0; m_0)$ at the start, p_0 is chosen such that p_0^2 is the square closest to N and q_0 is taken as 1 so that $m_0 = p_0^2 - N$. Next, the integer x_0 is chosen to satisfy the congruence $x_0 \equiv -p_0 (\text{mod } m_0)$ besides ensuring at the same time that $x_0^2 - N$ is "small" and in fact, more precisely, least in absolute value among all possible choices for x_0 with $x_0 \equiv -p_0 (\text{mod } m_0)$. Then the triple $(p_1, q_1; m_1)$ is defined as the composite

$$(p_0, q_0; m_0)(x_0, 1; x_0^2 - N) = \left(\frac{(p_0 x_0 . N)}{m_0}, \frac{(p_0 + x_0)}{m_0}; \frac{(x_0^2 - N)}{m_0} \right)$$

which is a genuine triple due to our congruence condition on x_0. If we note that $x_0^2 - N = m_0 m_1$, we may see that keeping $N - x_0^2$ "small" helps to keep also m_1 "small". The next step in the *cakravāla* is to find x_1 in **Z** so as to enable us to obtain the composite $(p_1, q_1; m_1)(x_1, 1; x_1^2 - N)$ is a genuine triple to be defined as $(p_2, q_2; m_2)$. Actually x_1 is to satisfy the congruence $q_1 x_1 \equiv -p_1 (\text{mod } m_1)$ as well as the condition that $x_1^2 - N$

is "small" (i.e. least in absolute value among possibilities for x_1 got by using *kuttaka*. Having got the triple $(p_2, q_2; m_2)$, one proceeds to find suitable x_1 (modulo m_2) to move on to a triple $(p_3, q_3; m_3)$ and eventually, as mentioned above to a solution of (2).

Example. For $N = 31$,we have $p_0 = 6$, $q_0 = 1$, $m_0 = 5$ giving us (in the terminology of Bhaskara) the (corresponding) auxiliary equation $31 \times 1^2 + 5 = 6^2$. Then by Bhaskara's lemma (i.e. indeed composing (6, 1; 5) with $(x_0, 1; x_0^2 - 31)$ so that $x_0 \equiv -6 \pmod 5$ and further the absolute value of $x_0^2 - 31$ is least (among all integers x_0 congruent to –6 modulo 5), we obtain $x_0 = 4$ and $(p_1, q_1; m_1) = (6,1; 5)(4,1, -15) = (11,2; -3)$. Next with the auxiliary equation $31 \times 2^2 - 3 = 11^2$, *kuttaka* is used to find x_1 with $2x_1 \equiv -11 \pmod 3$ and $x_1^2 - 31$ least (in absolute value), yielding $x_1 = 5$ and $(p_2, q_2; m_2) := (p_1, q_1; m_1)(5, 1; -6) = (-39, -7; 2)$. Since $m_2 = 2$, a shortcut via the *bhavana* is to define directly $(p_3, q_3; m_3) := (-39, -7; 2)(-39, -7; 2) = (-1{,}520, -273; 1)$, solving $x^2 - 31y^2 = 1$ at once. On the other hand, one could follow the general method indicated in the preceding paragraph to get $x_2 = 5$ and the triples $(-39, -7; 2)$ $(5, 1, -6) = (-206, -37; -3)$, $(-657, -119; 5)$, $(-1{,}520, -273; 1)$ in that order. Further iteration of the method not only yields more and more solutions for $x^2 - 31y^2 = 1$ but also reveals a "cyclic" pattern in the *additives* m_i (vindicating the chosen name *cakravāla*). Using familiar notation for periodic simple continued fractions for quadratic irrationalities (e.g. Davenport 1990: 104–105), we write $\sqrt{31} = \langle 5, \overline{1, 1, 3, 5, 3, 1, 1, 10} \rangle$ and the relevant *convergent* $\langle 5,1,1,3,5,3,1,1 \rangle = 1520/273$ got by omitting the *partial quotient* 10 from the *very first period* $\overline{1, 1, 3, 5, 3, 1, 1, 10}$ gives the same solution for (2) as above. Weil's own version of the *cakravāla* has the merit of not only totally dispensing with the use of *kuttaka* (in Bhaskara's exposition of the *cakravāla*) but also making the "cyclic" pattern in the occurrence of the *additives* m_i quite transparent and *in tune with* the phenomenon of *periodicity* in the continued fraction expansion for $\sqrt{N}$. Are not the triples (1,766,319,049, 226,153,980; 1) for $N = 61$ and (48,842, 5,967; 1) for $N = 67$ discovered and offered to us by Brahmagupta and Bhaskara masterpieces adorning the lustrous history of *cakravāla*?

To be fair though, one should recall Weil's remarks that a rigorous treatment as explained above for constructing the successive triples $(p_i, q_i; m_i)$ "may have been known to Indian mathematicians only experimentally and there is nothing to indicate whether they had proof for them, or even part of them" and again that "For the Indians, of course, the effectiveness of *cakravāla* could be no more than an experimental fact, based on their treatment of a great many special cases, some of them of considerable complexity and involving (to their delight, no doubt) quite large numbers. Fermat was the first to perceive the need for a general proof and Lagrange the first to publish one. Nevertheless, to have developed the *cakravāla* and to have applied it successfully to such difficult cases as $N = 61$ or $N = 67$ had been no mean achievement". Weil is unsparing as well in his critical analysis of Euler's contribution to the topic of "Pell's equation" in the form of drawing attention to the periodicity and "palindromic" property of the "partial quotients" in the continued fraction expansion for $\sqrt{N}$ or their use in solving "Pell's equation" with perhaps merely experimental evidence to back up his assertions. Although the "Cattle Problem of Archimedes" (Davenport 1990) is usually associated with Pell's equation, one learns from Weil that equations such as (2) "do occur in Diophantus…, but it is a rational solution that is asked for, even when accidentally a solution in integers is obtained…". A detailed discussion of Kronecker's interesting solution (using elliptic functions) for Pell's equation can be found in Siegel's section 27.1 (1963).

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Calculus

K. V. Sarma

Calculus, both integral and differential, was known *to a limited extent* and used for specific purposes in India during early and medieval times, and is attested to by the works of Āryabhaṭa (b. 476), Brahmagupta (b. 598), Muñjāla (b. 932), Bhāskarācārya (b. 1114), Nārayāṇa Paṇḍita (1356), Nīlakaṇṭha Somayāji (b. 1444), and Jyeṣṭhadeva (ca. 1500–1610). In the same manner as Hindu geometry grew in response to the religious needs of designing sacrificial altars, it would seem that calculus too evolved when there was the need to ascertain favorable and unfavorable times for religious rites and rituals on the basis of the moments of the eclipses, conjunction of planets, and conjunction of planets and stars. Calculus did not evince further growth in India.

In order to determine the accurate motion of a planet at a particular moment (*tātkālika-gati*), Bhāskarācārya divides the day into a very large number of intervals of time units called *truṭi*, equal to 1/33750 of a second, and compares the successive positions of the planet, the motion during that very small unit of time being considered constant. He also suggests that the differential coefficient vanishes when the interval is diminished to the absolute minimum. He illustrates this by three examples.

Hindu ideas on infinitesimal integral calculus are shown in the methods employed and formulas arrived at for the calculation of the area of a circle, and the surface area and volume of a sphere, all of which are virtually the same as these derived by modern mathematics.

Two methods are adopted for finding the surface area of a sphere. One of them is to draw, from a point on the sphere taken as the pivot, a very large number of circles, parallel to each other and of small and equal interstices, and to slice the sphere at these circles. The sum of the areas of the strips peeled off each slice, the longest of them being at the equator, and the smallest, equal to zero, at the pivot and the bottom, would be equal to the surface area of the sphere. It is explained that when the breadth of the strips tends to zero, the total surface area could be obtained by the formula $4\pi^2$.

In the same manner, the volume of a sphere is equal to the sum of the numerous cones that would be formed with their bases on the surface of the sphere and their apexes being at the center of the sphere. When the number of cones is infinite, their bases could be taken as flat, and the volume of the cones could be calculated by the usual formula. From this postulate, the formula for the volume of the sphere is identified as $4/3\ \pi^3$. The several methods enunciated for the determination of the value of the circumference of a circle, involving the irrational quantity, π, as exposited in several works from Kerala, like the *Yuktibhāsā* of Jyeṣṭhadeva, also concern integral calculus.

See also: ►Āryabhaṭa, ►Brahmagupta, ►Muñjāla, ►Bhāskarā, ►Nārayāṇa Paṇḍita, ►Nīlakaṇṭha Somayāji, ►Jyeṣṭḥadeva

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Calendars in East Asia

Nakayama Shigeru

Successive attempts to improve a typical luni-solar calendrical system for reconciling two fundamentally incommensurable periods – the tropical year and the synodic month – were made throughout the history of Chinese and Japanese calendars until their replacement by the Gregorian solar calendar in modern times, the Japanese in 1883 and the Chinese in 1912.

The length of a synodic month varies between 29.0 and 30.1 days. The luni-solar calendar provided for "short" months of 29 days and "long" months of 30 days. Calendrical scientists attempted to arrange short and long months so that the moon's conjunction would take place on the first day of every month. The day notation of the lunar month represented the phase of the moon; for instance, the 15th day of the month was always a full moon, while the first day was a new moon.

In addition, the Chinese had an independent system of solar intervals (*qi*) for indicating seasonal changes, the most important phenomena in the regulation of agriculture. The tropical year was divided into 12 equal intervals of time, the element of a purely solar calendar. The middle point of each interval was called its *zhongqi* or interval center. The synodic month was always slightly shorter than an equal interval, and thus an interval center did not occur in certain months. Such months were designated as intercalary months, and in this way the sequence of synodic months was reconciled with the seasons of the tropical year. The year that included an intercalary month had 30 synodic months. This occurred roughly once every three years.

The Chinese calendar calculators were, however, not satisfied with providing a conventional calendar, in which the courses of the sun and moon were reconciled, merely for civil use; they also tried to include the anomalistic motions of the sun and moon.

Prior to the Tang period (roughly seventh to ninth centuries), a mean synodic month of approximately 29.5306 days was used for this purpose. Shortly before the Tang, however, a proposal was made to take anomalistic motions of the sun and moon into consideration in calendar making. Liu Zhuo (AD 544–610) used the term *dingshuo* (true synodic month) as opposed to the older concept of *pingshuo* (mean synodic month). During the Tang period the idea of the true synodic month was adopted in the official calendar in order to attain better agreement with the actual phases of the moon, and also for convenience in eclipse-prediction calculations.

Liu Zhuo also made the first recorded distinction between *dingqi* and *pingqi*. The former is the period of time for the sun to move through a 30° angle of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), which therefore varies in length in accordance with the anomalistic movement of the sun. The latter is the average length of time to move through a 30° angle. This concept, *dingqi*, however, was not actually adopted in the official calendar until the Qing period (the seventeenth century on).

Daily life is never affected by such small discrepancies in the calendar as those due to the anomalistic motions of the sun and moon. The astronomical attainments of the Chinese calendrical schemes went far beyond the concern of the common people. They included not only luni-solar phenomena but also the periodic motions of the five planets. They were called *li*, which corresponds to "ephemeris" as well as "calendar" in the narrow sense.

In the case of the Julian calendar reform data were doubtless gathered from prior calendars and not from actual observations. One recalls in this connection Lillius' effort in the Gregorian calendar reform to reduce the toil of observation and computation so as to provide an artificial system independent of astronomical tables and indeed of any link with actual celestial phenomena. The Western calendar was not, in terms of astronomical precision, overwhelmingly rigorous.

The difference of purpose between calendar-making in the West and East is clear. Whereas the Western calendar was divorced from the development of astronomical science, and aimed at schematic convenience for civil and religious proposes, the East Asian calendar, disregarding civil convenience, was an attempt to represent faithfully the movements of the heavenly bodies. It thus became much more complicated than its practical applications warranted. A sharp separation of scientific astronomy and civil calendar-making did not take place in traditional East Asia. Its scope was confined to the composition of a luni-solar ephemeris which stood or fell on the accuracy with which it could predict eclipses, which is the best way to check the validity of any luni-solar calendar. Analysis of planetary motions was rather ancillary to the main stream of Chinese calendar making.

Cosmological discussions often took place during the Han and Six Dynasties periods (second century BCE to sixth century AD), although they were discontinued soon after. In the Tang period the Chinese astronomers were no longer interested in this particular speculative pursuit. While occasional cosmological debates were found among philosophers, scientific cosmology was long set aside and forgotten in professional calendrical science circles until the time of the Jesuits' impact in the seventeenth century.

Perhaps the most striking thing about the recastings of the civil calendar in China was their frequency. In 2,000 years there were more than 50 revisions of the Chinese calendar, and then of the Japanese calendar, whereas in the West there was only one major reform, the Gregorian. Why were the Chinese so preoccupied with the calendar that they were driven to such repeated efforts? There were two major reasons, one political and the other technical.

Among the ancient Chinese the idea prevailed that a ruler received his mandate from heaven. In the early period, therefore, after important changes within individual reigns and always after important changes of dynasty, the new emperor was prompted to reform key institutions, especially the official calendar, in order to confirm the establishment of a "new order" which a new mandate implied. A new mandate meant a new disposition of celestial influences. The Han Emperor Wu (r. 1480–1487 BCE) was advised by his councilor to revise the calendar and change the color of ceremonial vestments, in order to make it clear that his rule was based on a true mandate. The result was the imperial edict by which the *Taichu* calendar was adopted.

This notion was responsible for the subsequent course of development of Chinese calendrical science. Calendrical science enjoyed governmental sponsorship throughout its history, and had more prestige than other branches of science; it was China's most genuine contribution to the exact sciences. The history of Chinese and traditional East Asian astronomy is, for the most part, the history of calendar-calculations.

In the course of time, however, the political importance of calendar reform dwindled. The restriction of calendar reform to change of dynasty was not strictly observed by the Northern Wei (fifth century AD) and succeeding northern dynasties. Some rulers unduly took advantage of calendar reform to gain or regain popular support. The calendrical significance and authority of calendar revision were thus largely lost. In the Tang dynasty, the motive for calendar reform became simply to correct disagreements of the calendar with observed celestial phenomena. Hence, reforms were carried out whenever a small error was found. This accounts for the frequent revisions in later phases.

Beyond the concern with timekeeping, the Chinese astronomers dealt mainly with apparent solar and lunar movements and eclipse prediction. The Chinese luni-solar calendar required revision whenever the discrepancy between calculation and observation became noticeable. For this purpose, the government founded the Office of Astronomy, and incumbent astronomers were responsible for the improvement of the calendar. The government enjoyed a monopoly on the regulation of time, which contributed to imperial control of daily life and which strengthened the central power and prestige at a sacrifice of civil convenience. People were forced, in matters of everyday life, to follow a calendar based on a complicated, “astronomically rigorous” and “state-authorized” ephemeris, which, unlike our solar calendar, could never be prepared by laymen, but depended on the skill of official astronomers.

Despite early recognition that a single perpetually valid calendrical scheme was impossible, the calendar calculators never tired of proposing revisions. Their incentive must be ultimately attributed to the rational desire to conform to the celestial order, a philosophical compulsion to accept the phenomena of the material sky as the most authentic reality. It was because of this orientation that calendar-making maintained its status as an integral part of Chinese science and learning for such a long time.

Modernization and Westernization

As the official calendar was quite an important part of the social system, westernization in modern times was first infiltrated through calendrical science.

Western astronomy had arrived in China with the Jesuits in the sixteenth century. Calendar-making was a vital function of the Chinese bureaucracy, and the Jesuits hoped that by demonstrating the superiority of Western astronomy they would succeed in persuading the bureaucratic elite that Western cultures and Christianity were superior. Astronomy was well suited to their purposes, not only because it was so important to the Chinese bureaucracy but because the phenomena with which it dealt possessed a universality that transcended East and West, and the objectivity of celestial phenomena did not permit much human manipulation. Furthermore, it was quantitatively precise. Thus, when the tally sheet was in, Chinese astronomers had to acknowledge that Western astronomy had superior features. All that the Jesuits made available from Western tradition, however, were peripheral data and methods of calculation. The structure, styles, and purposes of Chinese calendrical astronomy remained unchanged. As Xu Guangqi, a high Chinese official who collaborated with the Jesuit Matteo Ricci on several projects, put it, “We melted down their materials and poured them into the *Datong* (the traditional Chinese calendar then in use) mold.”

In Japan, the eighth Shogun Yoshimune (1644–1751) attempted to use this refurbished Chinese astronomy as the basis for calendrical reform, but he was effectively opposed by conservative court circles in Kyoto. The revision of Horeki that came into effect in 1754 was still modeled upon the traditional *Shoushi* calendar. Yoshimune’s desire was fully realized, however, in the Kansei revision of 1797.

After that, the scientific quality of the traditional luni-solar calendar was improved and perfected, but still the traditional mold was maintained throughout the Tokugawa period (1603–1867).

Despite the earlier recognition of Western superiority in science, a radical change of political institutions in Japan had to precede the official adoption of the Western Gregorian calendar in 1873. The decisive factor in the adoption of the Gregorian calendar was the high value the government placed on westernization. Many Japanese proposed a more reasonable solar calendar at the time of the reform, but the government preferred the Gregorian, despite its obvious shortcomings, because of diplomatic relations with the West.

With the establishment of the Republic of China in 1912, the Chinese luni-solar calendar was officially abolished.

To what extent the Gregorian calendar was observed among the populace is questionable, but after the second World War, it became firmly established in everyday life in East Asia.

See also: ►Time, ►Astronomy

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Calendars in Egypt

Jehane Ragai, Gregg De Young

Neugebauer described the ancient Egyptian civil calendar as “the only intelligent calendar which ever existed in human history.” His statement can be appreciated by tracing the ancient Egyptians’ gradually developing sense of time from an initial awareness of the day to the full realization that the year had a constant length of 365 days. The introduction of the civil calendar, based on solar years as opposed to lunar years, resulted in the development of our present-day Gregorian calendar.

Humans first became conscious of the existence of the day through the regular reappearance of the sun after its disappearance the evening before. Observing the regular change of one crescent moon to the next, they became aware of the longer time unit of the month. The practical demands of temple administration led them to develop their ability to count and calculate and they realized that one lunar month was made up of 29 or 30 days.

With the advent of the agricultural civilization in the Nile Valley, the season, rather than the month, gained importance as a time unit, since the Nile flood was a regularly recurring phenomenon that had to be predicted with a certain degree of accuracy. The ancient Egyptians must soon have realized that a purely lunar calendar was not capable of adequately predicting such annual events. They hit upon another device by which the onset of the inundation could be determined. This was the heliacal rising of Sothis (Sirius, the brightest star in the sky) which coincided closely with the beginning of the annual flooding of the Nile. They observed that after a 70-day period of invisibility, Sothis could be seen again just before sunrise, and this first appearance was taken by the Egyptians to signal the beginning of the new year.

The Egyptians, having reckoned that there was a 365 day span between two successive heliacal risings of Sothis, initially resorted to a luni-stellar calendar which consisted of 12 lunar months totaling 354 days, to which an additional 13 intercalary month was added every few years to make up for the cumulative discrepancy arising from the 11 day difference between the lunar and stellar years. The rule of thumb used was that whenever Sothis rose during the last 11 days of the fourth month of the last season, the intercalary month should be added.

Such a solution was somewhat cumbersome, and although the luni-stellar calendar was used to determine religious festivals, a more practical calendar had to be introduced to meet the demands of the state administrative system. Around 4200 BCE, the Egyptians adopted a 365 day Civil Calendar which was divided into three seasons, each of four 30-day months. The year consisted of 12 months, each of which would count 30 days plus “five days upon the year.” Events were dated as occurring on the first, second, third… day of the first, second, third… month of the specific season.

The 365 day common year of the ancient Egyptians has also been called the “vague year” because its length fell short of the astronomical year by just over a quarter of a day each year. In Greek documents, the 12 months of this vague year are referred to by Greek names which originated from a cult connected with these months. These months are (1) Thoth, (2) Phasphi, (3) Altyr, (4) Choriak, (5) Tybi, (6) Mechir, (7) Phamenoth, (8) Pharmuthi, (9) Pachon, (10) Payni, (11) Epiphi, and (12) Mesori. These months are still preserved today in Egyptian folk tradition.

Each of these 30-day months was divided into three 10-day “weeks” or decans. Thus, there were 36 decans each year. The Egyptians defined each decan to begin when a particular star or constellation appeared on the horizon. The period of time between the appearance of one decan on the horizon and the next was defined to be an hour. From the surviving “diagonal calendar” examples, it is clear that the night was considered to contain only 12 h, rather than the 18 which might have been expected when we consider that we see approximately half the celestial sphere on any given night. The discrepancy seems to arise because the Egyptians did not include the period of twilight and the darkening of the sky as part of the night. Only the period of totally darkened sky corresponded to the term “night.”

The idea that the day also included 12 h seems to be developed merely in analogy with the night. These hours might be measured on a shadow clock, since the length of shadow cast by any object changes relative to the position of the sun in the heavens. The position does not just change over the course of the day, however, but also over the course of the year as the sun travels between the tropics. As a result, these shadow clocks do not give more than approximate seasonal hours. The use of clepsydra (water clocks), in which water escapes from a graduated container at a regular rate, may be closer to our modern concept of equal hours.

The Egyptian calendar constructors and time keepers did not go beyond the hour in measuring time. It is to the Baby-lonians, with their sexagesimal mathematical system, that we owe our modern concepts of 60 min in an hour and 60 s in a minute.

In time, the Egyptian 365 day calendar became completely out of step with the real tropical year, as it fell behind the latter by one day every 4 years. Thus, in

4 × 365 years, i.e., in 1460 years, the civil year would have lost a complete solar year and would again correspond with the seasons. This 1460 year period is generally referred to as the "Sothic Cycle" and reflects the fact that every 1460 years the so-called "heliacal rising of Sothis" fell on New Year's Day and thus marked the onset of a new Sothic period. The Egyptians seem not to have noticed the discrepancy between their civil calendar and the true solar year. If, at some point they did become aware of this difference, the strong conservative element in the culture apparently made them reluctant to make any amendment to their calendar.

In 238 BCE, King Ptolemy III made an unsuccessful attempt to correct the "vague year" by adding an extra day every 4 years. Modification of the ancient calendar only ensued two centuries later when, after Julius Caesar's conquest of Egypt in 46 BCE, he followed the advice of the famous Alexandrian astronomer, Sosigenes, and adopted a modification of the ancient civil calendar for the Roman Republic. Sosigenes suggested that the length of the year should be $365\frac{1}{4}$days; that there should be a 4-year cycle of 3 years of 365 days and a 40 year of 366 days; and that the year should begin on the first of January.

The Julian method of intercalation was not only convenient, it also provided a calendar whose year closely approximated the tropical year. Nevertheless, its deficiency appeared in time, making further reform imperative. The Julian Calendar, as we now call it, assumed the length of the year to be equal to 365.25 days, whereas the tropical year (defined as the passage of the sun from one equinox to the next) is nearly 365.2422 days. Thus, the error amounted to a gain of one whole day in 128 years. To deal with this problem, Pope Gregory XIII decreed that the 11 days, that had accumulated over the 16 centuries since the Julian Calendar had been introduced, should be removed from the calendar and that henceforward no century should be considered a leap year unless divisible by 400. This Gregorian Calendar, which we use today, can thus be seen to be based on the principle of the Civil Calendar of ancient Egypt.

See also: ►Clocks and Watches, ►Sexagesimal System

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Calendars in India

A. K. Chakravarty

Calendrical science developed in India in three distinct phases, and each phase influenced the succeeding one. The first phase produced the Vedic calendar, covering a period from an unknown antiquity to the Mauryan emperor Aśoka (ca. 300 BCE); the second had the Greco-Indian calendar for a short period between the post-Aśokan and post-Kuṣāṇa period (ca. AD 300). And the third produced the Siddhāntic calendar from the Gupta period (AD 319) which is still used in India today. All three phases are characterized by formulations of fitting a lunar year into a sidereal solar one by suitably intercalating lunations.

References to calendrical elements like lunation, intercalation, year, and solstice occur even in the earliest part of Vedic literature. A separate calendrical literature, deemed a part of the Vedas, was developed in a small text, *Vedāṅga Jyotiṣa*, but this text has not been fully deciphered yet. There are some astronomical statements in the text, and also in the earliest part of Vedic literature, which do not hold true in the latitude belt and in the time period when the Vedic Aryans are believed to have settled in India.

It is a separate course of study as to how and when the Vedic Indians obtained this calendar, but they adopted it without verifying it.

This calendar is based on the following imperfect parameters:

5 sidereal years = 1,830 days
62 lunations = 1,830 days
67 sidereal lunar months = 1,830 days

The star *beta Delphini* indicates the winter solstice (which was indeed the case around 1500 BCE) which is apparently a fixed point. The lunar orbit is divided into 27 equal arcs from *beta Delphini* each equal to 13°20′, called *nakṣatra*, the first arc named *Dhaniṣṭhā*. The arcs are named after a prominent star of the division. The theory is that if, in five years, two lunations are intercalated, then the lunar year will remain tied with the solar one. This period is called a 5-yearly cycle or *yuga*.

In practice, a cycle begins when the sun and the moon are in conjunction at *beta Delphini* (i.e., from the winter solstice). The first, second and fourth year each contain 12 new moon ending lunations. One lunation is intercalated at the middle of the third year and another at the end of the fifth. The second cycle then again begins from a similar new moon at winter, solstice.

This imperfect calendar was destined to collapse, as the succeeding cycles will begin from new moons shifted by some 4.5 days from the winter solstice at *beta Delphini* per cycle, accumulating to one lunation in six or seven cycles. However, the calendar did not collapse, and so the accumulated lunation was extra-calated, but we are not told in the text how this was done. Perhaps the rule is hidden in an obscure part of the text, and so we have to guess it.

A lunation is divided into thirty parts called *tithis*. Accordingly, 30 *tithis* = 1,830/62 days. The excess 30/62 of a *tithi* over a day is called an omitted *tithi*. A month's days are designated by the *tithi* of the day and not by ordinal numbers. The Jainas used this cycle in their calendar with a marginal change: that months were full-moon-ending and a cycle began from a full moon at summer solstice in the middle of the *Āśleṣā* division (180° away from *beta Delphini*).

Kautilya wrote a book entitled *Arthaśāstra* which is believed to reflect the social and administrative conventions of the Mauryan empire. This book, on the subject of measuring time, only reproduced the Jain school of the 5-yearly cycle. We are thus assured of its use until then.

The second phase of the Indian calendar began by the first century BCE after Śaka penetration into northwestern India.

The Śakas, a central Asian people, conquered Bactria in 123 BCE and established an era with epoch at 123 BCE, now called the Old Śaka Era. This epoch has variously been fixed at 88 BCE (Konow) and 110 BCE (Herzfeld), but, as M.N. Saha has shown, 123 BCE fits into all the circumstantial evidence.

The Śakas used the Greek calendar based on the Metonic cycle in their homeland. This was a nineteen year cycle at whose beginning and end the sun and moon are in the same relative position to each other. When they reached India they adopted Indian culture and Aryanized or Indianized the Greek calendar, producing a Greco-Indian calendar. It replaced the classical 5-yearly cycle and it circulated in India up to ca. AD 200. The Kuṣāṇas, another Śaka tribe, penetrated further inside India, adopting Indian culture and using this calendar. Kings of the Śaka and Kuṣāṇa dynasties left behind some inscriptions bearing dates. These always refer to an era, as in era of king Kaṇiṣka. Further, they contain a mysterious expression – *etaye purvam* – whose meaning has not been deciphered.

The Indian form of the calendar is that the months are full moon ending; the 19-year cycle begins from a full moon at the autumnal equinox in the month Kārtika; months are assigned Sanskrit or Sanskritized Greek names; and, in special cases, the day is designated by the moon's *nakṣatra* on that day. The Greek form is that days are designated by ordinal numbers and not by *tithis*, and intercalation is made at the middle of the year in Chaitra.

All these features are fully reflected in the inscriptions of the Kuṣāṇa kings. For example, present researches have shown that Kaṇiṣka established his era in AD 78 after deleting the 100th place in the old Śaka era for that year.

Now, 123 + 78 = 201 = 1, deleting the hundredth place. Hence, AD 78 = 1 Kaṇiṣka era (current) and 0 Kaṇiṣka era (elapsed).

We interpret *etaye purvam* as elapsed year, and accordingly the Julian equivalent of Kaṇiṣka era in these inscriptions is:

AD 78 = 0 Kaṇiṣka era.

The day of the month can also be identified with the *tithi* with tolerable accuracy. We have seen that the moon gains 12° over the sun per *tithi*. In case of new-moon-ending months, we should expect, on 20th Āṣāḍha:

Moon – sun = 20 × 12° = 240° (near about)
or sun = moon – 240°.

If the moon is near *Uttara Phalguni* (tropical longitude in AD 90 = 144°46′), we should have: sun = 144°46′ – 240° = 265° (say), so that the sun's position comes near the winter solstice, which cannot happen in Āṣāḍha. However, if the month is full-moon-ending, then the moon–sun = 5 × 12° = 60°, or sun = moon – 60° = 144°46′−60° = 85° (say), i.e., near the summer solstice, which indeed happens in Āṣāḍha.

If we compute the mean tropical longitude of the sun (L) and mean elongation of the moon in days (D), we get:

Date	L	D
June 21, AD 90	87°.16	4.81

These lunisolar positions are in complete agreement with the inscriptional dates. We may perhaps identify these dates as Julian equivalents of the inscriptional dates. Using this scale we can decipher all the other dates in the inscriptions of the Kuṣāṇa kings and use the same method to decipher the dates of the old Śaka Era.

This second phase was short-lived, but had far-reaching effects on the later Indian calendar. In fact, this was perhaps the most productive period in Indian calendrical history.

This Greco-Indian calendar was discontinued after the fall of the Kuṣāṇa empire.

In the third phase, the Indian calendar was thoroughly revised. New calendrical elements were introduced, new techniques in computational works were formulated, and the application of cycles for intercalation was abandoned. The new calendar that emerged is called the Siddhāntic calendar. This calendar was perfected by later Indian astronomers and is still used all over India with some marginal changes in some regions. In this phase the solar zodiac with 12 signs was introduced. The *nakṣatra* division was recast so that the first arc-division, renamed *Aśvinī*, began from the first sign *Meṣa* (Aries). This common point was the vernal equinox. By AD 550, the vernal equinox shifted to *zeta Piscium*, and this star (or a point very close to it) has since been the beginning of the Indian zodiac.

The new technique for computations was that an epoch, *Kaliyuga*, was formulated such that all the luminaries, like the sun, moon, and planets, were assumed to be in conjunction at the initial point of the zodiac at this epoch. Sidereal motions of the luminaries were so assigned that each of them made an integral number of revolutions in a period of 4,320,000 years (see Table 1).

Calendars in India. Table 1 In a period of 4,320,000 years

	Āryabhaṭa	***Sūryasiddānta***
Sidereal revolution of the sun	4,320,000	4,320,000
Sidereal revolution of the moon	57,753,336	57,753,336
Sidereal revolution of Jupiter	364,224	364,220
Total civil days	1,577,917,500	1,577,917,828
Intercalary lunations	1,593,336	1,593,336
Omitted *tithis*	25,082,580	25,082,252

Astronomical parameters in this phase were not uniform in different schools. We cite below some calendrical parameters from the Āryabhaṭian school (AD 476) and the *Sūryasiddhānta* school of the tenth century.

For any day in question, elapsed days from *Kali* are computed from the above figures, and from the rates of sidereal motion of the luminaries their positions are found in the zodiac. The epoch of *Kali* was computed by Bentley at 18th February, 3102 BCE midnight at Ujjain (longitude 75°45′ east). This date has been generally accepted by all astronomers.

Āryabhaṭa formulated corrections of mean motions of the luminaries, but such formulations are not found in earlier works. Our presumption is that only mean motions were considered in the pre-Āryabhaṭian period.

In this revised calendar, the luni-solar year begins from the new moon just preceding the sun's entry to the initial point in the spring month *Chaitra*. Now, 12 lunations fall short of 10.8 days from a sidereal year, and this accumulates to one lunation in 2 or 3 years. Whenever such an extra lunation forms, it is intercalated in the year; there is no role of any cycle here. This luni-solar year, with days designated by the *tithi* of the day, is used all over India for religious purposes.

A solar year is also devised beginning from the sun's entry into the first sign *Meṣa*, and is divided into 12 solar months, each month being the period the sun stays in a sign. Days of solar months are designated by ordinal numbers. The first month is *Vaiśākha*. Datings are recorded by luni-solar year in some regions, and by solar year elsewhere. The era generally used is the Kaṇiṣka era renamed the Śaka era.

In a year containing 12 lunations, the 12 new moons will, most generally, be distributed over the 12 signs, i.e., each sign will contain a new moon. However, in an intercalary year when 13 lunations are distributed over 12 signs, two new moons must occur in one sign, and in extreme cases, one sign may not contain any new moon at all. Such situations are natural phenomena and are no problem for astronomers.

Out of the 13 lunations occurring in an intercalated year, any one may be earmarked as the extra month. However, metaphysics has taken a toll here. As one sign will contain two new moons, so two lunations, one from each new moon, will occur in that sign. One lunation out of these two has to be selected as the intercalary one. Volumes of religious literature have been written, perhaps more voluminous than their astronomical counterparts, on which lunation is the proper one and which is the intercalary one. Similarly, when a sign becomes void of a new moon, religious literature is controversial as to which lunation is to be assigned to that sign. Almost every region of India has its own convention on these points.

See also: ►Astronomy, ►Lunar Mansions, ►Astrology

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Calendars in Islam

Mohammad Ilyas

Even the most ancient peoples considered the day the earliest unit of time-telling. However, the day is not convenient for long intervals of time. Even allowing for a primitive lifespan of 36 years, a person would live some 13,500 days, and it is very easy to lose track of some of those.

It seems natural to turn to the Earth's next most prominent body, the moon, for another unit. Here, the readymade period of the lunar phases provides the natural unit called the *lunar month*. The lunar month is approximately 29.5 days (more exactly 29.5306 or 29:12:2.8). In pre-agricultural times, the month provided a convenient and simple method for measuring moderately long periods of time. A lifetime of something like 400 months is a more convenient figure than 13,500 days. Lunar months united to the seasons, as they would have been initially, would produce some problems for a settled agricultural society, which is not the case for a hunting or herding society of nomads, who could wander more freely in search of grain or grass. Farmers not only had to stay where they were, but also needed to increase their chances of a good harvest by sowing at a proper time to take advantage of seasonal rains and seasonal warmth. Therefore, to keep the lunar months approximately seasonal, an intercalary month needed to be added in seven of each 19-year cycle (19 solar years = 235 lunar months, i.e. 19 lunar years of 12 months each, +7 lunar months). In due course, the practice of intercalation was gradually perfected; the intercalary months came to be added in the third, sixth, eighth, eleventh, fourteenth, seventeenth, and nineteenth year of each cycle, in a popular scheme which transformed the lunar calendar into a seasonal, or lunisolar calendar, in which a month remained in pace with the sun to within 20 days.

The lunisolar calendar practice was adopted by the Hebrews, Greeks, and Romans and remains in use in the Jewish, Hindu, and Chinese calendars of today. The early Christians continued to use the Jewish (lunisolar) calendar tied to the new moon for more than three centuries and established the day of Easter on that basis. On the other hand, the Roman Republic, which had also used a lunisolar calendar for a long period, moved to a purely solar calendar in 46 BCE as a result of abuse of power by Pontiffs in the matter of intercalation.

Julius Caesar decided to put an end to this chaotic situation by introducing the solar calendar system. In this transformation, 46 BCE was allowed to continue for 445 days (!) and came to be known as "The Year of Confusion", in effect the last one. The adopted solar calendar with a year length of 365.25 days became known as the Julian calendar.

The month, being tied to the moon, begins at a fixed phase in the lunar calendrical system. Since any phase will do, the month can begin at each full moon, the first quarter, etc. However, the obvious way is to begin each month with the new moon – on the evening when the growing crescent first becomes visible immediately after sunset. Practically all lunar calendars began their new months with the new visible crescent. Some modern users of the lunar calendar (the Chinese and Jews) have changed this to the astronomical new moon, i.e. the conjunction, while Muslims maintain the first visible phase of the new crescent as the beginning of a new month.

The Islamic calendar was both a religious as well as a civil calendar, necessary to determine periods of the annual month-long fast, pilgrimages, times of marriage and divorce, years of taxes on wealth for the needy, religious observances, and general and historical timekeeping.

In Arabia, the use of a lunar calendar is known to have existed from very early times. The original practice is believed to have been to use 12 lunar months to a year. On the pre-Islamic Arab calendar, the annual Pilgrimage (*Ḥajj*) to *Kaʿbah* in Mecca was a most significant and important event. Although the event of the pilgrimage to *Kaʿbah* was basically religious, it was also important for trade and business. When the *Ḥajj* was out of season, it created difficulties in procuring the crops and sacrificial animals for trade and use. To overcome this, the Arabs in Mecca are believed to have introduced a system of intercalation known as *al-Naasi*. A Meccan by the name of Qalmas is reported to be the first person assigned this task who, during each pilgrimage, would announce the dates for the coming years' *Ḥajj* and inform whether the intercalation was due for the coming *Ḥajj* season.

In addition to the month of *Dhu'l-Hijjah* (in which the pilgrimage is held), three other months (*Rajab*, *Shawwal*, and *Thu'I Qa'dah*) were sacred to the pre-Islamic Arabs. During these months, certain things, such as wars with opponents, were forbidden. In time, the practice of intercalation was much abused (as with the Roman calendar) thus affecting the sacred months and the related prohibitions by changing a sacred month into a non-sacred one.

The calendar in use in Medina (North of Mecca) remained in the original "twelve months to a year" form. The early Muslims continued to use the Meccan calendar while in Mecca, but shifted to the *Medinan* calendar after the Prophet Muḥammad and his companions migrated to Medina in AD 622. Following the conquest of Mecca in the eighth year of *Hijrah* (December AD 629), the Muslims continued to use the Medinan calendar, and the *Meccan* calendar ran parallel.

However, during the Prophet Muḥammad's last pilgrimage in the tenth year of *Hijrah* (AD 632), the Meccan practice of intercalation was abolished through a Quranic injunction, thus reverting the Arab-Islamic calendar to the simple "twelve months to a year" practice.

The Islamic calendar also required that the beginning of a month be based on the first sighting. This was particularly important for religious events like the beginning and end of the fasting month and the date of the pilgrimage to the *Kaᶜbah*.

There was no commonly accepted permanent calendar in pre-Islamic Arabia. Nevertheless, the custom of counting years was, in one form or another, prevalent among the Arabs and their neighbours. Opinions are divided as to the origin of this practice. According to Ibn al-Jazwī, it dates from the time when the children of the prophet Adam multiplied and spread on earth. In South Arabia, a calendar system originated in 115 or 109 BCE when the Himyarites adopted one using the regins of the Tubba as the epoch years of their era. The inhabitants of Sanaa (Yemen) also adopted a calendar, using the victory over the Yemen by the Abyssinians, and later, the Persian conquest.

The origin of a chronology of events in North Arabia may be traced as far back as the construction of the *Kaᶜbah* by the prophet Abraham and his son the prophet Ismail. The northern Arabians are also reported to have their famous battle days as marking epochs of eras. A local calendar is supposed to have existed in Medina also. Al-Masudi maintains that the people of Medina used the dates of their castles and palaces as their local calendar at the time of the prophet Muḥammad's migration, but others reject this, claiming the adoption of an era by the people of Medina to a month or two after the prophet's arrival, which continued until his death in AD 632. According to a widely held view, the *Hijrah* era was set up at the time of Caliph ᶜUmar ibn Khattab in AD 637/638, i.e. about 5 or 6 years after the introduction of the purely lunar calendar. After many consultations, the year of the prophet Muḥammad's *Hijrah* was accepted for the beginning of the Islamic (or *Hijrah*) calendar.

Based on scientific understanding, certain ground rules were laid down which form the part of *sharīᶜah* (the Islamic legal system) governing the calendar. Some of these were:

1. The length of a month should be 29 or 30 days.
2. The length of a year should be 354 or 355 days.
3. The maximum number of consecutive 30-day months is 4; the maximum number of consecutive 29-day months is 3.

4a. Each new month begins with the first light of the new crescent moon visible on the western horizon after sunset.
4b. One should try sighting the new moon on the 29th day of the month, but if it cannot be seen (even due to clouds), complete the month as of 30 days.
4c. The visual sighting report must be corroborated by a witness.
4d. The persons involved in the reporting must be reliable, adult, truthful, and sane, with good eyesight (implied). They are punished if proved to be purposely misleading.
4e. The visual sighting report should not conflict with basic scientific understanding and natural laws. Indeed, professional scientists' involvement is essential to ascertain the reliability of the reported sighting, and the scientific test would include a check on related parameters (e.g. the shape of the crescent, its position and altitude, time of observation, sky conditions).
4f. The sighting must be carried out in an organized way every month.

Sharīᶜah also allows for the correction of a mistake. If on the 28th day of an Islamic month, the new moon has been sighted, a correction will be made to the beginning of the month, since a month should have only 29 or 30 days. If the month concerned is *Ramaḍan* then an extra fast would have to be completed after Eid celebrations.

Clearly, earliest visibility of the new moon plays a very critical role in Islamic calendar regulation. The Islamic "State" placed special emphasis on astronomy research, and it became a standard element in formal religious and legal education. The early Muslim community, based under the clear skies of Arabia and assisted by State-sponsored research, had no serious problems in following these injunctions to regulate their calendar. Muslims contributed enormously to the development of the science of the new Moon's earliest visibility and its advance prediction for greatly varying geo-environmental situations. In this, they built upon the work of earlier researchers as well (e.g. Babylonians, Hindus, Jews). Besides the rigorous science, simple schemes were devised to construct long-term calendars especially to interconvert Islamic dates with Christian and other lunisolar calendrical dates. Based on technical information, one of the simple schemes (known as the schematic or *Istalahi* system) involved a cycle of 30 lunar years in which months approximately alternate between 29 and 30 days and 11 years consist of 355 days, the rest 354.

Backed by extensive research, Muslim scientists developed visibility tables and produced many reference works. All were well when astronomy and scientific endeavour were at their zenith in the Muslim lands.

Scientific interest in predicting the time of the first (earliest) new Moon sighting (for a clear sky) goes back to a period at least as early as the Babylonian era. Based on careful observational data, a simple criterion was developed and passed on to the Muslims through the Hindus, apparently with very little further improvement. This problem was thoroughly investigated by the early Muslim astronomers in the eight to tenth centuries AD and included such notable persons as Ḥabash al-Ḥāsib and al-Battānī. The physics-based system(s), developed up to the eleventh century, saw very little further development until more recent times, when improvements were made. There has also been a series of simpler criteria involving time difference (lag) between moonset and sunset and the "age" of the moon.

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Calendars in Mesoamerica

Tom Jones

For many reasonably educated persons, the greatest single achievement of ancient Mesoamerica was the Maya calendar. In fact, a calendar was in use throughout Middle America, but it is its Maya form that has captured the world's imagination, the claim often being made that its accuracy exceeded that of the calendar in use in Europe at the time of the Conquest and, by some, even of that which we use today. While most of their neighbors kept account of time with three periods of differing numbers of days, the combinations of which formed a repeating calendar of 18,980 days, the Maya employed a mechanism that synchronized these same periods and others of their own making with a system that tracked cumulative time.

This cumulative record, or Long Count, expressed historical dates with five-place numbers that recorded days accumulated from an arbitrary zero-point which has been determined to correspond to August 13, 3114 BCE in our present Gregorian calendar. (The correlation of Maya dates to European are to the no-zero-year Gregorian calendar, employing Thompson's 1935 correlation of 584,285 days.) Accumulating 1-day (*k'in*), 20-day (*winal*), and 360-day (*tun*) periods, the Long Count employed a qualified vigesimal (20-base) place-number system – the qualification being an 18-base for the third place. The names and values of the Long Count places, from the unit up, were expressed in the writing system with distinct hieroglyphs for each order of magnitude (Fig. 1).

Thus, for example, a Long Count date with the numerical value of *9 bak'tunob, 8 k'atunob, 9 tunob, 13 winalob,* and *0 k'inob* records a day that was 1,357,100 days after August 13, 3114 BCE, which is to say March 26, 603. These values were communicated by positioning the numbers as prefixes or superfixes of the glyphs for the periods. The *-ob* inflection of Mayan nouns indicates plural. Because double digits are often required to express decimal equivalents of numbers in the places of the Maya system, Mayanists have adopted the convention of inserting periods between the places of Long Count dates. The above date, for example, is written 9.8.9.13.0. Though Maya historical dates that employed the Long Count were generally limited to five places, the calendrical system itself was open-ended

PLACE	NAME	DAYS	CALC	VALUE	GLYPHS
1	*K'in*	1 day	(1 X 1)	1 *K'in*	
2	*Winal*	20 days	(20 X 1)	20 *K'inob*	
3	*Tun*	360 days	(18 X 20)	18 *Winalob*	
4	*K'atun*	7200 days	(20 X 360)	20 *K'atunob*	
5	*Bak'tun*	144,000 days	(20 X 7200)	20 *Bak'tunob*	

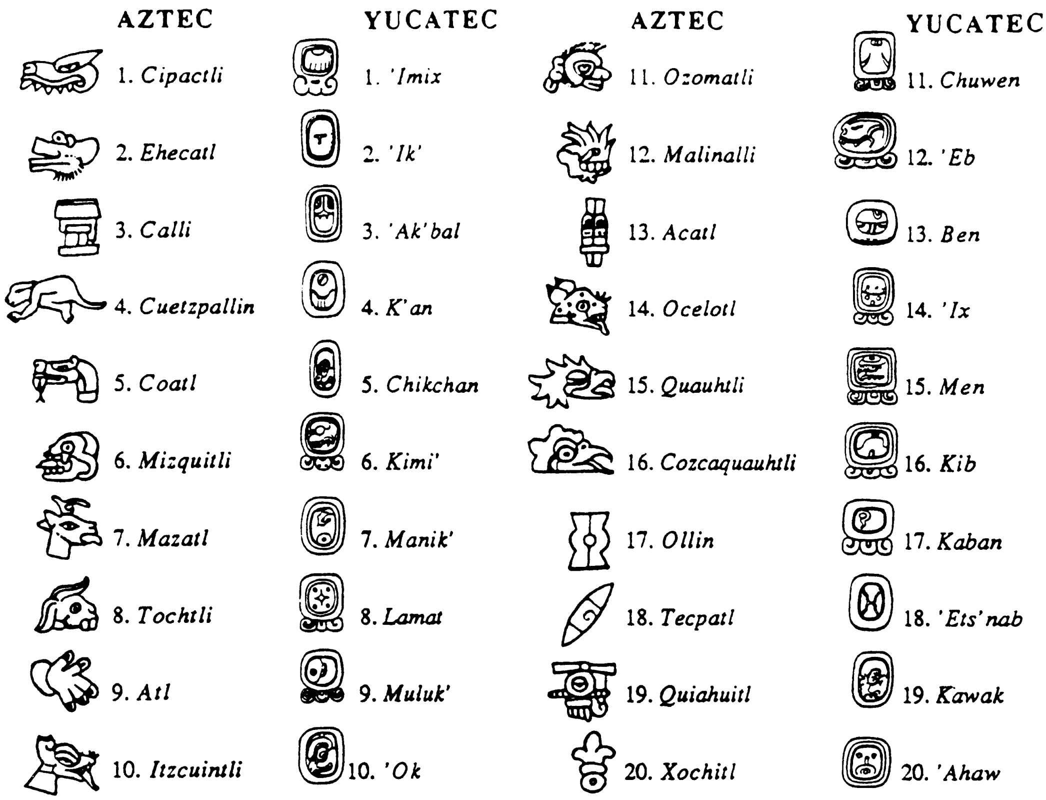
Calendars in Mesoamerica. Fig. 1 The names and values of the Long Count places with their respective glyphs. [Drawings by the author]

and, when called upon to do so (as to meet mythological needs) could accommodate any number of places and express any full number of days. The greatest known to have survived is recorded at Coba as 13.13.13.13.13.13.13.13.13.13.13.13.13.13.0.0.0.0, which expressed in our decimal-system amounts to almost 22 quintillion tropical years!

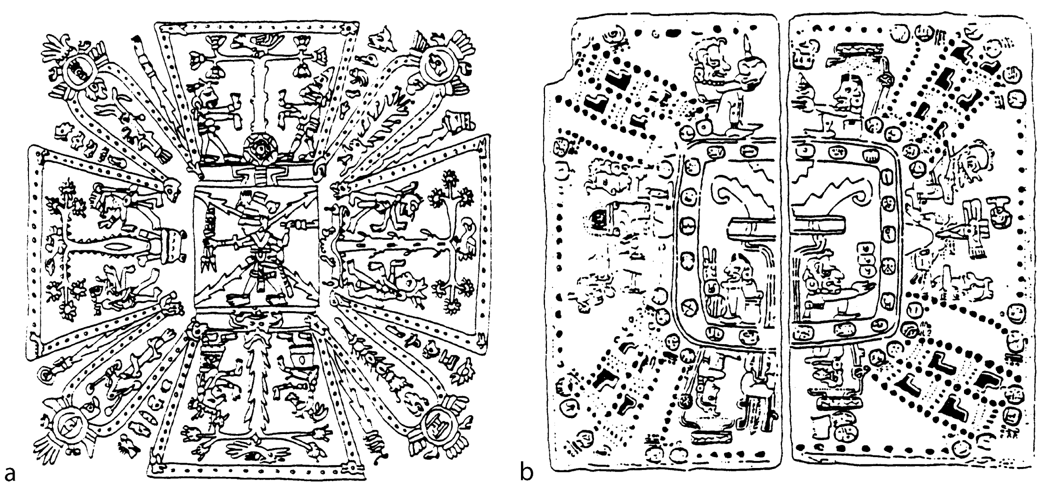
Long Count dates were carved on monuments in the Maya heartland for over 600 years, the earliest known being 8.12.14.8.15 (8 July 292), the latest 10.4.0.0.0. (20 January 909). Moreover, the *Dresden Codex* records the much later date, 10.17.13.12.12 (29 October 1178). Though extensively used by the Maya, the Long Count was probably not their invention. Earlier Long Count dates have survived on several monuments on the southwestern Maya periphery – the earliest, 7.16.3.2.12 (7 December 36 BCE), at Chiapa de Corzo – in what was probably a proto-Zoquean (non-Mayan) speaking area.

The Maya coordinated this cumulative Long Count with the pan-Mesoamerican repeating calendar of 18,980 days. Known generally as the Calendar Round and called the *xiuhmolpilli* by the Aztecs and *hunab* by the Maya, this period consisted of three component cycles of 13, 20, and 365 days. The first two of these were a set of consecutive day-numbers (1–13) and a set of 20 day-names specific to each of some 60 language-groups within Mesoamerica (Fig. 2). The permutations of the 13 numbers and 20 names designated each passing day with a combination that repeated every 260 (13 × 20) days. This resulting 260-day period was termed the *tonalpohualli* by the Aztecs and is called the *tsolk'in* by Mayanists. Mesoamericans visualized this period as a four-sided cosmogram (Fig. 3) that can be described as a "Maltese" cross (the broad arms of which are identified in a counterclockwise order as East, North, West, and South) superimposed over a "St. Andrew's" cross (the narrow arms of which define the diagonal directions Northeast, Northwest, Southeast, and Southwest). The eight projecting arms of this scheme are each comprised of 13 days proceeding out from the center and 13 more returning, with the four outer edges of the "Maltese" arms also each contributing 13 to complete the round of 260 days. This 260-day *tonalpohualli* was the most significant aspect of the calendar for the daily life of the typical Mesoamerican. It formed the basis of numerous rituals, character evaluations, omens, and prognostications, traced out in Aztec, Mixtec, and Maya books.

While the 260-day ritual period seems to have been the result of the combination of a cultural fascination with the number 13 and a vigesimal counting system derived from the number of digits of the hands and feet, the 365-day period – the Maya *haab* or Aztec *xihuitl* – to which we now turn, was an attempt at a full-number approximation of the tropical year (of 365.2422 days, as calculated today). This "vague year" was achieved by a set of 18 named periods of 20 consecutively numbered days each, and five extra consecutively numbered terminal days (*Nemontemi* in Aztec, *Wayeb* in Maya) to total 365 days (18 × 20 + 5) (Fig. 4). Every day, then, could be expressed with a day-number, a day-name and a numbered position in one of the periods of the "vague year." The workings of this Calendar Round system are well illustrated by comparing the modes of expressing succeeding dates that include the five terminal days of the vague year in the Aztec *xiuhmolpilli* and Maya *hunab* (Fig. 5). The presence of these 5 days causes the position of any given *tsolk 'in* day to drop back by 5 days with each



Calendars in Mesoamerica. Fig. 2 The twenty Aztec (Nahuatl) and Yucatec (Mayan) day-names and signs. [Drawings by the author]



Calendars in Mesoamerica. Fig. 3 The 260-day period as Portrayed by the (a) Aztecs in the *Fejervary-Mayer Codex* and (b) Maya in the *Madrid Codex.*

successive vague year. Because 260 and 365 share a common denominator of 5, any specific combination of day-number, day-name, and vague year position repeats every 18,980 days (260 × 365 − 5 = 18,980), or about 13 days short of 52 tropical years. As with the Long Count, evidence for the origins of the Calendar Round lies beyond the western pale of the Maya, dating from as early as the sixth century BCE in the Zapotec region.

The *xiuhmolpilli* was of particular importance to the Aztecs, whose mythology claimed that the age in which they lived and in which the current Sun-God, *Tonatiuh*,

YUCATEC	AZTEC	YUCATEC	AZTEC
1. *Pop*	1. *Tlaxochimaco*	10. *Yax*	10. *Izcalli*
2. *Wo'*	2. *Xocotlhuetzi*	11. *Sak*	11. *Atlcahualo*
3. *Sip*	3. *Ochpaniztli*	12. *Keh*	12. *Tlacaxipehualiztli*
4. *Sots*	4. *Teotleco*	13. *Mak*	13. *Tozoztontli*
5. *Sek*	5. *Tepeilhuitl*	14. *K'ank'in*	14. *Hueytozoztl*
6. *Xul*	6. *Quecholli*	15. *Muwan*	15. *Toxcatli*
7. *Yaxk'in*	7. *Penquetzaliztli*	16. *Pax*	16. *Etzalcualiztl*
8. *Mol*	8. *Atemoztli*	17. *K'ayab*	17. *Tecuilhuitontlii*
9. *Ch'en*	9. *Tititl*	18. *Kumk'uh*	18. *Hueytecuilhuitl*
		Wayeb	*Nemontemi*

Calendars in Mesoamerica. Fig. 4 The eighteen 20-day periods and final five days of the Aztec *xihuitl* and Maya *haab*.

AZTEC		MAYA	
XIUHMOLPILLI		***HUNAB***	
TONALPOHUALLI	***XIHUITL***	***TSOL K'IN***	***HAAB***
1. *1 Cipactli*	*14 Huetecuilhuitl*	1. *1 'Imix*	*14 Kumk'u*
2. *2 Ehecatl*	*15 Huetecuilhuitl*	2. *2 'Ik'*	*15 Kumk'u*
3. *3 Calli*	*16 Huetecuilhuitl*	3. *3 'Ak'bal*	*16 Kumk'u*
4. *4 Cuetzpallin*	*17 Huetecuilhuitl*	4. *4 K'an*	*17 Kumk'u*
5. *5 Coatl*	*18 Huetecuilhuitl*	5. *5 Chikchan*	*18 Kumk'u*
6. *6 Mizquitli*	*19 Huetecuilhuitl*	6. *6 Kimi*	*19 Kumk'u*
7. *7 Mazatl*	*20 Huetecuilhuitl*	7. *7 Manik'*	*20 Kumk'u (0 Wayeb)*
8. *8 Tochtli*	*1 Nemontemi*	8. *8 Lamat*	*1 Wayeb*
9. *9 Atl*	*2 Nemontemi*	9. *9 Muluk*	*2 Wayeb*
10. *10 Itzcuintli*	*3 Nemontemi*	10. *10 'Ok*	*3 Wayeb*
11. *11 Ozomatli*	*4 Nemontemi*	11. *11 Chuwen*	*4 Wayeb*
12. *12 Malinalli*	*5 Nemontemi*	12. *12 'Eb*	*5 Wayeb (0 Pop)*
13. *13 Acatl*	*1 Tlaxochimaco*	13. *13 Ben*	*1 Pop*
14. *1 Ocelotl*	*2 Tlaxochimaco*	14. *1 'Ix*	*2 Pop*
15. *2 Quauhtli*	*3 Tlaxochimaco*	15. *2 Men*	*3 Pop*
16. *3 Cozcaquauhtli*	*4 Tlaxochimaco*	16. *3 Kib*	*4 Pop*
17. *4 Ollin*	*5 Tlaxochimaco*	17. *4 Kaban*	*5 Pop*
18. *5 Tecpatl*	*6 Tlaxochimaco*	18. *5 'Ets'nab*	*6 Pop*
19. *6 Quiahuitl*	*7 Tlaxochimaco*	19. *6 Kawak*	*7 Pop*
20. *7 Xochitl*	*8 Tlaxochimaco*	20. *7 'Ahaw*	*8 Pop*
21. *8 Cipactli*	*9 Tlaxochimaco*	21. *8 'Imix*	*9 Pop*
22. *9 Ehecatl*	*10 Tlaxochimaco*	22. *9 'Ik'*	*10 Pop*
23. *10 Calli*	*11 Tlaxochimaco*	23. *10 'Ak'bal*	*11 Pop*
24. *11 Cuetzpallin*	*12 Tlaxochimaco*	24. *11 K'an*	*12 Pop*
25. *12 Coatl*	*13 Tlaxochimaco*	25. *12 Chikchan*	*13 Pop*

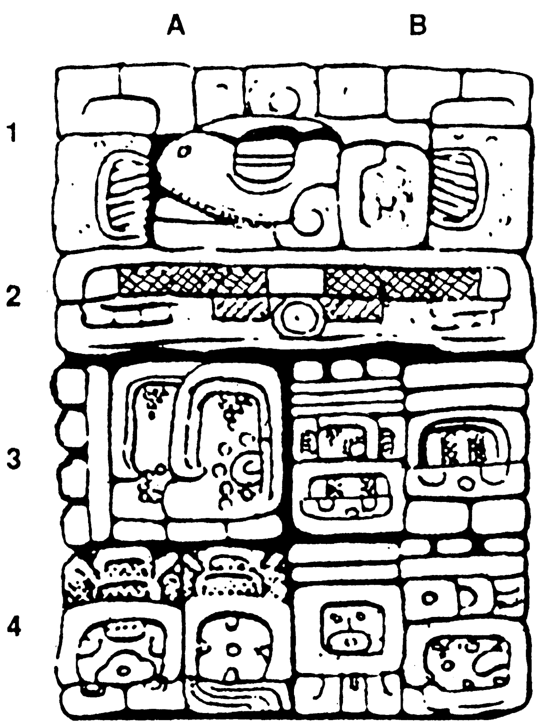
Calendars in Mesoamerica. Fig. 5 The succession of 25 Calender Round dates that pass through the five terminal days of the *xihuitl* of the Aztec *xiuhmolpilli* and the *haab* of the Maya hunab.

reigned was preceded by four earlier ages, each with its own sun and each of which had been destroyed in its own way – the first by devouring jaguars, the second by winds, the third by a rain of fire and the fourth by a world-flood. During this fifth era, under *Tonatiuh*, the future seems to have been doled out to the Aztecs one *xiuhmolpilli* at a time. Each successive *xiuhmolpilli* had to be freshly solicited by a great deal of bloodletting and an elaborate "New Fire" ceremony that was carried out during the five *Nemontemi* days of each 52 *xihuitl*. If, following the ceremony, the stars continued on their steady march across the midnight-sky of the last day of the *xiuhmolpilli* – presumably because the gods had found the ritual to their satisfaction – the people could be assured that another 52 "years" had been granted them.

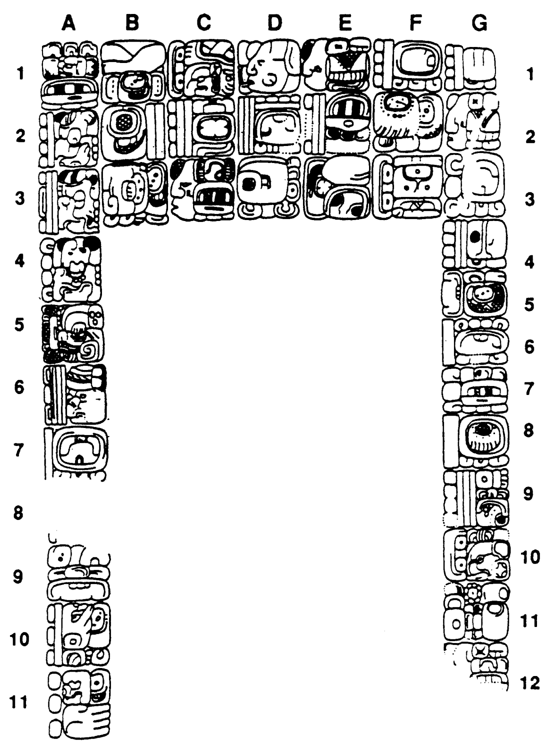
In the Maya region, this endlessly repeating pan-Mesoamerican cycle was synchronized with the accumulated days of the Long Count as the mathematical consequence of the arbitrary assignment of the Calendar Round date *4 ʻAhaw 8 Kumk'u* to the Long Count zero-date (13 August 3114 BCE). Written out in full and preceded by a distinctive hieroglyph that served to introduce them, dates so synchronized stood at the very beginning of the hieroglyphic texts on the carved monuments of Mayadom – whence their designation, Initial Series dates. To take an example, the Initial Series date on Quirigua Stela I (Fig. 6) – which reads in typical Maya fashion, from top-left to bottom-right, two columns at a time – displays a large initial series introductory glyph (ISIG) in the initial position (Al–B2) followed by the Long Count *9.18.10.0.0* (A3–A4) and the Calendar Round *10′ Ahaw 8 Sak* (B4), establishing a date corresponding to August 19, 800. (Glyphs are conventionally located by assigning upper-case letters to the columns of a text, numbers to its rows, and lower-case letters to divisions within the glyph-blocks and designating them in that order, as A3, C2a, F7b, etc. Number–values are dots for 1, bars for 5, and various special symbols for 0.

At times, supplementary to the Long Count and Calendar Round and inserted parenthetically between the *tsolk'in* and *haab* entries, were glyphs that recorded additional cycles of 7 or 9 days duration, as well as certain lunar information. Supplementing the cycles mentioned, the Maya tracked one of 819 days – a product of three basic periods (7 × 9 × 13) – relating it to a 4-day cycle (which the Aztecs also recognized) that linked each day with one of the four cardinal directions and associated colors (East, red; North, white; West, black; South, white). On Piedras Negras Stela 1 (Fig. 7), for example, the ISIG (A1) is followed by the Long Count *9.12.2.0.16* (A2–A6) and the *tsolk'in* position *5 Kib* (A7), while the *haab* position, *14 Yaxk'in*, does not appear until eight glyph-blocks later (C2). The intervening blocks include two that record the seventh position of the 9-day cycle (A8–A9), one that records the moon's age as 8 days (A10), another the moon's number as third in a set of six (A11), two that name the moon (B1–C1), and one that identifies it as a 31 month (B2). Following *14 Yaxk'in* are four noncalendrical glyphs (B3–E1) describing the event of the Initial Series date (July 7, 674).

When there was a need to record multiple dates, each new one (expressed as a Calendar Round date) was typically linked to its predecessor by what scholars call a Distance Number. The Distance Number employed



Calendars in Mesoamerica. Fig. 6 Quirigua, Stela I: hieroglyphic text with Initial Series date. [Drawing after Annie Hunter.] From *Biologia Centrali-Americana*, by Alfred P. Maudlsay, reprinted in 1974 by Milpatron publishing corp. used with permission of the publisher.



Calendars in Mesoamerica. Fig. 7 Piedras Negras, Stela 1: heiroglyphic text. [Drawing by John Montgomery.]

the same place system as the Long Count, but because the number of days to be recorded usually did not require all five places, they were entered in the reverse order of the Long Count – commencing with *k'inob* and proceeding only through those higher places necessary to record the distance. Thus on the Piedras Negras stela, following the initial event, come two glyphs that record the Distance Number *15 k'inob, 9 winalob*, and *12 tunob* (D2–E2), then two more that indicate an advance of that distance forward in time (D3–E3), and finally, two glyphs that record the Calendar Round date, *9 Chuwen 9 K'ank'in*. The calendrical mathematics are:

9.12. 2. 0. 16	*5 Kib*	*14 Yaxk'in*	(July 7, 674)
+12. 9. 15			
9. 12. 14. 10. 11	*9 Chuwen*	*9 K'ank'in*	(November 16, 686)

After two noncalendrical glyphs (F2–G2) that describe the event of the date so reached, come a second Distance Number, *5 k'inob* (F3), and the resulting third Calendar Round date, *1 Kib 14 K'ank'in* (G3–G4). The mathematics are:

9.12. 14. 10. 11	*9 Chuwen*	*9 K'ank'in*	(November 16, 686)
+5			
9. 12. 14. 10. 16	*1 Kib*	*14 K'an-k'in*	(November 21, 686)

This new date is followed by the single glyph that describes the event (G5). Then come the Distance Number, *5 k'inob, 2 winalob*, and *1 k'atun* (G6–G7), a fourth Calendar Round date, *5 Imix 19 Sak* (G8–G9), and fourth event (G10–G12). This final calculation is:

9. 12. 14. 10. 16	*1 Kib*	*14 K'ank'in*	(November 21, 686)
+1. 0. 2. 5.			
9. 13. 14. 13. 1	*1 Imix*	*19 Sak*	(September 23, 706)

As was the case for the second of these two monuments, the Maya often accompanied their calendrical entries with lunar data. From this propensity and from the structure of a Lunar Table in the *Dresden Codex*, it is clear that their concern was to anticipate eclipse-possible dates. Because eclipses (both lunar and solar) can only take place during a period of 18 days on either side of node-passage of the Moon over the path of the Sun, which occurs twice during a tropical year, the Maya grouped the months in semesters of six (and for corrective purposes, occasionally of five). In an attempt to approximate the Moon's 29.53059-day synodic period (as calculated today), they ascribed 29 and 30 days, alternately, to successive months, compensating for the gradual accumulation of excess time by introducing an extra 30-day month at predetermined intervals. One result was the *Dresden Codex* Lunar Table with its eclipse-period of 11,960 days, or just over 405 complete lunations. However, that excess time would be allowed to accumulate until after eight repetitions of the period (95,680 days), when the table could be adjusted to correspond more closely to the moon's position by subtracting 1 day. The mathematics behind this adjustment are: 29.53059 × 405 = 11,959.88895; 11,960 – 11,959.88895 = 0.11105; 11,960 × 8 = 95,680; 11,959.88895 × 8 = 95,679.116; 95,680 – 95,679.116 = 0.884, or 21.216 h. To further refine the Lunar Table's use, follow-up adjustments had to be made with succeeding repetitions of the cycle.

Though not central to the calendar itself, the planet Venus was nevertheless also a concern of Maya calendrical savants. Observations and calculations recorded in the inscribed monuments show that the Maya employed a 584-day period to predict culturally important points in the planet's synodic period. Both the Maya and the Aztecs assigned numerological significance to the correspondence between five of these Venus-periods and eight *haabs* (5 × 584 = 2,920; 8 × 365 = 2,920). Also, in the *Dresden Codex* is an elaborate table that consists of 13 sets of five periods of 584 days, or 37,960 days. Here again, because of the discrepancy between the full number 584 and the actual synodic period of Venus (583.97 days, by modern measurements) and because of the added cultural requirement that the first heliacal rising of the planet should occur on the *tsolk'in* date *1'Ahaw*, an adjustment like that in the Lunar Table had to be made after several runs of the Venus Table.

The Mesoamerican calendar, if by no means invented by the Maya, nevertheless reached its most elaborate form at their hands. Tracking basic periods of 4, 7, 9, 13, 20, 365, and 584 days and greater periods that were the products of various combinations or lowest common multiples thereof – 260(13 × 20), 819 (7 × 9 × 13), 2,920 (8 × 365; 5 × 584), 3,276 (4 × 7 × 9 × 13), 18,980 (13 × 20 × 365) and 37,960 (13 × 20 × 365 × 2 = 13 × 5 × 584) days – and groupings of months of alternately 29 and 30 days in duration, they synchronized them all with the cumulative and open-ended Long Count that recorded every passing day from its original *4 'Ahaw 8 Kumk'u* zero-point. Where the European calendar intercalated extra days as a device for keeping its dates in close harmony with the seasons (the vernal equinox, for example, occurring always on or about March 22), the Mesoamerican calendar, even in its most refined (Maya) mechanism, simply ground out the 1-day intervals of its several parts, accumulating or repeating them endlessly and without interruption, all of its components creeping gradually backwards through the seasons. It was thus impossible to identify a position in the tropical year by knowing a Calendar Round date. The first *4 'Ahaw 8 Kumk'u* fell on August 13, but the second fell 12 days earlier on August 1 and the third, 12 more on July 19. In the year 265, near the beginning of the Classic Period, after having returned to its original August 13 date 113 times, *4 'Ahaw 8 Kumk'u* fell on May 16, and by the close of the Classic in the late ninth century, it had fallen back to December 15.

However skillfully the Maya may have combined their astronomical observations with calendrical calculations to predict lunar and solar eclipse stations, heliacal risings and settings, conjunctions, stationary points, and retrograde motions of the five visible planets, the fact remains that, for all its reputation, the calendar itself was no more accurate than the 365-day calendar the ancient Egyptians adopted around 4250 BCE which was the product of twelve 30-day months (12 × 30 = 360), plus – like the Mesoamerican *xihuitl* or *haab* – 5 extra days. Indeed, it was an Egyptian mathematician, Sosigenes, who, recognizing the faults of the rigid 365-day year, persuaded Julius Caesar to adopt his scheme for reforming the Roman calendar in 45 BCE, by intercalating an extra day every fourth year into an otherwise 365-day year. However, it would be unhistorical to judge the Maya calendar by a standard set by the Egyptian, the Julian, or the later Gregorian calendar. The cultural need of the Egyptians was to anticipate (for agricultural reasons) the annual flooding of the Nile. That of the Julian reform was to ensure that the Roman solsticial festival *fors fortuna* would fall regularly on June 22. The Christians, in turn, adopted the Julian calendar in 325 at the Council of Nicaea from a need to establish predictable dates for Easter, which – for religious reasons – had to fall on the first Sunday following the first full moon after the vernal equinox. It was this same need that led Pope Gregory XIII to authorize a further reform of the Julian calendar in 1582.

However, the cultural needs met by the Mesoamerican calendar were of a numerological–astrological nature. Quite apart from the divinations of the purely numerical *tsolk'in*, the Maya assigned significance to astronomical predictions based upon complex multiples of their several whole-number cycles which were often linked to the actions of remote or fabled ancestors or mythological supernaturals or to multiples of the never whole-numbered synodic periods of the heavenly bodies. Contrived calendrical calculations into the remote past and distant future were made to establish mythological beginnings, regenerations, and calamities to come. Day-to-day events, even to the timing of military attacks or battles among themselves or surrender to the Spanish, seem to have fallen under this numerological spell. However closely the *Dresden* Venus Table may appear to approach a modern astronomical ephemeris of Venus, its purpose was to return the latter's heliacal rising to *1′Ahaw*, the birth date of the mythological Venus-associated hero, *Hunahpu* – irrespective of any temporary losses in accuracy its mechanisms may have produced. If the calendrical efforts of Mesoamericans can be described as an attempt to bring about a marriage between their whole-number numerology and their perceived rhythms of the Sun, Moon, planets, and stars, it was one in which it was the latter who were to love, honor, and obey. However, if the test of a good marriage is its durability, then the Mesoamerican calendar – particularly in its Maya form – was not only mathematically sophisticated, conceptually elegant, and visually beautiful, but a highly successful one as well.

See also: ►Time, ►Long Count

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Calendars in South America

R. Tom Zuidema

At the time of the Spanish conquest around the year 1530, the Incas had integrated different cultures, all belonging to Andean civilization, into a large empire, stretching from southern Colombia through Ecuador, Peru, and Bolivia, into northern Chile and Argentina. Much can be learned from the art of the Incas and their predecessors, including architecture, stone sculpture, pottery, and textiles. However, we have no access to written records as defined by western culture; understanding intellectual aspects of this civilization is almost exclusively dependent on what informants from Cuzco, the Inca capital in southern Peru, told the Spanish chroniclers. These were most impressed by Inca statecraft, although they were never present when it was still practiced. Their interpretation of Inca religion was heavily influenced by Christian opinions. Religion to them included memories of the Inca past and of state and private rituals related to, for instance, the calendrical organization of agriculture and llama husbandry. As Inca history is discussed in the article on Knowledge Systems of the Incas, this one concentrates on the calendar as it functioned in Cuzco.

Most of our information on the Inca calendar and related astronomical practices derives from only a few chroniclers: Juan de Betanzos [1551],[1] a soldier and the first chronicler to write on this subject in the context of a full account of Inca culture; an anonymous author [ca. 1565] with precise information on the integration of astronomical observations into the calendar; Cristóbal de Molina [1574], a priest with great knowledge of Inca rituals but excluding those for one-third of the year; and Bernabé Cobo [1653], a late Jesuit author who gave our most comprehensive description of Inca culture including the calendar for the whole year. His information probably derives from a now lost account by Juan Polo de Ondegardo [1559], whose own description of the calendar only survives in a much revised short version [1585] for use by Catholic priests. Later chroniclers and dictionaries mostly follow Polo's version and add little information toward a reconstruction of the original Inca calendar. This reconstruction provides very different results from the general picture that the chroniclers present us with.

All chroniclers conceive the Inca calendar as consisting of 12 months. Notwithstanding this agreement, there is much confusion about the nature of the months, their order, and their correspondence to Christian months. Some of this confusion may derive from much local variation among calendars in the empire, but most of the blame is due to Spanish misreporting on the Cuzco calendar itself. Betanzos, Polo, and Cobo describe a system of 12 "months" with a fixed position in the solar year. Molina speaks of "months" *and* "moons" and refers to rituals according to the phases of the moon for three times of the year, roughly corresponding to June, September, and January. Some modern scholars therefore argue that the whole calendar was lunar, but this was not the case (Ziólkowski and Sadowski 1992). On each of the three occasions important lunar rituals were celebrated after an independent solar observation had been made for that time of the year. We have no information on lunar rituals in Cuzco for other times of the year; we can only conclude that the integration of solar and lunar rituals in Peru was done in a way different from Western (Christian, Jewish) presuppositions in this respect.

There are various difficulties in accepting the Inca organization of months according to the Polo version of 1585. For instance, two names are taken together for one month that in other versions refer to separate months; in other calendars a name may be used as an alternative for either one or a next month. In some versions, a month name is suppressed for no apparent reason at all; months were said to be of rather different lengths, either longer or shorter than 30 or 31 days. And the anonymous chronicler mentions for two double-months that the moon observed in one month (either the first or the second) would always reach the other, leaving us to conclude that the fixed double-month was shorter than two movable synodic (lunar) months $(2 \times 29\frac{1}{2} = 59 \text{ days})$. Comparing the various descriptions of the Inca year, it becomes clear that originally it contained 13 and not 12 months and that each version suppressed one or another month name to accommodate this calendar to the Spanish one. It may have been a goal of Catholic missionaries fighting against "pagan" rituals, but there was also Inca consent, realizing the advantages of combining Inca and Catholic celebrations, first openly and later secretly.

From indications by Molina and Cobo we can conclude that the Inca calendar placed one month around the June solstice (21 June), celebrating *Inti Raymi* (feast of the sun), and two months, *Capac Raymi* (royal feast) and *Capac Raymi Camay Quilla* (royal feast, feast of the moon) around the December solstice, which honored the fact that in the southern hemisphere the sun is strongest then. For practical reasons, *Inti Raymi* may have been celebrated not on the days of the June solstice but within its month during the full moon either before or after in a given year. People took advantage of the dry season's clear skies when the moon shone the whole night.

During *Capac Raymi*, considerations were different. While the June solstice marked the middle of a month, the December solstice, six and a half Inca months apart, marked the date separating the two months of *Capac Raymi*. Moreover, these months fell in the middle of the rainy season when normally no good observations of the sun and the moon could be made. The month of *Capac Raymi Camay Quilla* was celebrated, first awaiting the new moon with some celebrations. The major celebrations came with the next full moon and took some 7 days. If the new moon arrived early after the solstice (December 21), all celebrations took some 22 (15 + 7) days; but if it was late, they could take up some 52 (30 + 15 + 7) days. Then the full moon

[1] In case of an old text, square brackets indicate the date of writing or first publication.

celebrations would not occur in *Camay Quilla* but extend into the next month. Although after those days the moon would still be visible late at night, no more attention would be paid. However, the day after these 52 days (February 13) was important for another reason. Then the sun in Cuzco – this city being $13\frac{1}{2}^{\circ}$ south of the equator and within the tropics – passes the zenith point in the sky at noon. Although the chroniclers were only vaguely aware of the importance of this event, Polo indicates that then a new year began, with people preparing for the coming harvest. The sun also passes the zenith 53 days before the December solstice, and we can assume that a similar calendrical calculation was made for this period. The anonymous chronicler considered it as one in which the moon of one month would always reach the other. Its beginning was celebrated with a feast, the *Itu*, which only Inca nobility could attend, and the last 6 days before the December solstice were also important for celebration. These days could begin with a full moon if the new moon had arrived late in this 53 day-period.

Apparently, the Incas divided the time from the first to the second passage of the sun through the zenith (107 days) into four months, of which the central ones of *Capac Raymi* were most important. The average length of the 13 months was about 28 days and as the connection to the length of a synodic month (29 days) was lost, there is no reason that the months could not be of various lengths as reported by the chroniclers. Having established the framework of the Inca calendar, an outline can be given of its ritual organization serving various, often contrasting, social needs.

The calendar organized, first, a multitude of sacrifices (llamas, guinea-pigs, birds, sometimes children) and offerings (mostly cultivated plants). The months were organized according to four seasons of three months and an independent month after the sun's second zenith passage. Sacrifices and offerings expressed the different seasonal concerns.

A quite different organization of the months attended more political interests in terms of tribute due by Inca and non-Inca subjects and of the large feasts of state presented by the king, queen, and high nobility. In this organization, months were brought together in groups of two and then of four. This organization cross cut the seasonal one but kept the same independent month. Our first chroniclers mention how tribute was brought to Cuzco every four months and how non-Inca nobles accompanying these deliveries stayed for the same time in town. Betanzos adds to this that services of labor and distribution of food, especially meat and cloth, followed the same schedule. At first, the colonial administration showed interest in adopting this schedule for its own needs, but after about 1570 it changed to the European custom of having tribute paid twice a year, around Christmas and St John (24 June), and chroniclers no longer paid attention to the earlier system.

I mentioned above the most important four month-period around the December solstice. In between the times of planting and harvest, this was a season when the fields needed less attention and when heavy rainfall made travel difficult. *Capac Raymi* and its preceding month were dedicated to the initiation rituals of noble boys, these being assisted by noble girls who had had their own rituals of first menstruation at other times of the year. In the lunar rituals of *Camay Quilla* and the following month, noble men and women pledged their allegiance to the king, and rains were ritually dismissed awaiting the ripening of the fruits. In the four months around planting, land was first prepared for cultivation, ploughed and planted, and then rituals followed to help the budding plants grow and attract rains. Again, the two central months were dedicated to state rituals. First, the king himself helped with the planting. Keen observations were made of sunset throughout the first month to have the various timings for planting and irrigation of different sorts of plants, at lower, warmer and higher, colder places well orchestrated. In the second month, dedicated to the moon, the queen, and women in general, "evil" and "illnesses" were ritually driven out of town in support of peace among people and of the growth of plants. Finally, the four months of harvest included the early harvest, the general harvest around Cuzco, the reception of foreign lords with their presents and the tribute of their people, and storage. Again the most important ceremonies occurred in the central months when first harvest was ritually brought into town and then the Inca himself ploughed, opening a new agricultural year, and ate with all nobles and foreign lords in the plaza.

Good descriptions of Andean rituals were also made for the central provinces around Lima, the vice royal capital in colonial times, and some of these ceremonies can be compared with Incaic ones in Cuzco. But when those other records became available in the early seventeenth century, more than 80 years had already passed after the Spaniards had arrived in the Andes. Much research still has to be carried out making those comparisons fruitful for a reconstruction of pre-Hispanic calendars in general.

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Candraśekhara Sāmanta

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Candraśekhara Sāmanta (1835–1904) was a self-made astronomer who had the distinction of revising the traditional calendar of Orissa during the nineteenth century. He was a scion of a junior branch of the chiefs of the small estate of Khandapara and bore the title *Sāmanta* (Feudatory) on that account. His full traditional name was Sāmanta Śrī Candraśekhara Singh Harichandan Mohāpatra, and he was called locally Pathani Sāmanta. Young Candraśekhara had little modern education, but learned Sanskrit and astrology from his uncle, which he further developed by an intensive study of two of the authoritative texts of the times, the *Sūryasiddhānta*, and the *Siddhāntaśiromaṇi* of Bhāskarācārya. Exhibiting an uncanny interest in watching the skies, he became aware that the times of the rising and setting of the sun and moon and of the other celestial bodies were at variance with the times indicated in local almanacs arrived at by computation based on traditional texts. Often, when almanacs differed in their indication of times, and even of dates (*tithis*), there was confusion in the matter of fixing the days for domestic and social festivals and of sacred worship at temples like that of Lord Jagannātha at Puri.

Deeply religious and equipped with the fundamentals of traditional astronomy, Candraśekhara took it upon himself to remedy the prevailing state of affairs, and from the age of 23 he commenced watching the transit, conjunction, rising, and setting of the celestial bodies, and recorded his observations consistently and systematically. As aids to accuracy in observation, he designed, all by himself, several astronomical instruments which had been described in the *Sūryasiddhānta* and the *Siddhāntaśiromaṇi* and their commentaries. Among the instruments were an armillary sphere and a vertical wheel, which in modern terms served the purpose of the transit and alta-azimuth instruments. He also used the clepsydra (water clock) for measuring sidereal time. An instrument which he designed and used constantly for celestial observation in place of a telescope was a T-square frame which he called *mānayantra* (measuring instrument) with the main limb 24 digits and the crosspiece marked with notches and having holes at distances equal to the tangents of the angles formed at the free end of the main piece. He also designed an automatically revolving wheel (*svayam-vāhaka*), with spokes partly filled with mercury, which he also used to measure time. He effectively used the gnomon, which when fitted with a small mirror could be used at night for measuring time and angular distances.

Candraśekhara's observations, experiments, and recordings, on the basis of which he coined corrections to earlier enunciations and innovated new methodologies and practices, lasted 34 years. This enabled him to introduce reforms to all aspects of astronomical computation, which he set out in an extensive work, *Siddhāntadarpaṇa*, in 2,500 verses. This is an astronomical manual in five chapters, devoted, respectively, to Mean planets (*Madhyama-adhikāra*), True planets (*Sphuṭa-adhikāra*), Problems of Direction, Time and Place (*Tripraśna adhikāra*), Spherics (*Gola-adhikāra*), and Time and Appendices (*Kāla adhikāra* and *Pariśiṣṭa*). The main contributions of Candraśekhara include corrections to the sidereal periods of the star planets and to the main inclinations of the planetary orbits to the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), identification, and evaluation of evection [solar perturbation of the lunar orbit], variation, and annual equation among the moon's inequalities, and horizontal parallax of the sun and the moon. Recognition and honors were late in coming when the Government of India conferred on him the title of *Mahāmahopādhyāya* (Scholar of scholars), the highest title for a Sanskritist.

See also: ►Armillary Sphere, ►Sūryasiddhānta

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Caraka

Guy Mazars

Caraka is the editor of a treatise of Āyurveda which bears his name, the *Carakasaṃhitā* or "Caraka's Compendium", a work with which classical Indian medicine really begins. The *Carakasaṃhitā* is supposed to contain the teaching of the sage Ātreya Punarvasu, recorded by one of his disciples, Agniveśa, and revised by Caraka. Ātreya and Agniveśa belong to the realm of legend, but Caraka is likely to have been a historical figure. Indeed, according to the Chinese version of a Buddhist text, translated from Sanskrit in the fifth century AD, a physician of the same name was practising at the court of the Scythian king Kaniṣka. Several scholars place this king at the end of the first or second century AD. Like Aśoka (264–227 BCE) some centuries earlier, Kaniṣka was well disposed towards Buddhism and protected it. During his reign, Indian culture underwent a great expansion. The redaction of the *Carakasaṃhitā* thus goes back to this period, if it is indeed the same Caraka.

However, the text which has come down to us is a composite work. It contains more recent portions added at the time of its revision by an author from Kashmir, Dṛḍhabala, who probably lived in the fifth century AD. But the core of its content is much older since Caraka himself had only reconstructed an already existing work, cited under the name of *Agniveśatantra*, the "Book of Agniveśa". At least one of the redactors of the "Compendium" was familiar with the diets and habits of peoples from different parts of the world. The *Carakasaṃhitā* was commented upon before the ninth century by Jejjaṭa, who may have been a Kashmirian or an inhabitant of Sindh. Then, in the eleventh century, Cakrapāṇidatta wrote a commentary called *Āyurvedadīpikā*, which has been preserved and edited. Cakrapāṇidatta was a native of Bengal, himself the author of the *Cikitsāsaṃgraha*, a well-known manual of therapeutics. He wrote other works, including the *Dravyaguṇasaṃgraha*, a short treatise of materia medica. According to the Arab bibliographer Ibn an-Nadīm, in his *Kitāb al-Fihrist* (Index of Arabic books, completed in 988 AD), a Persian version of the *Carakasaṃhitā* had been translated into Arabic by the time of the first 'Abbāsid caliphs (eighth century).

In its present form the *Carakasaṃhitā* consists of 120 chapters which are divided into eight parts (*sthāna*):

1. Thirty chapters in the *Sūtra* section dealing with various topics, including pharmacology, diet, some diseases and their treatments, physicians and quacks;
2. Eight chapters in the *Nidāna* section dealing with the causes of eight main diseases;
3. Eight chapters in the *Vimāna* section dealing with different topics such as "taste", logic, vessels, pathology and medical education;
4. Eight chapters in the *Śārīra* section dealing with embryology and anatomy, and on the connection between the body and the mind;
5. Twelve chapters in the *Indriya* section devoted to diagnosis and prognosis;
6. Thirty chapters in the *Cikitsā* section dealing with therapy;
7. Twelve chapters in the *Kalpa* section on pharmacy; and
8. Twelve chapters in the *Siddhi* section devoted to general therapy.

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Cashewnut Processing on the Malabar Coast

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The cashewnut processing industry on the Malabar Coast grew around the port towns of Quilon, Calicut and Mangalore, which had cashew-growing hinterlands. Cashew was not a systematically cultivated tree crop. In earlier days, poor people gathered the nuts, roasted them in mud pans, removed the shells by hand and sold the kernels in nearby markets. From the early decades of the twentieth century, trading companies from the West operating on the coast began to purchase shelled kernels from local people for export. After sun drying, cashew kernels were packed in mango wood cases lined with newspaper and shipped out, mainly to Marseilles and occasionally to London from where these would be re-exported. From the 1930s, with the emergence of the United States as a major buyer, the industry gained substantial momentum. To meet the increased demand, the trading companies resorted to the putting out system of production. The companies bought raw nuts locally (and also imported nuts from East Africa) and distributed these to people, who pan-roasted and returned the shelled kernels to the company. The kernels were dried, peeled, graded and packed at the company premises. Later, as the putting out system gave way to direct production by firms, factories where all the operations were undertaken emerged. The factories employed women and children of lower castes and outcastes who were paid very low wages. Over 90% of the workers were women. Men, again drawn from lower and depressed castes, were engaged primarily in roasting.

Cashewnut processing involved five principal operations: roasting, shelling, peeling, grading and packing. In the early factories roasting of nuts was done in the open air in iron pans. From 1932, iron pan roasting was replaced by drum roasting. Under the new method, an open-ended drum (rotary cylinder) was placed over a fire in a tilted position. Raw nuts were fed from one end, and roasted nuts were collected from the other. Each cylinder needed six persons to operate: the first person attended to the furnace, the second and third fed the raw nuts, the fourth rotated the cylinder, the fifth removed the roasted nuts, and the sixth sprayed water on the roasted nuts. The workers wrapped themselves in gunny bags to protect themselves from burns. By the mid-1930s, hot oil roasting replaced drum roasting. Here, raw nuts were roasted in a bath of cashew shell oil maintained at about 200°C. Due to the high temperature, the oil cells of the nuts broke, releasing their contents; and the nuts were then roasted to the desired degree. Cashewnut processing yields a by-product – cashewnut shell oil that has industrial and strategic uses. This could be extracted in full only in oil-bath plants. All these methods used cashewnut shells as fuel.

After roasting the nuts were shelled. This was the most arduous operation and had to be done in an uncomfortable squatting posture. Nuts were placed on a flat stone and were gently hammered with the help of small wooden mallets, to remove the shells. A high degree of skill was required to ensure that the kernels did not break. Peeling the skin off kernels was also a dexterous, repetitive and loathsome task. The kernels were then graded and packed.

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C

Celestial Vault and Sphere

Cornelis Plug

The celestial vault is the apparent surface of the sky – both the night sky against which the stars appear to be placed and the blue expanse of the daytime sky.

The idea that the celestial vault, and particularly the daytime sky, is a physical cover of some kind is found in the cosmologies and myths of many cultures. Ethnic groups in northern Eurasia, for example, thought of the sky as a roof to protect the earth and life, and often described it as resting on a central pillar. In the hero tales of the Yakuts, the sky was said to be hemispherical, resting on the outer edge of the world. In the mythologies of Finland, Lapland and neighbouring regions, the celestial pole or the pole star was described as the "nail of the sky" which supports the celestial vault and around which it revolves. The Lapps, Finns, Yakuts, Japanese and Hebrews sometimes described the sky more specifically as a tent roof. The most popular conception of the sky in ancient Egypt was that of a blue water surface, a continuation of the sea or the Nile. Similar ideas were applied to the night sky. The Milky Way appeared to some as a stitched seam, and the stars as tiny holes in the fabric of the celestial vault.

In sub-Saharan Africa a widespread belief is that the daytime sky is a solid blue vault resting on the earth, on which the sun moves. During the night the sun is thought to return to the east either by passing under the earth (e.g. the Luyia of Kenya) or behind the solid sky (e.g. the Zulus of South Africa), in the latter case producing the stars by shining through small holes in the vault.

Although these speculations implied a fixed form for the sky, that form was seldom clearly defined. There was some debate among early astronomers in China on whether the celestial vault might be strongly flattened, perhaps even a plane parallel to the earth's surface. Thus the astronomical chapters of the official history of the Chin dynasty (AD 265–420), written in the seventh century under the supervision of Emperor Tai Zong, contain a discussion by the scholar Ge Hong (283–343) of the theory that the sun cannot be seen at night because it moves a great distance away from the earth. Ge Hong argued (Ho 1966: 57): "If it is said that the sun can no longer be seen because it has gone a very great distance from us, then when the sun sets, on its way towards the north, its size should diminish. But, on the contrary, the sun becomes larger at sunset". This refutation of the flattened vault theory did not originate in China. It was stated in similar words by the Greek astronomer Claudius Ptolemy in the *Almagest* (Book 1, Chapter 3), written around AD 142. The similarity of the wording leaves little doubt that intellectual contacts existed between China and the Middle East at the time.

The idea that the celestial vault is actually flattened has been ascribed to Empedocles, a Greek philosopher of the fifth century BCE. Ptolemy's refutation of the theory was later transmitted to Islamic scholars as part of the *Almagest*, and was slightly elaborated by the astronomer al-Farghānī in the ninth century. However, by this time most astronomers had long accepted that the celestial vault represents the upper half of an imaginary (or sometimes real) spherical surface, called the *celestial sphere* (or of a set of concentric celestial spheres). The other half of this sphere is below the horizon. The apparent positions, sizes and movements of the sun, moon, planets, comets and stars were described as if these bodies were situated on the inner surface of a real celestial sphere. Estimates of the sizes and separations between the celestial bodies were therefore expressed as lengths or distances on the celestial sphere, rather than in terms of angles. For example, Chinese observations of comets from the second century BCE to the nineteenth century were expressed in terms of the *zhi*, a length standardized as 311 mm in the ninth century. The *zhi* appears to have corresponded to an angle of a little less than 1°. Similarly, the Babylonian *ammat* (about 524 mm) represented either 2° or 2.5° at different times. And the Islamic *fitr* and *shibr* (spans later standardized as 152 and 178 mm, respectively) were equivalent to about 0.6° and 0.8°, respectively, in the astronomical work of Ibn Yūnus during the eleventh century. These lengths and angles seem to imply that the astronomers in each of the three cultures assumed that the imaginary sphere used to express their estimates had a radius of only some tens of metres. Numerous estimates of the perceived sizes of the sun and moon (usually seen as some 200–300 mm across) from classical to modern times in Europe support the same conclusion: there exists a universal tendency to describe perceived sizes and distances on the celestial vault as if the height of the sky is only a few tens of metres.

Although astronomers had long rejected the idea that the celestial bodies move along flattened trajectories, the Islamic physicist Ibn-al-Haytham pointed out in the eleventh century that the sky usually *appears* flattened. He explained this as an illusion created by our perception of distant objects towards the horizon, and the lack of such indicators of distance towards the sky. He furthermore used the flattened appearance of the celestial vault to explain the illusion that the sun and moon are enlarged near the horizon – an explanation that was transmitted to Western Europe during the thirteenth century and survived well into the twentieth century. Its importance lies in the fact that, for the first time, the perceived flattening of the celestial vault and the perceived enlargement of the horizon sun and moon were described as perceptual illusions (now studied by psychologists), rather than measurable phenomena to be studied by astronomers.

See also: ►Astronomy, ►al-Farghānī, ►*Almagest*, ►Ibn-al-Haytham, ►Ibn Yūnus

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Ceramics, Mimbres

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Mimbres pottery, made primarily in southwestern New Mexico between 750 and 1150 AD, is renowned for its spectacular, often naturalistic, black-on-white designs (Fig. 1). Although painted pottery is common in the archaeological record of the North American Southwest, Mimbres pottery stands out because of its elaborate representational designs, which depict everything from the ubiquitous rabbit to scenes of everyday life and apparently mythical creatures. Because of the pottery's beauty and appeal to collectors, many Mimbres archaeological sites have been destroyed by looters searching for pottery to sell, and irreplaceable information about the past has been lost.

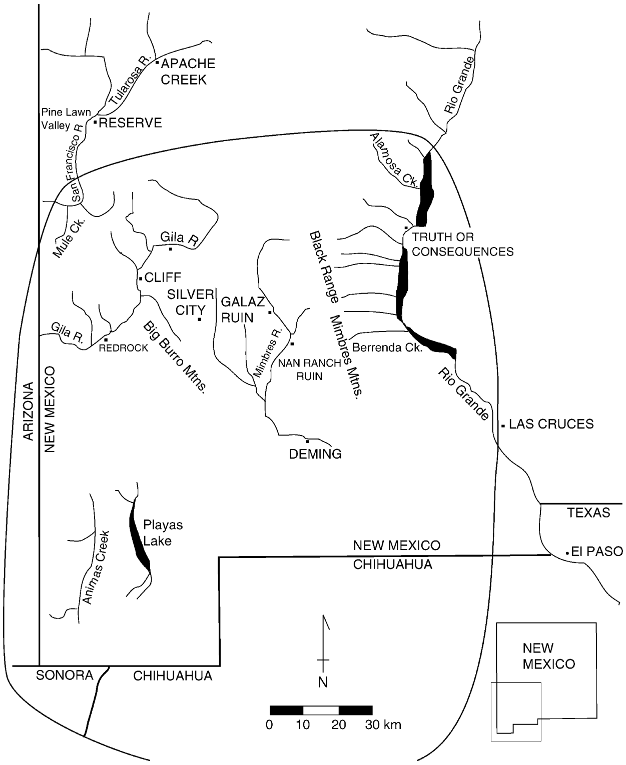
Mimbres, from the Spanish for "willows," is the name given to a small river in southwest New Mexico. The name came to be applied to the pottery found in archaeological sites along the river, and eventually to

Ceramics, Mimbres. Fig. 1 Classic Mimbres Black-on-white bowl from Ronnie Pueblo (Nelson 1999: 96–97). The bowl is part of the permanent collections of the Museum of Anthropology, Arizona State University.

the people who made the pottery. However, it is important to keep in mind that these are labels applied (mostly by people of European descent) to pre-Hispanic Native Americans. We do not know what the people called themselves, although we can be sure it was *not* Mimbres. In fact, recent approaches in archaeology have attempted to decouple pottery styles and cultural identity, and have challenged the extent to which the people who made the pottery we call Mimbres were united culturally, socially, or politically. They were maize farmers living in fairly simple hamlets and villages that housed from a few households to a few hundred people. They had no writing, draft animals, or metal tools. And while their social organization was elaborate in many ways, they did not have a well-developed political hierarchy or marked social inequalities. Syntheses of Mimbres archaeology include Anyon et al. (1981), LeBlanc (1983, 1989), Hegmon (2002), Hegmon et al. (1999), and Nelson (1999) and a recent issue of *Archaeology Southwest* (2003). Book-length treatments of Mimbres pottery, especially the designs, include Brody (1977, 2004), Brody et al. (1983), Brody and Swentzell (1996), Fewkes (1989), Kabotie (1982), LeBlanc (2004), Moulard (1984), and O'Bagy Davis (1995). In addition, reports on Mimbres sites include numerous pictures and analyses (e.g., Anyon and LeBlanc 1984; Cosgrove and Cosgrove 1932; Shafer 2003).

Situating the Pottery in Time and Place

The Mimbres region (Fig. 2) is part of the larger Mogollon archaeological culture area, which includes much of southern New Mexico and northern Chihuahua, as well as central Arizona. Mogollon pottery, made



Ceramics, Mimbres. Fig. 2 Map showing the Mimbres region in southwest New Mexico and surrounding states.

with iron-rich volcanic clays, is generally brown or red in color, while pottery made in the northern Southwest (what had been called the Anasazi area but is now more properly known as Ancestral Pueblo) is generally white or gray, sometimes with black designs. Because Mimbres pottery is black-on-white, it was initially thought to be northern in origin. However, it is now well known that Mimbres pottery is indeed a Mogollon brown ware, covered with a thin slip of white clay that provides a backdrop for the black designs. The local development of Mimbres pottery – from plain brown to red-on-brown to red-on-white and finally to black-on-white – is well understood and well dated (see especially Anyon et al. 1981; Scott 1983; Shafer and Brewington 1995; Shafer and Taylor 1986). Because the painting style changed fairly rapidly, archaeologists are able to date the pottery quite precisely. For example, Fig. 3 illustrates a bowl with a design that extends all the way to the rim and that has straight-line hachure with framing lines thicker than the hatch lines; these are both relatively early characteristics and together they indicate that this bowl should be classified as Early Style II (ca. AD 880–920; Shafer and Brewington 1995). Later designs (generally classified as Classic Mimbres Black-white or Style III, and illustrated in Figs. 1 and 4–7) have various kinds of rim framing lines. Scott (1983) illustrates the stylistic changes over time, and Shafer and Brewington (1995) present a detailed

Ceramics, Mimbres. Fig. 3 Style II Mimbres Black-on-white bowl from the Galaz Ruin (Anyon and LeBlanc 1984: Plate 12a). Photo courtesy of the Mimbres Archive [#2963)]. The bowl is part of the permanent collections of the University of Minnesota.

microstyle chronology. Mimbres pottery includes various forms including storage and cooking jars as well as bowls. However, most of the painting and virtually all of the representational designs are found on bowls. Painted

Ceramics, Mimbres. Fig. 4 Jackrabbit depicted on Classic Mimbres Black-on-white bowl from the Swarts Ruin. Photo courtesy of the Mimbres Archive [#2051]. The bowl is part of the permanent collections of the Peabody Museum, Harvard University.

Ceramics, Mimbres. Fig. 6 Bear hunt depicted on Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon and LeBlanc 1984: Plate 83E). Photo courtesy of the Mimbres Archive [# 2902]. The bowl is part of the permanent collections of the University of Minnesota.

Ceramics, Mimbres. Fig. 5 Geometric design on Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon and LeBlanc 1984: Plate 23E). Photo courtesy of the Mimbres Archive [#3033]. The bowl is part of the permanent collections of the University of Minnesota.

Ceramics, Mimbres. Fig. 7 Pregnant woman with parrot-like bird (possible macaw) depicted on a Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon and LeBlanc 1984: Plate 76F). Photo courtesy of the Mimbres Archive [# 2845]. The bowl is part of the permanent collections of the University of Minnesota.

pottery was most elaborate and probably most common during the Mimbres Classic Period (1000–1130 AD), and painted bowls at that time had an average volume of 2.2 l (based on data from the Galaz Ruin [Anyon and LeBlanc 1984: 169]).

Chemical and mineralogical analyses (summarized in Gilman et al. 1994) clearly indicate that Mimbres pottery was made in many locations and villages; it was not centrally produced. The elaborateness of the designs suggests that some may have been produced by specialists, but if this were the case they were likely part-time specialists. Recent calculations (LeBlanc 2004) suggest that all Mimbres black-on-white vessels could have been made by just a few potters, each making only 50–100 pieces annually. While most pottery makers and painters in the pre-Hispanic Southwest were probably women, several authors have suggested that at least some of the Mimbres designs were painted by men, because they depict rituals probably controlled by men (Brody 1977) and because the birth scenes are anatomically unusual (Hegmon and Trevathan 1996). The issue is controversial, and a clear resolution is unlikely.

Mimbres painted pottery is found in many contexts, including in trash middens, on living floors, and in burials, across the Mimbres region. Many burials – in simple pits in middens and under house floors – were interred with a bowl placed over the skull. Most of these bowls had a small hole carefully punched out of the base (see Figs. 3 and 6); these bowls are said to have been "killed," and some have speculated that the hole allowed the deceased's spirit to escape. Many of the bowls found in burials have wear patterns that indicated they had been used before they were interred (Bray 1982). It is possible that most individuals had a bowl that they used for eating and other purposes, and that bowl accompanied them into the grave.

The Designs

Before considering the designs and their analyses, two caveats should be noted. First, although many designs appear to be realistic, in that they accurately portray details such as the topknot on a Gambel's quail and the black tips on jackrabbit ears (Fig. 4) the corpus of designs as a whole should not be assumed to reflect Mimbres life accurately. Rather, the pre-Hispanic artists – for various aesthetic, cultural, and social reasons – *chose* to depict certain scenes in certain ways. The designs are representations of what people believed should be portrayed on pottery, and they should be interpreted from this perspective. Second, as Brody (2003) has emphasized, the designs were painted on hemispherical surfaces (i.e., the interior of bowls) that were often placed below the user and viewer's eye level; most reproductions do not convey the designs' three-dimensional aspect or use context.

Mimbres pottery designs have been the focus of much attention, by archaeologists, art historians, and the public (Brody 1977; Brody et al. 1983; Brody and Swentzell 1996; Moulard 1984), and much is known about what they depict. However, there is still a need for comprehensive quantitative analyses of the designs and their distribution, as I noted in my recent review (Hegmon 2002). Designs with representational elements (Figs. 1, 4, 6, and 7) are less common than those that are purely geometric (Figs. 3 and 5) (221 versus 494 in the Galaz Ruin collection [Anyon and LeBlanc 1984]). Most representational designs are depictions of animals native to the Mimbres region, some show scenes that include humans, and others depict apparently mythical creatures. Early Mimbres representational designs are similar to designs on pottery from the Hohokam region in southern Arizona, but by the Classic Period, the Mimbres style was unique.

Interpretations of the meanings of the designs are best made by considering their larger cultural context. Maize was a staple food in the Mimbres region, supplemented by other crops, wild plants, and meat from small animals such as rabbits, as well as occasional larger animals such as deer. In comparison, almost no maize or other plants are depicted on the pottery, and while there are many rabbit paintings (Fig. 4), there are few scenes (possibly only one in the known corpus) of rabbits being trapped or hunted. In contrast, quite a few paintings depict the hunting of larger animals, including bear and elk (Fig. 6). Taken together, these patterns support the argument that the paintings represent what people wanted to emphasize (i.e., hunting), not what they actually ate. One unpublished but widely cited analysis (LeBlanc 1977) found that bowls depicting certain animals were associated with certain villages or areas, suggesting the animals were relevant more to social identity (e.g., as clan symbols) than to food.

While many of the animals depicted on the bowls would have been local to the Mimbres region, a number of exotic and probably symbolically important species are also depicted. In many cases, biologists have been able to identify particular species because the Mimbres paintings include relevant details, such as fin and beak shapes. Macaws, particularly their red feathers, have great ritual significance to contemporary Southwestern Native Americans, and a few macaw skeletons have been found in archaeological sites in the Mimbres region and elsewhere in the Southwest, suggesting that this ritual significance extends far back in time. Parrot-like birds are occasionally depicted on Mimbres bowls, and analyses of their traits indicates that most are scarlet macaws, native to the lowlands of southern Mexico and central America, more than 1,000 miles from the Mimbres region (Creel and McKusick 1994). Similarly, analyses of the fish (and a possible whale) depicted on Mimbres pottery indicate that many are saltwater species, probably from the Gulf of California, approximately 640 km distant (Jett and Moyle 1986). Thus it is clear that the people who painted the Mimbres designs had knowledge of distant regions, either through travel or trade and interaction.

In the past two decades, archaeologists have devoted significant attention to understanding women and gender relations in the past. Mimbres paintings give particular insights (see Hays-Gilpin 2002) because some depict men and women engaged in various activities (almost all depictions of humans show them engaged in some activity; there are almost no simple portrait-like treatments). Some humans have clear sexual characteristics (breasts or penis), and inferences about styles of dress and body decoration associated with each sex make it possible to identify the sex or gender of many of the human figures (Munson 2000). For example, when string aprons (Fig. 7) are depicted on individuals with clear-cut sexual characteristics, they are always associated with females; thus, string aprons are interpreted as good indicators of gender (i.e., women). Drawing on this and similar analyses, Munson (2000) was able to conclude that there was a gendered division of labor in Mimbres society (men are more often associated with hunting, women with child care). However, there is at least one famous scene of a pregnant woman (seemingly triumphant) carrying a hunted antelope; this image graces the cover of a milestone volume on gender and archaeology (Gero and Conkey 1991). Furthermore, although more men than women are depicted engaged in apparently ceremonial activities, women are consistently shown handling ritually important parrot-like birds (often macaws) (see Fig. 7).

Contemporary artists often state that their art conveys meanings that cannot be put into words, and it is likely that the same applies to art of the past. It is also likely that Mimbres pottery painting – done by perhaps hundreds of artists over approximately four centuries – conveys a range of meanings. However, researchers have gained some insights into the general range of meanings associated with the pottery. Because the bowls are often found in burials, and some depict scenes from what appears to be the Puebloan World of the Dead, Brody and Swentzell suggest the images refer to "the unity of man and the cosmos, the living and the dead, and of the structures of harmony" (1996:38). Moulard (1984) similarly concluded that the designs symbolize transformations, such as from life to death or childhood to maturity.

Collections

Mimbres pottery – particularly pieces with representational designs – has long had great appeal to collectors. The result has been the destruction and desecration of Mimbres sites. The large site of Old Town is well known for looking like a mine field because it is so full of large holes, many made by backhoes and bulldozers. Galaz Ruin (Anyon and LeBlanc 1984), one of the largest Mimbres villages, no longer exists; it was completely removed by bulldozing. Much of this activity is illegal (i.e., it is illegal to disturb archaeological remains on public land, and it is illegal to disturb human remains even on private land), but law enforcement cannot always keep pace (Turnbow 2001). In an attempt to stop the destruction and preserve some of what remained of Mimbres archaeology, Steven LeBlanc formed the Mimbres Foundation in the 1970s, and today the Archaeological Conservancy undertakes similar activities on a much wider scale (LeBlanc 2003). Also, many responsible authors are today refusing to publish images of looted bowls so as not to increase their value (e.g., the second edition of Brody's *Mimbres Painted Pottery* [2004]), a strategy in line with the ethnical guidelines of the Society for American Archaeology. Thus the situation is improving, though destruction continues (Turnbow 2001).

The problem with collections is not simply private ownership of the remains of past Native American cultures. A more serious issue is that the demand for collections, and the high prices paid for Mimbres pottery on the art market, encourage the illegal looting of sites. And because many bowls are found in burials under house floors, the search for pottery results in the destruction of architecture and the desecration of burials. People who want to possess privately the beauty of a Mimbres bowl are advised to purchase some of the well-made replicas available from various sources, including Laurel and Paul Thornburg of Sonoita, AZ.

The End of the Mimbres Pottery Tradition

The style, color, and sizes of the pottery we know as Mimbres changed, more and less rapidly, during the entire period of its production, from at least 750–1150 AD. It became less common by AD 1150, and it was certainly no longer made by the end of the twelfth century. Instead, people in the Mimbres region began using and making an array of different kinds of pottery. An understanding of the end of this famous style provides insights into how archaeologists understand prehistoric peoples. Again, "Mimbres," is a Spanish word, a label we have applied to a river and a style of pottery, among other things. But the decline of the pottery does *not* mean the decline of a people. It simply is yet another example of a style change.

We know, through detailed studies of architecture and radiocarbon dates (Nelson and Hegmon 2001), that people continued to live in the Mimbres region during the time that Mimbres pottery became less common. So why did the style change? Mimbres pottery is unique in the Southwest, and it is reasonable to think that it meant something special to the people who made it. Mimbres villages were among the largest and most densely populated in the Southwest at the time (with the exception of the Hohokam area in southern Arizona). Life in these villages may have been fairly difficult; the Mimbres Classic period was a time of environmental degradation, and eventually drought and subsistence stress (Minnis 1985). The beauty of the pottery is not an indication of the ease of the artists' lives. Rather, Mimbres pottery, especially the elaborate Classic period paintings, may have been part of the tradition of living in large villages, including the hard times.

Beginning by 1130 AD, many people left the villages and resettled in small hamlets, a process known as regional reorganization (Hegmon et al. 1998; Nelson 1999). As people resettled, they developed new social networks and learned about new styles, which they eventually adopted as part of their changing social identities. The new generation chose to make new styles of pottery for new reasons.

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Ceramics in Africa

Olivier P. Gosselain

Pottery making is a very ancient craft in Africa, as some of the oldest pottery remains known in the world were discovered on this continent. Dating from around 10,000 BCE – i.e., one or two millennia after the inception of the Jomon pottery in Japan – they were excavated in the Aïr Region of Niger (West Africa) (Haour 2003).

Despite its age, the craft is still alive in many parts of the continent. It has of course witnessed a lot of changes through the centuries, in regard to the forms, functions and decorations of the products, but also in terms of manufacturing techniques, scale of production or the social status of the potters. The last decades have been particularly significant, due to the massive introduction of plastic and metal containers, social and economic upheavals, the development of tourism and urban lifestyle, and the geographic extension of individual movements. In most places, ancient pottery functions such as cooking, handling, and serving have been abandoned, while new categories of products such as ornamental or commemorative vases and bibelots, flower pots, tiles, braziers or incense burners are booming. Water jars, however, continue to be massively produced as they provide the cheaper, or even the only way to keep cool water in rural areas.

Social Background

A comparison of several hundred ethnographic sources[1] indicates that at last four-fifths of the African potters working today are women, confirming the usual description of pottery making in Africa as a female activity. Male potters are also at work in various regions of the continent, where they either specialize in the making of particular vessels (big water jars, elite ware, and bottles) while women make the bulk of the production, produce the whole range of vessels in contexts where women are excluded from the craft, or work together with female relatives, carrying out specific operations such as clay extraction and transport, clay preparation, firing and, above all, plastic decoration (Schildkrout and Keim 1990).

The scale of production is highly variable, ranging from part-time, isolated artisans, whose products are essentially consumed locally, to full-time specialists working in workshops, whose vessels are distributed by middlemen in a 100–200 km radius. If men tend to be proportionally more frequent in the latter category, female potters are also associated with mass production, especially in West Africa.

In many instances, pottery making is open to anyone. All one has to find is someone who is willing to serve as a teacher. This means, in practice, having a close relative, friend or neighbor who engages in pottery making and does not mind spending time with someone who may subsequently become a competitor. But restrictions are also observed throughout the continent, which pertain to age, gender, geographical origin and, above all, socio-professional affiliation. For example, in many Sahelian societies, potters belong to caste-like subgroups such as blacksmiths, bards, tanners, weavers, woodcarvers, hunters, or jewelers (Da Silva Gaspar et al. 2005; Drost 1968; Frank 1998; Gallay et al. 1997; Gosselain 2001; Haaland 1978; Sterner and David 1991, 2003; Tamari 1997). The members of these endogamous specialist groups are associated with specific activities and duties, and distinguished from the remaining population. They are regarded with a mix of awe and contempt by nonspecialists, who often consider them "dirty" and "impure", and fear being harmed by their "power." Due to recent economic changes, however, caste-like structures may become permeable to other social groups in specific places.

Manufacturing Process

There are seven main stages of the pottery manufacturing process (1) clay extraction, (2) clay processing, (3) shaping, (4) decoration, (5) drying, (6) firing, and (7) postfiring. While most of these stages are mandatory, some – such as decoration and postfiring – are optional, although widely recorded across the continent (previous surveys of pottery chaines opératoires in Africa include Devisse 1984; Drost 1967; Gosselain 2002; Krause 1997; Livingstone Smith 1999, 2001b).

[1] Information examined in this article comes from two bodies of data. Since 1990, members of the *Ceramic & Society Project* developed at the University of Brussels, and its research associates have conducted fieldwork in Senegal, Gambia, Mali, Niger, Burkina Faso, Togo, Benin, Nigeria, Cameroon, Chad, and D.R. Congo, collecting information about some 1,000 potters in nearly 100 linguistic groups. The second body of data comes from a systematic perusal of the ethnographic and ethnoarchaeological literature devoted to pottery making in sub-Saharan Africa. These sources are of varying relevance and accuracy as they range from large-scale and detailed studies to more local/regional observations, or mentions in ethnographic monographs, administrative reports, and religious publications. Altogether, more than 700 sources have been processed, which relate to some 550 linguistic groups.

Clay Extraction

Available data indicate that most African potters collect their clay within a 3-km radius from the place where they live and/or practice the craft (see Gosselain 2002: 40–41). Those who exploit sources beyond this threshold generally use animals, cars, trucks, or pirogues (canoes) to carry the clay. Also, they often make stocks that last from several weeks to the whole potting season.

Four categories of extracting techniques are observed in Africa: surface collection, pit extraction, underground gallery, and underwater extraction.

In surface collection, the raw material is extracted on, or just below the surface, either on the ground (plain, fields, dried ponds, or riverbeds), a hill, or the wall of a slope or an embankment. After having eliminated the superficial organic and mineral layer, the potter extracts clay without really digging underground. The operation may be described as "peeling" a clay bed.

Pit extraction consists of digging the ground vertically or diagonally until an appropriate layer is reached. Most pits are some 1 or 2 m deep, and 2 or 3 m in diameter. But they may be as large as quarries, reaching some 15 m deep as in southeastern Nigeria (Nicklin 1979: 349). Variations are observed in the way potters exploit and manage these structures. For instance, some use them until the clay layer is completely exhausted, while others abandon the pit until a specific depth is reached, or as soon as it shows risks of collapsing.

Raw materials may also be extracted from galleries. This type of structure generally starts with the excavation of a vertical shaft. When the access shaft reaches the clay bed, the structure is extended horizontally (Livingstone Smith 2001b; Nwafor 1980; Schneider 1993). Galleries, like pits, are generally abandoned at the end of the potting season, but some may be used several years in a row. In the latter case, only the access shaft is re-excavated each year.

Finally, the rather uncommon technique of underwater extraction has been observed among the Tikar of Cameroon and Punu of Gabon (Gosselain 2002: 52–53). Here, artisans build two small dams in a river, bale out the water and dig the clay before the upstream dam gives way.

Usually, it is while performing other activities, and especially activities which force them to dig the ground (e.g., tending fields, building houses, and digging wells) or to frequent places such as riverbeds or swamps, that potters, members of their family, or any of their acquaintances may "discover" a new source and get the process leading to its possible exploitation under way.

A first requirement is that the clay must have the "right" physical properties; i.e., plasticity, texture, color, and even its taste and odor fit with the personal requirements of the potter (see also Barbour 1989; Brown 1989; Frank 1998; Trowell 1941: 61; Woods 1984: 305). If newly discovered clay is judged suitable, a second requirement is that it must be located nearby the potter's main occupational areas and/or working place. Since pottery making is usually subordinated to other activities, such as farming and domestic tasks, potters tend to restrict their investment in time and energy or, at least, to avoid scheduling conflicts between their different activities. Sources located nearby living or working sites, fields, rivers frequented for fishing, roads, or tracks, are therefore more likely than others to be selected and subjected to long-term exploitation. In fact, about 90% of the hundreds of sources that we visited in sub-Saharan Africa were situated nearby or within sites used primarily for other activities. Such a situation has an obvious impact on clay exploitation strategies. More importantly, it shows that clay extraction sites are not distributed randomly or according to a specific logic, but are an integral part of the overall territory frequented by both potters and nonpotters.

Finally, the selection and exploitation of clay sources are also surrounded by a series of rituals and taboos (Barley 1994; Berns 1993; Drost 1964; Gosselain 1999; Herbert 1993; Pinçon 1993). For instance, certain persons are systematically kept aside from the extraction site or the places were the potters store and manipulate the clay: men if the craft is practiced by women, women in other contexts, uninitiated people, members of other social groups than the potters, little girls or boys, pregnant women, menstruating women, twins, warriors, etc. Likewise, artisans must avoid doing particular things on the eve of extraction, during the trip to gather clay or at the site: e.g., having sexual intercourse, talking, singing, swearing, urinating, manipulating certain objects, eating particular food, etc. Rituals and sacrifices (i.e., food offering) may also be performed at the extraction site, a practice still widely recorded in Muslim societies.

Clay Processing

As in most places around the world, African potters never use the clay in its raw state but prepare it in one way or another. While processing practices are usually very simple, they may also involve complex combinations of techniques. These may be grouped into four main categories: pretreatments, removal of nonplastics, addition of nonplastics, and homogenization.

Pretreatments usually involve leaving the raw materials to dry, soak or sour for some hours, some days, some weeks, or even some months. Soaking is usually done in a pit, an old jar or a plastic container, and used when clay is extracted in a dry state. Its aim is to allow the material to regain its plasticity. If clay is already wet, the aim may be to give it a better workability through increasing the amount and distribution of water between particles and pores. A long soaking time may also help in increasing plasticity through pH alteration and the subsequent flocculation of clay particles, but such souring process seems quite rare among African potters.

When the clay is appropriately dried or soaked, a series of techniques may be used to remove undesirable nonplastics. The most common way is hand sorting, as potters always remove coarse impurities such as pebbles, roots, or leaves at some point during the process. But there are several other ways of controlling clay composition and texture. For example, potters may pound the clay with a stone or a wooden hammer on a stone, or they may simply pound it in a wooden mortar, grind it with lower and upper grinding stones, or grind it on a rock. Finally, nonplastics may be removed by sieving with baskets, pierced calabashes, or imported nylon meshes. Potters may also remove the coarser fraction of nonplastics by shaking the crushed raw materials in a calabash or by winnowing it with a winnowing basket or a calabash. A last technique, levigation, is quite rare in Africa. Here, the material is mixed with water until it reaches a colloidal state, the larger particles are retrieved at the bottom of the container, and the water is allowed to evaporate (David 1983; Gallay and Sauvain-Dugerdil 1981).

Generally called tempering, the addition of plastic or nonplastic elements to the clay may be done with a great variety of materials: another clay (or several clays), dust, organic rich earth (soil), mud, termite heap clay, sand, gravel, rocks (calcareous rocks, gneiss, schist, and asbestos), iron stone, grog (crushed, grounded, and/or sieved potsherds; Fig. 1 – by far the most common material), fired earth, ash, straw, cereal husks, grass, stems, bark, dung (horse, cow, goat, or donkey), shells, calcareous solution (grounded and sieved calcareous rock mixed with a large amount of water; Sall 2001), or bark decoction.

The last processing step generally consists in a thorough homogenization of the paste. This operation is mandatory in clay processing and has a determinant impact on clay workability. It may be done in different ways: kneading with the hands, trampling with the foot, or pounding with various kinds of tools and supports (the most current of which are mortars and pestles, lower and upper grinding stones, and handles of diverse farming tools). If one considers the different combinations of these four categories of treatments, as well as the diversity of behaviors, postures, and tools, there are probably hundreds of ways of preparing the clay.

Potters usually explain that they act the way they do because of “tradition” (i.e., the way they have been taught), but also because vessels made with a clay prepared differently would not survive the drying or firing stages, or would break during utilization. Such conceptions explain why some potters use different processing techniques according to the intended function of vessels, or according to vessel parts. Among the Koma-Gimbe of Cameroon, for example, potters simply pound the clay when making small vessels, but add sand when making large beer brewing jars. They explain that jars would crack when drying if

Ceramics in Africa. Fig. 1 Pounding sherds in wooden mortars for making grog. Note that tools and postures are identical to those used in the realm of food preparation (photo by Olivier Gosselain).

they did not do so (Livingstone Smith 2001b). Others examples of the use of different processing recipes have been collected elsewhere in Africa (Gallay and Sauvain-Dugerdil 1981; Herbich and Dietler 1991; Nicholson 1929; Tobert 1984; Trowell 1941). Most commonly, however, potters use the same preparation technique, whatever the intended function of the vessel.

Another factor that explains the local use of particular processing techniques is the existence of ties to techniques used in other realms of activity, such as food processing and agricultural practices. For instance, staple foods and clay may be prepared with the same tools and gestures, and according to the same recipes. In the Bariba village of Tourou (Benin), for example, potters pound the clay in a wooden mortar and separate the fine and coarse fraction by shaking the material in a calabash. Then, they pound the coarse fraction a second time, and let it soak in a jar placed in the sun. When the liquid is sufficiently thick, it is sieved through a pierced tin can and mixed with the fine fraction of the raw material. Potters explain that this mixture acts as “cement” and that the best millet porridge is obtained in a similar way. Similarly, the clay desalinization technique observed among certain Jola Kasa potters of Casamance echoes, the practices for agricultural land preparation in mangrove swamp zones (Sall 2001).

Symbolic or religious concerns may also influence clay-processing strategies. For example, some Boko potters of Benin take great care in extracting all rootlets from the raw material. This is because rootlets are used to prepare a medication that prevents potters from “swelling” when fashioning vessels. Some West African potters often recycle archaeological sherds into grog, as they consider this material to possess particular qualities because “ancestors knew how to make stronger pots,” or because “what has lain underground is stronger than what lies on the ground” (Da Silva Gaspar et al. 2005; Livingstone Smith 2001b). Another example comes from Tukulor potters of Senegal who stop putting dung in the clay when they settle in Soninke communities since the latter consider dung impure (Gelbert 2001).

Shaping

In most instances, shaping techniques may be divided into two specific operations that differentiate both in their purpose and the set of tools and gestures used to carry them: (1) roughing out and (2) preforming. During roughing out, potters transform a lump of clay and/or joint pieces of clay together in order to constitute a hollow volume – the rough shape – whose form, often cylindrical, has not yet reached that of the finished product. During preforming, potters give the hollow volume its final geometric characteristics through scraping and smoothing operations, with the help of a series of tools.

Wheel throwing – not considered here – is only documented in North Africa, where it has been practiced for centuries by male potters. South of the Sahara, only passing references are made to the use of wheel throwing by a few male potters in the Lower Congo area. The technique would have been introduced by Portuguese in the late seventeenth century (Vincentelli 2003: 44), but given the lack of precision, it is not clear whether it is still practiced as such by Kongo potters or has been modified.

Roughing Out

Techniques used in sub-Saharan Africa belongs to seven main categories (1) pounding in a concave form, (2) drawing of a ring-shaped lump, (3) superimposition and drawing of large rings, (4) molding (on concave or convex molds), (5) pinching, (6) drawing of a lump, and (7) coiling. As the last three techniques are widely documented outside Africa, only the first three will be considered here.

The pounding technique – also called “tamper and concave anvil technique” – consists of placing a lump or a pancake of clay on a mat-covered depression or a concave anvil made in wood, clay or stone, and beating it with the fist, a wooden pestle or, more generally, a stone or a clay tamper (Fig. 2). Continuing with rhythmic beating, the potter rapidly obtains a concave form that he/she turns continuously on the anvil or the depression while beating the clay. This technique is used throughout the Sahel, from Mali to Egypt (Drost 1967; Gosselain 2001; Huysecom 1992; Sterner and David 2003).

In the drawing of a ring-shaped lump, the potter fashion a ring of 20–60 cm in diameter with one or several slab(s) of clay, and pulls its wall up with the help of the fingers (Krause 1985; Lawton 1967; Livingstone Smith 1999, 2001b; Roy 1989). In most cases, the lower part of the vessel is fashioned later with coils or a pancake of clay, after the upper part has been preformed and is sufficiently dry to be put upside down. In a variant observed in western Cameroon, the bottom part is made before the upper one (Nyst 1996).

The superimposition and drawing of large rings is similar to the previous technique, except that the initial volume is made with two to eight crown-shaped rings of clay which are superimposed and carefully joined together. So far, the technique has only been recorded in the southeastern part of Central Africa, among several Bantu-speaking groups (Lorenz and Plesner 1989; de Maret and Bulckens 1978; Woods 1984).

The seven techniques mentioned above are seldom used as such by African potters. The shaping of medium to large vessels usually involves the combination of the last two of these techniques, with the consequence that a detailed comparison of actual shaping processes allows one to identify more than 50 variants across the continent.

Ceramics in Africa. Fig. 2 Shaping a vessel with the pounding technique, on a concave wooden anvil with a clay tamper (photo by Olivier Gosselain).

Compared to clay extraction and processing, the most striking aspect about the roughing out process is that it is based mainly on movements. While techniques such as molding and pounding require special tools and devices, it is especially the artisan's hands and fingers that are in action during the major part of the shaping process. The movements employed are also distinctive because of their relatively specialized character: few ties exist to other activities and only body postures (for example, working while standing bent over, seated with legs spread, or with one leg folded in front) find an echo in domains other than pottery making.

This preponderance of specialized gestures has been identified as a crucial factor for explaining the usual stability of shaping technique through time and space and its possible coincidence with major social boundaries such as language, socio-professional groupings, or political units (Gosselain 2000, 2002; Wallaert 1999). Their mastery involves a close interaction between two individuals and a training period that may span over several years, so that motor habits would be more resistant to change than other stages of the manufacturing process. Recent studies have showed, however, that borrowing processes also affect the shaping stage (Gelbert 2001; Sterner and David 2003). Another way of explaining stability in shaping techniques is that they are widely viewed by potters as an inheritance and a material correlate of social boundaries. Stability could thus be deliberately sought, as among the Songhay blacksmiths of Niger who acquired the molding technique from their Bella neighbors (considered as former slaves), but have chosen to pass on the pounding technique to their daughters, the later being regarded as the "true Songhay technique."

Preforming

This stage, which is carried out as a continuation of roughing out, consists of giving the just constituted hollow volume its final geometric characteristics. To this end, potters perform scraping and smoothing operations, with the help of a series of tools, which allow them to distort the wall of the vessel gradually to the desired curvature by applying pressure.

In order to round the body and make it bulge, potters scrape the outside and inside walls and modulate the pressure exercised on the tool, while supporting the wall with the other hand. Tools used for scraping the inside wall are generally round or spherical: rounded off pottery sherds, pieces of calabash, pods, large seeds, nuts, shells, or spoons. Moved horizontally or obliquely, they do not generate much displacement of clay since internal scraping aims essentially at modifying the shape of the body. Scraping and smoothing operations made on the outside wall, on the other hand, allow the potter to mask irregularities and to heighten the vessel through the displacement of a rather large amount of clay. Such operations are typically carried with flat and oblong tools such as flat sticks, spatulas, bones, blades, pods, shells, or corncobs.

Forming the neck may be done with different methods, either as a continuation of preforming the body or after having added one or several coil(s). A first method consists of bending the upper part of the wall through horizontal smoothing of the inside wall. In this case, the potter exercises increasing pressure on the smoothing tool, while supporting the wall with the other hand, until the appropriate curvature is reached. Another method consists of smoothing the outside wall of the vessel horizontally with a tool whose curvature

Ceramics in Africa. Fig. 3 Forming the neck and the lip of a vessel with the fingers. A constant pressure is exerted on the wall while the vessel is rotated slowly with the other hand (photo by Olivier Gosselain).

corresponds to that of the neck. Rounded off sherds or calabash pieces are typically used to that aim. A later method consists of pinching the rim between fingers (directly or with the help of a leaf, a rag, or a piece of leather) and rotating the vessel slowly with the other hand, while exerting a constant pressure on the rim and progressively tipping up the hand toward the exterior (Fig. 3).

Finally, lips may be formed through constant pressure between fingers – or with the help of any supple material – as in the neck-forming method described above. Depending on the position of fingers, the pressure exerted and the materials used, resulting lips may acquire a rounded or sharp profile, or bear a groove. The rim may also be shaped through smoothing with a flat or slightly concave tool such as a spatula, a stick, a bone, or the nervure (principal vein) of a large leaf. Here also, the potter usually rotates the vessel while exerting a constant pressure on the tool, placed perpendicularly on the rim. Instead of rotating the vessel, the tool may be displaced itself on the rim, especially when shaping the lip of large and heavy vessels. A last method consists of adding one or several coil(s) above the rim or on its side, and smoothing it with fingers or a supple material.

The very personal character of the preforming operations described above must be stressed. Minute variations in profiles – the shape of the neck, lip, handle, or base – are also likened to "signatures," which can be recognized as readily by eye as by touch (Gosselain 2002: 113, 115).

Another striking characteristic of the preforming stage is its permeability to innovation and outside influences. From simple widespread forms, artisans seem to be able easily to meet new requests (flowerpots, moneyboxes, stills, and incense holders) or to modernize the aspect of their products (Argenti 1999). This explains the current appearance of a new generation of flat-bottomed pots fitted with handles, faithful copies of the aluminum pans produced in urban environments. The realization of such products may allow a few individuals to position themselves as experts and agents of modernity.

Decoration

Plastic decorations – i.e., made when the clay is still wet – belong to four large categories (1) grooving, (2) incising, (3) impressing, and (4) appliqué.

Grooving consists of tracing lines or figures on the surface of the vessel with the fingers or various tools whose end(s) is/are rounded or sharp: sticks, stalks, thorns, ends of calabash scrapers, sharp stones, bones, shells, nails, bicycle spokes, bracelets (drawn on the surface), bundles of stalks or thorns held between finger or driven into a clay ball (Fig. 4), hair combs, and indented pieces of calabash, wood, plastic, or metal.

Incising is similar to grooving, except that the tools used have a sharp cutting edge so that clay surfaces are actually incised. Such tools include knives, spearheads, and scraps of metal.

Impressing is done with distinct tools and methods. The simplest is to press any kind of device or material (fingers, natural objects, sticks, combs or carefully designed wooden or iron stamps, as those used in the Inland Niger Delta; Gallay et al. 1998), in order to make a single impression that may be subsequently repeated on the surface. Another method consists of pressing while simultaneously rocking convex devices such as blades or indented combs and bracelets, so as to obtain zigzag-like rows of impressions. "Rouletting" is

Ceramics in Africa. Fig. 4 Decorating a vessel with a comb-like device (photo by Olivier Gosselain).

a third impressing method, done either with natural objects such as corn cobs, shells, fish vertebrae and various plant parts, or, more generally, with tools made by carving wood or twisting, knotting, braiding, coiling, or wrapping fiber strips or cords (see examples in Gosselain 2000; Soper 1985). Such tools and materials are rolled on the vessel's surface to impress regular patterns.

Appliqué comprises all types of clay elements added onto the surface: e.g., coils, buttons, spikes, and human or animal figures.

Besides plastic decoration, vessels may also be ornamented with painting and/or specific surface treatments. The most usual treatment consists of applying a slip made from iron-rich clays, crushed beforehand on a stone or in a mortar, and subsequently sieved and diluted in water. The application is made on a dried surface, directly with the hand or with a rag. In many instances, slipped surfaces are then carefully polished with round stones or strings of seeds (mostly from baobabs) or cowries. The resulting effect, after firing, is a dark red and shiny surface. Polishing may also be done on unslipped surfaces or with graphite, as among several South African populations (Bell and Calder 1998; Lawton 1967).

Painting occurs either before or after firing, the first being widespread on the continent, the second especially observed in South Africa or on modern ornamental vessels aimed at tourist or city markets. Prefiring painting is done with various mineral pigments diluted in water and occasionally mixed with gum Arabic, salt or sugar, all elements that are said to "strengthen" the adherence. The application is made with a feather, a millet ear, a stalk, or a stick with a crushed or rag-wrapped end. In southwestern Niger, Bella and Zarma potters use a blade for drawing thin lines and motifs (Fig. 5). Postfiring paintings are made with industrial paints and inks.

Regardless of the techniques, tools, and materials used, a striking feature of decoration is the casual way in which most potters talk about it. Decoration would be a matter of "simple embellishment," "like a hairstyle or clothes," the main function of which is to "attract the customer's eye." In some cases, even the esthetic function of decoration is questioned, as when potters explain that roulette impressions are simply a matter of modifying wall texture to prevent wares from being slippery (Bredwa-Mensah 1996; Priddy 1971).

This does not mean that artisans work with no references or precise rules. On the one hand, pottery decoration is generally only one realization among others in a much broader decorative system. For example, the existence of numerous parallels has been found between vessel ornamentation and tattooing or scarification (Barley 1994; David et al. 1988; Ritz 1989), and parallels also exist with architecture, certain technical devices such as cast iron ovens, or other containers (baskets, gourds, and aluminum pots). On the other hand, while decoration is obviously very susceptible to innovation (e.g., the current generalized use of letters of the alphabet in the painted decorations of West Africa), change is seen to particularly affect the components of decorations rather than their organization or "grammars." Some think that it would be at this second level that the symbolic function of decoration comes into play and that collective identities would express themselves (David et al. 1988).

Drying

A comparison of data indicates that there are no "rules" as regards drying modes and duration. For instance, some potters deem it necessary to place the wares in the

Ceramics in Africa. Fig. 5 Applying a mineral paint with the help of a blade (photo by Olivier Gosselain).

sun during the early stage of drying, while others take great care to shelter them during the first hours, the first days, or even the whole drying process. Similarly, some may wait several weeks or several months before firing the vessels, while others do it after 2 or 3 days. While drying periods are often shorter in the Sahel than in tropical areas, differences in practice appear to proceed essentially from personal conceptions and ways of scheduling manufacturing operations, rather than climatic variations or the chemical and physical characteristics of raw materials. Thus, potters who make vessels on demand or frequent weekly markets generally resort to short drying periods. If necessary, wares cracked from too fast a drying are simply repaired with fresh clay.

Such flexibility in drying procedures is due, in part, to the accommodating nature of the raw materials used in Africa. But it may be reinforced through the use of prefiring techniques that allow the gradual evaporation of residual water through preheating. For instance, pots may be placed around or above a cooking earth (Gosselain 2002: 145–146; Priddy 1971; Woods 1984), on glowing embers (Kanimba and Bellomo 1990; Mercader et al. 2000) or a rack-like structure below which a fire is kept going, as among several Kongo groups from Central Africa (de Maret 1974; Mpika 1986).

Firing

Although the emphasis will be put here on fuels and structures, several other aspects of firing may be taken into consideration, including the scheduling of firing events, the location of firing structures, the way vessels and fuel are positioned within the structure, the overall firing schedule (duration, refueling, way of assessing the degree of firing of the wares), or the identity of people taking part in the operation.

Fuel

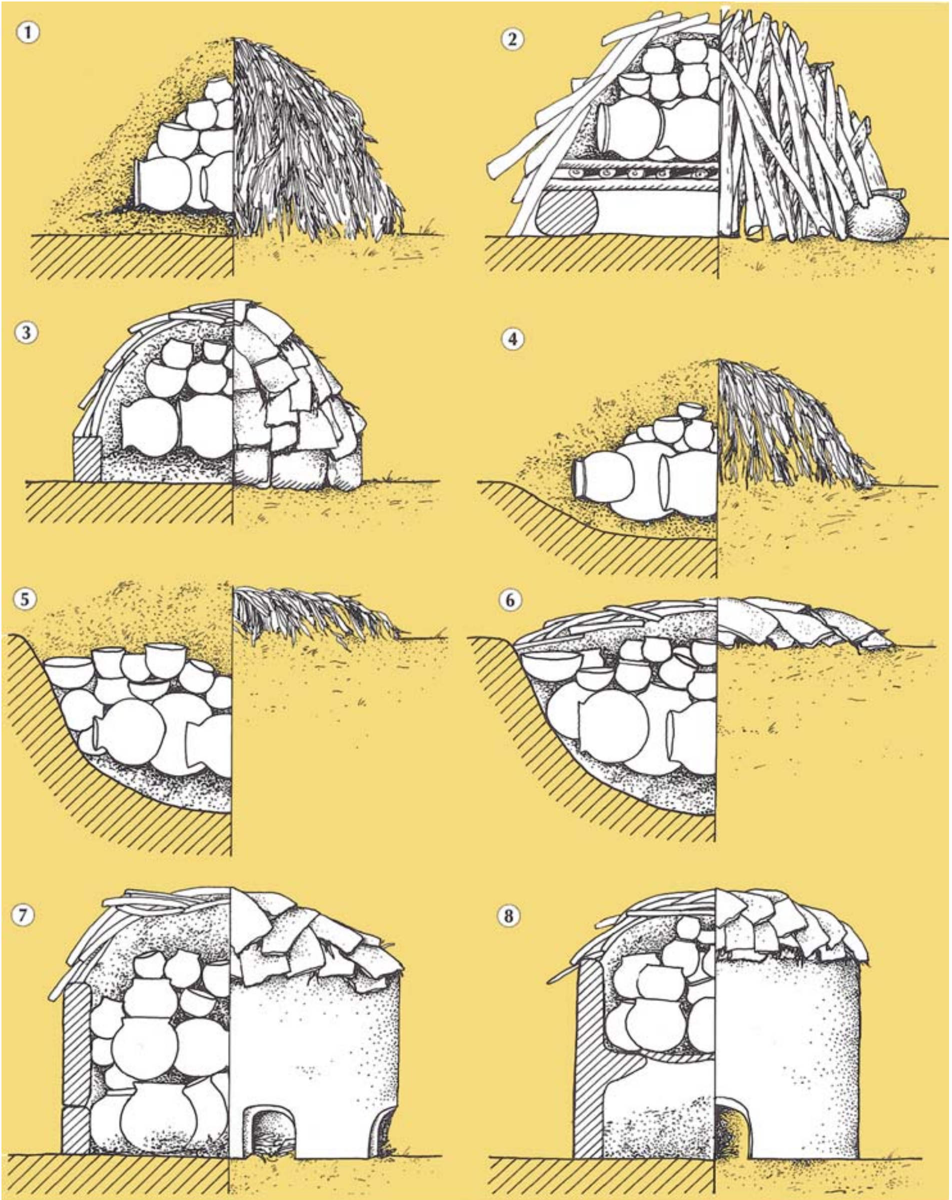
As summarized by Livingstone Smith (2001a: 993), almost everything that can be burned is used for firing pottery in Africa. Used independently or combined in various proportions, the materials may be grouped into three categories corresponding roughly to those made by the artisans themselves when asked about the nature of "appropriate" and "inappropriate" materials (1) manure – cows, donkeys, camels, or horses; (2) "light" fuels – dry grass or cereal stalks, cereal chaff, palm fronds, leaves, twigs, barks, or roots; and (3) "heavy" fuels – branches and logs from dozens of tree species.

Neither the firing structure nor the firing conditions possibly sought by potters seem to impose restrictions on the selection of fuel materials. With the notable exception of manure, whose combustion is slower, all the fuels used throughout Africa allow potters to obtain similar firing schedules and temperatures.

Structure

Eight firing structures are documented in Africa (see details in Drost 1967; Gosselain 2002: 153–162) (1) bonfire, (2) elevated bonfire, (3) bonfire with isolation, (4) depression, (5) pit, (6) pit with isolation, (7) oven, and (8) updraft kiln (Fig. 6).

The bonfire – also called "open firing" – is one of the simplest and most widespread technique in Africa. Pots are placed on a bed of fuel, at ground level, and covered with another layer of fuel. Those structures vary tremendously in dimension (50–250 cm in height and 50–700 cm in diameter), firing duration (from



Ceramics in Africa. Fig. 6 Firing structures used in Africa (1) bonfire, (2) elevated bonfire, (3) bonfire with isolation, (4) depression, (5) pit, (6) pit with isolation, (7) oven, and (8) updraft kiln (drawing by Yvette Paquay).

20 min to several hours), as well as the number of vessels fired at once (from 1 to 500). This number depends both on the stock of wares available at the moment of firing and on the personal conceptions of the potters. For example, some Gbaya potters from Cameroon deem it impossible to fire more that one to three vessels at once. They thus multiply firing sessions or construct several bonfires side by side.

Elevated bonfires have only been recorded so far in the Great Lakes region, among the Twa of Burundi and Rwanda and the Konjo of Uganda (Célis and Nzikobanyanka 1984). The technique consists of placing the vessels on an elevated bed of fuel constituted of a rack-like layer of branches placed on four or five big stones.

Bonfires with isolation differ from simple bonfires in that a layer of fireproof materials – sherds, old basins, and sheets metal – is placed either between the vessels and the upper layer of fuel or upon the whole structure. In the first case, the aim is to avoid color variations due to contacts between fuel and the surface of vessels; in the second, it is to protect the structure from the wind and keep the fuel in place.

Depressions are shallow excavations made in the ground (between 20 and 40 cm depth) in which vessels stand higher than ground level after having been placed on the bed of fuel. Their shape is circular, oval, or rectangular, with diameters (or sides) between 100 and 500 cm. As for the bonfire technique, important variations are observed in the number of wares fired at once and the duration of the firing. Variations also exist in the way vessels are positioned within the structure. For instance, while most potters place them horizontally or vertically, some place them upside down on the bed of fuel, in order to obtain a dark and shiny internal surface (Zaghawa of Sudan (Tobert 1984) or Hausa and Kanuri of Niger).

What differentiates pits from depressions is the fact that vessels stand below the ground surface after having been placed on a bed of fuel. Thus, their depth always exceeds 50 cm and may reach as much as 100–150 cm, for a diameter between 50 and 400 cm. Another difference pertains to the duration of the firing, often observed to be several hours long. In a variant observed among Bamileke fe'fe' from western Cameroon (Gosselain 2002) and Kongo Manyanga from Kongo (Mpika 1986), the wares are placed on a rack-like wooden structure standing above the pit and carefully tipped in the hole in the course of firing.

Pits with isolation resemble bonfires with isolation in that a layer of fireproof materials is placed either on the vessels or on the upper layer of fuel. This technique is often used in southern Africa (Lawton 1967; Krause 1985), but also in the Sahel area, from Senegal to Sudan. Here, firing is usually a whole night long, even though the fire actually burns for a few hours.

Ovens correspond to wall-enclosed firing structures within which fuel and vessels are put together. Such structures have only been documented in West Africa. Their walls are made of mud, with a height between 50 and 180 cm, and a diameter between 100 and 400 cm. One or several holes is/are made at the base of the wall, through which fuel is put in during firing. From 20 to 200 vessels are fired at once, which are piled and subsequently covered with fuel and/or a layer of sherds. Burning stalks or grasses are then put in the hole(s), either at the beginning or throughout the whole firing. A simpler oven technique, observed among some Yoruba of Nigeria (Fatunsin 1992: 39–40) and Bariba of Benin, consists of using a bottomless jar placed on mud bricks upon a small fire. Such technique is only used for firing small vessels.

Updraft kilns are even more rare than ovens, as they would be used in Nigeria only, among Nupe of Bida (Nicholson 1934; Vernon-Jackson 1960) and Yoruba of Abeokuta (Fatunsin 1992). The firing structure is also enclosed in a mud wall, but fuel is put in a distinct chamber and separated from the vessel with sherds or a perforated clay plate.

As stated above, measurements performed in the field show that the variety of fuels and structure used results, paradoxically, with a considerable homogeneity of firing conditions. Whether it is a question of temperature rise, temperatures reached, or the duration of exposure at temperature thresholds, each variant makes it possible to achieve the same global results (Livingstone Smith 2001a). This homogeneity in firing conditions is echoed by the way in which potters judge the degree of pottery firing; most of them interrupt the process or stop refueling when the wall of the pots becomes incandescent.

As regards relationships to other activities, certain similarities exist with cooking techniques (Gosselain 2002: 165). However, an activity such as metallurgy, a priori much closer, maintains no link with pottery making, even in societies where blacksmiths and female potters belong to the same endogamous subgroup. The fact that these two activities are practiced by different actors seems to present an obstacle to transfer. At the same time, firing is surrounded by a series of prescriptions and prohibitions, but these are less numerous than at other levels of the operating chain and do not seem to have much influence on the artisan's technical behavior. They mainly concern avoiding the situation in which badly intentioned people or those in impure states jeopardize the operation solely by their presence.

This worry stems from the generally public and collective character of the firing stage. In most regions of Africa, artisans habitually associate with relatives, friends, or neighbors for firing their wares. These associations have several advantages; they not only allow artisans to invest less effort in gathering fuel, organizing wares, or sharing in firing surveillance, but they also allow artisans to conform to a restrictive firing calendar (for example, weekly markets) when placements reserved for the operation are few in number.

Postfiring

In many regions of Africa, vessels receive a last treatment after firing, either when retrieved red hot from the fire or after having cooled off. These postfiring treatments, that aim at improving the physical characteristics and appearance of vessels, may be grouped into five categories (1) organic coating, (2) resin application, (3) smearing, (4) smoking, and (5) water sprinkling or soaking.

Organic coating is by far the most common treatment. It consists of coating the surface with an organic mixture made from the bark, fruits, leaves, branches, or root parts of several dozens of tree species, the most common of which are *Bridelia* *ferruginea*, *Bridelia micrantha*, *Parkia biglobosa*, *Parkia filicoidea*, *Diospyros mespiliformis*, *Ximenia americana*, *Pterocarpus angolensis*, and several species of *Acacia* and *Syzygium* (see details in Drost 1967: 174–182; Gosselain 2002: 184–190). After having been crushed, the part used is soaked in water for several minutes, several hours, or several days. It may be boiled (decoction), put into hot water (infusion), or kept at ambient temperature (maceration). As for the application, it is done by plunging the hot vessels in the mixture, sprinkling them with it, or smearing the surface with the help of a series of brush-like tools. Alternatively, cooled off vessels may be coated with the help of a rag. Besides having a decorative purpose, organic coatings are said to strengthen and waterproof the vessels.

Resin application is solely aimed at waterproofing the vessels. Here, the inside surface is coated with resin extracted from several tree species – e.g., *Canarium schweinfurthii*, *Copaifera demeusei* or *mildbraedii*, various *Acacia* species, *Euphorbia candelabrum*, *Dodonea viscosa*, and *Guizotia abyssinica* – either by melting it directly in the vessel or separately. In both cases, the vessel is rotated rapidly so as to ensure a homogeneous surface coating.

Other organic materials may also be smeared on the surface or cooked in the vessel in order to strengthen or waterproof them: leaves of *Ricinus communis* or *Sida rhombifolia*, oil or sap from *Raphia vinifera* or *Elaeis guineensis*, fruits, fibers, roots, cereal husks, milk, porridge, or cow dung (see examples and details in Gosselain 2002: 191–192).

Smoking aims at covering the vessel surface with wood tar in order to give it a black shiny aspect and, according to some potters, improve their strength and imperviousness. To that aim, vessels retrieved red hot from the fire are usually buried in organic materials such as grass, maize spaths, cereal husk or chaff, animal manure, fruit pods, bark or wood shavings (see examples in Gosselain 2002: 192–193). Another technique, observed in the Great Lakes region, consists of maintaining vessels above a fire made of grass, plantain leaves, or reeds (Trowell 1941).

Lastly, vessels may be plunged in, or sprinkled with, fresh water or boiling water (see examples in Gosselain 2002: 193). Here again, the aim would be to waterproof and strengthen the wares.

As with clay preparation or firing techniques, artisans generally have a very clear-cut opinion about the ingredients that it is advisable to select and the way to prepare them. These opinions are extremely divergent. In sub-Saharan Africa, about 50 plants are currently used for making organic coatings, as we have seen above, but few potters know about more than one and each potter believes there is no alternative to his or her choice. Similarly, those who prepare their coating in decoction or maceration form and apply them hot or cold consider it inconceivable to proceed otherwise. In reality, all choices are perfectly justified from the point of view of technical and esthetic aims. An analysis of the various fruits and barks used in certain zones of sub-Saharan Africa indeed reveals the presence of one same category of tannins, the procyanidins, which have excellent coloring and waterproofing properties (Dialo et al. 1995).

In general, the most striking aspect of the postfiring stage has to do with its numerous relationships to other spheres of activity. Thus, most of the plant types that artisans select are used for diet, leather dyes, fabrics or baskets, wall and pavement waterproofing and, above all, pharmacopoeia. This last domain is particularly interesting as the illnesses and injuries treated with the help of the same preparations that potters use are characterized especially by discharges (Gosselain 1999, 2002: 197–198, 210–211): various wounds, diarrhea, gonorrhea, hemorrhage, menorrhagia, ulcers, etc. Use of these preparations also appears during birth and circumcision rites. What we find at work, here, is simply the materialization of an extremely widespread association between pottery making and human beings (Barley 1994; David et al. 1988; Gosselain 2002: 205–208; Ritz 1989). And since treating a pot or treating a body are related activities from a symbolic point of view, a strong channeling of behaviors can occur when selecting ingredients or preparation modes.

This fact illustrates perfectly why a *chaîne opératoire* cannot be reduced to mere actions on matter. As stressed by Lemonier (1991) and several other scholars, techniques do not solely aim at transforming materials or acting upon the material world. They also respond to a series of social, political, economical, and symbolic concerns, whose components may be found at any level of the manufacturing process as we have seen throughout this article.

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Ceramics in China

Jiazhi Li, P. L. Leung, K. N. Yu, R. Wu

China was one of the earliest countries that possessed pottery, and was also the country that invented porcelain. She has a unique and sustained history of technique development of 10,000 years. The entire development can be summarized by five milestones and three technological breakthroughs. The outstanding achievements in this development constituted an indispensable contribution to Chinese culture (Table 1 and Map1).

Five Milestones

The First Milestone: Appearance of Pottery in the Early Neolithic Age

According to archeological information, after the discovery of potteries of the Yangshao culture, the following were discovered:

- Those of the Hemudu culture in Yuyao, Zhejiang Province about 7,000 years ago
- Those of the Cishan culture and the Peiligang culture about 8,000 years ago
- Those of the Pengtoushan culture in Li County, Hunan Province and the Jiahu culture in Wuyang County, Henan Province about 9,000 years ago
- Those at the Yuchanyan site in Dao County, Hunan Province, the Xianrendong site in Wannian County, Jiangxi Province, and the Nanzhuangtou site in Xushui County, Hebei Province about 10,000 years ago

Ceramics in China. Table 1 Chronology of ancient Chinese history

Neolithic period	**6500–1700 BCE**
Xia	2100–1600 BCE
Shang	1600–1100 BCE
Western Zhou	1100–771 BCE
Spring and autumn annals	770–476 BCE
Warring States	475–221 BCE
Qin	221–206 BCE
Han	206 BCE–AD 220
Three Kingdoms	220–280
Jin	265–420
Southern and northern	420–581
Sui	581–618
Tang	618–907
Five Dynasties and Ten Kingdoms	907–960
Sung	960–1279
Yuan	1279–1368
Ming dynasty	**1368–1643**
Hongwu	1368–1399
Jianwen	1399–1403
Yongle	1403–1424
Hongxi	1425–1426
Xuande	1426–1435
Zhentong	1436–1450
Jingtai	1450–1457
Tianshun	1457–1465
Chenghua	1465–1487
Hongzhi	1488–1505
Zhengde	1506–1521
Jiajing	1522–1566
Longqing	1567–1572
Wanli	1573–1619
Taichang	1620–1621
Tianqi	1621–1627
Chongzhen	1628–1643
Qing dynasty	**1644–1911**
Shunzi	1644–1661
Kangxi	1662–1722
Yongzheng	1723–1735
Qianlong	1736–1795
Jiaqing	1796–1820
Daoguang	1821–1850
Xianfeng	1851–1861
Tongzhi	1862–1874
Guangxu	1875–1908
Xuantong	1909–1911

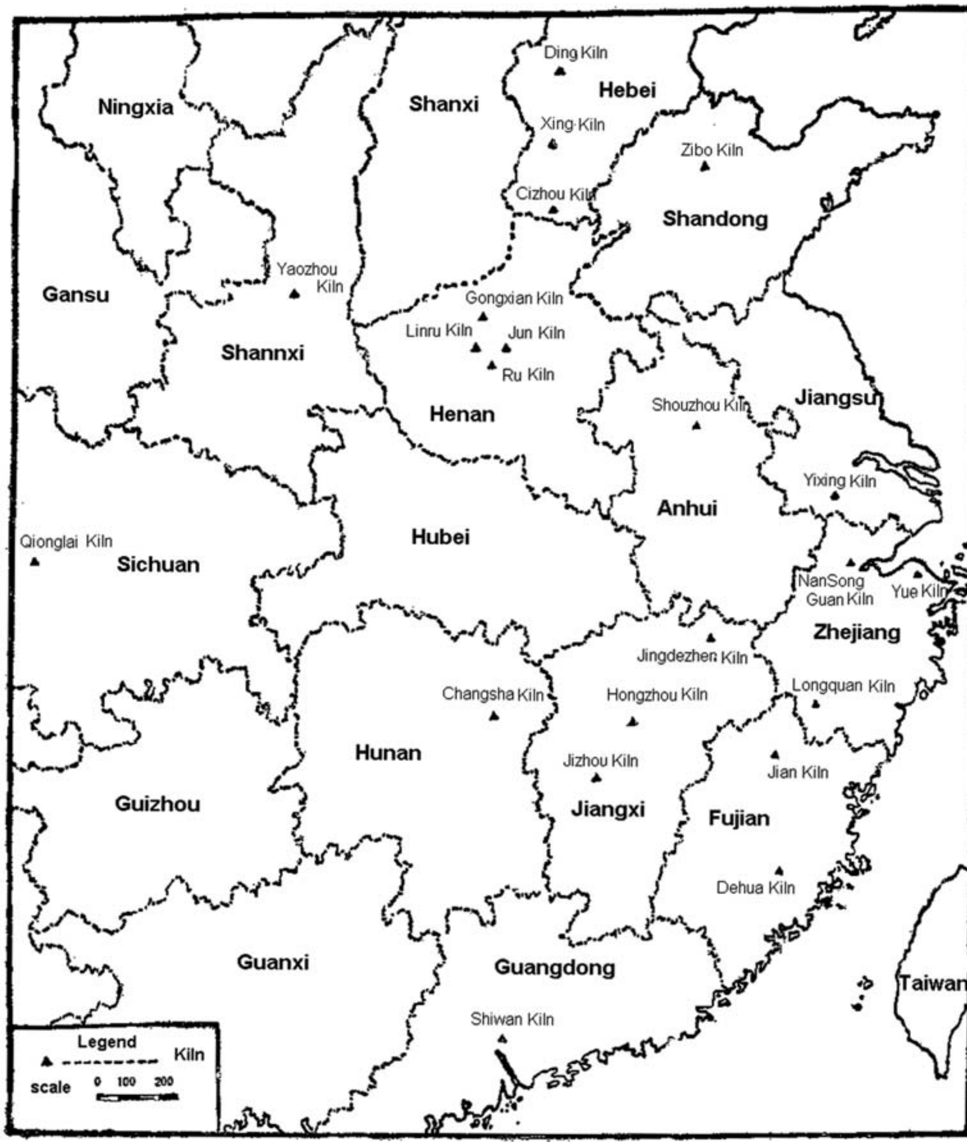
The raw materials for early pottery were all obtained locally. In particular, a common feature for the pottery of about 10,000 years ago is that they were all coarse sandy pottery with coarse and loose textures, so most of them were only small shards when unearthed, and only very few whole pieces could be restored. Their firing temperatures were about 700°C. For examples, pottery from the Nanzhuangtou site in Xushui County contained big grains of hornblende and vermiculite (Fig. 1), and pottery from the Xianrendong site in Wannian County contained large grains of quartz, dickite, and muscovite (Fig. 2; Li et al. 1996). This also explained why the pots from the Nanzhuangton site contained more calcium oxide (lime, CaO) and magnesium oxide (MgO), and those from the Xianrendong site contained more silicon dioxide (SiO_2) and potassium oxide (K_2O). In this way, the amounts of calcium oxide and silicon dioxide can be used as characteristic constituents to differentiate between pots manufactured in the northern part and those manufactured in the southern part of China. The microstructure of the black pottery including charcoal from the Hemudu culture was rather peculiar (Li et al. 1978) and is shown in Fig. 3.

The Second Milestone: Successful Firing of Stamped Hard Pottery in the Late Neolithic Age and Appearance of Proto-Porcelain in the Shang–Zhou Dynasty

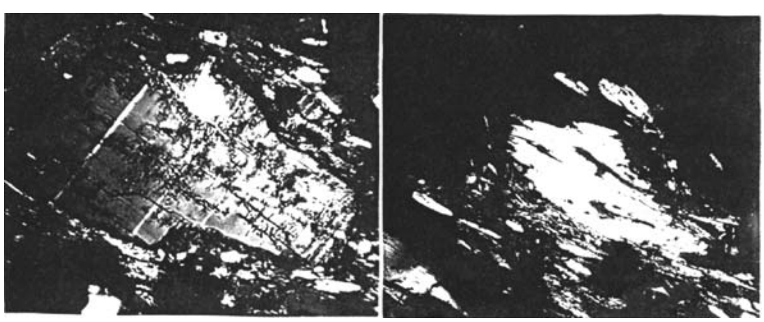
It is generally accepted that stamped hard pottery first appeared in the late Neolithic age about 4,000 years ago (which could be regarded as the Xia period according to dating results) and that proto-porcelains first appeared in the Shang dynasty. Stamped hard pottery had lower contents of iron oxide (Fe_2O_3) than general potteries. The firing temperature was above 1,000°C, and the maximum temperature could reach 1,200°C. Proto-porcelains had even lower iron oxide content; they were in general below 3%. The highest firing temperature reached 1,280°C. There were glaze layers of nonuniform thicknesses on the interior as well as the exterior surfaces of proto-porcelains. The glazed layer could be a green glaze with a grayish green or yellowish green color, or a yellow glaze with a greenish yellow or brownish yellow color. Generally speaking, the glaze was not tightly bonded to the body and could be easily delaminated. The glaze contains relatively high contents of calcium oxide, and is thus called *calcium glaze*. This kind of glaze is a unique high-temperature glaze created in China and is the earliest high-temperature glaze in the world (Fig. 4; Li et al. 1985).

The Third Milestone: Appearance of Green-Glazed Porcelain (Celadon) in Southern China in the Han–Jin Dynasty

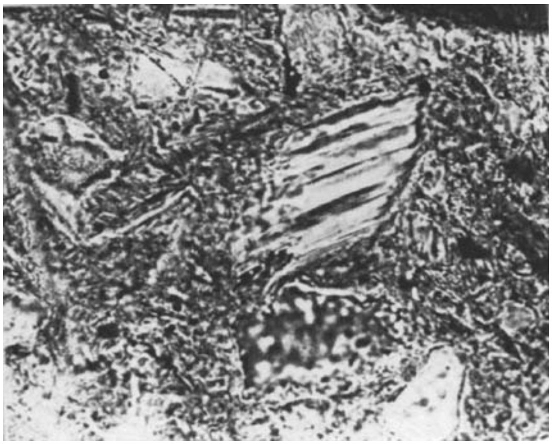
The successful firing of the southern green-glaze porcelains, represented by the Yue wares in Zhejiang Province during the late East Han dynasty (AD 25–220), signified another leap in the development of ceramic technique in China. Porcelains first appeared in the world from this period.



Ceramics in China. Map 1 Map showing the kilns in different provinces in China (Adopted from Chen 1990).



Ceramics in China. Fig. 1 Microstructure (70×) of sandy pottery from the Nanzhaungtou site in Xushui County, Hebei Province.



Ceramics in China. Fig. 2 Microstructure (350×) of sandy pottery from the Xianrendong site in Wannian County, Jiangxi Province.

Ceramics in China. Fig. 3 Microstructure (165×) of black pottery including charcoal of the Hemudu culture in Yuyao, Zhejiang Province.

Ceramics in China. Fig. 4 Microstructure (140×) of an early proto-porcelain of Western Zhou dynasty from Jiang Shan, Zhejiang Province.

Porcelain differed from pottery in that the porcelain appeared to be stronger and more compact. Most were white; some had a grayish tint. Their cross-sections had a glass-phase luster and the thin layer was slightly translucent. They had relatively high contents of silicon dioxide and aluminum oxide (Al_2O_3) and smaller amounts of fluxing agents; they could be fired at higher temperatures and had higher strength. The porosity as well as the water absorption rate was very small. As regards their microstructure, they contained relatively larger amounts of glass phase as well as a certain amount of Mullite crystals. The quartz remnants were small and rounded. The appearance, chemical composition, physical properties, and the microstructure described above are the characteristics of porcelain. Yingxing Song (a famous scientist in the Ming dynasty) describes them as having the "…appearance of white flesh and jade skeleton" in his publication *Tian Gong Kai Wu* (Exploitation of the Works of Nature).

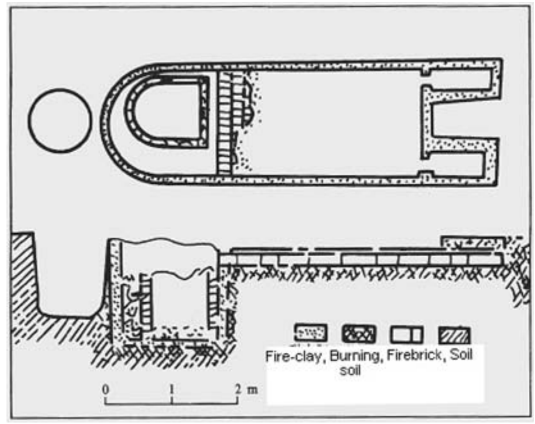
The success of green-glaze porcelains in southern China was primarily attributed to the rich reserve of China stone in the southern part of China. Since at that time only China stone was used as the raw material for porcelain, this led to the early quartz–muscovite series of porcelains with high silicon and low aluminum contents in southern China. The success of green-glaze porcelains could also be attributed to the techniques derived from extensive experience in firing the stamped hard pottery as well as the proto-porcelains.

We use as an example the shard from a green-glazed stamped *Ci Lei* (porcelain drinking vessel) unearthed from the Yue Kiln in Xiaoxiantan, Shangkyu, Zhejiang Province. The iron oxide and the titanium dioxide (TiO_2) contents in its body and glaze are relatively lower, and the titanium dioxide content in the glaze is particularly low. The firing temperature reached 1,300°C. The body contains relatively larger proportions of the glass-phase. The quartz remnants are small and uniform, while Mullite crystals are ubiquitous. The glaze layer contains extremely small amounts of bubbles and quartz remnants. The glaze layer is a rather thin transparent glass glaze. The anorthite crystallization layer is common at the body–glaze interface, which strengthened the bonding strength of the body and the glaze (Fig. 5). The water absorption rate of the body is only 0.28%, and the bending strength is as high as 71 MPa. Its chemical composition, microstructure, and physical properties perfectly satisfy the requirements for contemporary porcelains (Li et al. 1978).

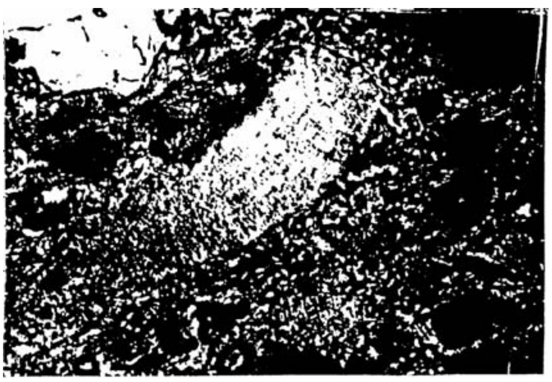
The Fourth Milestone: Breakthrough of White-Glazed Porcelain in Northern China in the Sui–Tang Dynasty

The breakthrough in white-glazed porcelain in northern China in the Sui–Tang dynasty (AD 589–907) was the result of the rich supplies of high-quality raw materials in northern China as well as experience over a long

Ceramics in China. Fig. 5 Microstructure (405×) of the glaze of a green-glazed porcelain from the Yue Kiln, Xiaoxiantan, Shangkyu, Zhejiang Province.



Ceramics in China. Fig. 7 Qichun relics of a Xing Kiln in the late Tang period.



Ceramics in China. Fig. 6 Kaolinite remnant in the body of a white-glazed porcelain of the Xing Kiln (350×).

period of time. Its occurrence was another leap forward in porcelain techniques in China, and made China the first country to possess white-glazed porcelains (Li et al. 1985).

The techniques required by the white-glazed porcelains of Xing, Gong, and Ding Kilns are summarized below.

Use of New Materials and Improvements in the Recipes for the Body and Glaze

All the bodies of white-glazed porcelains of the Xing, Gong, and Ding Kilns made use of secondary settled clay with higher contents of kaolinite or kaolin clay, so their bodies contained more than 30% of aluminum oxide. Figure 6 shows the microstructure of the body of a white-glazed porcelain of the Xing Kiln, in which a kaolinite remnant can be seen. Furthermore, feldspar was found in the recipes of the body of some white-glazed porcelains, and the potassium oxide content in these bodies could be above 5%. According to the silicon dioxide contents and α-quartz contents in the microstructure of the bodies, it can be inferred that the kaolin–quartz–feldspar porcelains emerged in the Sui and Tang periods in China. These were not found in the southern green-glazed porcelains. Even when kaolin clay started to be used for the Jingdezhen white-glazed porcelains during the late Song and early Yuan dynasties, these were only kaolin–quartz–muscovite porcelains. These two types of porcelain represented the two major white-glazed porcelain systems in northern and southern China. For some white-glazed porcelains of the Sui dynasty, the potassium oxide content far exceeds that of calcium oxide, the glaze of which is referred to as the alkali–calcium glaze. This is also never seen in the southern early green-glazed porcelains, and only starts to appear in the Jingdezhen sweet white-glazed porcelains during the Yongle period of the Ming dynasty and the Dehua white-glazed porcelains during the Qing dynasty.

Increase in the Firing Temperature and Improvement of the Kilns

The firing temperatures of white-glazed porcelains of the Xing, Gong, and Ding Kilns of the Tang dynasty reached 1,300°C, and some reached as high as 1,380°C. The increase of the firing temperature was certainly linked to the improvement of the kilns. The kilns used for the northern white-glazed porcelains in the Sui and Tang periods were up-draught Mantou kilns (Fig. 7). The improvements included big firing chambers, small kiln chambers, and double chimneys, which increased the drag force to enhance the firing temperature.

Use of Saggers and Improvement in Firing Techniques

The firing of Xing Kiln white-glazed porcelains during the late Sui and early Tang dynasties already made use of saggers (a sagger is a case made of fired clay in which porcelain and similar delicate items are enclosed while they are being fired in the kiln) for assembling and firing. The transition from open firing to firing in saggers was a breakthrough to enhance the quality of porcelains. This kiln was one of earliest ones which employed devices for firing in saggers, and possessed various saggers as well as various techniques according to the different forms of porcelains.

The Fifth Milestone: Time of Monochrome-Glazed, Polychrome-Painted, and Sculpted Porcelain from the Song to Qing Dynasty

All the famous porcelains from the Song dynasty to the Qing dynasty (AD 960–1911), such as the imperial wares, Ge wares, Jun wares, Ru wares, Yaozhou wares, Linru wares, Cizhou wares, Jizhou wares, Longquan wares, Jian wares, Changsha wares, Qionglai wares, Dehua wares, Yixing wares, and the later Jingdezhen wares, were all world famous for their monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains. These porcelains illustrated the great achievements in the sciences, techniques, and arts needed for Chinese porcelains.

Starting from the late East Han dynasty, the Zhejiang Province had been firing celadon with iron oxide as the colorant. Until the South Song dynasty, the black body celadons manufactured in its imperial kiln and the Longquan kiln were crystallization-phase separation-crackle-glaze porcelains. These porcelains made use of the microcrystals of Anorthite and the immiscible liquid droplet separated from the glaze to enhance the jade-like appearance, and exploited the different expansion coefficients of the body and the glaze to generate cracks with different patterns and to become a unique world famous decoration. On the other hand, the white-body celadons were manufactured in the Longquan kiln in large numbers and were transported to different places in the world and have been collected by all major museums.

The celadons from the Ru Guan kiln and Linru kiln of Baofeng in Henan Province, as well as those of the Yaozhou kiln of Tongchuan in Shaanxi Province, also used iron oxide as the colorant. These porcelains also enjoyed a very good reputation in the world. The celadons from the Ru Guan kiln were particularly precious due to the short manufacturing periods and their small handed-down number.

Black-glazed porcelains emerged almost at the same time as the celadons. All the famous kilns in north and south China manufactured this kind of black-glazed porcelain from time to time, which used iron oxide as the main colorant. With the arrival of the Song dynasty, the techniques in manufacturing black-glazed porcelains had been significantly improved. The most unusual products included the hare's fur bowl of Jianyang, Fujian Province and the black-glazed bowl of Jizhou, Jiangxi Province. These developments were partially attributed to the habit of drinking tea at that time, and partially to the availability of the extremely complicated technology, which was unique in the world. The "hare's fur" was formed by crystallization and then phase separation (or direct phase separation), and then by recrystallization. Under different environments, products with different colors, such as the golden hare's fur and the silver hare's fur, can be formed (Chen et al. 1983a,b). Among these, the fur streaks of some will display different colors in the optical spectrum, which can interchange with each other when observed from different angles. This product is called *Hao Se Bian Yi* bowl (hare's fur bowl with alterable colors), which is a product of the science and technology that integrated the phase separation and crystallization in physical chemistry and thin-film interference or diffraction grating in physical optics. The Hao Se Bian Yi cup transported to Japan was called the *Yohen Temmoku* and was considered a national treasure.

The glaze of the Jun kiln in Yu County, Henan Province was a new product. It was a red glaze colored by copper compounds, or a multicolor glaze with nonuniform red patterns distributed on a bluish opalescent glaze surface with different tints. The blue Jun glaze was not colored by cobalt oxide, but was caused by the stronger scattering of the blue light with a shorter wavelength by the liquid droplet phase which fulfilled the size requirement for Rayleigh scattering. (Rayleigh scattering refers to the scattering of light off of the molecules of the air, and can be extended to scattering from particles up to about a tenth of the wavelength of the light. It is Rayleigh scattering off the molecules of the air which gives us the blue sky.) In other words, this was a kind of physical coloration. The copper-colored liquid phase droplets and cuprite formed the red patches, while the purple streaks were formed by the bluish polycrystals of chalcocite (Chen et al. 1983a,b). The phase separation of the Jun kiln glaze was a physicochemical process taking place within a range of chemical compositions and under the actions of the firing temperature, atmosphere, and time. Because of complicated factors, it was difficult to control the formation conditions, so the appearance of the products could not be controlled easily; this was referred to as furnace transmutation.

Starting from the white-glazed porcelain manufactured in the Five Dynasties to the bluish-white-glazed porcelains in the Song dynasty, Jingdezhen has been one of the greatest kiln sites in terms of quality, quantity, and impact. Before the Yuan dynasty and the early Ming dynasty, there had been ground-breaking developments in the techniques required for Jingdezhen porcelains. The white-glazed porcelains of Shu Fu (Center government in Yuan dynasty) and the sweet white-glazed porcelains of the Yongle period were not only superb in terms of the quality and appearance, but also provided sound techniques and physics foundations for the further manufacturing of monochrome-glazed porcelains and polychrome-painted porcelains. Starting from the Yuan dynasty, Jingdezhen started to fire the blue-and-white underglaze colored by cobalt oxide and the red underglaze colored by copper oxide (CuO), as well as the blue-and-red. This started the manufacture of products with polychrome high-temperature underglazed colorants. In particular, the blue-and-white porcelains were a unique long-lasting product with the largest sales in Jingdezhen. Furthermore, the different colors created by various metal oxides, such as iron, cobalt, copper, manganese, and their combinations, were the basis for the vibrant color-glazed porcelains from Jingdezhen. At the same time, overglazed painted porcelains started to emerge. When it came to the middle of the Ming dynasty, firing of the so-called *doucai* porcelains was successful, which incorporated the underglazed blue-and-white as well as overglazed paint. The best painted porcelains in the Ming dynasty were the doucai porcelains in the Cheunghua period, which were famous for their vibrant colors, white and moist appearance of the glaze, vivid patterns, and intricate skill work. They were collected in all major museums as well as by private collectors. In the Qing dynasty, there was another type of low-temperature overglazed painted porcelain called *wucai*. These were most famous during the Kangxi period. The subsequent *fencai* porcelains in the Yongzheng period also received great admiration.

After the Ming and Qing dynasties, major kilns all over China perished or stopped manufacturing, except that Jingdezhen kept firing its own colorful porcelains in large quantities and was able to imitate the products from other major kilns. In this way, Jingdezhen became the porcelain center in China and was nicknamed the "Porcelain City."

The Dehua kiln in Fujian Province, which was developed some time later than the Jingdezhen, was also world famous for its high-quality white-glazed porcelains and sculpted porcelains. The semitransparent bodies of Dehua white-glazed porcelains, due to the relatively larger proportion of glass and the very thin glaze layer, made the Duhua porcelains uniquely bright.

Before the emergence of the polychrome underglazed painted porcelains in Jingdezhen, the dark brown underglazed painted porcelains colored by iron minerals and those colored by copper materials had already appeared in the Changsha kiln in Hunan Province and the Qionglai kiln in Sichuan Province during the Tang dynasty. These successes had far-reaching influences on the painted porcelains in later generations. When it came to the Song dynasty, the painted porcelains manufactured by all the kilns in the Cizhou ware type in northern China reached another height. Since these were all folk kilns, the portrayed patterns were all derived from the daily lives of the general public, so the patterns had rich flavors of folk lives, which were in great contrast to those of the imperial wares with many more restrictions. These folk wares also created unique decorations which did not exist in the wares from other kilns.

From the proto-porcelains at the second milestone to the monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains at the fifth milestone, porcelains dominated the history of Chinese ceramics. Interestingly, however, in Yixing, Jiangxu Province, which was also known as the *pottery city*, a world famous pottery called *Zisha pottery* (purple stone ware) has been manufactured since the Song dynasty.

Zisha pottery had many unique features. First, it was especially designed for tea drinkers. The most famous as well as the most manufactured products were teapots with various unique and beautiful forms. Second, it was derived from a unique raw material. The Yixing region is extremely rich in different kinds of Zisha minerals, which were used to produce Zisha pots with different colors. Third, most of the Zisha pottery were handmade, and made use of different tools in the manufacturing process, which fully reflected the wisdom and the skills of the pottery masters. Fourth, the decorations of the Zisha pots were unique in that they integrated the form, painting, poems, calligraphy, and seal cutting, and were thus very rich in Chinese culture characteristics. Starting from the Ming dynasty, there were great masters who made long-lasting famous pots. Therefore, Zisha pottery played a role in the fifth milestone.

When Chinese ceramic techniques developed into the fifth milestone, Chinese ceramics no longer referred to a single region or a particular monochrome-glazed porcelain. Instead, they included the monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains from different kilns in both southern and northern China.

Three Technological Breakthroughs

The five milestones described above relied on continuous breakthroughs in firing techniques. The latter can be summarized as described below (Li 1978a,b).

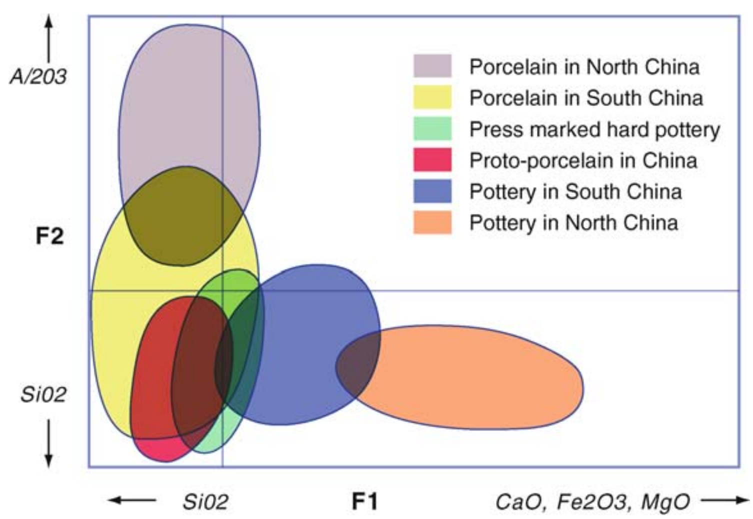
Selection and Refinery of Raw Materials

The raw materials of pottery in general, particularly the early ones, came from the local soil. Therefore, the soil around the residences of early people became the raw materials for firing their pots. Since most of these people resided near hills or close to water sources, the collected raw materials were, in general, soils containing different sand grains. Early pottery was mostly sandy, containing different types of sand grains with different sizes. Strictly speaking, these soils were not suitable for firing pots. After a relatively long period of time, the people became aware that some soils might be more suitable for firing, and they started to select these soils for their pots. In other words, the people started to select the soils locally and clay pottery appeared as a result. When the people discovered that using a particular clay could not satisfy the requirements for forming, drying, and firing, they added different sand grains, ashes of vegetation, and shells of corn, as well as ashes of shells, etc., to get pottery including sand, charcoal, or mussel. The black pottery including charcoal from Hemudu culture was a typical example (Fig. 3).

The raw materials for the stamped hard pottery, proto-porcelains, or even celadons and white-glazed porcelains were still selected locally. However, the people had higher standards for the suitable raw materials. This explained why the stamped hard pottery, proto-porcelains, and celadons were first successfully fired in some regions in southern China, while the white-glazed porcelains were first successfully fired in some regions in northern China. All in all, the raw materials derived from regions which were only suitable for particular types of ceramics.

Differences in raw materials will be reflected by the different chemical compositions of the ceramics. Principal component analyses have been performed on the chemical compositions of the bodies of 700 pieces of ancient ceramics spanning from the Neolithic Age to the Qing dynasty. The cumulative variance explained by the first three principal factors (F1, F2, F3) was more than 80%. Figure 8 shows the factor loadings of F1 and F2.

From Fig. 8, we can clearly see the changes in the chemical compositions of ceramics in southern China. During the development from the stamped hard pottery to the proto-porcelains and then to porcelains, the silicon dioxide in the bodies increased gradually while the fluxing agents calcium oxide, magnesium oxide, and particularly iron oxide decreased. The contents of aluminum oxide did not change much until after the Song dynasty when the aluminum oxide contents increased due to the use of kaolin clay. The chemical compositions of the ceramic bodies had overlaps, which demonstrated their close relationships. However, the ceramics from northern China did not have this pattern. The northern Chinese pottery came from an area with high fluxing agents and low silicon dioxide contents, while the porcelains were in an area with low fluxing agents and high aluminum oxide contents. This is explained by the use of clay which is more readily melted as the raw material for the former and the use of clay with kaolinite as the raw material for the latter. The two regions were well separated, which showed that they had no relationships with each other. The chemical compositions of the small number of stamped hard pottery and proto-porcelain unearthed in northern China did not show any transitional zone between the two regions, so no relationships between their chemical compositions can be inferred. It can be said that the development from pottery to porcelain took a different path in northern China. However, the development from pottery to porcelain together with continuous improvements in their quality was primarily attributed to the selection and refining of raw materials. The raw materials were the fundamental substances for firing the ceramics.



Ceramics in China. Fig. 8 The scatter plot of the F1 and F2 factors for the chemical composition of the bodies of Chinese ancient ceramics.

Improvements of Kilns and Increase in Firing Temperatures

According to the vast amount of experimental data obtained for firing temperatures from ancient ceramic shards, it can be concluded that there were two breakthroughs in firing temperature. The first one was realized for the firing of stamped hard pottery in the Shang and Zhou dynasties. The highest firing temperature of 1,000°C and the average value of 920°C for pots were increased to 1,200 and 1,080°C, respectively. The second one was realized for the firing of white-glazed porcelains in northern China in the Sui and Tong dynasties. The highest firing temperature of 1,280°C and the average value of 1,120°C for proto-porcelains were increased to 1,380 and 1,240°C, respectively, for white-glazed porcelains, the latter being the highest firing temperature for porcelains in the history of China. Table 2 summarizes the statistical data for the experimentally determined firing temperatures for pottery and porcelains.

From the archeological data for kilns, we can conclude that pottery from the early Neolithic Age might be fired without kilns, i.e., firing on the ground. Kilns were found from the Jiahu and Peiligang cultures. Kiln firing might have started later in southern China. After a long period of development and improvement, the dragon kiln and the chamber kiln with chimneys appeared during the Shang period in Zhejiang and Jiangxi Provinces. The stamped hard pottery and the proto-porcelain were fired in such kilns. The upward slope and the length of the dragon kilns, as well as the chimney of the chamber kilns, increased the drag force, thus enabling the rise in the firing temperature. This was the first breakthrough in the kiln structure, which facilitated the first breakthrough in raising the firing temperature.

In the Sui and Tang dynasties, big firing chambers, small kiln chambers, and multiple chimneys appeared in Hebei Province in northern China. As seen from the above, improvements in the kilns were closely related to the increase in firing temperatures.

Ceramics in China. Table 2 Changes in the firing temperature of ancient ceramics

Product	Sample number	Highest firing temperature (°C)	Average firing temperature (°C)
Pottery	15	1,000	920
Stamped hard pottery	55	1,200	1,080
Proto-porcelain	37	1,280	1,120
Porcelain	146	1,380	1,240

Invention and Development of Glaze

The earliest glaze which was transparent, bright, and which did not absorb water was the glaze for the proto-porcelains fired in the Shang dynasty more than 3,000 years ago. Therefore, glaze must have been created before the Shang dynasty.

It is well known that the proto-porcelains and the earliest porcelains were fired in southern China. Recently, a large amount of clay-glazed black pottery prior to the Shang period has been discovered in ancient kilns and tombs, and *Tao Yi* (pottery coat) has been discovered on the surface of colored pottery from the early Neolithic era in southern China. The creation and development of glazes in China can be divided into the following four stages, according to their chemical composition, microstructure, and appearance:

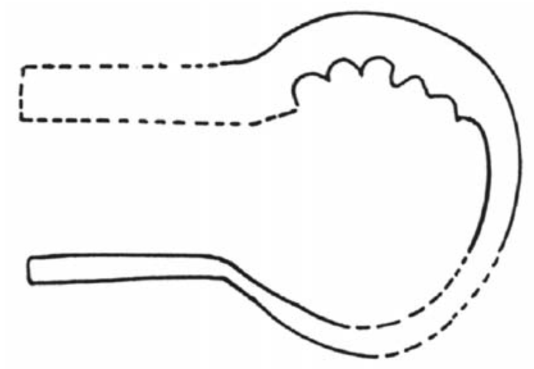
1. Breeding period of glaze – Shang dynasty
2. Formation period of glaze – Shang and Zhou dynasties
3. Mature period of glaze – Han, Jin, Sui, Tang, and Five Dynasties
4. Flourishing period of glaze – from the Song to Qing dynasties (Li 1983)

Similar to the five milestones, the three technological breakthroughs signified improvements and achievements during the 10,000 years of history from the Neolithic Age to the Qing dynasty.

Contribution to Chinese Culture

Chinese ceramics have a long history, rich technological and arts contents, and are highly acclaimed all over the world. The contribution of ceramics to Chinese culture can be briefly summarized:

1. The early pottery was based on very simple techniques. Pottery techniques were an integral part of Chinese culture. These techniques were made up by the three stages of raw material selection, forming of the wares and the firing of the pottery. The basic ideas behind the whole set of techniques developed more than 10,000 years ago; they have been used until now, and have laid the foundations of ceramic industries in later generations. With pottery cooking utensils, the people could enjoy cooked food, which enhanced their quality of life. This is important not only for the Chinese culture, but also for world culture.
2. The Chinese culture is one of the four ancient cultures in the world (China, India, Near East, and Greece) that has been sustained until today, with the development of Chinese ceramics as an example of its sustainability.
3. Pottery kilns appeared in the relics of Peiligang in Xinzheng (Fig. 9) and Jiahu in Wuyang in Henan



Ceramics in China. Fig. 9 Schematic diagram showing the relic pottery kiln T31 in the Peiligang in Xinzheng, Henan Province.

Ceramics in China. Fig. 10 Microstructure of a clay pottery of Peiligang in Xinzheng, Henan Province (70×).

Province about 8,000–9,000 years ago (Kaifeng 1978; Zhang 1999). These kilns proved that China was one of the first places to fire pottery in kilns. The appearance of kilns enabled the increase in the firing temperature (Table 3). This greatly enhanced the quality of the Peiligang pottery (Fig. 10) and at the same time enabled the first effective step in the history of high-temperature processes for mankind.

4. Slow wheel trimming for pottery appeared in the middle of the Yangshao culture, 4,000 years ago. Fast wheel trimming occurred during the Dawenkou culture. The fast wheel is also called the *potter's wheel*, which is the rudiment of the jolley (a mold to produce uniform hollow ware) used today. The fast wheel was a necessary requirement to throw as well as trim, and was instrumental in enhancing both the quality and the quantity of the products. The appearance of the fast wheel reflected the use of wheel shaft machines as well as the effects of inertia in manufacturing pottery, which inspired machining processes in later generations.
5. Early pottery contained certain amounts of sand grains with different sizes. Some of these sand grains occurred naturally in soils, while others were purposely added. The latter ones were referred to as *Chan He Liao*. For example, the burned vegetation found in Hemudu pottery was purposely added (Fig. 3; Li et al. 1978). These additions were used to mitigate the contraction of clay during drying and firing, which served the same purpose as the clinker (a hard brick used as a paving stone) does today.
6. Pottery can be both containers and tools. Earthen spinning wheels, net weights, pills, and casts have been found in many relic sites of the Neolithic

Ceramics in China. Table 3 Firing temperatures of some early porcelains from the Neolithic Age

Sample number	Unearthed site and layer	Firing temperature (°C) ± 20
1-64WXT$_5$ ④	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (fourth layer)	810
2-62WXT$_3$ ③	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (third layer)	740
12-64WXT$_4$ ②	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (second layer)	800
15-64WXT$_4$ ②		840
6-99WXE$_{10}$N$_{12}$ · 2A		780
18-64WXT$_6$ ①	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (first layer)	800
13-93WXE$_1$N$_{12}$ · 1A		740
	Sandy pottery from Zengpiyan in the Guilin of Guangxi	680
	Sandy pottery from Qingtang in the Yingde of Guangdong	680
EN2	Clay pottery of Peiligang in Xinzheng in the Henan Province	910
EN3	Sandy pottery of Peiligang in Xinzheng in the Henan Province	920
EN4		820

Age, which were tools for textiles, fishing, and pottery manufacturing. Despite the very simple forms, these served as the first examples of using pottery as tools, and demonstrated that pottery was an indispensable material in human lives. In particular, the earthen pills and earthen net weights not only signified the exploitation of elastic stress and gravity machines in the manufacturing process, but they also illustrated that pottery needed chemical reactions, which were unlike stone wares which needed only physical processing. This was pioneering in the chemical industry.

7. Pottery was the earliest product integrating technology and arts. Colored pottery was discovered in Jiahu in Wuyang, Henan Province as well as in Hemudu, Yuyao, Zhejiang Province. Colored pottery and pottery statues were also found for the late Neolithic Age. These not only showed the artistic talents of the people, but also reflected their daily lives. For example, carved symbols were found on pottery from the relic site of Jiahu, which provided information on the emergence of Chinese words. Colored pottery was an ancestor to polychrome-painted porcelains in later generations; pottery statues were ancestors to sculpted porcelains.
8. The crucibles for alloy melting for bronze wares and the pottery moulds for casting illustrate the required skills for techniques. The emergence of pottery kilns and the attainment of higher firing temperatures as a result of the improvements in the kilns facilitated the development of bronze wares and thus the early arrival of the bronze-ware era. The early pottery marked the start of the Neolithic Age, but improvements and extended applications played an indispensable role in marking the end of the Neolithic Age and in marking an unacknowledged ceramic Age.
9. Porcelains are recognized as one of the greatest inventions in China. The manufacturing techniques of porcelain masters in different times were adopted by different countries in Europe and Asia, which had significant influence on the manufacture and the development of porcelains in certain countries in the world.
10. One of the main reasons that the Jingdezhen porcelains could survive and their quality improve was that the recipe contains kaolin clay and its percentage kept increasing. The good quality of the white-glazed porcelains from the Xing Kiln in northern China starting from the Tang dynasty was also attributed to kaolin clay. Firing of hard porcelains in Europe was also successful after the use of kaolin clay. China was the first country to discover kaolin clay. The terms *kaolin clay* and *kaolinite* were translated from Chinese.
11. The famous porcelains manufactured in various areas in China not only satisfied the needs of different people in China, but were also exported in large quantities or used as precious gifts. These exquisite porcelains, as part of Chinese culture, were thus dispersed to different areas in the world. This inspired their techniques and at the same time built the reputation of Chinese porcelains over the world.

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Ceramics in Korea

Carolyn K. Koh Choo

Korean ceramics is a culture that has been close to the hearts and minds of Korean people throughout its history. In many parts of the country, one can still touch the centuries-old remnants of everyday bowls and dishes and even artistic masterpieces. For those who seek them out by research or consulting with experts and village elders, waste mounds of shards and dragon kilns are invariably found on sunny mountain slopes with flowing brook water nearby. Such artifacts reveal many details of the forming, designing, and firing methods of traditional Korean ceramics.

Today, Korean ceramics is enjoying an active phase of development. For the first time, all four major types of pottery – *togi*, celadon, *punch'ŏng*, and whiteware – are produced simultaneously in numerous studios. With the continued unearthing of kiln sites in major excavations have come new theories about the rise and development of Korean ceramics history. The overseas museum space dedicated to exhibiting ceramic art pieces has increased noticeably in the last decade. Special fairs, biennales, and competitions are held in many locations that attract both Korean and international audiences. The World Ceramic Biennale, held in 2005 for the third time in the greater area of Kwangju (near Seoul; this was the center of ceramic activities during the Chosŏn dynasty), is developing as an important event for ceramic arts and crafts.

Coming of Age for Korean Hard-Paste Porcelain

Among countless types of ceramic products that make ceramics culture ubiquitous, the position held by Korean porcelain and stoneware is due to their hard-paste raw material. Korea and China were the first countries to possess the know-how for using this material, readily available in nature, and obtaining the necessary firing power for its proper vitrification (forming a glassy or noncrystalline material). Although the dates are still being debated actively among ceramics scholars, a long tradition of making high-fired unglazed stoneware, called *togi,* enabled Korea to adopt porcelain technology from China sometime between the early ninth and late tenth centuries. The making of refined tea bowls must have been a strong motivation for the import of the technology because shards of such bowls are found in abundance in early kiln sites. The Japanese porcelain industry began only after many Korean potters were taken to Japan during the Hydeyoshi Invasion (1592–1598), which is also known as the Ceramics War or the Tea Bowl War.

While China and Japan benefited enormously from the export of their porcelain wares to Europe until the technology successfully developed there in the eighteenth century, Korea maintained its unique aesthetics that were appreciated mainly within East Asia. Never developing the overglaze that was so popular in Europe, Korea produced one major type at a time: *togi* up to the Unified Silla Kingdom (AD 668–935), celadon during the Koryŏ dynasty (AD 918–1392), and *punch'ŏng* and then more commonly whiteware during the Chosŏn dynasty (AD 1392–1910). Although several other types were also produced – including a substantial amount of white tea bowls in the initial stages of porcelain technology, a small amount of black temmoku-type, and a very small amount of ware known as Chosŏn celadon with white body and celadon type glaze – the linear sequential development of the four major types is undeniably the predominant feature of Korean ceramics history.

It is not surprising, therefore, that Korean ceramics remained largely unknown in the world, as attested by Bushell's report in his comprehensive 1896 book *Oriental Ceramic Art.* "Korea has been thoroughly explored during the last few years, and it is now known that no artistic pottery is produced there in the present day, and no indisputable evidence of any original skill in former times has been discovered." Within a decade of this report, an enormous amount of porcelain (including thousands of pieces in many shapes and types) was unearthed during the building of railroads. Many accolades were bestowed on Koryŏ *pisaek* celadon as early as the twelfth century. For example, a Song connoisseur, Taipyŏng Noin, said they were the "First Under Heaven" and a famous calligrapher envoy to Korea, Sŏh Keung, referred to the celadon as being very refined with workmanship surpassing that of the Yüeh kiln (in China). The isolation of Korea from development in other parts of the world resulted in the unique characteristics of simplicity and quietness that today are acclaimed as the quintessence of oriental spirit.

Togi Up to the United Silla Kingdom

The term *togi*, with a literal meaning of earthen or clay ware, is used inclusively for a wide variety of mostly unglazed earthenware or stoneware produced from the beginning of the Neolithic Age (ca. 6000–1000 BCE) through the Bronze and Iron ages (ca. 1000–0 BCE), the proto-Three Kingdoms period (ca. AD 0–300), the Three Kingdoms period (ca. AD 300–668; Koguryo in the north, Paekche in the southwest, and Silla in the southeast), and much of the Unified Silla Kingdom. On a much smaller scale, the production of *togi* continued during the Koryŏ and Chosŏn dynasties. One of the oldest Korean ceramic wares known today, a reddish comb-patterned jar with a pointed bottom, is carbon dated to 5770 BCE. Red and black (Fig. 1) pottery from the Bronze and Iron ages attest to the high level technology and aesthetics that the ceramics culture already obtained. These soft-textured wares were painted with iron pigments and burnished and most likely fired in an open pit.

By the end of the proto-Three Kingdoms period around the fourth century, two breakthroughs allowed the technology to become much more sophisticated and efficient. The potter's wheel was introduced and the knowledge of high firing power, originally developed

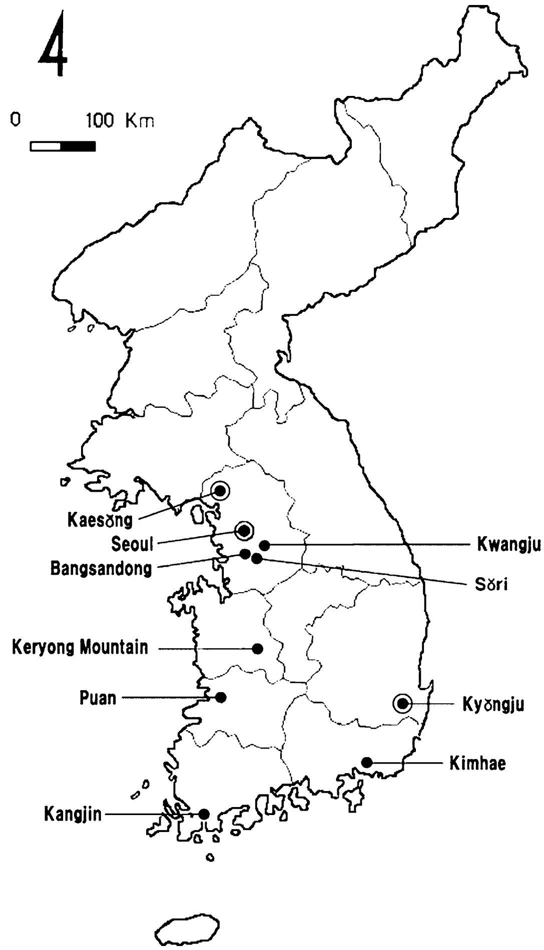
Ceramics in Korea. Fig. 1 Long-necked jar. Black pottery. Excavated at Koijeong-dong. Taejeon. Bronze age. National Museum of Korea, Seoul.

for bronze and iron casting, was applied to ceramics production. The type of dragon kilns and the method of reduction firing that Korea used continuously throughout its ceramics history were developed at this date. The *togi* fired in this way was highly vitrified and hard textured to the extent that it rings like porcelain when struck with the fingers. These wares were colored usually blue-gray or black-gray.

The first of these grayish stonewares is known as Kimhae ware after the southeastern area where they were first produced (Fig. 2). Kimhae prospered as an independent state known as Kaya until absorbed into Silla in the sixth century, and the highly vitrified *togi* characteristic of this area is also referred to as Kaya *togi*. Such ware became more refined and was produced in such vast amounts during the Three Kingdoms period and Unified Silla Kingdom that they are found in abundance even today.

The forms of the *togi* bowls and jars already possess the elements of beauty that characterize Korean ceramics in general, especially the slender gracious line of Koryŏ *maepyŏng* and the voluptuous roundness of Chosŏn whiteware jars. Both of these elements make the Kaya pedestalled jars, usually with lids, very attractive. The tall and short pedestals are basic components in much of the *togi* form. Shaped either as part of the whole ware or separately, they often have beautiful contours.

The naturalistic forms of humans, animals and birds, transportation means, and houses were favored motives both as shapes and as decorations. There were many varieties of warriors mounted on horses or carriages (Fig. 3). A roof end tile, in spite of its monstrous appearance, stimulates the feeling of warmth that is a



Ceramics in Korea. Fig. 2 Map of Korea with historically important kiln sites and capital cities of different dynasties. Kaesŏng is the capital city of the the Koryŏ dynasty (AD 918–1392), Kyŏngju that of the United Silla Kingdom (AD 668–935), and Seoul that of the Chosŏn dynasty (AD 1392–1910) as well as modern Korea.

Ceramics in Korea. Fig. 3 Ceremonial vessel in the shape of mounted figures. Excavated at Tomb 127 (the Gold Bell Tomb) in Nodong-dong, Kyŏngju. Three Kingdoms period (Silla). National Museum of Korea, Seoul.

hallmark of Korean ceramics (Fig. 4). A handsome inkstone is a forerunner of small equipment for calligraphy, which was made both in the Koryŏ and Chosŏn dynasties (Fig. 5). A Silla long-necked jar is decorated with many symbols of fertility and well being, such as figurines of a snake, a frog, a bird, a duck, a turtle, a woman playing a *kayakum* (a traditional musical instrument), and a man and a woman engaged in a sexual act.

The Unified Silla wares with lead and tricolored glazes of the Tang style are rare examples of low-firing glazes, because they were discontinued in the following Koryŏ dynasty (Figs. 6 and 7). Why Korea stopped this line of development and never adopted or developed the lead-containing materials for overglaze decoration that became so popular and profitable in China and Japan is one of the most interesting questions concerning the Korean ceramics industry.

Some later *togi* wares were glazed, often only partially, but this occurred due to ash falling on them unintentionally in the process of wood firing. Recent excavation of an eight to ninth century *togi* site at Kurimni in the southwestern area near the important celadon centers of Kangjin and Haenam offered some circumstantial evidence of glaze being intentionally applied. Such a suggestion is a topic of interest, because it raises the possibility that celadon technology might have arisen indigenously within Korea.

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Ceramics in Korea. Fig. 4 Round eaves-end tile with goblin-mask design. From Pyŏng-an-do province in northwestern Korea. Three Kingdoms period (Koguryŏ). Diameter 18.1 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 5 Covered ink slab with 13 legs (one is lost). Place of discovery unknown. Three Kingdoms period (Paekche). National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 6 Green-glazed covered bowl containing six small covered bowls (cinerary urn). From Kyŏngju area. Middle Unified Silla period. National Museum of Korea, Kyŏngju.

Ceramics in Korea. Fig. 7 Covered bowl with three-color glaze (cinerary urn). From Kyŏngju area. Middle Unified Silla period. National Museum of Korea, Seoul.

Celadon in the Koryŏ Dynasty

The appreciation of Korean ceramic art usually begins with numerous celadon masterpieces in the shape of *maepyŏng* vases, which inherited from the *togi* tradition the graceful elegant contours of the pedestalled jars and other vessels. This type developed widely and artistically with many variations in the shape and styles of decoration. The earlier ones decorated with only incised designs are often *pisaek* and beautiful. Many were decorated with inlaid designs of clouds and cranes (Fig. 8) and some rare pieces were painted with iron-black slip before the glazing (Fig. 9). The gourd-shaped ewer with decoration of copper red is a variation in shape (Fig. 10).

The love of naturalistic forms of plants, animals and birds was also inherited from the *togi* tradition. Notable among them are many water droppers, such as a child holding a bottle and a monkey holding a jar as big as itself (Fig. 11). A ewer in the shape of a dragon-headed tortoise seated on a lotus pedestal (Fig. 12) and an incense burner with the lid and feet in the form of lion figures (Fig. 13) are some of the celadon vessels with elaborate naturalistic forms.

Another form that was dominant in the Koryŏ dynasty was the tea bowl (Fig. 14), as the act of drinking tea was a highly valued means to clear one's mind for meditation in the Buddhist Koryŏ dynasty. The tea bowl shards excavated in the earliest porcelain kiln sites have a particular style of wide foot rim that resembles the sun's halo and is called that in Korean, *haemurigup*. The similarity in these foot rim styles, glaze colors, and general shapes of these wares with those found in Yüeh kiln is one of reasons to believe that the Korean porcelain technology was strongly influenced by the Chinese technology, or even that it was directly imported from China (Fig. 15).

Haemurigup tea bowls in recent excavations included surprisingly both celadon and whiteware. In particular, a series of excavations in Sŏri and Bangsandong in the 1980s and 1990s near Seoul showed that whiteware was just as important as celadon in the earliest stages of porcelain technology in Korea. During the latter part of its two-century long production, Sŏri produced only whiteware, and another nearby site of Chungamni also produced mainly whiteware during its entire existence.

Sŏri, Bangsandong, and Chungamni were among some 50 sites located inland in the western mid-section of the country, and they are now considered one of two distinct routes of technology transfer from China. The other route consists of a group of sites in the Kangjin area on the southwestern coast. These two different routes show several remarkable differences. Unlike in the inland kiln sites, only celadon is found in Kangjin. From the beginning, Kangjin kilns were constructed with mud and rock in a similar style to *togi* kilns, while kilns in inland sites were first constructed with bricks as in some Chinese kilns. Only later was the Kangjin type kiln of mud and rock introduced to some of the longer running inland sites such as Sŏri. Kangjin fired the wares in two steps – once before and again after glazing – while inland kilns fired wares in one step like the Chinese.

Ceramics in Korea. Fig. 8 Celadon *maepyŏng* with inlaid decoration of cloud and crane. Twelfth century. Height 30 cm. Provenance unknown. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 9 Celadon glazed iron-black *maepyŏng* decorated with floral design in white slip. Mid twelfth century. Height 27.5 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 10 Gourd-shaped celadon ewer with stopper and bowl, decorated with over-all inlaid design of boys among grapevines. The grapes are painted in underglaze copper red. Second half of the twelfth century. Height 36.1 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 11 Celadon water dropper in the shape of a monkey holding a jar. The eyes are marked with iron spots and the hairy body is executed with incised lines. First half of the twelfth century. Height 7.2 cm. National Museum of Korea, Seoul.

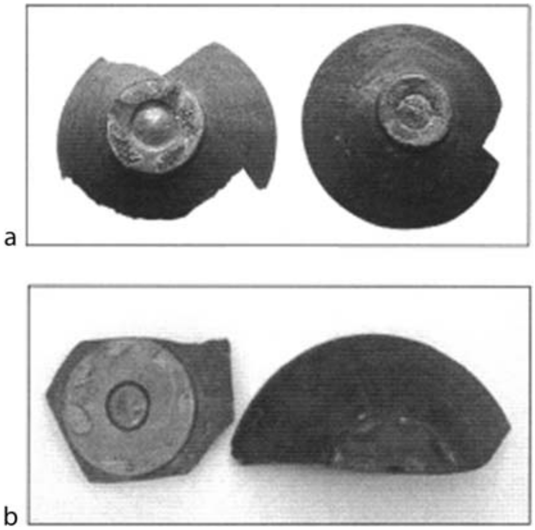
Ceramics in Korea. Fig. 12 Celadon ewer in the shape of a dragon-headed tortoise seated on a lotus pedestal. The head, body, and twisted lotus-stem handle are modeled. First half of the twelfth century. Height 17.0 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 13 Celadon incense burner with cover. The vessel has three lion-headed feet and decorated exterior with incised clouds. First half of the twelfth century. Height 17.5 cm. National Museum of Korea, Seoul.

By the middle of the eleventh century the inland kilns were mostly closed, while another center at Puan about 200 km north of Kangjin was newly established. The founding of Puan and closing of the inland kilns represented a new and indigenous phase of porcelain technology. In the two centers of Kangjin and Puan on the southwestern shore, porcelain production became highly centralized and reached a high technical and aesthetic level. Dedicating their efforts only to celadon rather than producing several styles, Koryŏ potters and their patrons made three original achievements in ceramic arts and crafts: *pisaek* glaze, the decorative technique of white and black inlay, and that of copper red.

Pisaek, represented by two different Chinese characters, mainly appears in a jade color and kingfisher's color (after the bird's blue-green plumage) in Korea, and as a secret color in China. In the Koryŏ *pisaek* celadon, the thin glaze blends with the body of the ware, revealing it just enough that the observer yearns

Ceramics in Korea. Fig. 14 Celadon bowl with inlay decoration. Mid twelfth century. Height 6.4 cm. National Museum of Korea, Seoul.



Ceramics in Korea. Fig. 15 (a) Whiteware shards with *haemurigup* foot rim, excavated in Sŏri, Korea. (b) Celadon shards with *haemurigup* foot rim, excavated in Yüeh, China.

to see more. Chung Yangmo, a leading historian of ceramic arts and former director of the Korean National Museum, likened the Korean celadon glaze to clear water flowing through brooks and streams in the mountains and valleys and to a partition screen made of ramie fabric.

The thin transparent glaze that showed off the celadon body in a harmonious way was ideal for underglaze decorative techniques. Perhaps such a success enabled and motivated Koryŏ and later Chosŏn potters to persist with only underglaze decorations. The first decorative effect was achieved simply by incising figures such as flowers and birds or making them stand out in relief. The second of the three achievements was made when the incised lines were filled with white or red (which turns into black when fired) clay material to contrast with the gray body color. Flying cranes among

Ceramics in Korea. Fig. 16 Celadon *maepyŏng*, decorated with black and white inlaid peony sprays and chrysanthemum scrolls and underglaze copper red. Mid twelfth century. Height 34.6 cm. National Museum of Korea, Seoul.

stylized clouds (Fig. 8), ducks playing underneath plants such as willow trees and reeds, and various renditions of lotus, chrysanthemum and peony flowers are some of the inlaid designs.

The third original achievement was the use of copper red, and this represented a technical challenge that required a good control of firing atmosphere and schedule. The volatile copper turns green when oxidized to its divalent state of cupric oxide (CuO). By the first half of the twelfth century, the subdued red from the reduced state of cuprous oxide (Cu_2O) and copper metal in colloidal state was used only sparingly in most cases to represent grapes (Fig. 10) and peony sprays (Fig. 16). It was used to outline lotus petals in gourd-shaped ewers and to cover the entire ware (Fig. 17).

Though the predominant wares were glazed gray-green or blue-green similar to *pisaek* celadon, some unusual glaze and decorative methods were produced. The entire body of *maepyŏng* (Fig. 9) is first coated with black pigment and decorated by brush painting with white slip before a clear glaze is applied. Another type is colored light brown, most likely to have been fired in an oxidizing atmosphere. Often it is brush painted with iron pigments and resembles Cizhou wares. Even a small amount of porcelain whiteware, in general much more vitrified than the whiteware

Ceramics in Korea. Fig. 17 Celadon cup and stand, decorated entirely in underglaze copper red. First half of the twelfth century. Height 6.7 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 19 *Punch'ŏng* jar with lid. Arabesque design painted in underglaze iron. Sixteenth century. Height 17.2 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 18 White porcelain *maepyŏng*, decorated with black and white inlaid floral designs. Mid twelfth century. Likely to have been made in Puan. Height 28.8 cm. National Museum of Korea, Seoul.

tea bowls of the earliest stage, was produced at Puan (Fig. 18).

Punch'ŏng and Whiteware in the Chosŏn Dynasty

Punch'ŏng grew directly out of inlaid celadon in the last decades of the Koryŏ dynasty when the government became too weak to keep the ceramics activities supervised and centralized. In the first two centuries of the Chosŏn dynasty *punch'ŏng* blossomed into a folk craft and art that was unique to Korea. Some of the earliest pieces are difficult to differentiate from heavily inlaid celadon. The white inlay material was eventually coated or brushed over the entire body surface before any further decoration was applied (Fig. 19). The name *punch'ŏng* was coined for this type of ware by Koh Yusŏp, a scholar of Korean ceramics in the first decades of the twentieth century, and was adapted from the longer term, *pun-ch'ang* (powder-decorated) *whe-ch'ŏng* (gray-blue) *sagi* (stoneware). The white slip was first used as a decorative medium easier to apply than white inlay, but eventually it became a means to make the wares appear whiter to meet the demand of royalty and officials who favored heavily the whiteware. The production of *punch'ŏng* came to an abrupt end after the Ceramics War. With so many potters taken to Japan, only the whiteware production was revived afterward in Korea.

Punch'ŏng is vigorous in form and decoration modes. Unlike celadon, it was produced in all parts of the country, and different styles reflected the people's daily lives, rooted deeply in the earth and other natural environments. The free-spirited spontaneous flow manifested in *punch'ŏng* led Koh Yusŏp to characterize Korean ceramics as made with "a plan without planning" and "technique without technicalities."

Celadon inlaying techniques became modified in many ways. The incision of designs was replaced by stamping with engraving tools or even with rope. Instead of filling individual incised lines or surfaces with inlay material, white slip was applied on the whole stamped body. When the body and the slip were leather dried, the surface was scraped off evenly with the stamped areas left with white inlay. In another modified method all the areas except those of such designs as flowers and plants were scraped off. Sometimes the scraped background was painted with iron-rich clay to contrast with the decorative area.

In more casually made wares, the only decorative element was white slip that was applied freely and unevenly with a large coarse brush. The abstraction of designs is bolder and more freely executed when they are brush painted with iron-rich pigment over white slip (Fig. 19). Those made in such styles in the area of Keryŏng Mountain became particularly popular with the Japanese.

Together with *punch'ŏng*, white porcelain replaced celadon as the dominant type in the Chosŏn dynasty. Chosŏn potters were able to produce much more vitrified whiteware than Koryŏ counterparts by adopting the two-step firing method that Kangjin and Puan had developed and used throughout their celadon production history. The adoption of Confucianism and its stern frugality from the Ming dynasty as the guiding principle of the new society to replace the Koryŏ life style of pleasure and luxury provided the crucial force for the ascent of the whiteware technology. The undecorated pure white was preferred, and the decoration was again limited to underglazing. The import of cobalt blue from China to produce white and blue represented the only innovative element in the new Chosŏn technology.

The raw material for Chosŏn whiteware was rediscovered in the area nearby Sŏri and Bangsandong, two centers where Koryŏ whitewares were produced at the beginning stage of porcelain technology centuries earlier. Except for the lower contents of iron and titanium oxide, it is basically the same porcelain stone that is used for celadon. This general area with plentiful raw material, Kwangju near the ruling center in Seoul, was soon established as the official kiln for producing high quality wares for the use at court. In much the same way as in Kangjin and Puan, the ceramics activity in Kwangju was supervised and centralized by court officials for nearly 500 years. So far some 285 sites have been discovered in this area, where the potters had to move to new sites approximately every 10 years in search of firing wood. Unlike celadon, the production of whiteware, however, was not restricted to this area and was produced all over the country.

The majority of Chosŏn whiteware was undecorated. As mentioned before, the colorful overglaze decoration was never developed and even the underglaze decoration with cobalt, iron, and copper oxides was sparingly used. However, the various shades of white for body and transparent glaze, combined with beautiful forms, resulted in some of the most appreciated masterpieces. The eighteenth century jar with globular body is representative of such pure white, imparting the feeling of abundance and warmth (Fig. 20). This particular form is made in diverse modifications and decorated with various designs and colors. The brush painting

Ceramics in Korea. Fig. 20 White porcelain jar with everted lip and globular body. Late seventeenth century. Height 40.8 cm, National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 21 Blue and white jar with cloud and dragon design. Second half of the seventh century–early eighteenth century. Height 35.3 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 22 Blue and white porcelain angular bottle with orchid design. Second half of the seventeenth century. Height 41.5 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 23 White porcelain bottle coated with underglaze iron. Second half of the eighteenth century. Height 27 cm. National Museum of Korea, Seoul.

Ceramics in Korea. Fig. 24 White porcelain water dropper coated with underglaze copper red with molded double crane design. Nineteenth century. Height 5.4 cm. National Museum of Korea, Seoul.

with cobalt blue on a late seventeenth century or early eighteenth century globular jar is executed freely and boldly in the same characteristic manner as *punch'ŏng* wares (Fig. 21).

The cobalt blue decorated wares, made mostly for royal use, are usually refined and restrained. The cobalt pigment, imported and expensive, was usually used sparingly (Fig. 22). When its use became even more difficult after the war with Japan, iron pigment was substituted as the main pigment. It was used more freely and effectively in various styles of brush painting, some refined and some very daring (Fig. 23). The use of copper red, which became more liberal in the eighteenth and nineteenth centuries, produced various styles of jars, bottles, and water droppers that are very free-spirited (Fig. 24). In some rare pieces two of the three pigments are used in combination, and very rarely all three pigments are used, always very sparingly.

This short treatment of 8,000 years of Korean ceramics art and culture, linearly developing *togi*–celadon–*punch'ŏng*–whiteware as distinct phases of creative and original achievements, leaves many important stories untold. Many tea bowls of the Koryŏ and Chosŏn dynasty that became national treasures in Japan and the brown pottery known as *onggi*, which ranges from small boilers for herbal medicines to enormously large storage jars, are important examples that have been omitted altogether. The masterpieces and coarse everyday utensils are testimony not only to the availability of diverse materials and technical know-how of Korean potters and their clients, but also their creative spirits, their love of nature, and their dreams and ideals.

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Ceramics: Maya Pottery

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A social analysis of pottery investigates how potters translated into clay the social values and representations of people's lives, simultaneously considering how these objects defined their being-in-the-world.

The Maya region is a vast terrain with varying geologies and topographies that provided the raw materials for many different recipes to make pots. A wide range of techniques deriving from the physical, chemical, and natural sciences is helping archaeologists to identify how potters chose to select raw materials. These were washed or levigated (made smooth) and nonplastic temper (to create hardness and elasticity) of certain grain sizes was added or mixed with other clays. Maya potters had a thorough knowledge of the different properties of the available natural resources, including their thermal behavior, to make a functional vessel. Natural resources were used to make pots to support numerous daily life activities, for everything from cuisine preferences to cave rituals.

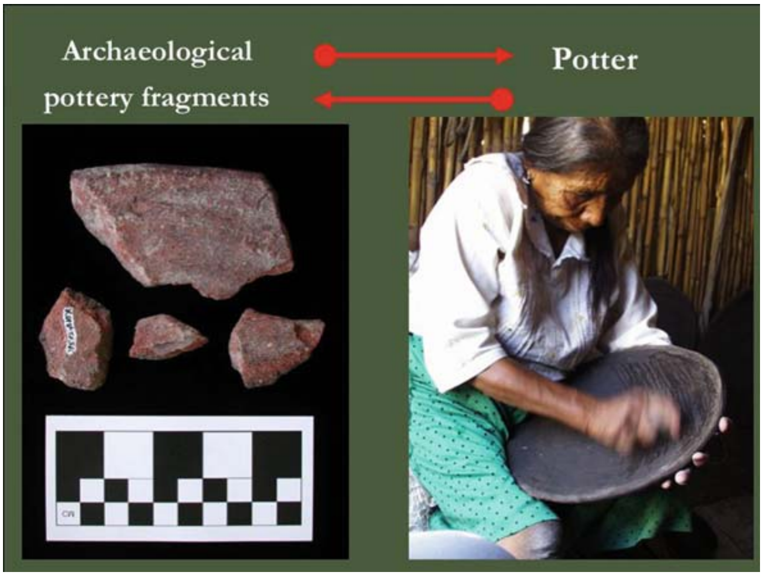
The natural and the social conditioned the making of Maya pottery (Fig. 1). In recent years, archaeologists have become interested in learning how social values are communicated through different kinds of objects and their uses (López Varela and Dore 2005). Throughout the history of humankind, people have used objects differently from their intended function. In the Maya region, pots painted with "Maya blue," a color created with palygorskite[1] were not a constant in every house (Arnold 2005a). Those who owned them expressed their social status and power with these vessels. When a cooking jar was placed in a burial site or a cave it extended its meaning beyond the domestic realm into that of the underworld. Learning about the physical and chemical properties of the clay bodies is important to determine the suitability of a vessel for cooking or storing different kinds of products. With this knowledge, archaeologists may distinguish if a vessel was used for its intended function or if it was used to signify, empower, embody, and/or engender the living spaces of those we now called "the Maya."

Analytical Approaches to the Study of Maya Pottery

Since the beginning of the twentieth century, archaeologists have studied pottery mostly to order archaeological remains in time and space so they can interpret past cultures. There are many reasons why pottery became the ideal data to reconstruct culture. Basically, pottery fragments can be arranged in a sequence of formal characteristics and styles called attributes. By determining the location of the pottery type in a stratigraphic column, the archaeologist dates a particular time and is able to produce a ceramic sequence. These goals conformed to cultural relativism, a scientific program established by Franz Boas, concerned with documenting culture-historical sequences and influences (Hodder 2004: 23).

Deriving from these goals, the type-variety system was introduced in 1960, as a systematic procedure from which to describe Maya pottery (Willey and Gifford 1960). To establish a type, the analyst takes into consideration decorative techniques and vessel form. When the analyst notes differences in ware, decorative techniques, vessel form, design, or temper, a variety of a type is established. The ware describes the paste composition (texture, temper, hardness, porosity, and color) and surface finish. When several types share the same ware, they form a ceramic group. Simultaneously, all of the known attributes are indicative of a particular class of pottery that was produced during a specific time interval known as the ceramic complex (Sabloff and Smith 1969: 77). By 1965, use of the "system," as colloquially referred to by its users, had created analytical and methodological problems that were revised during the Maya Ceramics Conference, held in Guatemala City (Willey et al. 1967). In 1969, Sabloff and Smith introduced a format to present the type descriptions of the Seibal pottery, similar to the one used in describing the ceramics from the Southwest of the United States (Colton and Hargrave 1937). For many analysts, the format, later extended in the Seibal monograph (Sabloff 1975), introduced a comparative framework for understanding pottery network distributions and extended the possibility to recognize new pottery attributes, leading to the establishment of new categories (e.g., Adams 1971; Kosakowsky 1987; López Varela 1989; Smith and Gifford 1966; Valdez 1987; Varela Torrecilla 1998). Each resulting monograph, presenting the description of the pottery and chronology, is to Maya pottery analysis like any

[1] Palygorskite is a fibrous clay mineral composed of two silica tetrahedral sheets and one aluminum and magnesium octahedral sheet that make up the 2:1 layer that occurs in strips. Palygorskite is most common in soils of arid regions.



Ceramics: Maya Pottery. Fig. 1 Learning how potters translated into clay the social values and representations of people's lives is a challenge for pottery analysis. Illustration by Sandra L. López Varela.

taxonomy book is to biology. The analyst learns the taxa by reading the descriptions of the pottery and looking at the illustrations reported in the monograph. The type-variety system has become a common artificial language for Maya ceramicists. The system provides artificial identities that are necessary for archaeologists to state what something is and what it is not; otherwise, there would be no process of communication for their results.

After World War II, the North American school of archaeology adopted the scientific method (Binford 1962), as a reaction to the tendency to describe artifacts and time, instead of investigating the processes that produced the differences between objects. This new way of doing science involved the testing of hypotheses, using technology and rigorous methods, such as statistics, that could produce a law, model, or theory that could adequately account for cultural phenomena. Both ruling schools of science were concerned with a search for objectivity, systematization, and the need to provide explanations of the observed phenomena. Their differences relied more in the incommensurable ways of seeing the world that has played a fundamental role in the making of science, as described by Kuhn (1996: 4).

The search for objectivity raised criticism of the failures of taxonomic systems to appraise the meaning of pottery (e.g., Dunnell 1971). Krieger (1944: 272), for example, suggested that objectivity may be reached if the researcher could base their definitions upon demonstrable historical factors not only on "the inclinations of the analyst or the niceties of descriptive orderliness." Later, Dunnell (1971: 116) specified that only "classes" of objects, not groups of objects, exist independently of time and space, that when provided with intentional definitions, together with the necessary and sufficient conditions for membership, these can be used to order real objects. Most of the debates were trapped in an endless circular discussion of subjectivity versus objectivity, as determining how many conditions are necessary and sufficient for membership in a class and the definition of what is a demonstrable historical factor are subjective decisions made by an analyst. If these analysts had observed the pottery under a polarized microscope their definitions of categories might have been very different, as the identified minerals composing the pottery would create a new group or taxa (Shanks and Hodder 1995: 9). Statistical methods, such as seriation,[2] were used to learn about the inherent space and time dimensionalities of Maya pottery (Henderson and Beaudry-Corbett 1993; López Varela 1989; Vallo 2002). The seriation method, however, is not an objective means for finding the life span of artifacts, as it orders the number of subjectively defined pottery attributes of the type-variety system.

Technology compelled the integration of physico-chemical or mineralogical analysis, aiming to reveal the provenience[3] and characterization of pottery, mainly

[2] Seriation is a relative dating technique based on the chronological ordering of a group of artifacts or assemblages, where the most similar are placed adjacent to each other in the series. Two types of seriation can be recognized, frequency seriation and contextual seriation.

[3] Also called provenance. The provenance is the source and ownership history of an archaeological find.

through instrumental neutron activation analysis (INAA) and X-ray diffraction (XRF) (Rice 1976: 542). Interest in understanding the craft specialization and technology of pottery was lost over the years, reinstating that the only use of artifacts is to construct and compare culture-histories by their ordering through a variety of methods (Rice et al. 2004). Based on this approach, results from instrumental techniques are far removed from the behavior of potters and from the society in which they live (Arnold 2005b: 15). Archaeologists use INAA, for example, to learn where pottery was made. Pottery is a complex mixture of raw materials often from disparate sources with clay and nonclay minerals mixed together in different forms and varying ways to produce a pottery fabric. Instrumental techniques are giving us information about the provenance of customarily 13–19 chemical elements in "pure" form (Kosakowsky et al. 1999; Neff et al. 1994, 1999). The given set is integrated by some of the most abundant chemical elements on earth. Absent from INAA results is silicium (Si, silicon in English) and aluminium (Al), the main components of silicate minerals and aluminium oxides that constitute the clay from which pottery is made. Contrary to Neff's (2005: 210) position, if we were to guide these studies from an anthropological perspective it would matter if we used chemical or mineralogical approaches to source determination or how many chemical elements of the periodic table would be measured. There is a substantial difference between learning about the technology from which pottery was made and defining the geological provenance of chemical elements.

Archaeologists have accepted the resulting data, under the strength of "scientific authority", without being able to interpret the nature of the data adequately or the problems regarding the analytical sensitivity, precision, and accuracy of physical or chemical techniques, including the preferential use of some laboratories (Bishop et al. 1990). Already, instrumental techniques have shown to have limitations in the study of Maya pottery. In the literature, we have already discussed the limitations of thermoluminescence technology for dating samples with a sedimentary origin (Wagner et al. 1999). In this case, the claim that the "system" is used as a quick and reliable method to compare and date pottery (Smith 1979) it proved to be an accurate description. In the field, the analyst is able to date any context, "good, fast, and cheap" with the type-variety system. Stemming from the inaccuracy of radiocarbon dated contexts (Hammond 1977) and the authority conveyed to instrumental techniques over other types of data, the Cuello data is a well-published example of the difficulties of timing archaeological findings (Andrews 1990; Andrews and Hammond 1990; Coe 1980; Joyce and Henderson 2001; López Varela 2005a).

Ethnoarchaeological studies have been crucial in leaning about pottery production. In fact, the concern of using instrumental techniques to define human behavior originates from analysts doing ethnoarchaeology (Arnold 1971, 2005b). For several decades, ethnoarchaeological studies have continued to address the transformation of human behavior as material culture to interpret the past (Arnold III 1991; Arnold 1971, 1978; Deal 1983, 1998). This comparative procedure allows the analyst to compare the archaeological and the living contexts. The making of Maya pottery in the past cannot be easily compared with a modern context. Indirectly, this idea suggests that people and their social values, concepts, representations, and symbols have remained unchanged (Hodder 1982: 16). The social logic of our actions, our being in the world, is embedded in history and tradition, so the detachment with the past is not absolute either. However, assuming that people can live unaffected for more than five hundred years of history entails some naïveté. Thus, the meaning of the past is created from our own experiences with the present (Thomas 1996).

Hermeneutic Relations with Maya Pottery

A social approach to the study of Maya pottery is concerned about investigating how material culture expresses the ways in which we conceptualize the relationships between others and ourselves. This new paradigm is interested in approaching the ways people have used objects or natural elements for daily life activities (Meskell and Preucel 2004). There is a genuine interest in learning about how individuals in a society communicate their particular values through objects and natural elements (Buchli 2004; Hodder 2004; Hoffman and Dobres 1999; Pfaffenberger 1999). Learning about the "social life of things" is a theoretical approach contributing to an understanding of the spatiality of objects, to the ways in which people organize living spaces and how these objects define their being-in-the-world (Tuan 1977; Low and Lawrence-Zúñiga).

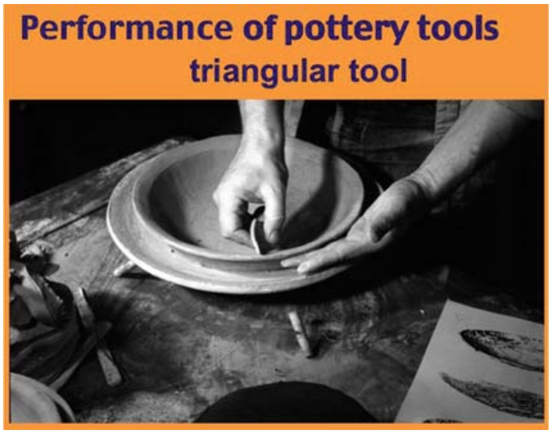
The social embedded in material culture communicates its materiality, but only if we are familiar with the meaning objects intend to convey. At the Institute of Archaeology at Belmopan, there is a distinctive piece of pottery, an orange, nonglazed piece recovered from Actun Chanona, a cave located at the base of the Sibun Gorge, Belize. This lion effigy bears a remarkable resemblance to those found in the Lion's Courtyard of the Alhambra in Granada, Spain. These lions conveyed the Quranic and Biblical images of paradise, a garden with four rivers, sprouting from the lions' mouth. All of these elements – water, plant fertility, directionality and the transition of humans into a paradisiacal world – were shared concepts with the Maya. Meaning does not reside in the object itself or in its immediate surroundings, but in the way that one makes sense of the object. Within this sense of materiality and agency it is essential to recognize that both elements, the social and the natural, are intertwined, both constructing individuals and the space they live in.

Materiality occurs in a time that results from our own lived experiences. Meaningful events and experiences construct our perception of time. Ceramic sequences, for example, are references for the archaeologist to measure time and are distant from the events that constructed peoples in the past. These sequences have constructed "Maya" time following a plot (Hodder 1995: 164) in which everything must have a beginning (Early Classic period), a climax (Late Classic period), and an end (Terminal Classic period). Over the last 40 years, analysts have struggled to define the pottery that characterized the Terminal Classic and the subsequent post-Classic period. Despite the observed persistence of pottery forms and wares from one period to the next, innovation and continuity have to be accommodated to the theories suggesting that a foreign population took over sites of the Maya Lowlands putting an end to Maya culture around AD 800 (Adams 1971; Sabloff 1973; Sabloff and Willey 1967). Over the course of new excavations, we have learned that fine paste pottery a considered trait of such population, was not exclusively made during the Terminal Classic, that alternative regions were producing the pottery, and that the pottery did not always display militaristic images (Bishop and Rands 1982; Foias and Bishop 2005; Lopiparo et al. 2005; López Varela 2005b; Rands 1987). The literary process has governed the ways analysts analyze pottery data. Instead of searching answers as to why new forms were introduced at a time of political turmoil, including environmental changes, analysts are more concerned about fitting innovation and continuity in pottery making as exceptions to the beginning–end cycle that ceramic complexes are forced to express.

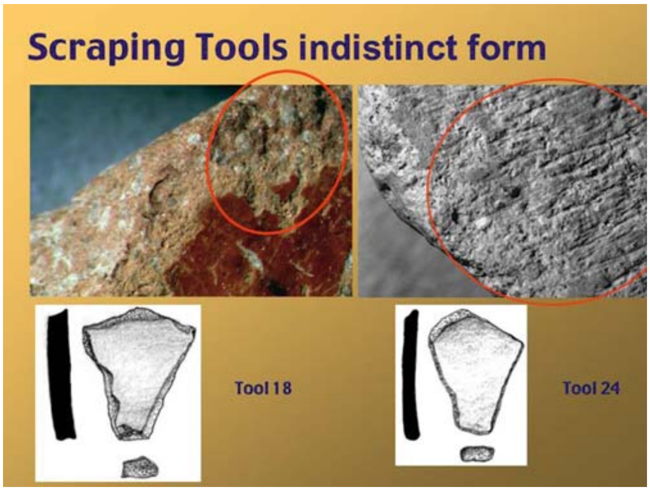
A Social Analysis of the Making of Maya Pottery

In recent years, archaeological research has provided further evidence of pottery making and tools (López Varela et al. 2001, 2002). Already, analysts have identified different kinds of firing features, ranging from open hearths to double-chamber kilns (Lopiparo et al. 2005; López Varela et al. 2001; Urban and Edward 2004). The seminal work of Anna O. Shepard (1956, 1964) stated the relevance of investigating the technological character of Maya pottery, but the number of such studies is very limited (e.g., Angelini 1998; Daszkiewicz et al. 1999; López Varela et al. 2002). Results deriving from these studies describe the sequence of steps by which natural resources were transformed into meaningful and functional objects. The chaîne opératoire (operational sequence) (Leroi-Gourhan 1943–1945), as an analytical concept, leads to an investigation of the decisions made by the producer, as to which resources to use and which form to make. The decisions made by Maya potters encountered recognition only recently in the archaeological record (López Varela et al. 2002). These decisions related to their selection of tools for the making of Late Classic vessels. Basically, potters chose to recycle broken pieces of pottery to make their tools for smoothing, scraping, incising, polishing, and boring. To make ceramic fragments suitable as tools, the edges need to be shaped; otherwise, it would be difficult to hold the piece with the fingers to perform a smoothing or scraping activity. Also, potters worked the edges of the sherds to create particular geometric forms and sizes. Selecting the shape of the pottery tool represents another choice to determine the effectiveness and performance of these implements. In the case of small tools, the angles allow reaching the joints quite easily, facilitating shaping, and retouching of the vessel. These shapes adapted to the pottery grammar of simple clean curvatures and preferable angles characteristic of the Late Classic vessel repertoire (Fig. 2) (López Varela et al. 2002).

Not all pottery fragments made useful tools. Potters intentionally selected broken pieces of pottery based on the characteristics of the fabric over hardness. Still, potters needed tools that could last to perform a particular task. Fragments were selected based on the texture properties of the fabric and the adhesive bond power of particles, as these affect resistance to abrasion (Fig. 3). Tools used for scraping characterized by a fabric containing angular, coarse, crystalline calcite, and rare grains of quartz, representing natural fine sand inclusions that facilitated its use in such activity. Also, most of these tools were made from jars that had a high



Ceramics: Maya Pottery. Fig. 2 Experimental use of a triangular tool. Photographs by Eric Mulder. Illustration by Sandra L. López Varela.

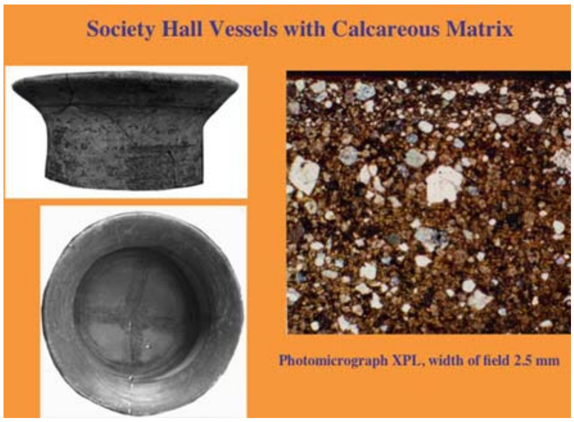


Ceramics: Maya Pottery. Fig. 3 Examples of scraping pottery tools. Photographs by Annelou van Gijn. Illustration by Sandra L. López Varela.

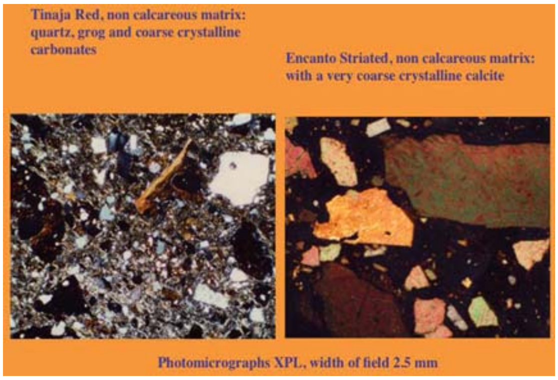
frequency distribution. Broken pieces of jars or bowls that could no longer be mended could be recycled to fabricate the necessary tool fairly quickly, according to our experimental studies (López Varela et al. 2002). Consequently, cost was a factor in the making of Maya pottery.

A social study of Maya pottery considers that the chemical and physical properties of the natural resources condition not only form and function, but also, the objectification of the social. For instance, vessels with a calcareous matrix (a substance containing calcium carbonate), according to chemical analyses, were not used in cooking or in any other activity that could involve their use in a fire atmosphere. Most of the pots with a calcareous matrix exhibited appliqués, slip clay, or paint (e.g., Hillbank Red or Saxche Orange Polychrome). On the contrary those vessels with a noncalcareous matrix and coarse crystalline calcite, added as temper, allowed their exposure to fire (Daszkiewicz et al. 1999). Most striated jars from the Formative to the post-Classic period have a noncalcareous matrix. We learned that potters changed their recipes to make pots, as certain jars of the Encanto Striated type contain aggregates of grog and clay in its noncalcareous matrix. Adding grog represents another choice the potter had to make either because it was necessary to recycle pottery against the lack of resources or the need for experimentation. There is evidence of the making of new recipes to make jars for post-Classic times, as the body shows large crushed particles of calcite that caused the jars of Piste Striated to bloat (Figs. 4 and 5).

To acquire their raw materials, Maya potters did not have to move a long distance. There is possible evidence that potters were quarrying in the surroundings of the pottery workshop found at K'axob (López Varela et al. 2001). In the surroundings of this workshop, nine roughly rectangular blocks of fine-grained consolidated sediment share physical attributes, such as texture, with Belize Red pottery, easily recognized by its thin walls and fine-grained but gritty paste composition. Their size and shape are ideal for tumpline (a band or strap strung across the forehead or chest to support a backpack) or canoe transport. Samples of Belize Red type, originating from excavations at Barton Ramie, showed that the gritty texture of Belize Red was attributable to fragments of pumice and volcanic glass and, to a lesser extent, grains of calcite (Gifford 1976: 255). The analyzed sample from K'axob is characterized by a noncalcareous matrix with grains of



Ceramics: Maya Pottery. Fig. 4 Examples of Society Hall vessels with a calcareous matrix. Photomicrographs by Daszkiewicz et al. (1999). Illustration by Sandra L. López Varela.

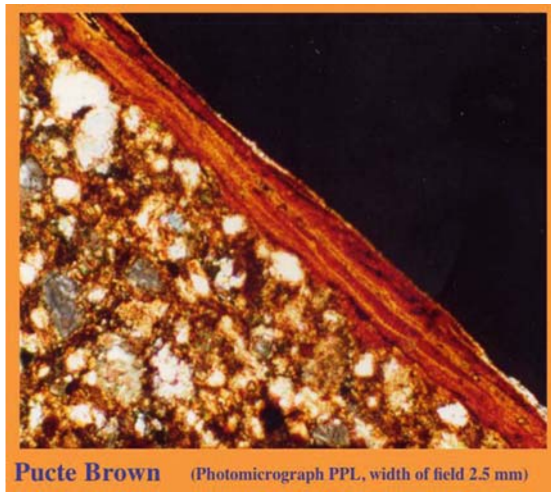


Ceramics: Maya Pottery. Fig. 5 Examples of vessels with a non calcareous matrix that could have withstand fire exposure. Photomicrographs by Daszkiewicz et al. (1999). Photographs and Illustration by Sandra L. López Varela.

quartz and two aggregates of cryptocrystalline calcite. The composition is not common in the chemically analyzed samples. The making of Belize Red shows that potters accommodated the available natural resources to fulfill social demands (López Varela et al. 2001).

Maya potters received or provided stylistic and form conventions from and to a large-scale sphere of influence that includes, at various times, the Peten, Teotihuacan, the Usumacinta-Pasión regions, and the Yucatan. These pots represented individuals' thoughts and actions, like the making of the tripodal cylinder vessel of Early Classic times. The vessel form was used as far as Teotihuacan and has appeared in numerous contexts in the Maya region, unifying social or political values that are still being debated (Varela Torrecilla and Braswell 2003).

In the Maya region, social identity and power was displayed on painted vessels, such as those of the Saxche Orange Polychrome type. A calcareous matrix with rhombohedric carbonates of coarse silt and fine sand fraction characterizes the fabric. This fine texture provided relatively flat surfaces that could be smoothed with a pebble, for example. Most painted images are displayed on the outside surfaces of vases or the bottom of a dish. According to microprobe analysis, potters used brushes that facilitated the application of several coatings of slip (Daszkiewicz et al. 1999) (Fig. 6). Preparing the surfaces to display the images on a Saxche Orange Polychrome vessel, the potter applied a fine base layer of engobe,[4] then added a very thin iron-rich red slip. The black color of Actuncan Orange Polychrome contains both manganese and iron, contrasting with the red part that only contains iron.



Ceramics: Maya Pottery. Fig. 6 Micropobe Analysis of Pucte Brown pottery. Micrographs by Daszkiewick et al. (1999).

Manganese was also detected in the black paint of samples from Ixcanrio Orange Polychrome and Saxche Orange Polychrome. By controlling the original oxidizing and reducing atmosphere, the potter achieved both a red and a black color.

The Power of Knowledge

In writing about the social in the making of Maya pottery, it is of concern to me that the reader understands that those that made pots in the past had a thorough knowledge of what we now refer to as physical and chemical properties. The word technology may be inadequate to refer to the steps of how pottery was made in the Maya region. Reading the past in the realms of technology represents our ways of seeing the world, as its practice is implicated in acquiring and maintaining relations of power (Hoffman and Dobres 1999: 219). Technologies are media to express, materialize, and mediate social relations and world-views. The word technology is a representation of the current economic division of the world that situates the non-Western in a weak position against the powerful.

My search for social explanations must not be interpreted as an indigenous approach to archaeology. It does not represent the voices of Latin America. The on-going globalization of science, created by the dynamics of our own discipline, the belief that out there, in the external world, one can find indigenous archaeologies, is difficult to believe. Such a discourse is in itself another construct that supports the status quo of the powerful that inadvertently non-Western people continue to emphasize. Investigating the social aspects of pottery results from the long-time quest in archaeology of providing a human face to the pottery that we excavate.

[4] Engobe is liquid clay used to decorate a ceramic piece before it has been fired and usually applied before the piece has dried.

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Ceramics: Olmec Pottery

Jeffrey Blomster

After 1200 BCE (years presented in this essay are uncalibrated), distinctive ceramic vessels – Olmec pottery – appeared at select sites across the vast region that anthropologists refer to as Mesoamerica (southern Mexico, Belize, Guatemala, and eastern Honduras; Fig. 1). While exchange and interaction between regions existed prior to this time, in the case of Olmec pottery, the ceramic vessels display a consistent iconography that often contrasts with local pottery traditions. The iconography exhibited on Olmec pottery may represent developing religious beliefs, cosmology and ideology, elements of which can be found in subsequent Mesoamerican groups. While features of the religion and cosmology existed prior to 1200 BCE, Olmec pottery synthesizes and abstracts these concepts on durable material. As such, understanding the origin and spread of Olmec pottery has important implications on the nature of Mesoamerican civilization.

In discussing Olmec pottery, the focus here is only on the earliest Olmec ceramic phase, which corresponds with the ascendance of the site of San Lorenzo from 1200 to 900 BCE – often referred to throughout Mesoamerica as the San Lorenzo Horizon.

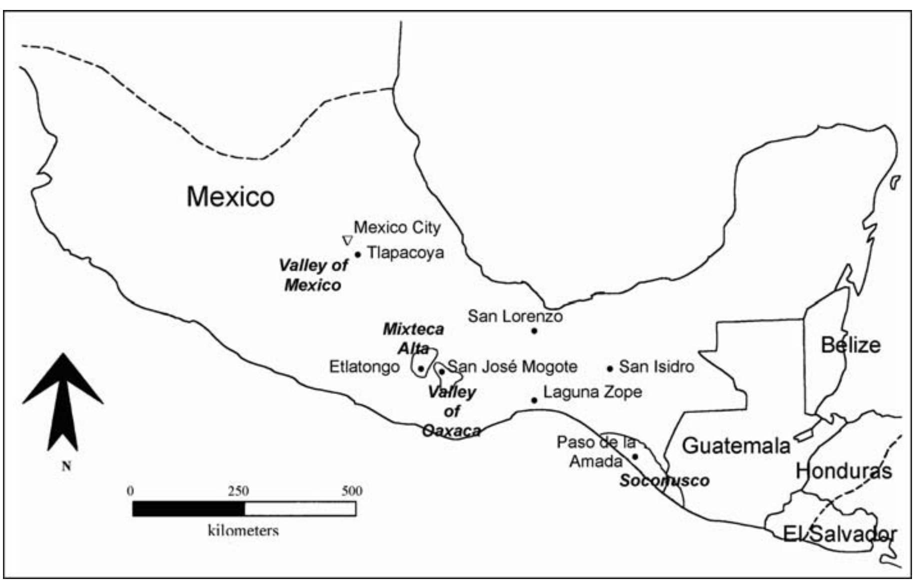
Mesoamerica Prior to 1200 BCE

For millennia after the adoption of agriculture, small villages – marked by very limited political organization and social differentiation – flourished throughout Mesoamerica. In the centuries before 1200 BCE, sociopolitical change began to occur. In the Soconusco region of coastal Chiapas, early chiefdoms of the so-called Mokaya people have been documented (Clark 1991; Clark and Pye 2000), where competing leaders vied for prestige and redistributed imported goods, such as obsidian (a volcanic glass). Each Mokaya chiefdom was centered on a main village, such as Paso de la Amada, where leaders lived in what were probably combinations of public structures and elite residences.

By 1200 BCE, chiefdoms also appear in the Valley of Oaxaca and the Nochixtlán Valley in modern Oaxaca state. In the Valley of Oaxaca, where most small villages covered only 2–5 ha, the village of San José Mogote had a 20 ha "downtown" area of public structures and higher status houses which contrasted slightly with normal houses in terms of quality of construction and plaster, and the occasional outbuilding or ramada (Flannery and Marcus 1994). Similar developments occurred to the northwest, where the site of Etlatongo became the head of a small chiefdom in the Nochixtlán Valley. Beyond Oaxaca, chiefdoms are evident at Basin of Mexico sites such as Tlapacoya and Tlatilco.

The Olmec and the San Lorenzo Horizon

Around 1200 BCE, all of the villages mentioned above exhibit a distinctive new style of ceramic vessels – Olmec pottery – that contrasts with local pottery traditions, which continued to be produced alongside Olmec pottery. While the origin of this pottery has been highly debated, the name applied to it – Olmec pottery,



Ceramics: Olmec Pottery. Fig. 1 Map of Mesoamerica, with modern national boundaries and Mexico City shown for reference. Important San Lorenzo Horizon sites from which Olmec pottery has been analyzed are indicated.

as well as the associated concept of Olmec style – has been criticized for linking this material with the archaeological Olmec people, who flourished at the Gulf Coast site of San Lorenzo, Veracruz, from 1200 BCE to 900 BCE (Blomster 1998; Coe 1968; Diehl 2004; Grove 1989). In this article, the terms Olmec style and Olmec pottery are used separate from the Gulf Coast Olmec, to indicate that the link between Olmec style material culture scattered across Mesoamerica and the Olmec people of the Gulf Coast is one that must be robustly documented rather than assumed. Much of the problem with incautious use of the terms “Olmec style” and “Olmec pottery” is that these concepts were created in the first half of the twentieth century by museum curators examining looted objects, lacking provenience, prior to the discovery and exploration of the archaeological Olmec (Blomster 1998, 2004; Grove 1996). Thus, many objects that have loosely been labeled “Olmec style” over the past 50 years have no actual correspondence with Gulf Coast Olmec material culture. To really discuss the Olmec style and Olmec pottery from a Gulf Coast perspective, objects from excavated and well-documented Olmec sites must be employed to define it, and then compared with the many disparate objects from throughout Mesoamerica that have been labeled as part of this style (Blomster 2002; Coe 1965).

The location of San Lorenzo, on an artificially modified salt dome above the surrounding floodplain, seems to have been an important reason for the growth of this center, which Cyphers (1996, 1997; Symonds et al. 2002) estimates as close to 500 ha – dwarfing all contemporaneous settlements in Mesoamerica. San Lorenzo is almost an island amongst various streams and rivers, with soils constantly replenished by the Coatzacoalcos River. The San Lorenzo Olmec appear to have exerted a tight control over their immediate hinterland, with secondary sites deployed throughout the landscape for controlling the flow of resources (Symonds 2000). Some archaeologists believe the Olmec at San Lorenzo represent a more complex form of political organization, perhaps an incipient state, while all other contemporaneous Mesoamerican regions featured chiefdoms. The debate over the sociopolitical organization of the Olmec has implications for their impact on other regions of Mesoamerica (see Note on Olmec interaction).

Olmec artists created the first monumental art in Mesoamerica, including multiton basalt colossal heads – representing Olmec rulers – and large, rectangular thrones for leaders. The Olmec style is different from other Mesoamerican art styles in formal qualities of shape, line, and space. This art is sculptural – made both in the round and in relief. In addition to the naturalistic imagery on monumental Olmec art there is iconographic or symbolic imagery that abstracts important concepts of Olmec religion, cosmology and ideology (Coe 1965; de la Fuente 1992). The sculptural nature of this style is expressed in pottery, where one of the important types (see below) features carved designs and symbols, some of which appear on monumental Olmec art.

Types of Olmec Pottery at San Lorenzo

In terms of Olmec pottery from San Lorenzo, four types have corresponding examples elsewhere in Mesoamerica (Fig. 2): Xochiltepec White, Conejo Orange-on-White, Calzadas Carved, and Limón Incised (Coe and Diehl 1980).

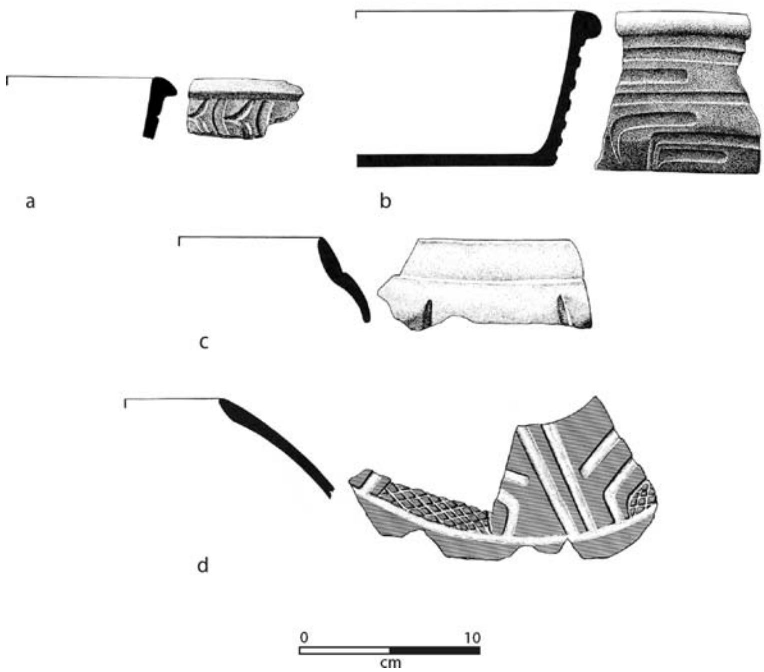
Xochiltepec White pottery is made of clay so low in iron that if fires pure white. In terms of vessel shape, this type is frequently expressed in effigy vessels that represent squashes, usually without additional decoration. Conejo Orange-on-White represents a related – and even scarcer – type (Coe and Diehl 1980: 179). It exhibits the same paste as Xochiltepec White, but has an orange slip, through which potters sometimes carved designs – contrasting the orange with the underlying white of the paste.

Calzadas Carved pottery exhibits distinctive carved Olmec-style symbols. Many of these stylized images contain elements of possible supernaturals referred to as the fire-serpent and were-jaguar, represented by what has been interpreted as flame eyebrows, crossed bands, opposed lines, and music brackets. Limón Incised pottery represents more abstract designs, which generally occur on the exterior of the vessel. Incised lines form curvilinear designs, emphasizing the *ilhuitl* or opposed volutes motif.

Olmec Pottery in Oaxaca

As my work has focused on Oaxaca state, I discuss primarily Olmec pottery present in San Lorenzo Horizon villages in the Valleys of Oaxaca (home of the Zapotec people) and Nochixtlán (home of the Mixtec people). Sherds – broken pottery vessel fragments – of Calzadas Carved and Xochiltepec White have been excavated in the large village of San José Mogote (Flannery 1968), as well as secondary sites such as Tierras Largas (Winter 1972), in the Valley of Oaxaca. Vessels that feature Olmec designs in Oaxaca, such as Leandro Gray and Delfina Gray (Fig. 3), have been interpreted as locally made without any priority by the Olmec in their creation (Flannery and Marcus 1994) – an example of a “peer polity” model (see Note). Accumulating evidence from both the Gulf Coast and Oaxaca, however, fail to support this position.

Excavations at Etlatongo, in the Nochixtlán Valley (Blomster 2004), recovered a large sample of Olmec pottery in an area once characterized as peripheral to the Valley of Oaxaca in terms of both sociopolitical



Ceramics: Olmec Pottery. Fig. 2 Types of Olmec pottery at San Lorenzo, with exterior shown to the right of the profile. (a, b) Calzadas Carved pottery. (c) Xochiltepec White pottery. (d) Conejo Orange-on-White. Adapted from Blomster, Neff and Glascock 2005: Fig. 2.

Ceramics: Olmec Pottery. Fig. 3 Examples of gray Calzadas Carved pottery from Oaxaca. Left, from San José Mogote; right, from Etlatongo. Photo by J. Blomster.

Ceramics: Olmec Pottery. Fig. 4 Cylindrical Calzadas Carved bowl excavated at Etlatongo but through compositional analysis determined to be an import from San Lorenzo. Photo by J. Blomster.

complexity and interaction (Marcus 1989). In addition to examples of Calzadas Carved (Fig. 4) and Xochiltepec White vessels, types of Olmec pottery that have not been published from the Valley of Oaxaca – Limón Incised and Conejo Orange-on-White (Fig. 5) – have also been recovered at Etlatongo. Thus, it appears that Etlatongo has a fuller suite of Olmec pottery types than the large chiefdom centered at San José Mogote.

Compositional Approaches to Olmec Pottery

The origin of Olmec pottery proved elusive through primarily stylistic analyses. If the peer polity model or "sister culture" model is correct, Olmec pottery made in Oaxaca should occur readily at San Lorenzo, while sites like San José Mogote should have little imported Olmec pottery. Oaxacan graywares – Leandro and Delfina Grays – have been interpreted as produced in

Ceramics: Olmec Pottery. Fig. 5 Conejo Orange-on-White vessel excavated at Etlatongo but through compositional analysis determined to be an import from San Lorenzo. Photo by J. Blomster.

the Valley of Oaxaca and exported to Tlapacoya and San Lorenzo (Flannery and Marcus 1994).

In order to determine more robustly the origin of Olmec pottery, chemical characterization techniques were used. Approximately 1,000 archaeological pottery and modern clay samples from the Gulf Coast, Oaxaca state, Chiapas and Central Mexico were subjected to Instrumental Neutron Activation Analysis (INAA) at the University of Missouri Research Reactor. This was a collaborative process, with specialists from both archaeology and compositional analysis contributing to the database and its analysis (Blomster et al. 2005; Neff and Glascock 2002). The INAA process determines the basic chemical composition of a sample through the measurement of various forms of radiation emitted as the radioactive isotopes in an irradiated sample decay. After counts of concentrations of 32 elements have been performed, the chemical data are then analyzed in order to recognize compositionally homogeneous groups within the sample; these groups represent geographically similar zones. Samples that fall within these groups originate from the same geologic zone, and are more similar to each other than samples from other zones.

Through INAA, it was possible to determine the compositional group and region of origin for 726 archaeological samples of Olmec pottery (Table 1). The results fundamentally change the way in which the production and distribution of Olmec pottery is modeled (Blomster et al. 2005).

The San Lorenzo Olmec produced both fine white paste pottery (Xochiltepec White and Conejo Orange-on-White) and decorated Olmec-style pottery (Calzadas Carved and Limón Incised) and exported them to other regional centers across Mesoamerica. Clays collected from various sites around San Lorenzo demonstrate the close chemical relationship between ancient Olmec pottery and modern clays in this region. Some Olmec pottery from other parts of Mesoamerica are in the same compositional group as those manufactured at San Lorenzo. Most regional centers produced local variants of Olmec pottery (Fig. 6), with much variation between regions.

Table 1 documents that the local variants of Olmec pottery were not exchanged between these villages. Of special interest is the data from San Lorenzo itself. A total of 203 archaeological pottery sherds were tested from San Lorenzo, and none of them comes from Oaxaca, or any other part of Mesoamerica. Calzadas Carved sherds found at San Lorenzo that appeared most

Ceramics: Olmec Pottery. Table 1 Regional Assignments for San Lorenzo Horizon Pottery (Adapted from Blomster, Neff and Glascock 2005: Table 2)

Archaeological context	Region as identified by INAA							
	Gulf coast	Mazatán	Valley of Oaxaca	Nochixtlán valley	Valley of Mexico	Chiapas central depression	Isthmus of Tehuantepec	Total
San Lorenzo (gulf coast)	203	0	0	0	0	0	0	203
Mazatán (various sites)	23	177	0	0	0	0	0	200
Valley of Oaxaca (various sites)	13	0	42	0	0	0	0	55
Etlatongo (Nochixtlán valley)	35	0	0	26	0	0	0	61
Tlapacoya (valley of Mexico)	17	0	0	0	87	0	0	104
San Isidro (Chiapas central depression)	1	0	0	0	0	41	0	42
Laguna Zope (isthmus of Tehuantepec)	3	0	0	0	0	0	58	61
								726

Ceramics: Olmec Pottery. Fig. 6 Small Calzadas Carved vessel determined through compositional analysis to have been made at Etlatongo, where it was excavated. Photo by J. Blomster.

similar to "Oaxacan variants" (Flannery and Marcus 1994) were included in the sample to determine if Oaxacan villagers exported Delfina and Leandro Gray pottery to the Gulf Coast. Contradicting a central tenet of the peer-polity model, none of the locally produced Olmec-style pottery in the sample was exported to the Gulf Coast.

While it is possible that if every sample of Olmec pottery at San Lorenzo could be tested, a few may come from outside of the Gulf Coast, this does not impact the general findings of this study. The Olmec at San Lorenzo generally did not receive foreign-made variants of Olmec pottery; the Olmec were its primary exporters.

Olmec pottery and associated symbols were valued by elites at the largest chiefly centers in Mesoamerica. While regions outside of the Gulf Coast made their own unique innovations and contributions to local versions of Olmec pottery, it does not appear that these other regions contributed substantially to the assemblage of Olmec-style symbols employed beyond each region. The Olmec appear to have been the primary disseminators of this pottery, which often displays rich iconography. Furthermore, important villages in adjacent regions such as San José Mogote and Etlatongo received pottery from the more distant San Lorenzo rather than from each other. This attests to the high value that was placed on Gulf Coast produced Olmec pottery.

The Olmec interacted with groups across Mesoamerica that were already chiefdoms; both the Olmec and regional groups had various interests in this interaction. The symbols exhibited on Olmec pottery suggest the dissemination of elements of Olmec religion and cosmology, which may have been received and utilized in widely different manners based on the interests of regional leaders and negotiations between and within local populations. While investigators in the Mazatán region propose that this interaction transformed the local population from Mokaya to Olmec (Clark and Pye 2000), the impact in the Nochixtlán and Oaxaca Valleys appears to be substantially different and less profound. At Etlatongo, both imported and locally made Olmec pottery probably never exceeded 5–10% of the total ceramic assemblage (Blomster 2004). Access to foreign produced versus local imitation may reflect increasing differences in social status within Etlatongo society.

Note: The Debate on Olmec Interaction

Much of the debate over Olmec interaction revolves around two perspectives. The nuclear-linear or so-called "mother culture" school views the Olmec as a precocious group in terms of social complexity, synthesizing, and disseminating traits essential to all Mesoamerican societies. While Covarrubias (1957) proposed the Olmec created Mesoamerican civilization, modern proponents reject this idea, arguing that while the Olmec had achieved a different level of sociopolitical complexity than their contemporaries, they interacted with groups that already exhibited complexity (Diehl 2004). Due to the charged nature and contested meanings of the term "mother culture," scholars who explore Olmec influence in Mesoamerica attempt to move beyond this term by focusing on the actual impact of the Olmec outside of the Gulf Coast (Neff et al. 2006b).

The peer polity model or so-called "sister culture" school views the Gulf Coast Olmec as just one of many groups utilizing a shared symbol set with other regions of Mesoamerica, without any priority in developing these symbols or attainment of a greater level of social complexity (Flannery 1968; Flannery and Marcus 1994). Proponents of this perspective view the Olmec as a chiefdom, although the ongoing research at San Lorenzo (Symonds et al. 2002) demonstrates the more complex sociopolitical organization of the Olmec relative to contemporaneous groups.

Peer polity supporters (Flannery et al. 2005; Stoltman et al. 2005) banded together to contest the results of the INAA of Olmec pottery project, claiming a different approach to analyzing the ancient pottery – thin-section analysis (which looks at specific minerals in sherds) – contradicts the results of the INAA, viewing one method as superior to the other. The reality is these two methods complement each other. The conclusions of the Flannery and Stoltman group lack a substantive sample of local geology around San Lorenzo. Their claim, for example, that the volcanic materials in pottery excavated at San Lorenzo proves they are made in Oaxaca (Stoltman et al. 2005) founders on the fact that volcanic materials are also present in soils around San Lorenzo, as documented by petrographic analysis from the Cyphers project at San Lorenzo (Neff et al. 2006b). The INAA project (Blomster et al. 2005; Neff et al. 2006a) documents that the Gulf Coast Olmec produced and disseminated Olmec pottery. While this research contributes to a stimulating debate on Olmec interaction and contrasting scientific methods, basic questions about what the Olmec and the various groups received from this exchange await further exploration.

See also: ►Obsidian

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Ceramics in Southeast Asia

DAWN F. ROONEY

The mainland region of Southeast Asia has a rich, indigenous tradition of ancient ceramic production with centers in the modern nations of Cambodia, Lao People's Democratic Republic (Laos), Myanmar

(Burma), Thailand, and Vietnam. The main output was ware for domestic and ritualistic use and regional trade. The insular Southeast Asian region (Brunei, East Timor Indonesia, Malaysia, Philippines, Singapore) made only utilitarian earthenware such as cooking and storage vessels for foods and liquids. It did, though, import trade ceramics from the mainland, China, and Japan beginning in the fourteenth century.

By the second millennium BCE inhabitants of early rice-agriculture settlements in Southeast Asia were making similar types of red-slipped, painted, stamped, and cord-marked pottery. Roulette-made ware from India found in Java and Vietnam testify that trade contacts between India and Southeast Asia were established by the last century BCE.

Ban Chiang, Udon Thani Province, Northeastern Thailand, is a representative, prehistoric site for the region. Excavations of burials conducted between 1974 and 1986 yielded tons of shards. Various forms of vessels with geometric designs painted in red on a buff-colored body were made using the anvil and paddle technique. The site is dated from BCE 3600 to AD 200.

The prehistoric tradition of making indigenous pottery in Southeast Asia continued into the next period. Thousands of shards unearthed at Angkor Borei, Ta Keo Province, southern Cambodia, are typical pottery of the early historic period, particularly the spouted vessel (*kendi*) with a bulbous body and a spout on the side, which is a ubiquitous form at all early sites in Southeast Asia (Fig. 1).

The earliest transitions from low-fired, unglazed to high-fired glazed ware occurred in Cambodia and Myanmar between the eighth and ninth centuries AD.

Cambodia

Green-glazed roof tiles from temples of the Angkor Period (AD 802–1432) capital of Hariharalaya (now Roluos), built by King Indravarman I (r. AD 877–889), attest that the Khmers were making glazed stoneware by the late ninth century. Their repertoire expanded to include brown-glazed ware in the eleventh century. Ceramic production in Cambodia continued at least until the end of the thirteenth century. Although the Khmer Empire lasted for another 150 years, ceramics have not yet been positively attributed to the later period.

The first discovery of kilns producing Angkor Period ceramics was in the 1970s in Northeastern Thailand on the Khorat Plateau, an area that was part of the Khmer Empire between the eleventh and the thirteenth centuries. Kilns in Cambodia, however, were not confirmed until 1995.

Groslier proposed the first chronology for Khmer ceramics. He analyzed types of glazes on wares found in excavations in the mid-twentieth century at the Angkor Period Royal Palace compound and in a burial at Srah Srang, the royal bath. Brown published a later refinement of Groslier's chronology (1981).

Two extensive kiln sites have been identified in Buri Ram Province – Ban ("village") Kruat and Ban Baranae. The oval-shape, crossdraft kilns were built of clay slabs with two chambers and a chimney. Both made green- and brown-glazed ware.

Over 12 groups of kilns operating during the Angkor Period in Cambodia have been identified in Siem Reap, Banteay Meanchhey, and Kandal provinces. Anlong Thom, on the southern ridge of Phnom ("Mount") Kulen, 25 mile (40 km) northeast of Angkor, produced high-quality, green-glazed stoneware. The main shapes were architectural fixtures (tiles and finials), covered jars, and bowls (Fig. 2).

The iron-rich body of Khmer stoneware is gray with impurities. Larger vessels were coil-built; smaller ones

Ceramics in Southeast Asia. Fig. 1 Spouted vessel (*kendi*). Earthenware. Sisophon, Cambodia. ca. AD sixth century.

Ceramics in Southeast Asia. Fig. 2 Green-glazed roof tile. *L* = 7.5 in. (19 cm). Khmer. Tenth century.

Ceramics in Southeast Asia. Fig. 3 Brown-glazed storage jar. *Ht* = 26 in. (66 cm). Khmer. Twelfth century.

Ceramics in Southeast Asia. Fig. 4 Brown-glazed footed jar. *H* = 16 in. (40.6 cm). Khmer. Late eleventh century.

were thrown on a wheel. The glaze was either brown or green with fine-line cracks. Flaking of the glaze is a common defect. Decoration is always minimal and consists of repetitive geometric patterns encircling the neck, shoulder, or body (Fig. 3).

Some Khmer forms, uncommon in other ceramic traditions of Southeast Asia, may have metal prototypes. Examples are:

Ceramics in Southeast Asia. Fig. 5 Unglazed pipe. Stoneware. *L* = 3.5 in. (8.9 cm). Laotian. Seventeenth Century.

– A green-glazed cylindrical covered jar and a bowl with slightly flaring walls and unglazed firing scars around the lower body
– A brown-glazed flattened globular pot with a broad shoulder, a flat base, and a narrow mouth with a rolled rim
– A footed jar with a round body, a flat shoulder, tubular neck, flaring mouth with a flange, and a pedestal base
– Small pots with animal-shape (birds, elephants, rabbits) appendages (Fig. 4)

Laos

Excavations conducted at Sisattanak, near the modern capital of Vientiane in Lao People's Democratic Republic (Laos), in 1970 and 1989 identified a kiln site that operated between the fifteenth and seventeenth centuries based on radiocarbon dating of associated finds. Quantities of unglazed and brown-glazed stoneware shards and wasters were spread over a wide area. The shapes are utilitarian and include bowls, dishes, jars, and pipes (Fig. 5).

Myanmar (Burma)

Architectural plaques and tiles (unglazed and glazed) were used on temples at Bagan (formerly Pagan) in the eleventh century. Geometric tiles are square, round or octagonal and decorated with applied lotus leaves or a lozenge with a blue-green glaze and yellow and white accents. Pictorial plaques portray episodes from the Buddha's former lives (Fig. 6).

Myanmar archaeologists recently discovered hundreds of ancient kilns in Twante district, approximately 11 mile southwest of the capital, Yangon (formerly Rangoon). They produced only celadon and probably operated between the fifteenth and seventeenth centuries. Previously unidentifiable celadon found in burial sites in Indonesia, the Philippines, and Tak and Om Koi are now attributed to Myanmar.

Ceramics in Southeast Asia. Fig. 6 Glazed tiles at Naga-yon temple. Bagan, Myanmar. Eleventh Century.

Ceramics in Southeast Asia. Fig. 7 Excavated kiln at Twante, Myanmar. Fifteenth to seventeenth centuries.

Ceramics in Southeast Asia. Fig. 8 Celadon bowl (shard). Twante, Myanmar. Fifteenth to seventeenth centuries.

Two kilns were excavated in 1999. The characteristics are (1) oval-shape, (2) crossdraft, and (3) built of clay slabs on a slope with two chambers separated by a low wall and a chimney. An unusual feature of the Twante kilns is the remains of columns in the firing chamber, which were probably used to support a dome-shaped cover. The kiln dimensions are 39 × 16 ft (11.9 × 4.9 m). Tubular, clay supports were used to stack the ware. The body contains quartz, other silica, and a high concentration of iron. The characteristics after firing in a reducing atmosphere to a stoneware temperature are: a nonporous body and a wood-ash glaze with iron that produced a transparent, green color. Pooling of the glaze is common. Forms are medium-sized vessels that were hand-built or thrown on a potter's wheel. Typical shapes are simple bowls, dishes, and plates with minimal geometric decoration (Figs. 7 and 8).

Other known kiln sites in Myanmar include: Lagunbyee, a former Mon center, southwest of Bago (formerly Pegu) where remains of a brick, crossdraft kiln were discovered in 1987 and excavated in 1998–1999; the kiln is 120 × 70 ft (36.6 × 21.3 m) and provisionally dated between the eleventh and the thirteenth centuries. Ten kilns and firing supports have been discovered at Myaung-Mya, west of Yangon, near Bassein.

Although kilns have not been found, it is certain that distinctive earthenware with an orange body and an opaque white, vibrant red, or green glaze was made in Myanmar. A variation is a design painted in green under the white glaze (Fig. 9).

Thailand (Sawankhalok or Si Satchanalai Ware)

Three sources have enabled recent advances in our knowledge of ancient ceramic production in Thailand: underwater archaeology in the Gulf of Thailand where 130 shipwrecks have been reported; excavations of kilns at Sawankhalok and surveys in satellite areas – Phitsanulok, Suphan Buri, and Sing Buri; and ceramic finds in burials at Tak and Om Koi, western Thailand, near the Myanmar border. The quality of ware from the latter is extremely fine and the wide range includes ceramics from China, Vietnam, Thailand, Cambodia, and Myanmar.

Glazed architectural fixtures were made in the late thirteenth century for the temples of the burgeoning Kingdom of Sukhothai in north-central Thailand (279 mile (449 km) north of the modern capital of Bangkok). As the kingdom expanded, a second city developed at Si Satchanalai, 43 mile (69 km) north of Sukhothai, where kilns producing glazed ceramics were also set up. In the middle of the fourteenth century when Sukhothai became vassalage of the southern Kingdom of Ayutthaya, 49 mile (79 km) inland from the Gulf of Thailand the place name "Si Satchanalai" was changed to "Sawankhalok." Today, either name is acceptable when referring to the kiln site and the wares. The kilns continued to operate at least through the sixteenth century despite the shift in power.

The dates of operation for the two ceramic centers are not conclusively known. Evidence from shipwrecks

Ceramics in Southeast Asia. Fig. 9 Green and white earthenware shards. Myanmar. Fourteenth to sixteenth centuries.

Ceramics in Southeast Asia. Fig. 10 Excavated kiln at Ban Ko Noi. Sawankhalok, Thailand. Fourteenth to fifteenth centuries.

Ceramics in Southeast Asia. Fig. 11 Tubular support for celadon bowl; scar after firing. Sawankhalok, Thailand. Fifteenth century.

carrying ceramics found in the Gulf of Thailand reverses a previously held theory and confirms that the Sukhothai kilns began production later than those at Sawankhalok. During the peak period for the export of ceramics from north-central Thailand (fifteenth and early sixteenth centuries) an estimated 1,000 kilns were operating. Changes in social, economic, and political circumstances of the kingdom most likely impacted on the kilns, causing a gradual decline in ceramic production.

Some 800 kilns have been discovered in the modern village of Ban Ko Noi, 4 mile north of the old city wall on the banks of the Yom River. Ban Pa Yang, a smaller kiln site in the area, produced architectural fixtures, human and animal figures, and brown- and white-glazed trade ware.

Kiln technology at Sawankhalok evolved from a simple bank kiln for firing unglazed, low-fired ware to one constructed of clay slabs that was more sustainable and could hold larger vessels. Finally there was a crossdraft kiln built of prefired bricks. A typical kiln of the latter type is oval shape, crossdraft with a sloping chamber for the wares in the center, a recessed fire-box at one end, and a round chimney at the other. A typical kiln was 29 × 11 ft (8.8 × 3.4 m). For firing, a fixative was applied to the base of a vessel, which was then placed on top of a tubular clay support that was sunk into the sandy floor of the kiln. A black ring on the unglazed base resulted from the fixative of the vessel after firing (Figs. 10 and 11).

Green-Glazed Ware (Celadon)

Sawankhalok celadon is the most widely known product of the ancient Thai kilns. An iron-rich glaze was mixed with ash and fired in a reducing atmosphere. The thick, translucent glaze varies in color from a sea green to olive. Motifs incised in the center of plates and bowls, around the cavetto (a hollow or concave molding in the form of a quadrant) and rim, and on the exterior, drew inspiration from the regional flora, such as lotus and peony. Primary shapes are plates, bowls, bottles, kendis, and jarlets (a small, squat, rounded, or square jar with a small mouth) (Fig. 12).

Brown and White Ware

Sawankhalok kilns produced two other monochrome glazes – brown and white. A typical brown-glazed form is a jar with a tall body, a thick-rolled mouth rim and two handles. A combination of the two glazes on a single piece was a specialty of the export ware made at the Ban Pa Yang kilns (Fig. 13).

Exceptionally large water jars were also made (Fig. 14).

Architectural fixtures, such as tiles, were usually white-glazed (Fig. 15).

Ceramics in Southeast Asia. Fig. 12 Celadon plate. Diameter = 11 in. (28 cm). Sawankhalok. Fifteenth century.

Ceramics in Southeast Asia. Fig. 13 Brown-glazed jar. *H* = 5 in. (13 cm). Sawankhalok. Fifteenth century.

Ceramics in Southeast Asia. Fig. 14 Brown-glazed storage jar. *H* = 3 ft. Sawankhalok. Fifteenth century.

Ceramics in Southeast Asia. Fig. 15 White-glazed tile. *H* = 4 in. (10 cm). Sawankhalok. Fourteenth century.

Quantities of figures (animal and human) were made at Tukatha (Ban Pa Yang kiln site) for the religious and cult needs of the native inhabitants (Fig. 16).

Iron-Decorated Ware

A design was painted on the body with iron oxide; then a transparent clear glaze applied over it. Sometimes a slip was put on the body for a lighter color which created more contrast between the design and the background. Forms include plates, bowls, bottles, kendis, and architectural fixtures. A particular type of round covered box was produced prolifically for export. The body and cover of the box form a continuous line with modeled knob on the cover that is shaped like a lotus bud or in the form of a fruit stem (Fig. 17).

Thailand (Sukhothai Ware)

Two clusters of over 50 kilns have been identified at Sukhothai – one near Wat ("temple") Prah Phai Luang and another north of the city wall. The kiln shape and

Ceramics in Southeast Asia. Fig. 16 Brown-glazed chicken. $L = 3$ in. (7.6 cm). Sawankhalok. Fourteenth century.

Ceramics in Southeast Asia. Fig. 18 Disc firing support. Diameter = 4 in. (10 cm). Sukhothai. Fifteenth century.

Ceramics in Southeast Asia. Fig. 17 Underglaze glaze painted box with cover. Diameter = 4 in. (10 cm). Sawankhalok. Fifteenth to sixteenth centuries.

Ceramics in Southeast Asia. Fig. 19 Painted shard. Sukhothai. Fifteenth century.

construction are essentially the same as those at Sawankhalok except the Sukhothai kiln is narrower. The average dimensions are 29 × 8 ft. Plates and bowls were stacked for firing by placing one on top of the other separated by a disc-shaped clay support with spurs (usually five). A distinctive feature in the center of Sukhothai plates and bowls is five circular scars resulting from separating the disc after firing (Fig. 18).

Sukhothai kilns produced two types of ceramics – painted ware and a white-glazed ware. To achieve the former, a slip was applied to a dark body; next, a design was painted using iron oxide; then a thin, transparent glaze was applied. After firing, the texture of the gray body was coarse with visible white flecks of quartz; the color of the iron pigment varied from gray to olive, brown or black; and the glaze is often opaque, or milky in appearance with fine-line crazing and pin holes. A painted fish plate (average diameter = 10 in. (25 cm)) is characteristic of the Sukhothai kilns. The central motif is a single fish, painted in profile, and encircled by one or more rings. Other designs on plates, bowls, and a few bottles such as a single stemmed flower surrounded by leaves and a solar whorl and architectural forms were made at Sukhothai (Fig. 19).

Thailand (Suphan Buri Ware)

A complex of kilns at Ban Bang Pun in Suphan Buri Province, northwest of Ayutthaya, was discovered in the 1980s. The main output was unglazed stoneware footed jars, which were previously attributed to Sawankhalok or Sukhothai. Distinctive, repetitive bands of a leaf motif were stamped around the base of the neck and outer shoulder. The crossdraft, clay kilns were of a similar design to those at Kalong in northern Thailand.

Thailand (Phitsanulok and Nakorn Thai Ware)

Phitsanulok, a small state east of Sukhothai and controlled by the Sukhothai Kingdom in the thirteenth century, became a provincial capital of the Ayutthaya Kingdom in the fifteenth century. Excavations in 1984 at Ban Tao Hai ("village of the jar kilns") on the eastern bank of the Nan River, 2.5 mile (4 km) north of the modern town of Phitsanulok, revealed two brick, crossdraft kilns of the type developed at Ban Ko Noi with another estimated 40 kilns in the area. A typical jar is baluster-shaped with a flaring mouth and applied decoration. The kiln structure and the output suggest the site operated in the late fourteenth or early fifteenth century.

The identification of six kilns at Nakorn Thai, east of Phitsanuloke, indicates that it was also a production center for stoneware jars with dates of operation the same as the Phitsanulok kilns.

Ceramics in Southeast Asia. Fig. 20 Excavated kiln at Sankampaeng. Northern Thailand. Mid-fourteenth to mid-sixteenth centuries.

Ceramics in Southeast Asia. Fig. 21 Brown-glazed plate. Diameter = 9 in. (23 cm). Sankampaeng, Northern Thailand. Mid-fourteenth to mid-sixteenth centuries.

Thailand (Northern Thai Ware)

Lan Na, founded by King Mengrai in 1292, with a capital at Chiang Mai in Northern Thailand, was an extensive ceramic center making glazed stoneware for domestic and ritualistic needs between the mid-fourteenth and the mid-sixteenth centuries.

The northern kilns were dug from river banks, or made with clay slabs in-ground, or brick-constructed above ground. General characteristics are: small size, simple construction, and crossdraft with two chambers and a chimney. Plates, dishes, and bowls were stacked in the kilns lip to lip and base to base.

Kalong

Over 200 kilns are mid-way between Chiang Mai and Chiang Rai near the valley of the Lao River. Kalong kilns produced ware painted with iron oxide under the glaze in the style of those from north-central Thailand but with more flamboyant motifs executed with broader brush strokes. Dishes with an abstract leaf and flower design are typical. The Kalong kilns also made a fine, thinly potted ware covered with a soft rain-cloud gray glaze. Vases, bowls, bottles, and dishes comprise this group.

Sankampaeng, Phayao, Nan

Eighty-three kilns are located by the Ping River valley, approximately 15 mile (24 km) east of Chiang Mai. Average dimensions of a kiln are 10 × 4 ft (3 × 1.2 m). Plates and dishes (either painted or brown-glazed) with a central medallion of two fish are typical Sankampaeng ware. Celadon, painted ware, and two-color jars were also common (Figs. 20 and 21).

Kilns were reported at Phayao, in Cham Pawai district, near the remains of an ancient walled city, in the 1950s. The site is unexcavated but shards of celadon, brown-glaze, and two-glaze wares have been found. Stamped motifs and incising through a slip are distinctive characteristics of Phayao ware.

An extensive kiln site was found at Nan, western Thailand, in 1982. It produced painted ware (underglaze black) with a milky white glaze that was placed in a sagger (a box of baked fireproof clay used to protect pieces during firing) for protection during firing.

Phan

Twenty-seven brick kilns situated between Chiang Rai and Phayao are of the crossdraft type with the average dimensions of 20 × 11 ft (6 × 3.4 m). The Phan kilns only produced celadon. It is more carefully potted and more finely finished than other northern wares. The shapes include plates, bowls, jars, oil lamps, miniatures, elephants, and kendis. The sophistication and the narrow range of these wares suggest a slightly later date, perhaps from the mid-fifteenth to the mid-sixteenth century.

Thailand (Lamphun (Haripunjaya) Ware)

Although no kilns have been found, shards litter the area of Lamphun, the old Haripunjaya kingdom, and similar ones were found at Tak and Om Koi. These finds suggest a mid-fourteenth to mid-sixteenth century date. The finely textured body is either orange or brownish black. A typical form is a thinly potted, globular, long-necked bottle with a flat base, inlaid with slip, and either intricate white or black geometric motifs on the neck and body.

Thailand (Sing Buri or Maenam Noi Ware)

Excavations conducted in 1987 in Bang Rachan district of Sing Buri Province at the Tao Maenam Noi kiln site established the provenance of a class of brown-glazed storage jars previously believed to be Sukhothai. As the kilns are located near a temple, the ware is popularly called Wat ("temple") Phra Prang Pottery. The oval-shape, crossdraft, brick kiln measures 44 ft (13.4 m) long and is the largest one found so far in Thailand. Both unglazed and glazed ware was made, mostly storage jars but also unglazed kendis. A typical jar is heavily potted, with an ovoid body and a narrow neck with a rolled lip and partially covered with a brown glaze. These jars have been found in the cargo of a number of shipwrecks in the Gulf of Thailand dating to the late sixteenth or early seventeenth centuries (Fig. 22).

Ceramics in Southeast Asia. Fig. 22 Brown-glazed jar. *H* = 18 in. (45.7 cm). Sing Buri, Thailand. Late sixteenth to early seventeenth centuries.

Vietnam

The glazed ceramic tradition of Vietnam is unlike any other in Southeast Asia as it was strongly influenced throughout history by China, both technically and stylistically. Its development, forms, and motifs, therefore, are parallel approximately that of Chinese ceramics. Extensive excavations of burial grounds in the early twentieth century in Thanh-hoa Province, northern Vietnam, yielded quantities of ceramics dated between the tenth and the thirteenth or fourteenth centuries. Kilns near the modern city of Hanoi, the site of capitals of the Ly (AD 1009–1225) and the Tran (1225–1400) dynasties, were most likely the source of the Thanh-hoa ware. Vietnamese ceramics entered the export market in the fourteenth or early fifteenth century with painted ware in both underglaze blue and black. Despite the Chinese influence, some forms are distinctively Vietnamese. A storage container for lime to use for betel chewing is an example. The squat form has a small opening on the shoulder, a pedestal foot, and a "basket-like" handle with elaborate decoration. Ritualistic ceramics made in the late sixteenth or seventeenth century at kilns near Hanoi are distinguished by large altar vases and incense burners (Fig. 23).

Ceramics in Southeast Asia. Fig. 23 Green-glazed lime pot. *H* = 7 in. (18 cm). Vietnamese. Fifteenth to sixteenth centuries.

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Chao Yuanfang

Fabrizio Pregadio

Virtually the only known detail of the life of Chao Yuanfang, Chinese physician and medical author, is that he was Medical Erudite (*taiyi boshi*) at the court of the Sui dynasty sometime between 605 and 616. In that position he supervised the compilation of the *Zhubing yuanhou lun* (Treatise on the Origin and Symptoms of Diseases), the first Chinese text comprehensively devoted to etiology and symptomatology. The work, which is integrally preserved, was submitted to the throne in 610.

The 50 chapters of the *Zhubing yuanhou lun* discuss more than 1,700 syndromes, classified into 67 categories of internal and external diseases. The final sections are concerned with gynecology, obstetrics, and pediatrics. A special feature of the text lies in its therapeutic methods. Rather than ingestion of drugs or acupuncture, Chao advocated a therapy based on such practices as diet and *daoyin* (a set of bodily postures, similar in some respects to Indian *hatha yoga*). The *Huangdi neijing* (Inner Canon of the Yellow Emperor) provides the broad theoretical foundation to Chao's work.

The *Zhubing yuanhou lun* exerted a remarkable influence on the history of Chinese medicine, as reflected for example in the *Qianjin yaofang*, written by Sun Simo. It was highly esteemed in Japan as well, where it inspired the classification of diseases in the earliest extant medical compilation, the *Ishinpō*.

See also: ▶Acupuncture, ▶*Huangdi Neijing*, ▶Sun Simo

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Chemistry in China

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Of all the sciences in antiquity chemistry was one of the least understood. Until people had some comprehension of chemical elements, compounds, atoms, molecules, ions, and bonding, they found it difficult to make much sense of the chemical processes occurring naturally. This does not mean that there is no real history of chemistry; it means only that we should assess the early chemical practitioners on the accuracy of their observations rather than that of their interpretations. The modern Chinese term for chemistry is *huaxue*, the study of change, and what the ancient Chinese did well was to note and describe the chemical changes which were observed when substances were mixed, heated, dissolved, or treated in some way. The fact that their interpretation may seem a little abstruse by modern standards does not detract from the worth of their observations.

Before chronicling chemistry in ancient China it is important to understand exactly what had stimulated an interest in chemical processes. The Daoist religion sought to lead its adepts into such a harmonious relationship with the world that they would escape the horrors of disease and the tragedy of death. It was not life after death but life without death, although the precise notion varied from age to age. Those who had discovered the *dao*, through meditation, study, forms of exercise, appropriate sexual activity, and purity of life, would retire to an isolated mountain retreat and there live in complete harmony with nature. They were called *xian* or "immortals," nearer to gods then men. The idea of longevity as a reward for the godly life is not unique to Daoism; similar notions occur in Judaism. In the genealogy of the patriarchs we read, "And Enoch walked with God after he begat Methuselah three hundred years and begat sons and daughters" (Gen. 5^{22}). However, what is special to Daoism is the use of drugs to acquire immortality.

Until the Song dynasty, Chinese drugs were grouped into three classes: superior drugs which allowed one to realize vital powers, medium drugs to enrich one's nature, and inferior drugs which cure disease. This particular classification is given in *Zhenghe bencao* (Herbal of the Zhenghe Era) and it is the superior drugs that became associated with the attainment of immortality. Initially the drugs were quite crude materials: minerals straight from the ground or dried herbs, but subsequent developments lead to the compounding of these "simples" to give "elixirs of immortality." It was in the preparation of elixirs that the ancient Chinese made their first chemical observations.

The preparation of elixirs was not an activity associated with a popular or debased version of Daoism and abhorred by the more sophisticated Daoist adepts. Although the importance of elixirs in Daoist practice varied somewhat from dynasty to dynasty it always played some part in the pursuit of the Daoist goal. Several emperors of ancient China expended considerable effort to obtain the elixir of life. Shihuangdi (259–210 BCE), of the Qin dynasty, equipped large expeditions under the command of Xu Fu and others to go abroad to uncover arcane secrets of preparing elixirs. Emperor Wu (156–87 BCE) appointed numerous magic specialists to high positions.

Two prominent components of Daoist elixirs were cinnabar (mercuric sulfide) and gold. The reasons for this selection are not difficult to appreciate. Cinnabar is bright red, reminiscent of healthy blood, and it was thought that the infusion into the body of extra healthy blood would enhance health and lifespan. The absence of understanding of chemical composition among the ancient Chinese meant that the physical appearance (i.e., the color) had greater significance than the obviously different chemical properties of cinnabar and blood. Gold was probably the most prized component of an elixir because it was obtained from the ground in an uncombined (and thus, uncorrupted) form and in the air it did not tarnish. If these attributes could be acquired by the human body then it would, indeed, last forever. One difficulty recognized by Chinese alchemists was that both cinnabar and gold are insoluble in water and, therefore, unlikely to be absorbed in the body. Much effort, therefore, was expended in devising methods of solubilizing both cinnabar and gold.

A manual in the Daoist Patrology (*Dao Cang*) entitled *Sanshi liu Shui Fa* describes the use of niter (potassium nitrate) in vinegar (dilute ethanoic acid) to bring numerous minerals, including cinnabar, into solution. In some cases there appears to be some confusion between solution and suspension; in other cases solution would occur in any aqueous solvent. However, in a few cases, particularly in the solubilization of cinnabar, some interesting chemistry is involved. A solution of pure niter in pure aqueous ethanoic acid has no effect on cinnabar but solubilization does occur if chloride ion is present as an impurity. This is probable as niter was obtained from marine sources. Thus the fanciful descriptions of Chinese alchemy may have a sound basis in chemistry if allowance is made for probable impurities. The same applies to an account in the *Sanshi liu Shui Fa* for the solubilization of gold where the required contaminant is iodate, a common impurity in crude niter deposits. The fact that these accounts of Chinese alchemical activity can be explained in modern chemical terms is evidence of the accuracy of the original observations.

Gold is not common in China and it was not regularly used as a form of currency. Because of the shortage of gold, much alchemical activity was directed at making gold from more commonly available materials. This appears, at first sight, to be identical with European alchemical activity but the motivation was completely different. In Europe it was, until fairly late in the thirteenth century, the pursuit of wealth; in China it was from earliest times the pursuit of immortality. Cinnabar was a popular material upon which to work (gold and cinnabar often occur together in the earth) and the *Gui Jia Wen* contains the lines:

> The span of life is up to me, not heaven.
>
> The reverted cinnabar becomes gold, and millions of years are mine.

In the most famous alchemical manual (the *Neipian* of the *Bao puzi*) the author, Ge Hong, gives a recipe for preparing gold from tin by heating with various forms of alum (potassium aluminum sulfate) on a horse dung fire. What was made was tin sulfide or mosaic gold, a yellow material which glitters just like gold. Present-day repetition of the procedure, using an electric furnace rather than a horse dung fire, confirms the production of tin sulfide.

The elixirs made from simples like cinnabar and gold contain, in general, so many components, some of which will contain impurities, that it is difficult to hazard a guess at what chemical changes are occurring. Picturesque titles were given to many elixirs. A mixture of calomel (mercuric chloride), cinnabar, sulfur, and realgar (arsenic sulfide) was known, according to the *Danjing Yaojue* of Sun Simo of the Tang dynasty, as Grand Unity Three Envoys Elixir. Needless to say, the elixirs did not have the required effect and their use in Daoist practice gradually died out, leaving only a memory of sustained but flawed chemical activity. There are just a few exceptions to this generalization of futility in Chinese alchemical activity, the most famous of which is the production of gunpowder, known originally as *huoyao* or “fire drug”. Niter and sulfur are mentioned in early *materia medicas*, including *Shennong Bencao Jing* from the Han. Possibly in pursuit of elixirs, they were mixed and inadvertently contaminated with carbonaceous materials, giving a material which burned very brightly. Careful adjustment of the proportions gave an explosive, used in China for firearms and civil engineering and for fireworks. The first printed recipe for gunpowder is given in a military manual, *Wujing zongyao* by Zeng Gongliang, printed in AD 1044. It was the optimized formula which traveled to Europe and had such a dramatic impact on the conduct of warfare. It is ironic that the most significant achievement of Chinese alchemists in their efforts to make elixirs of immortality was an instrument of warfare.

With a decline in interest in alchemy during the Yuan, Meng, and Qing dynasties, there was no emergence of modern chemistry from alchemical activity as there was in Europe. The advanced state of modern Chinese chemistry (epitomized by the laboratory synthesis of insulin in 1965) is due to the introduction of chemistry from the West during the nineteenth century, partly by missionaries and partly by young Chinese students studying in Europe and America. Among missionaries (although the term is not entirely appropriate) was John Fryer, the son of a poor English clergyman, who worked at the Kiangnan Arsenal translating manuals and textbooks for the Chinese government. Between 1867 and 1897 he acted as focal point for the propagation of western scientific ideas in China. Even during the political upheavals of the first part of this century, there was a general increase in Chinese scientific education, and a number of Western style scientific institutions, like the Peking Union Medical College, were established. In chemical research the dominant figure was Wu Xian. He completed his Ph.D. at Harvard Medical School in 1920 and returned to the Peking Union Medical School. By 1925 he was a full professor and initiated an extensive program of research into blood chemistry. Chemical research started elsewhere and, fueled by the innate talent of the Chinese people, it has grown, in spite of all the political upheavals of the Communist revolution and the downfall of Mao, to make China one of the leading nations in the world for chemical research.

See also: ►Alchemy, ►Ge Hong

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C

Chen Yan

Hong Wuli

Chen Yan, a famous physician of the Southern Song Dynasty in the twelfth century, was born in Qingtian (now in Zhejiang Province), with Wuze as his surname and Hexi as his nickname. He was extraordinarily clever and proficient in prescription and pulse taking, as well as in treatment. It was said that he could prophesy the prognosis of incurable diseases. In 1161, he assembled a six-volume work of prescriptions, *Yi yuan zhi zhi* (Treatment Based on Etiology), with 81 categories which deals with the pulse and diagnosis of diseases, followed by their etiology, and the variorum of the *Canon of Pulsology*, all with relevant recipes. This work was never published.

Chen was especially interested in the study of pathogenesis. He claimed that the causes of all diseases could be divided into three categories; this was based on Zhang Zhongjing's hypothesis. Eventually, he compiled the *San yin ji yi bingzing zheng fang lun* (Discourses on the Manifestations and Recipes of Diseases of Three Pathogenic Categories) in 1174, in 18 volumes. He summarized all pathogens into three categories:

1. Endogenous emotional changes, the Seven Emotions (joy, anger, sadness, ratiocination, grief, apprehension, and fear), which originate from the internal viscera and affect the extremities.
2. Exogenous pathogenic factors, the Six Excesses (wind, cold, heat, damp, dry, and fire), which originate from the channels and affect the internal viscera.
3. Causes neither exogenous nor endogenous, which derive from immoderate food and drink, wounds, ulcers, and insect and beast bites. The etiological work exerted some influence on later generations.

Chen also summarized medical science in four Chinese characters, reading "title, substantial property application" claiming that all new commentaries on ancient classics could be categorized under four branches: sphygmology, manifestation, disease, and treatment. Hence, all medical students should recognize a disease on the basis of pulsology and make a diagnosis on the basis of manifestations.

In the years 1165–1173, he compiled the *Herbology of Compiled Categories* with subheadings based on the above-mentioned ideas. Though it was an anonymous compilation with a "Preface by Master Hexi," it was commonly believed to be Chen's.

See also: ►*Yin-yang*, ►Medicine in China, ►Zhang Zhongjing

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Childbirth

Margarita A. Kay

The pelvic changes that evolved when hominids became upright walking creatures resulted ultimately in what is known as the "obstetrical dilemma" for humans. The woman's pelvic bones must not obstruct safe passage of the infant's head, and her soft vaginal tissue must be able to stretch to the maximum. Meanwhile, the baby must be mature enough to survive outside the woman's body but small enough to pass through her narrowed birth canal. Managing childbirth within these parameters developed throughout human history by means of observation, trial, and errors accommodated, however, by high fertility. Obstetrics conducted in hospitals is a recent biomedical specialty, and in the past decades, Western obstetrics has developed still more technologies. However, for non-Western mothers, little has changed in 2,500 years of written record. From that record, we can draw one of two opposing conclusions: first that childbirth customs are appropriate adaptations to biological needs; or, second, that high technology is always better than childbirth in a natural setting.

Some writers portrayed childbirth practices in non-Western societies as ideal, resulting in a quick and painless process. Men who were not allowed to observe births were told about them by informants who themselves also had been excluded from the birth scene. These writers believed that the non-Western woman just goes in the fields, gives birth, and returns to work in a few hours. Later, women anthropologists who observed non-Western births gave very different reports. Management of childbirth anywhere requires attention to the problems of safety, pain, fatigue, protracted labor, malposition of the fetus, delivery, expulsion of the placenta, and healing. Solutions to problems are mandated by the universal physiology of childbirth. In Western obstetrics, these problems of childbirth are managed with technological equipment; in non-Western societies, the same problems are managed with hands.

Childbirth is not only a biological occurrence; it is also a sociocultural event. Differences in the management of birth reflect different values and beliefs. In some cultures, myth is used to explain pregnancy and birth. Sometimes birthing is a private process, sometimes a communal event. How a society reacts to physiological processes and the extent to which there is contact with other cultures accounts in part for diversity in the ways of managing childbirth. Each birthing system relates to the place women hold in a community, the value given individual children in that community's social structure, how much medical care is available and how it is distributed, and the religious belief system that is in place. Thus childbirth practices develop within the context of each particular society.

Such cultural strictures determine, among other things, how the pregnant woman should behave, who should take care of her, how abnormalities are to be explained and how to prevent them, what, it is believed, causes labor, how it should be stimulated, where the birth should take place with which persons in attendance, and what should be done after birthing for mother and newborn. Descriptions of diverse birthing practices can be found in the writings of George Engelmann and Hermann Ploss, Max Bartels, and Paul Bartels. Birth customs are catalogued in the Outline of World Cultures. MacCormack and Kay edited anthologies detailing birth practices in mostly non-Western cultures. Following are illustrations of some of this diversity from East India, Japan, Malaysia, the Navajo Nation, Seriland of the northwest coast of Mexico, Guatemala, Mexico, Ireland, and Ibo and Bariba tribal homelands in Africa.

Many "normal" activities of women are proscribed during pregnancy with the view of preventing childbirth difficulties. Some of these prebirth customs, are considered adaptive by Western medicine. For example, pregnant American Indian women are urged to keep moving and working during pregnancy and to limit their intake of food. The goal is not to have too large an infant for easy delivery. In West Africa, on the contrary, women are fattened in order to make them desirable for marriage and childbearing. Each custom is beneficial: genetically, American Indian women tend to have very large infants, whereas the babies of African and African–American women are likely to be quite small.

The women themselves explain their customs only as "we have always done it that way." The outsider sees the rationale for many proscriptions deriving from principles of sympathetic magic, like affecting like. Ancient Mexicans and recent Navajo, for example, believe that weaving is dangerous during pregnancy because the umbilical cord will tie up the baby. This belief has a very long history. It is recorded as fact by ancient Greek authorities of Aristotle, Galen, and Soranus. Across Western and non-Western cultures, the woman and sometimes her mate are told to avoid certain foods and actions to prevent problems in birthing or abnormalities in the baby. Conversely, a woman's cravings for exotic foods must be satisfied or the baby will be marked. Some of the rules placed to solve birth problems may be seen in the belief system of the larger culture; for example, the *bidan kampung* (traditional midwives) of Muslim Malaysia consider the humoral system of Islam in selecting a western-facing direction (with modification for days of the week) to align the woman for birthing; west faces Mecca. For Navajo, on the other hand, it is vital that the mother's head *never* face west, for that is their direction for death. Women who are taught that congenital malformations are caused by unnatural phenomena wear amulets to protect the unborn child. Charms include medals, pictures, and prayers that represent their religion, iron filings, and pieces of crystal, coral, or jet. It could be said that magical thinking can also characterize high technological Western cultures, for childbirth outcomes cannot always be predicted. Rituals of testing are enacted to resolve anxiety of the unknown. Childbirth is feared to a certain extent by all people.

Non-Western women are given prenatal massages in many cultures, notably Japan and Mexico. The purpose of the massage is to fix the fetus in a position favorable for delivery. In some societies, the fetal position is also assisted by a belt around the woman's abdomen. The Japanese apply the maternal *obi* in a special ceremony in the fifth month of pregnancy. Mexican women wear a narrow red cord, which shows the ascent of the uterus. Traditional Navajo women maintain their custom of wearing a red belt woven with green figures, 5–6 inches in width, throughout pregnancy. This belt is later used during labor and delivery.

When a woman believes that her childbirth labor is starting, she takes herbal teas. Mexican women drink *té de manzanilla*, camomile tea, believing that if it is false labor, the tea will make the pains go away, and if it is true labor, the pains will come stronger and harder. This belief has pharmacological support. Navajo women use tea from a penstemon for the same purpose, or one from rabbitbrush. Ideally, the birth should be fast. Mexican and Guatemalan women are given the ancient Aztec herb *cihuapatli*, which has strong effects on the uterus. They are permitted little sleep but are encouraged to walk with their contractions to hasten delivery. When in pain they are allowed to scream, unlike West African Bariba and Ibo. The proud Bariba women attempt to deliver alone to conquer their fear. Traditional Navajo women were trained to make no sound in order to preserve the secrecy of the process and today are silent and motionless during labor.

Because childbirth is the obvious result of sex, women in societies that value female purity, innocence, and virginity have particular difficulties. Irish peasants hide their pregnancies as long as possible, and do not publicize births. Hindu women also do not advertise their condition, resulting in little attention to their prenatal health, and distressing labor. Following Biblical injunction, the laboring woman was expected to suffer, until in the mid-nineteenth century, Queen Victoria accepted the newly discovered anesthesia for her birthings.

In non-Western childbirth, a midwife conducts the birth process. She uses many ways to stimulate labor, from placing an amulet on the laboring woman or an axe under her bed, to giving herbal teas or some of the husband's semen for her to swallow. To lubricate the birth canal, she massages with whatever is typically available, such as lard, clarified butter (*ghee*) or cooking oil.

Posture during labor also varies. In many non-Western societies, the laboring woman is encouraged to keep an upright position, utilizing gravity to move the fetus in the birth canal. Anderson and Staugård summarized traditional birth positions of 22 tribes in Africa and found kneeling to be used in 12, squatting in ten, holding rope in seven, lying in six, and half sitting in five. These postures may relate to different pelvic dimensions; for example, women of Biafra commonly used the squatting position, which works best for women who have a short pelvic outlet. The 80,000 women who have had traditional genital surgery (female circumcision) present special challenges for safe delivery, because scar tissue does not stretch.

A common practice of American Indians has the woman in either a kneeling or squatting position, with one attendant supporting the woman from behind, pushing on the abdomen above the uterus, while another attendant is in front, pressing from below. The mother might be pulling on a rope during contractions. Or she might pull on a hammock, which is suspended above where she stands, as has been recorded for the Kalopalo Indians of Central Brazil. In the latter case, four attendants help the laboring woman, two pressing down on each shoulder, and two pressing on her feet to direct force during a contraction. Navajo women pull on the special red belt that they wore during pregnancy, looped over a beam in the ceiling. For the Seri, a hunting – gathering people of Sonora, Mexico, two women who are usually close relatives help with the birth. One assistant sits on the ground, her legs spread but her knees doubled under her, to make a lap for the parturient to sit on. The second assistant, also sitting on the ground but facing the laboring woman, holds her hands in position to receive the infant. The parturient and midwives often wait for hours in the described positions. To speed the labor, the parturient may be given tea from the roots of indigenous plants, or a concoction of alcohol, limes, cinnamon, and aspirin. The women often say that they do not want to marry because childbirth hurts too much. Women of the nearby agricultural Yaquis drink an infusion of the narcotic plant Datura for childbirth pain.

For difficult deliveries, Punjabi midwives straddle the chest of the laboring woman, pressing hard on the abdomen with their hands; or they push with the heels of their feet on the pubic bone.

In matrilineal societies such as the Navajo, the attendants are commonly women from the maternal side of the family. Patrilineal societies such as Egyptian or Japanese, where descent is traced through the father's line, require the presence of the husband's kin, to assure continuity of the line. The birthing woman is accompanied by her husband's mother, and goes to her mother-in-law's house to recuperate from the birth.

Delivery of the placenta (afterbirth) is a grave concern in all societies. The medical ethnobotany of every group contains a variety of plants to give the woman whose placenta is slow to separate. According to humoral doctrines which are prevalent in many non-Western cultures including India, China, Middle America, and Latin America, those herbs that acted on the uterus were categorized as "hot" and "dry," and many of the same plant genera are used crossculturally. A retained placenta is a most dreaded complication of birth: "anyone can deliver a baby but it is the placenta which kills" (Bariba). Once the midwife delivers the placenta, she disposes of it according to its meaning in her culture, respect as a spiritual entity or fear of its power. In Malaysia, the placenta is considered to be the fetus's semi-human sibling, and thus is washed and ceremonially buried, which is similarly done by Guatemalans and Seri.

Some of the materials used to act on the uterus, either to bring on menstruation, stimulate labor, hasten birth, or separate the placenta, have been subjected to phytochemical analysis. *Artemisia* species, the botanical name first given by the Greeks for their goddess of women, and used worldwide in Europe, the Middle East, China, Latin America, North America, and Mexico, contain estrogens, female hormones. *Matricaria*, named since Roman times from the Latin word for womb, relieves painful uterine cramps through its spasmolytic compounds. Analysis of other materials, such as the husband's semen, given to the laboring woman in some African cultures, shows that they are high in prostaglandins, chemical compounds used in biomedicine to initiate labor by causing the mouth of the uterus to begin opening.

Indian peoples of Mexico use plants passed down in oral history from Uto-Aztecan forbearers (such as *yyahautli*, marigold, to stimulate labor, and *toloache*, jimson weed, for labor pain) and also those learned from Europeans who came in the colonial period, coriander and rosemary, for their actions on the uterus. Hindu mothers are given Ayurvedic herbs, while Chinese herbs are used all over eastern Asia. Childbearing women take herbs for prenatal care, labor strength, and postpartum healing. The woman may drink the plant material in teas; it may be applied to her abdomen, inserted in her vagina, inhaled, or she may sit over infusions in vapor baths.

After the baby is born, the umbilical cord must be tied and cut, and again there are many practices to be followed. The cord is cut with a piece of sharp bamboo in Malaysia, a razor blade or broken glass in Ghana. It may be tied with hair, string, or animal tendon. The variety of dressings include pounded pottery, herbs, salt, ground shells, and ash, materials that can harbor bacilli causing neonatal tetanus. The cord remains may be buried in a place that is associated with the anticipated sex role behavior of the child. For example, a Navajo woman may bury her infant son's cord near the sheep corral and her infant daughter's cord near the weaving room. Mexican, Malaysian, and Japanese mothers kept each child's cord for the child's future welfare.

The immediate postpartum period lasts for 3 days in cultures predominately Christian, and 4 days in American Indian societies, the respective magic numbers for each. After giving birth, and for a period of time prescribed by the culture, 20 days for many American Indians, 40 days for traditional Jews, Christians, and Muslims, the woman is supposed to be confined to her home. It is believed that the woman is vulnerable, requiring protection during the entire postpartum period. Some Mexican patients still observe *la dieta* during which time baths, walking barefoot, and otherwise being subjected to cold are proscribed. This includes avoiding "cold" foods, foods that are believed to have a quality of chilling the body.

The newly delivered woman is healed with heat in many cultures. The Navajo woman may have heat applied by warming green cedar and holding it to the abdomen with her red sash. She is bathed on the fourth day after delivery, especially if she had a ceremonial Sing during her labor. Her lacerations are treated with a salve of baked cactus, or a fumigant treatment may be prepared by digging a hole and heating stones therein. Soranus described a similar fumigant 2,000 years ago. "Mother roasting," as it is called, is a therapy used by many societies in Southeast Asia, including Malaysian. A fire is maintained beside the delivered woman for a prescribed number of days. This "dries out" the womb. A ritual fire is kept burning in the dwelling of the Seri woman for 4 days following the birth, in this case for the infant's sake. Hot leaves are pressed on the Ibo mother's abdomen, immediately after birth. The *temascal* or sudatory was used by ancient Aztecs after childbirth, as well as by ancient Romans and is used by present day orthodox Jewish women after menstruation as well as after childbirth.

Sexual intercourse is not permitted anywhere until the puerperium, however defined, is over. Mexicans, like so many others, believe that intercourse when there is vaginal bleeding is abhorrent. The Navajo believe that even indirect contact with vaginal blood is very dangerous to the husband and anyone else. In many cultures, contact with blood was considered polluting to the individual and to the community. The woman could now be purified, by bath and by religious ceremony. Leviticus XII, 2 provides the Laws of Purification and Atonement for Jews, Christians, and Muslims. The postpartum bath is a Shinto rite of purification in Japan.

Non-Western Birth Today

It is estimated that worldwide, 80% of births are attended by Traditional Midwives, Traditional Birth Attendants, or simply female relatives. The status of the traditional midwife has varied through time and place. For some non-Western cultures, her status has been very low, for it is women's work, and deals with blood. With many ethnic groups in India, midwifery was looked upon as a most degrading occupation.

The traditional midwife is typically a woman who is respected in her community, nonliterate, postmenopausal, has herself borne children, and learned her craft as an apprentice to another woman. She is often looked down on by the Western medical community. Traditional midwives may get Western training to meet difficult births, although they may not always find such instruction useful. When Western technology is not available, the traditional midwife's birth skills may prove to be superior. It may be hoped that the Certified Nurse Midwives of each culture may bridge the birth customs of the non-Western traditional midwife with the practices of Western biomedicine.

See also: ►Magic and Science, ► Ethnobotany

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Childbirth in India

Nitin Trasi

Obstetrics in Ancient India

The oldest sources of information about Indian culture are the four *Vedas*, sacred compositions probably compiled over several centuries during the second millennium BCE. The knowledge about Vedic medicine is contained mainly in the fourth and latest Veda, the *Atharva Veda*, and a related later work, the *Kauśika Sūtra*. Later, in the post-Vedic era, the ancient Indian system of medicine acquired the name *Āyurveda* (lit.: knowledge of life). The golden age of Indian medicine lasted almost 2,000 years, from about 1000 BCE to about AD 1000. The most famous works written at this time were the medical treatises known as the *Caraka Saṁhitā* and the *Śuśruta Saṁhitā*.

The art of obstetrics was well advanced in ancient India. Āyurveda had eight branches (*aśtānga āyurveda*), one of which was *Kaumārabhrtya* – gynecology, midwifery, and pediatrics. This included the classification of diseases of the female genital tract, including menstrual disturbances, and suggestions for treatment. It discussed the clinical course and various stages of labor, difficult labor (*mūḍagarbha*), the management of the puerperium (the period of confinement after labor), and miscarriage (*makkalla*). The different malpositions of the fetus were also known, and methods of treatment by version (the manual turning of the fetus to make delivery easier), embryotomy (an operation to destroy the fetus), forceps delivery, and even cesarean section were described (Keswani and Sharma 1972). In fact, the first mention of the obstetric forceps in world literature is to be found in the Vedas. It was called the *jugna ṣankhu*, and consisted of paired, semicircular-ended tongs, such as that used for holding hot utensils. It was probably used for extracting a dead and dismembered fetus from the mother's womb (Das 1929; Douglas and Stromme 1988: 367).

Caraka, the author of the *Caraka Saṁhitā*, was a famous physician. He is believed to have been the court-physician of the Buddhist king Kaniśka (AD 78–100), and attended on the king's wife as obstetrician during her difficult delivery (Saletore 1984: 300–301). The *Caraka Saṁhitā* lacked a detailed study of surgery, but was otherwise quite comprehensive.

Śuśruta was the most celebrated surgeon of ancient India. The *Śuśruta Saṁhitā* was originally written probably in the last centuries BCE, although some date it much earlier, even as far back as 1000 BCE. It is especially important from a surgical point of view. Śuśruta mentions as many as 121 instruments of various descriptions, made largely of steel. Alcohol in the form of medicated wines was used as a narcotic during and also after operations, and hot oils, tar, or caustics were used to stop bleeding. A drug called *Sammohinī* (producer of unconsciousness) was administered before major operations, and another drug, *Sanjīvanī* (restorer of life) was employed to resuscitate the patient after operation (Keswani 1961, 1967).

When delivery was impossible by natural means, the fetus – usually dead by then – was probably extracted using forceps; if necessary after dismemberment by embryotomy. Cesarean section, though mentioned in the literature, was not likely to have been a real choice. It had an extremely poor maternal outcome (almost 100% mortality) the world over until the twentieth century. In ancient India too, it was probably only performed on rare occasions on a dying mother (or one who had just died) in an attempt to save the baby. Embryotomy, on the other hand, seems to have been a well-known procedure, finding mention even in non-medical literature. The great monistic philosopher Ādi Śaṅkarācārya (AD 788?–820) refers to it, citing it as an example of human suffering even before life has begun.

> If, by chance, the child moves into a transverse position at the time of delivery, it is then turned out (extracted) forcibly, broken into pieces by instruments (*Prabhodasudhākara*, v. 10).

Charitable hospitals were established by many rulers, notably Rāhul, the son of the Buddha, and the famous Emperor Aśoka (ca. 273–232 BCE or 265–238 BCE).

The Populace

Although the art of obstetrics was well advanced in ancient India, most people probably had little access to it. Pregnancy and childbirth were generally managed at home, by practices based partly on experience and partly on cultural beliefs. Girls were customarily married off at a very young age, often even before they had attained puberty. Their obstetric career therefore began early, and they continued to bear as many offspring as their health would permit. The pregnant woman was subjected to many restrictions. The solar and lunar eclipses were believed to be especially inauspicious times for her, and she was forbidden from venturing out into the open at these times.

Childbirth was largely a domestic affair, the parturient woman being attended to by experienced elder ladies from her own and from her neighbors' families. The squatting position or the seated (kneeling) posture was often favored for childbirth, and even today many tribal societies in India prefer these positions. The vaginal canal was lubricated with clarified butter (*ghī*) and ghī was also fed to the mother in the belief that it would lubricate the birth canal. A normal delivery did not usually present too many problems, but there was no recourse when complications arose, and in such cases the baby was often lost, and at times the mother too. Unsanitary conditions and lack of proper training and knowledge contributed to a high maternal and fetal mortality. Neonatal tetanus was an important cause of infant mortality. Cow dung was believed to have purifying properties, and was commonly used to "purify" the floor of the house (Saletore 1943: 114). This could have been a contributory factor.

At some time, the system of the traditional birth attendant, the *dāi*, took root. These dāis were usually experienced elderly ladies who would provide their services for a modest fee. However, though experienced, the dāis had no scientific education or training. Even today, it is estimated that dāis conduct over 50% of births in rural India. However, since 1957, the dāis undergo scientific training, and dāi training is now an essential part of the maternal and child health program of the Indian government.

The Medieval Ages and Later

With the coming of the Muslim conquerors to India, from the tenth century onward, the golden age of Āyurveda began to decline. Some of the factors leading to the decline were want of patronage from the rulers, aversion of educated Hindus to contact with blood, pus and diseased persons, and absence of a system of regular education and training for practitioners. In the absence of professional standards, it became difficult to distinguish the genuine practitioners of Āyurveda (the vaidya's) from quacks. Medicine in India during the later medieval period was dominated by Persian and Arabic influences which introduced an amalgam of Greek and Persian medicine, known as the *Unānı system* of medicine.

From the 1800s until 1947, the British ruled over most of India (British India included what are now India, Pakistan, and Bangladesh). By then, both Āyurveda and the Unānı systems were unorganized, as they had not kept up with modern discoveries and research. Skills were passed by familial succession and not by institutionalized education, and the practitioners were for the most part uneducated and unwilling to incorporate the new knowledge and discoveries that were pouring in from the West.

The state of public health in India at the time was poor, and women and infants were the most neglected segments of society in matters of medical aid. Maternal mortality (maternal death during childbirth) and infant mortality were very high. Even when modern medical treatment was available, resistance to treatment by male physicians and the strict purdāh system prevalent among certain communities often ensured that women got little access to it. There were cases where women preferred to die in childbirth rather than submit to treatment by a male doctor (Kumar 1998).

Modern Obstetrics in India

The Portuguese first introduced modern Western medicine to India (Royal Hospital, Goa, 1510), but it was largely the British who later established and consolidated both its practice and its study in the subcontinent. Popularization of sound surgical practice led to great improvements in the health of the population. Specialization was introduced in Indian universities both in education and research, and India was kept abreast of all the major developments taking place in the fields of science and medicine all over the world. All-women managed hospitals were opened for women patients. In Bombay (now Mumbai), several hospitals for women were opened in the late 1800s; among them, the Cama Hospital (1886) and the Allbless Obstetric Hospital (1890) were entirely managed by women staff. Medical education was promoted among girls even at a time when this was not popular in Europe. Anandibai Joshee was the first Indian woman to go abroad for medical education. She obtained an American degree in 1886. Significantly, her MD Dissertation topic was "Obstetrics among the Aryan Hindoos" (Kumar 1998).

In the early twentieth century, several Indian obstetricians made valuable contributions in the field of obstetrics. Some of the pioneering Indian obstetricians were Dr. N. A. Purandare from Mumbai (1877–1964) and Rāo Sāhib Dr. Shivarao Trasi (1881–1954) from southern India. In 1929, Sir Kedarnath Das published his work on the history of the obstetric forceps, which is still considered a classic, and in which he described over 500 varieties of forceps and included over 2,000 references in ten different languages. Dr. V. N. Shirodkar (1899–1971) pioneered several new surgical techniques, the most famous of which was an operation for women suffering from repeated abortions. Other leading obstetricians were Dr. K. M. Masani (1903–1988), Dr. M. K. Krishna Menon (1908–1988), and Dr. B. N. Purandare (1911–1990), among many others.

In India today, women use both traditional and modern techniques, depending on their location and income. In remote rural areas, conditions are similar to what they were a hundred years ago, while women in the city have access to top hospitals and the best of equipment. Mortality statistics are still alarmingly high in certain parts of the country.

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Chinese Science

Ho Peng Yoke

Scholars in the past found it difficult to focus their attention on Chinese science because in traditional China knowledge did not come under the same groupings as in the West. For example the Chinese pharmacopoeias included knowledge on natural history; the official dynastic histories, some Daoist writings, and the works of some great poets contain information on astronomy and alchemy, and compendia on military science mention meteorology and firearms together with magic and divination. It is true that there are some Chinese monographs on science and technology, such as the *Tiangong kaiwu* (Exploitations of the Work of Nature) and the *Jiuzhang suanshu* (Mathematical Manual of the Nine Sections). Nevertheless knowledge of traditional Chinese science exists mainly in the official dynastic histories, the compendia (*leishu*), the gazetteers, religious works like the *Daozang* (Daoist *Tripitaka*), the numerous book collections (*congshu*), and the general literature.

In sixteenth-century Europe, Francis Bacon (1561–1626), Jean Fernal (1497–1558), and Jerome Cardano (1501–1576) all made reference to three great inventions, namely the compass, the art of printing, and gunpowder. In the minds of many there was only some vague connection between China and these three inventions. Indeed, prior to the middle of the twentieth century the history of Chinese science received little attention both from inside and outside China. It gained recognition in the middle of the twentieth century when Joseph Needham launched his monumental work, *Science and Civilisation in China*. Needham did not pioneer the study of the history of Chinese science. Sinologists and scientists before him had written on acoustics, alchemy, architecture, astronomy, gunpowder, hydraulics, mathematics, and medicine in traditional China. However, Needham demonstrated the originality of many Chinese discoveries and inventions, including the "three great inventions" of Renaissance Europe, and made Chinese science a new discipline of study. Modern scholarship and recent archaeological discoveries have increased our understanding of Chinese science and helped in the reappraisal of some old interpretations.

Excavations carried out first at Anyang between 1928 and 1937 and again after 1950, followed by those done at Zhengzhou in Henan province, substantiated the existence of the Shang dynasty (sixteenth–eleventh centuries BCE) and brought to light many bronze artifacts, foundry sites, and proto-porcelain wares. At the ruins in Anyang the remains of the capital of the last Shang kings were found. This later period of the Shang dynasty is known as Yin (fourteenth–eleventh centuries BCE). Besides bronze artifacts, archaeologists uncovered gold, jade, pottery, and shell objects, wooden artifacts with traces of lacquer, traces of silk fabric, and even a chariot. The most important find, however, was the oracle bones, which were carapaces of a specie of tortoise or shoulder blades of buffaloes that bear inscriptions written by the people of Yin for divination purposes. They contain records of eclipses and novae, as well as names of stars and asterisms. They also show that the Yin people were already using a lunisolar calendar with 12 moons or lunar months in one year. Each month consisted of either 29 or 30 days each, and every 2 or 3 years there was one extra month, known as the intercalary month, added to the year. The numerals in the oracle bones were the earliest known Chinese numerals until the discovery of the inscriptions on the pottery at the ruins of Banpo, which dated back to about the year 3000 BCE. From the oracle bone numerals we know that the Yin people were already using a decimal system. We also find that the Yin people already had some knowledge of irrigation, agriculture, sericulture, and wine-making. For example, for tooth decay they used a character that included the character for "worms," suggesting that they had made an effort to attribute the problem to a cause. Chinese archaeologists have been quite active in recent years trying to re-establish the Xia dynasty. According to their tradition this dynasty existed for four centuries immediately before Shang, which itself lasted six centuries. Erlitou in Henan province, where bronze vessels dating back to the year 1700 BCE were recovered in 1971, is one of the more promising sites where they hope to discover epigraphical evidence to confirm the existence of that ancient dynasty.

Bronze vessels and pottery are some of the works of art characteristic of the Chinese. Shang bronzes show that the technique of bronze casting had already reached an advanced level. It was also in Shang China that the earliest proto-porcelain ware was discovered. It took the form of a wine container (*cun*), made of kaolin clay, with a yellowish green glaze on the surface about the mouth and a translucent deep green glaze on the inner and outer surfaces. The Western Zhou period (eleventh cenrury – 771 BCE) produced beautiful bronze vessels with inscriptions and proto-porcelain wares, some of which can be seen in many museums today.

In the Spring-and-Autumn period (722–481 BCE) two early texts, which Confucius (551–479 BCE) himself referred to, namely the *Shujing* (Book of Documents) and the *Shijing* (Book of Odes), were written. Both contain astronomical material from about the tenth to the fifth century BCE. The earliest sighting of Halley's comet in the year 613 BCE is recorded in the *Chunqiu* (Spring-and-Autumn Annals), which also contains references to solar and lunar eclipses, meteor streams, and other comets. The *Zhouli* (Records on the Rites of Zhou) informs us that the Zhou kings employed star clerks to observe astronomical and meteorological phenomena and to make astrological prognostications therefrom. The earliest star catalog is said to have been made by a court astronomer Wu Xian, of whom little is known. Two other catalogs were produced by Gan De and Shi Shen between 370 BCE and 270 BCE. The three original catalogs have long been lost. Some fragments claimed to be from the originals are quoted in many old astronomical writings. In the early fourth century Chen Zhuo (fl. ca. 310) constructed a star map supposedly based on such information.

Two weapons with iron plates taken from meteorite sources and dating back to the Western Zhou period were discovered in 1949. In 1976 a steel weapon of the sixth century BCE was excavated in Changsha, Hunan province, showing that by then China had already entered the Iron Age. Subsequently more iron artifacts of the fifth century BCE were found in Jiangsu and Henan provinces. It is interesting that although Europe knew about iron earlier, the Chinese came to know about the making of cast iron not later than the fifth century BCE, soon after iron was known to them. Another interesting technology developed by the Chinese of about that period is the breast-strap harness seen on the horses among the terra cotta warriors guarding the tomb of Qin Shihuangdi in Xian. Showing good understanding of the horse, this method was far superior to the throat-and-girth harness of the Roman chariot adopted in Europe in the early days. Some time between the years 600 and 1,000 the breast-strap technique went to Europe and evolved into the modern harness.

Between the sixth and the fourth centuries BCE the "Hundred Schools of Philosophical Teachings" flourished in China. Some of these schools played an important role in the development of science and technology in China. The philosopher Mozi (b. ca. 479 BCE) is remembered for his techniques of defense and for his knowledge of mechanics and optics embodied in his *Mojing* (The Canon of Mozi). Confucius is said to have edited the *Yijing* (Book of Changes), which contains one of the most subtle and influential methods of Chinese divination. In the past, especially in China, it was difficult to draw a sharp line of demarcation between science and divination. These two subjects were included within the term *shuxue* (mathematics). The writings of the Daoist philosophers and the Naturalists exerted a great influence on early Chinese science, and indeed they provided a set of natural laws that was supposed to be "universal", even more so than what modern scientists believe. Indeed the attempt to be too universal made it difficult for science in traditional China to separate itself from philosophy and to develop into modern science. The greatest name among the Naturalists was Zou Yan (fl. ca. 300 BCE) who lived in the eastern seaboard state of Qi (in modern Hebei province). He was the greatest exponent of the *yin* and *yang* theory and that of the *wuxing* in ancient China.

Traditional Chinese science was based on the philosophy of Harmony of Nature, in which heaven (*tian*), earth (*di*), and human beings (*ren*) were all mutually related. Attempts were made to develop a philosophy to explain everything – from astronomy to astrology, from mathematics to fortune-telling, from alchemy to magic, from philosophy to ethics, from politics to fine arts, and from medicine to music – in a common concept based on *qi*. The word *qi* has a wide range of meanings, which cannot be adequately covered by a single term in translation. Its modern meaning includes "air", "gas", "vapor", "steam", "weather", "trend", "demeanor", "manner", "temper", and a sort of life-giving force, reminding us of the Greek concepts of *pneuma* and *psyche*, the Hindu idea of *prāṇa*, and what modern scientists call "matter-energy".

From *qi* the two opposite and yet complementary cosmological forces *yin* and *yang* and the five *xings* were derived. *Yin* conveys the idea of darkness, the shady part of a mountain, coldness, cloudiness, rain, anything that is feminine, and so on. *Yang*, on the other hand, refers to brightness, the sunny side of a mountain, warmth, clear sky, sunshine, anything that is masculine, etc. The term *wuxing* was generally translated as "Five Elements". This gave rise to some confusion. When the Jesuits rendered the Four Elements of the ancient Greeks into Chinese they used the term *siyuan*, (four *yuans*), but when they translated the Chinese term *wuxing* they called it Five Elements. Unlike the Greek Elements (earth, air, fire, and water), the Chinese *xing*'s were not stationary but were in a state of constant motion rather than rest. They are Fire, Water, Wood, Metal, and Earth. There is an order of production or generation in which Fire produces Earth, Earth produces Metal, Metal produces Water, Water produces Wood, and Wood produces Fire. Then there is an order of conquest or destruction in which Fire conquers Metal, Metal conquers Wood, Wood conquers Earth, Earth conquers Water, and Water conquers Fire. In Chinese medicine for example, the *Huangdi neijing* divides different parts of the body into *yin* and *yang* and associates them with the five *xings*. For example, the heart, the small intestines and the tongue are associated with Fire, the kidneys and the ears with Water, the gall-bladder and the eyes with Wood, the lungs, the large intestines and the nose with Metal, and the stomach, the spleen and the mouth with Earth. The foundation of health, tranquility, and well-being rests on the perfect equilibrium and harmony of the two cosmological forces *yin* and *yang*, which continually ebb and flow. Everything is produced by union and perishes by decomposition. From the two orders of mutual production and mutual conquest the Chinese derived two principles, namely the "principle of control" and the "principle of masking". Any of the five *xings* that conquers another *xing* is controlled by the *xing* that conquers it. For example, Fire conquers Metal, but the process is controlled by Water. Any *xing* that conquers another *xing* is masked by a *xing* that produces the conquered *xing*, i.e., Fire conquers Metal, but Earth masks the effect.

Then comes the system of the *Yijing* (Book of Changes) with its 64 hexagrams said to be derived from the theory of *yin* and *yang* and that of the *wuxing*, although the system was sometimes used to support those two theories instead. Traditionally the origin of the system traced back to the eleventh century BCE when the sage father of the founder of the Zhou dynasty got inspiration from two mystical diagrams, the *Hetu* (River Diagram) and the *Luoshu* (*Luo* Chart). These two diagrams supposedly held the secrets of *yin* and *yang* as well as the *wuxing*. In the *Yijing* heaven and earth, thus *yang* and *yin*, originated from *Dao*. This term probably refers to natural order in this context but is opened to a broad range of diverse interpretations. The system of the *Yijing* was mainly employed for the purpose of divination. Besides divination it also found its use in the "explanation" of scientific phenomena, such as in astronomy and alchemy.

In traditional Chinese thought, divination and mathematics were inseparable. The word *shuxue*, the modern term for mathematics, was only first used in the modern sense in the last century when Li Shanlan (1811–1882) translated Western mathematical works into Chinese. Before then the same term in traditional China referred not only to divination and mathematics but also to astronomy and music. One is reminded of the word mathematics as defined by Boethius (480–524) to include arithmetic, geometry, astronomy, and music, which became the *quadrivium* in medieval Europe. In the eyes of traditional Chinese mathematicians, such as Liu Hui (fl. 263) and Qin Jiushao (1202–1262), divination was the loftiest form of *shuxue* while mathematics (in its modern sense) was only its common form. *Shu* was something that could be predicted by calculations, whether by means recognized by modern scholars as mathematics, such as finding the unknown number in a mathematical equation, or predicting rain in weather forecasts and telling the future using the system of the *Yijing*.

Buddhism and Daoism gradually gained ground over the Confucianists after Han China in the third century. A revival of learning during the time of Song China

(960–1279) saw the neo-Confucianists attempting to cover science, particularly cosmology, within their schools of philosophy. The most celebrated among them was Zhu Xi (1130–1200), who sought to explain everything, both natural and human, with *li* (Nature's pattern), *qi*, and *shu*, while Zhang Zai (1020–1077) applied the concept of *qi* to explain natural phenomena and moral issues. Then there was the *xiangshu* (numbers of the symbols of the *Yijing*) school that focused its attention on the elucidation, verification, and application of the system of the *Yijing*. The most famous member of the school was Shao Yong (1011–1077), who used the system to explain natural phenomena and human affairs and to work out past and future events. His new order of the 64 hexagrams was shown by Leibniz (1646–1716) to be similar to the arrangements using the binary notation. Although Zhu Xi's philosophy was adopted as state orthodoxy, it does not imply that it met no opposition. For example, a contemporary, Lu Xiangshan (1139–1192) developed the neo-Confucian school of Idealism or of the Mind, which was later further developed by the Ming philosopher Wang Shouren (1472–1529), who had a large following.

The earliest text on Chinese astronomy and mathematics is the *Zhoubi suanjing* (Mathematical Manual of Zhoubi), which Christopher Cullen showed recently to be a compilation of the first century. In 1973 many important discoveries were made in the excavation of a Western Han (206 BCE–AD 9) tomb in Mawangdui, Hunan province. They included a manuscript recording the ephemerides of Jupiter, Saturn, and Venus between the years 246 BCE and 177 BCE and a silk manuscript illustrating comets in various shapes. Astronomical instruments such as bronze clepsydrae and bronze sundials have also been discovered in other excavations.

The Commentary to the *Jiuzhang suanshu* (Nine Chapters on Mathematical Arts) by Liu Hui (fl. 263) was the most influential text in the history of Chinese mathematics. In 1983 the *Suanshushu* manuscript (Mathematics Book), written on bamboo strips, was discovered in an ancient tomb dating back to the second century BCE at an excavation carried out in Hubei province. A preliminary study shows some similarities between this manuscript and the *Jiuzhang suanshu*. Liu Hui also wrote another, but much shorter text, the *Haidao suanjing* (Sea Island Mathematical Manual), using the right-angled triangle to measure distance and height. Before the time of Liu Hui, around the year AD 190, Xu Yue wrote his *Shushu jiyi* (Recording Omitted Items in Mathematics). Between AD 280 and 473 the *Sunzi suanjing* (Mathematical Manual of Sunzi) appeared. Of all the problems it contains, the one that has aroused most attention among modern scholars is that of the Remainder Theorem. The problem is to find a number, which when divided by three leaves a remainder two, when divided by five leaves a remainder three, and when divided by seven leaves a remainder two. The required answer is 23. Actually this problem involves three indefinite simultaneous linear equations of one unknown, and there is an infinite number of answers of which the required answer is the smallest. Historians of mathematics study this purely as a case of the Remainder Theorem. However, a more important application of this problem was recently revealed. It was found to be the method adopted by Chinese astronomers up to the eighth century to calculate and construct new calendars.

Several other mathematical texts were written in the following three centuries. One must note the evaluation of the ratio of the circumference to the diameter of a circle made by Zu Congzhi (429–500) and his son Zu Keng. They gave three different values, of which the most accurate was $3.1415925 < \pi < 3.1415926$. The method used by Zu Congzhi was described in his book, the *Zuishu*, which unfortunately is already lost. Chinese mathematics reached its golden age of development in the twelfth and the thirteenth centuries. During the twelfth century, mathematicians like Liu Yi and others could solve cubic equations numerically. Their writings are no longer extant, but fortunately we have the works of four great thirteenth-century mathematicians, namely Qin Jiushao, Li Zhi (1192–1279), Yang Hui (fl. 1261–1275), and Zhu Shijie (fl. ca. 1280–1303). The study of numerical solutions of equations of higher degrees is yet another of the characteristics of Chinese mathematics. Li Zhi also had a great influence in the development of mathematics in Japan.

The Chinese emperor regarded calendar-making as one of his duties that came with the mandate bestowed upon him from Heaven. The Chinese calendar took into account the apparent cycle of the sun and the cycle of the moon, both of which cannot be expressed in an exact number of days. The astronomer responsible for constructing a lunisolar calendar had to make accurate observations of the sun, the moon, and the planets, but however accurate his observations, his calendar would eventually, in just a matter of decades, go out of step with observations. In 1972 archeologists working at the site of a Han tomb at Linyi in modern Shandong province, discovered a calendar for the year 134 BCE. Throughout the history of China no less than one hundred calendars had been constructed, not to mention other unofficial calendars sometimes used in certain regions. The most renowned among the Chinese calendars were the *Dayanli* calendar completed by the Tang Tantric monk Yixing (683–727) in 727 and the *Shoushili* calendar prepared under the Mongols by Guo Shoujing(1231–1316) in 1280. They used the method of differences in mathematics to make their calculations. Accurate and new astronomical observations had to be made for the purpose of calendar making. New astronomical instruments were constructed for this purpose. Yixing, for example had to construct his own armillary sphere. The Song dynasty (960–1279) is remembered for the several large armillary spheres made for this purpose. The most famous was that made by Su Song (1020–1101). It was an armillary sphere driven by a water wheel using the principle of escapement.

In the early stages medicine and magic were indistinguishable from each other, as both were practiced by the shamans (*wu*). Shamans and doctors were together referred to as *wuyi* (shamans and doctors). During the Spring-and-Autumn Period (722–480 BCE) there were signs that physicians and shamans had already parted company. There was the celebrated physician Qin Yueren, better known as Bian Que (fl. 501 BCE), who was the counterpart of Hippocrates (465–370 BCE) in China. He was already acquainted with the four important diagnostic procedures used in Chinese medicine: observing external signs (*wang*), listening to sounds (*wen*), asking the patient's history (*wen*), and feeling the pulse (*qie*). These are sometimes referred to as looking, listening, asking, and touching. The earliest Chinese medical writing known to us until recently is the *Huangdi neijing* (The Yellow Emperor's Manual of Corporeal Medicine). Consisting of two parts, the book appears to have been written by several earlier unknown authors but took its final form during the second century BCE. Between the winter of 1973 and the spring of 1974 some valuable medical writings were discovered during the excavations at Mawangdui near the city of Changsha in modem Hunan province. The tomb where these writings were found dated back to the year 168 BCE and hence the medical writings concerned must have belonged to an earlier date. These are the two most ancient Chinese medical writings extant.

The earliest Chinese pharmacopoeia that we have is the *Shennong bencaojing* (Pharmacopoeia of the Heavenly Husbandman). We do not know its exact authorship and neither are we certain about when it was written, although the date could not be later than the second century. It sets a tradition followed by a long series of succeeding pharmacopoeias over a period of more than a thousand years. It mentions the *yin* or *yang* property and the indications of each medicinal substance, noting that some combinations of two or more of them are either beneficial or counter-indicative. It divides all the 365 items of medicine that it contains into three categories. Those in the first category have the efficacy of nourishing or prolonging life; those in the second are, as a rule, nontoxic and can be used to restore the constitution of the patient; and those in the third are usually toxic or have side effects. The last category is used for combating diseases. Thus the *Shennong bencaojing* catered to the needs of both the physicians and the aspirants of longevity.

While the physicians had parted company with the shamans, some of the latter devoted their attention to prolonging the human life span. Some of the substances they ingested, such as mercuric sulfide, mica, licorice, and asparagus, are listed in the *Shennong bencaojing* pharmacopoeia. The search for the way to physical immortality probably began in China at least 2,500 years before our time. It is recorded that in the Warring States Period (480–221 BCE) someone presented an elixir to the prince Jingxiang wang in the State of Qu. Some modern writers attribute the first practice of alchemy in China to Zou Yan. Later on the story of the elixir told by the shamans got the fancy of the emperor Qin Shihuangdi, who made several attempts to procure an elixir for himself so that he could live and rule his empire to eternity. Another patron of the shamans was the emperor Han Wudi, who reigned about 133 BCE. It was then that the shamans talked about making gold as the first step toward the elixir. At about the same time, Liu An, the Prince of Huainan, compiled, with the help of a group of shamans and alchemists retained by him, the *Huainan wanbishu* (The Ten Thousand Infallible Arts of the Prince of Huainan). Tradition says that this book dealt mainly with alchemy, especially the making of gold, but unfortunately we no longer have the complete text, and the fragments of the book now left are only concerned with magic. In the following century Liu Xiang, who was said to have inherited this book, was commissioned by the emperor to make gold for the Treasury. His failure landed him in prison.

The earliest Daoist alchemical treatise that is still extant today was written by the alchemist Wei Boyang in the second century AD. Entitled *Cantongqi* (The Kinship of the Three), the text is very obscure, containing a number of alchemical terms with "hidden" meanings. The use of the system of the *Yijing* (Book of Changes) has contributed directly to the obscurity of the text of the *Cantongqi*. Alchemy gained popularity following the work of Wei Boyang. During the fourth century Ge Hong wrote his *Baopuzi neipian* (The Esoteric Chapters of the Solidarity Master), showing the great advancement made in alchemy since the time of Wei Boyang. Ge Hong was at the same time an accomplished physician. Other famous physicians who were also great alchemists after Ge Hong were Tao Hongjing (456–536), Sun Simo (?581–?682), and his disciple Meng Shen (621–718). For the next eight hundred years or so after Ge Hong, alchemy continued to flourish and many alchemical works were written. Most of these works are lost; those that survived are included in the present version of the *Daozang* (Daoist *Tripitaka*), a collection of 1464 Daoist works, only a small fraction of which deal with the subject of alchemy.

In many of their experiments the Chinese alchemists used the process of sublimation and of distillation. They often made use of the reaction-vessel, called *yaofu*. Many of the elixir recipes contained toxic ingredients such as mercury, arsenic, and lead. Hence such elixirs would be quite poisonous. Quite a number of Chinese emperors showed great interest in the elixir and some of them unwittingly perished. For example, the Jin emperor Aidi died in his very prime, aged only 25, as a result of his attempt to avoid growing old. The emperor Wenxuandi of Northern Qi, on the other hand, exercised more caution. When presented with the elixir he decided that the most opportune moment to test it would be on his death bed. At least three Tang emperors died as a result of taking the elixir. Political motives might be behind the early demise of some Chinese emperors, but the alchemists responsible were quickly punished for their failure. With the evidence so efficiently destroyed the full case is difficult to investigate.

There were probably many charlatans among the alchemists, who, when their elixirs brought about the early demise of unfortunate emperors, managed to escape before it became too late. However, there were also alchemists sincerely interested in their work who believed in the elixirs they made. So strong was their faith that many alchemists must themselves have fallen martyr to their own beliefs, or become victims to mistakes in following the obscure and contorted instructions of their predecessors. The most experienced or industrious experimenters were often the most enthusiastic believers, and in the end the surest victims. In this respect the elixir mania must have acted as an inhibiting factor to the progress of chemical knowledge in China.

Many Chinese alchemists were aware of the toxicity of their products. Some tried to neutralize the poison; some recommended only symptomatic treatment; some believed that the ill effects were only side effects associated with the elixir and as such should be completely ignored; some turned to the vegetable kingdom to look for suitable ingredients; and some turned away from the material elixir and practiced "physiological alchemy" (*neidan*) following a regime of meditation and breathing exercise. By the ninth century alchemy in China had already seen its best days. The alchemists gradually relied more and more on the vegetable kingdom for their raw material. Hence there was an alchemical work that included the term *bencao* (pharmacopoeia) in its title, namely the *Waidan bencao* (Pharmacopoeia of Operative Alchemy) by Cui Fang (fl. eleventh century). After the turn of the fourteenth century several books on elixir plants made their appearance. The Chinese alchemists seemed to have gone round one full circle back to the days of the ancient shamans. Alchemy merged again with the tradition of Chinese medicine set by the *Shennong bencaojing* pharmacopoeia.

Hence traditional Chinese medicine and alchemy arose from the same source. At first the shamans practiced both magic and medicine. About the sixth century BCE medicine and magic took different courses. Some shamans developed the art of prolonging human life and reached the conclusion that one had to make gold by artificial means as a first step to physical immortality. That was the beginning of alchemy. Alchemy maintained a close link with medicine, dealing only with different aspects of human life. Quite a number of alchemists were at the same time famous physicians, as in the case of Ge Hong, Tao Hongjing and Sun Simo. A preliminary study shows a close connection between alchemy and Chinese medicine in the similarities between the basic principles used in medical and elixir prescriptions. Medicine and alchemy borrowed from each other. For example, alchemical works are liberally quoted in the more important pharmacopoeias of later time such as in the *Bencao gangmu* (the Great Pharmacopoeia) written in 1596. Although the Chinese alchemists did not succeed in their quest for the elixir of immortality, they played a part as the iatrochemist in Chinese medicine. Another by-product of their experiments was that they stumbled upon gunpowder when some of them caused an accident when they did not exercise sufficient caution in using saltpeter and sulfur, allowing some carbon impurities to get in from the charcoal or wood that they used as fuel.

There was early intercultural transmission of scientific and technological knowledge between China and her neighbors, especially west Asia, before the Christian era. Buddhism first came to China in the second century. Scientific knowledge followed the wakes of missionary and pilgrimage activities. During the eighth century Indian monks and calendar experts, Nestorians, Arab merchants, Korean and Japanese students, and others lived together in the Tang capital Changan (modern Xian) which had a population estimated to be over one million. Mutual exchange of knowledge was inevitable. Muslim astronomers found employment in the astronomical bureau in thirteenth-century China and some Chinese astronomers could have been sent by Hulagu Khan to work in the observatory in Maragha under its director Naṣir al-Dīn al-Ṭūsī (1201–1273). The Renaissance in Europe was influenced in no small measure by Arabic and Indian learning, but Europe also acquired knowledge of Chinese science and technology through the Arabs and the invasion of the Mongols during the thirteenth century. Since the seventeenth century science in Europe has advanced by leaps and bounds while Chinese traditional science remained in a state of stagnation. Toward the end of the sixteenth century the Jesuits arrived in China, using science as a tool to promote their mission. Science from Europe, particularly mathematics and astronomy, demonstrated its superiority to traditional science. In the latter half of the nineteenth century modern science came to China from Europe and North America, and by the twentieth century China had joined the world in the common enterprise of modern science.

See also: ►*Yinyang*, ►Astronomy, ►Metallurgy, ►Calendars, ►Armillary Sphere, ►Alchemy, ►Ethnobotany, ►Medicine, ►East and West, ►Magic and Science

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Cities and Towns in Ancient Israel (Bronze and Iron Ages)

Avraham Faust

Background

Many cities were uncovered in Bronze and Iron Age Israel, the vast majority of which were located on *tells* – artificial mounds created as a result of gradual human settlement activity. Notably, not every location is suitable for the emergence of a center, even of a local nature, and each site had advantages and disadvantages in relation to factors such as security, water supply, transportation (roads) and the availability of soils. Consequently, only several locations could, in antiquity, provide livelihood for a large population at any given region. This resulted with a repeating pattern in which the centers of many periods were continuously located one on top of the other, thus creating the famous *tells* which are so typical of the Middle Eastern landscape. Although in many instances extramural neighborhoods were built on the slopes of the tells (and in some rare instances cities were not built on tells), it is only in the later half of the first millennium BCE that the overall pattern changed; by then most *tells* were abandoned and cities were built practically everywhere. The gradual process of *tell* abandonment resulted from many factors, including changes in security conditions, increased population and improved technology, but this process lies outside the scope of the present discussion.

Notably, the towns (and *tells*) of ancient Israel were much smaller than their contemporaries in Mesopotamia and Syria. An average city of the Bronze and Iron Age covered some 3–5 ha (and sometimes even less); larger towns, in the scale of 7–12 ha, were also present. Towns of 20 ha, however, were exceptionally large, and megalopolis of 60 ha and more were extremely rare – very few such sites existed in the periods discussed here (e.g., Hazor in the Middle Bronze Age II and Late Bronze Age, and Jerusalem in the Iron Age II).

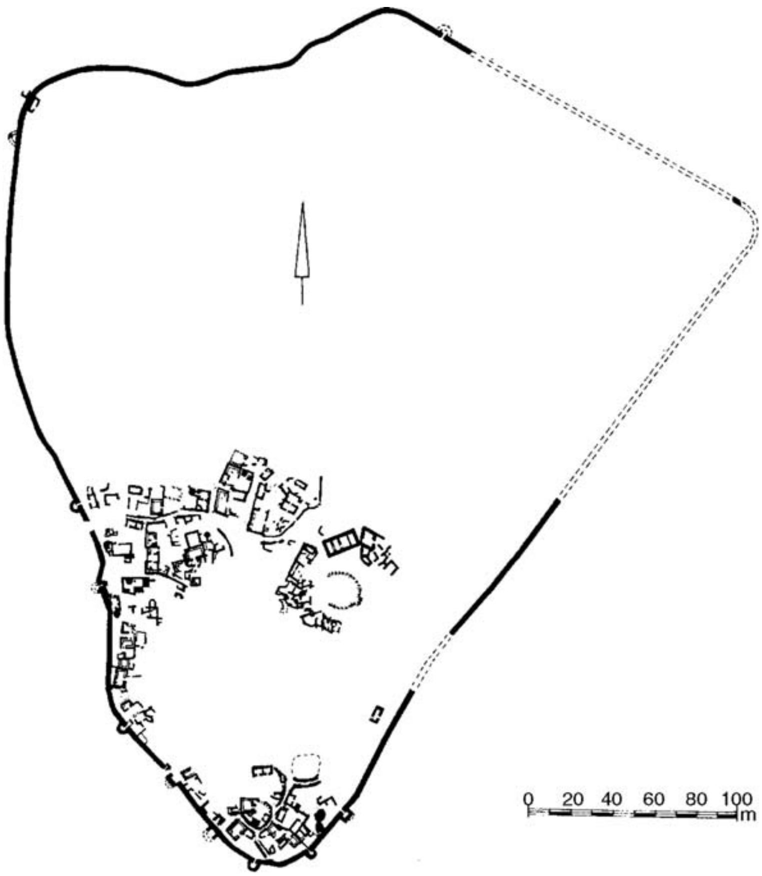
Defining a city is a complex enterprise. Within the scope of the preset paper, suffice it to note that the urban centers were much larger and more crowded then their rural contemporaries. Their inhabitants were of diverse backgrounds and occupations, and not all of them were engaged in agriculture. Social stratification is evident in practically all such sites, along with public buildings and royal construction activities (palaces, walls, storehouses, water system, etc.). These urban settlements served as political and economic centers for the villages that surrounded them, and probably also, during most periods, as centers of tax collection and as places of refuge in times of need.

History of Urbanization in Ancient Israel up to the Persian Period

Cities first appeared in ancient Israel around the transition to the third Millennium BCE (Early Bronze Age) (see Note 1). These first cities usually lie at the bottom of the tells, and in most cases not much is known for certain about their planning. It is mainly in the desert area, where the sites were not resettled in later periods, that we can discuss elements of city planning. ‘Arad, in southern Israel, is the best-known example of such sites (Fig. 1).

The site covers almost 10 ha, and seems to have been divided into several, public and residential, quarters. The former included several small temples and a modest palace. A large, but simple, water system into which rainwater were collected, was unearthed in the lowest part of the city. One should remember, however, that it is not certain whether ‘Arad is a representative of the Early Bronze Age urban phenomenon, as, due to its location on the desert fringe, it might have differed from the typical towns of the third millennium BCE.

The Early Bronze cities were gradually destroyed and abandoned toward the end of the millennium, and by the last two centuries of this millennium (the Intermediate Bronze Age) Cisjordan was devoid of any urban settlement.



Cities and Towns in Ancient Israel (Bronze and Iron Ages). Fig. 1 The Early Bronze Age city of ʻArad (based on Kempinski 1992a: 76; courtesy of the Israel Exploration Society).

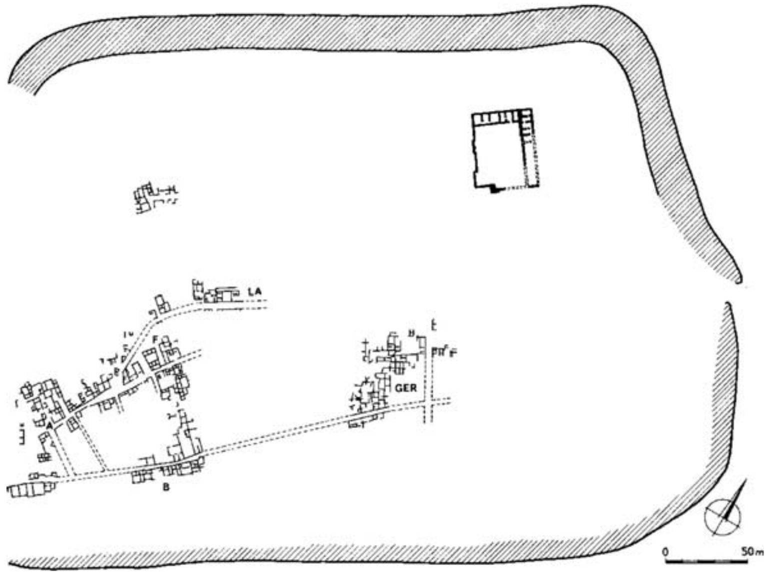
Urbanization resumed in the twentieth and nineteenth century BCE (Middle Bronze Age II; 2000–1550 BCE). New cities emerged throughout the country, with an emphasis on the lower regions. Port-cities were built for the first time. The largest Middle Bronze Age urban center was Hazor, which was apparently part of the Syrian system of city-states. Many sites were now surrounded with massive earth-works, whose purpose, however, is doubted since in many instances no city wall was unearthed on top of them. Some scholars have suggested that their construction, which required much labor but very few experts, served the local leaders as a substitute for the building of large and impressive city walls, as the latter would have required more experts which were not easily available for most rulers. Some towns show signs of planning, probably following a simple grid (Tell el ʻAjul) (Fig. 2).

While most characteristics of Middle Bronze Age culture continued during the Late Bronze Age (1550–1200 BCE), the number of towns declined, and they became smaller in size. Furthermore, hardly any settlement was fortified at the time (since the region was an Egyptian colony, the latter can probably be attributed to Egyptian policy).

Further decline occurred during the Iron Age I (1200–1000). The Egyptian domination over Canaan vanished, and many centers were destroyed or abandoned. Other towns, however, continued to exist, especially in the northern valleys, and a new wave of urbanization took place in the southern Coastal Plain, as a result of the arrival of the Sea Peoples (mainly the Philistines). The latter founded some new cities, for example in Ekron, covering relatively large areas.

Urbanization in many parts of the country was resumed on a larger scale only in tandem with the formation processes of the Israelite state, in the late eleventh and tenth centuries BCE, during the transition to the IAII (1000–586 BCE) (see Note 2). This urbanization probably involved, partially at least, forced settlement of population in urban centers.

The Iron Age II presents a settlement peak in the history of the region. Many urban centers were erected at the time throughout the country, with an emphasis on the highlands and the northern valleys. Excavations have uncovered various types of cities and a complex settlement hierarchy; from capitals, through administrative and regional centers of different sizes, to small field towns (in addition to rural settlements of course).



Cities and Towns in Ancient Israel (Bronze and Iron Ages). Fig. 2 The Middle Bronze Age II center of Tell el-'Ajul (based on Kempinski 1992b: 124; courtesy of the Israel Exploration Society).

The largest cities of the period were Samaria and Jerusalem, the capitals of the kingdoms of Israel and Judah (respectively). At its height the latter covered some 90–100 ha (including extramural neighborhoods) – larger than any other site in ancient Israel during the Bronze and Iron Ages. Also of significant size were several Philistine centers such as Ekron, Gath and Ashkelon.

Excavations have revealed clear evidence for socioeconomic stratification. Most of the population lived in small houses, which probably housed small nuclear families. The wealthy and some high officials were better off, and lived in large four room houses (see Note 3). In some settlements a form of a middle class is also identified. Palaces, which were identified in several cities, represent the upper part of the socioeconomic continuum, and this is where the royal family and the highest officials lived.

The Assyrian and (mainly) the Babylonian campaigns brought about large-scale destruction and population decline, and the number and size of towns decline dramatically. Urbanization in the Persian Period was more limited, and concentrated mainly in the Coastal Plain. Real large-scale urbanization re-emerged only in the Hellenistic period.

Iron Age Town-Planning

The Israelite towns of the Iron Age II (1000–586 BCE) have received a great deal of scholarly attention, resulting from the interest of scholars in this part of the biblical period, from its being a demographic peak in which more sites existed than ever before, and because the Iron Age II usually comprises the upper strata on the tells, therefore permitting large scale exposure, impossible for other periods.

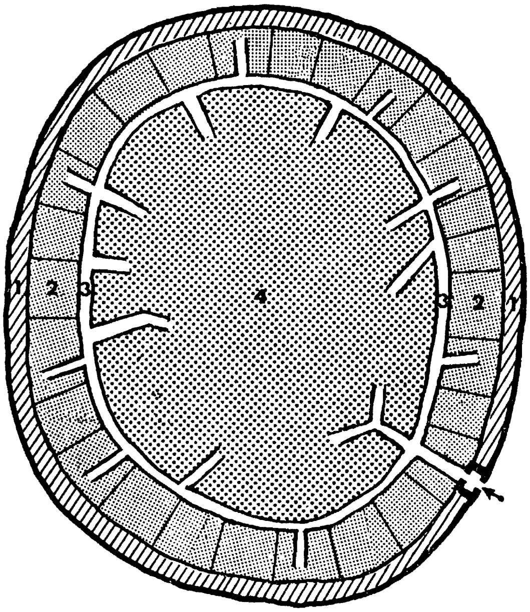
According to Yigal Shiloh's seminal study, the basic outline of the Israelite "town plan is clear: alongside the line of fortifications there is a belt of buildings bordered on the inner side by a ring road, running parallel to the fortifications, and separating these structures from the "core" of the city. The "core" itself was divided into many blocks of residential units of the four-room house type and its subtypes" (Shiloh 1978: 37–38) (Fig. 3).

Apparently, the outer belt was intersected by small alleys, separating the various houses, and leading to the city-wall, therefore enabling free access to the wall and to its casemate rooms (when these existed) (Fig. 4).

While some components of this plan can be found throughout the kingdoms of Israel and Judah, it is more typical of the Kingdom of Judah. In most cities in the kingdom of Israel (and probably also Philistia) a different planning prevailed. Here the city wall was accompanied by a road, and only inside this street were buildings built, divided into quarters by smaller streets.

Accessibility to the city wall seems to have been a major factor in Iron Age town-planning. A besieged city which fell to the enemy suffered a horrible fate, and both types of planning enabled the defenders easy and quick access to the city walls; through the small alleys in the "Judahite" plan, and from practically any place in the "Israelite" plan.

Another difference between Judah and Israel lies in the fact that most towns which were built according



Schematic model of the Israelite city, based on Tell Beit Mirsim, Tell en-Nasbeh, Beth Shemesh and Beer-sheba: 1. fortifications; 2. buildings of the outer belt; 3. ring road; 4. central core.

Cities and Towns in Ancient Israel (Bronze and Iron Ages). Fig. 3 A typical Israelite town (according to Shiloh 1978: 41; courtesy of the Israel Exploration Society).

to the latter plan were surrounded by a solid wall, while the "Judahite" plan is usually accompanied by a casemate wall. The alleys constructed in Judahite towns enabled the authorities not only access to the top of the wall, but also to some casemates, which could have been used for storage. The principle of accessibility to the city wall was adhered to in both plans, and it is likely that the reason for the adoption of different planning was due to space considerations. Larger cities could afford a massive wall, and a street that run along it. Smaller towns, in which space was scarce, tried to save as much area as possible; casemate walls were therefore built, and the ring-road was located inside the outer belt of houses (therefore reducing the space it consumed).

Another characteristics of the Iron Age city was a public quarter near the city gate. The impressive gate was usually accompanied by an open square, and near or around it were public structures, palaces, storehouses, barracks, water-systems, etc., as can be seen Beersheba, Tell en-Nasbeh, Beth-Shemesh, Jerusalem, Kinrot, Gezer, etc (see Note 4).

Furthermore, cosmological principles had also an influence on Israelite construction on all levels, from dwellings to cities. It seems that as part of their complex cosmology the Israelites regarded the east as the most auspicious direction, and the west as the most inauspicious one (like many other societies). Accordingly, they directed their structures in an easterly orientation whenever this was possible, and when this was not the case, they, at least, attempted to avoid the west. This was manifested also in city gates, and about 75% of those faced, roughly, the east. Following easterly orientation for dwellings in towns was difficult, and was carried out in the following manner (1) public buildings were adjacent to most of the Iron II city gates; (2) most city gates were oriented to the east.

The result was that no dwellings were built in the eastern part of the outer belt, and no dwellings in this belt were expected to face the west, therefore avoiding this inauspicious orientation. The same principle was followed also inside the ring-road, as in many cases houses were oriented toward small alleys (and avoided the main street when it was to their west).

The eastern orientation seems, therefore, to have been a major principle of town-planning, influencing not only the orientation of city-gates, but also of many dwellings and alleys.

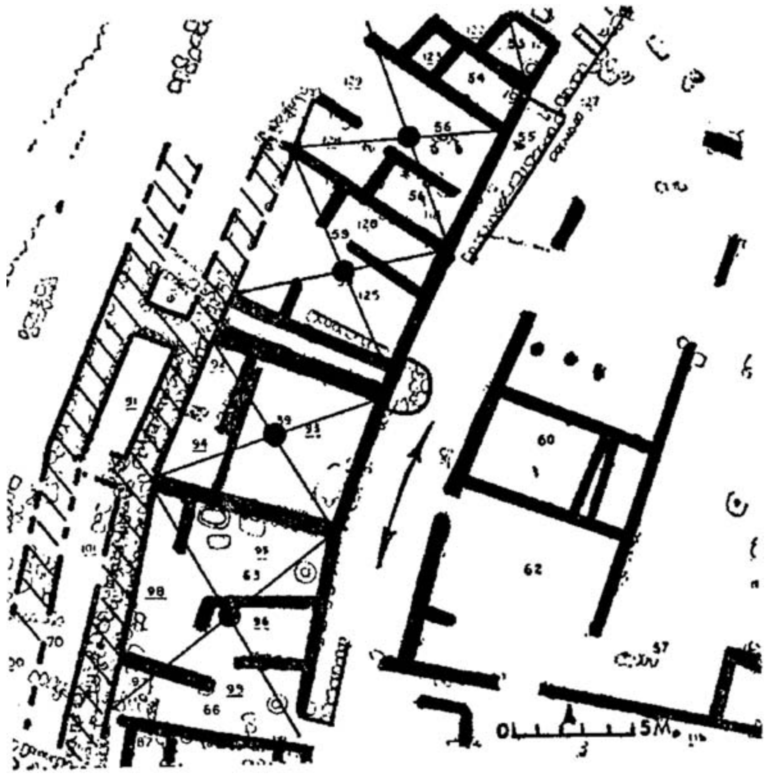
The town of Beersheba can serve as a good example of a planned settlement in the Iron Age (Fig. 5).

During the eighth century BCE Beersheba (stratum II) was a small but well-planned administrative center in the Negev. Its gate was in the southeastern part of the wall, facing this direction. Inside the gate, a small square was located, surrounded by pubic buildings of various sorts. The city wall was accompanied with a belt of houses, which used its casemates as their backrooms, and with a nicely built inner ring road that gave access to these houses. The outer belt of houses was intersected in various points by small corridors that connected the ring-road with the casemate walls, enabling easy access to the wall, and to some of its casemates. The inner part of the town – its core – was divided by smaller streets which cut through it, dividing it into blocks of houses.

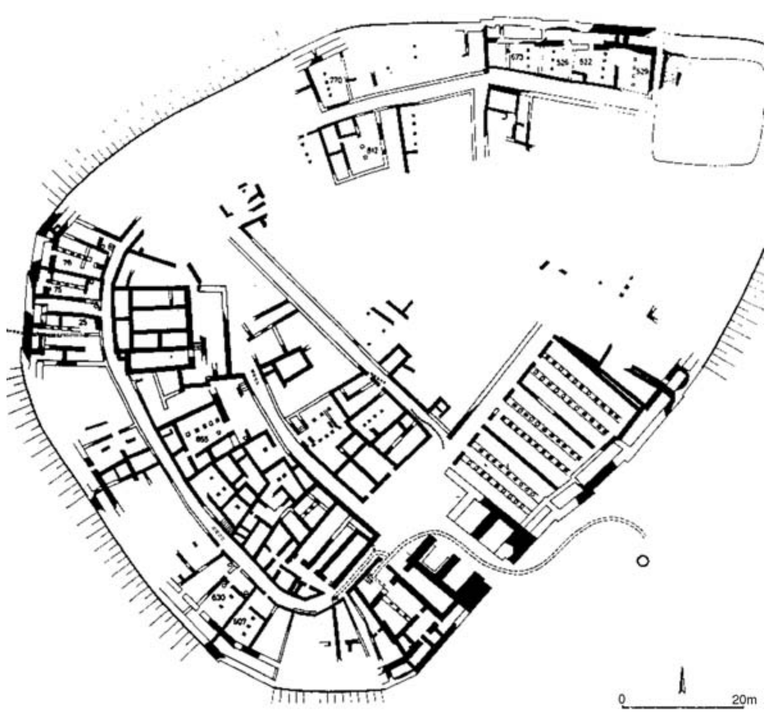
The eastern part of the outer belt of houses was composed by public buildings, and did not include any dwellings. The dwellings in this belt, therefore, were oriented to the south, east and north, but not to the west. Houses in the inner blocks were oriented toward the inner streets, usually avoiding the west. Adhering to the eastern orientation caused them, in some instances, to orient their backs to the main street, and to face small alleys.

Note 1

Notably, the emergence of towns was a long process, and it is not always easy to identify the exact point in time from which a settlement should be called a city. Some settlements were quite large and complex already in the last phase of the fourth millennium BCE (Early



Cities and Towns in Ancient Israel (Bronze and Iron Ages). Fig. 4 Part of Beth Shemesh city plan (based on Shiloh 1978: 40; courtesy of the Israel Exploration Society).



Cities and Towns in Ancient Israel (Bronze and Iron Ages). Fig. 5 General plan of Beer-Sheba (Singer-Avitz 1996: 168; courtesy of Prof. Ze’ev Herzog, Tel Aviv University).

Bronze Age I, traditionally regarded as a "proto-urban" period), and some have suggested that these were the first cities. Other scholars, however, had questioned the validity of the term "urban" not only for the centers of the third millennium BCE, but even to these of the later phases of the Bronze Age, suggesting that they were just complex villages. Most scholars, however, accept the traditional view, and regard these large settlements as cities.

Note 2

The late eleventh and early tenth centuries witnessed the gradual disappearance of rural settlements in most parts of ancient Israel. It is suggested that at least part of this process resulted from a policy of "forced settlement." The newly established Israelite monarchy transferred some of the population (especially in the newly conquered territories) to other/new settlements, and mainly to cities, in order to facilitate better control of the population, to lower costs, and to minimize the efforts involved in delivering sanctions, be it normative, remunerative or coercive, while maximizing its effectiveness.

Note 3

The term "four-room house" is a convention used to designate the typical Iron Age dwelling in ancient Israel whose ideal plan is composed of four main rooms. The "typical" house includes three parallel longitudinal spaces that are backed by a broad-room, with the entrance located at the central longitudinal space. The "rooms" are really spaces/areas and can be subdivided. There are subtypes of the "ideal" form, comprising three or two "spaces" and, in exceptional cases, even five "spaces." The high popularity of the four-room house was explained as either expressing its close relation with the Israelites (without elaborating the reasons for this relation) and/or its functional suitability to the needs of the Iron Age peasants, regardless of their ethnicity. Neither of these explanations, however, seem to account for the synchronic and diachronic dominance of the four-room house as a preferable architectural type in all levels of Iron Age settlement (from cities to hamlets; private dwellings and public buildings), all over the country (both in highlands and lowlands), for almost 600 years(!). It is likely that an adequate explanation for the unique phenomenon of the four-room house must relate to the ideological/cognitive realm, and to its place within the Israelite social and spiritual worlds.

Note 4

A typical public building in Iron Age towns is the "tripartite pillared building" (see Fig. 5, to the north of the gate). Such structures were discovered in many cities (especially near the city gate), but their interpretation varies greatly: the most common interpretation is that of a stable or a storehouse. In most instances, however, large quantities of "domestic" pottery (mainly bowls, jugs, juglets, cooking pots, and also storage jars) were found on the floors of these buildings. Since the finds do not easily fit with the above interpretations, some scholars have raised additional possibilities, including barracks, covered markets, customhouse, and a multipurpose public building which had many functions, including a shelter for the poor.

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C

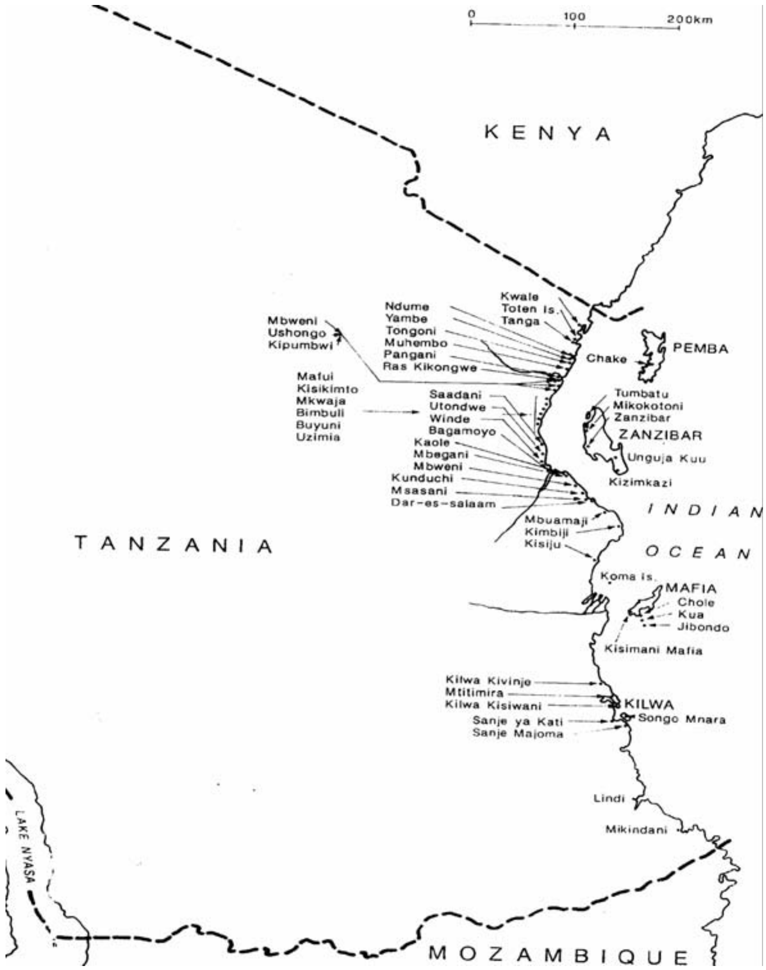
Cities and Towns in East Africa

Felix Chami

The towns of East Africa were built during two periods: pre-colonial and colonial. The former grew up along the coast, facilitating trade and communication between the rim of the Indian Ocean Seaboard and the interior of Africa. The towns, better known in history as Swahili City States, survived from about the beginning of the second millennium AD to about the 1890s. The latter were mostly new administrative centres established with the launch of German and British rule in East Africa from about the 1890s. Only a few settlements of the colonial period had a history predating the colonial era. Such towns include Mombasa, which is a Swahili town, and Mengo in Kampala, which was the seat for the Buganda Kingdom. This article examines the pre-colonial Swahili towns.

The Growth of the Swahili Towns

Swahili settlements spread all along the coast and islands of East Africa (Fig. 1). There were few



Cities and Towns in East Africa. Fig. 1 The Swahili towns on the Tanzanian coast. For the rest of East African coast see Horton and Middleton 2000: 6–7.

settlements before the Swahili towns of the thirteenth century, mostly built with mud and wattle. Concentration of these towns seems to have first occurred in the Mafia-Kilwa region on the coast of Southern Tanzania and on the Lamu Archipelago on the northern coast of Kenya. Individual settlements seem also to have flourished elsewhere on the coastal littoral and virtually on every island large enough to settle from Lamu archipelago to Madagascar. These early settlements are identified by archaeologists by remains there of early Islamic goods including Sassanian Islamic ware, Islamic copies of Chinese pottery and early Sgraffiato [decoration which is scratched through the clay surface coating to reveal the colour of the underlying clay].

Probably the largest earliest settlement of this period is that of Kilwa in Southern Tanzania (Figs. 2–4). The settlement seems to have become a larger centre by about AD 1000 when the earliest stone structures could have been built (Chittick 1974). Probably only a few stone structures would have been built then. The spectacular nature of Kilwa centre was the first to attract archaeologists in the1950s. Mortimer Wheeler led a team of researchers in 1955 to conduct a test excavation. This research paved the way to more intensive archaeological researches by Neville Chittick, not only in Kilwa but also in other Swahili towns (Chittick 1974, 1984).

Kilwa was large, the stone town itself estimated to have been about 50 hectares in the early period. This settlement must have controlled other larger settlements of the area more economically, as settlements of a similar nature existed on the islands of Mafia, off the Rufiji Delta, and on the nearby island of Songo Mnara. Other settlements of the period related to the development of Kilwa are found in Zanzibar and Pemba, the central coast of Tanzania, Comore and Northern Madagascar and on the northern coast of Mozambique and Zimbabwe. Archaeological work on sites located in those regions have yielded goods of exchange between these settlements, including coins, pottery and

Cities and Towns in East Africa. Fig. 2 The water facing side of Husuni Kubwa (Great Palace) in Kilwa Island.

Cities and Towns in East Africa. Fig. 3 Port of Kilwa with recent Portuguese to man fort.

Cities and Towns in East Africa. Fig. 4 Residential house around the Kilwa friday mosque.

stone vessels, suggesting that Kilwa was a centre with economic influence if not direct control of the peer settlements north and south.

The early towns of Lamu Archipelago were excavated later by Chittick (1984) and Horton (1996). Settlements like Gedi, Malindi, and Mombasa grew to compete with those to the north and even Kilwa at the time when Portuguese had entered the region. What is obvious in the archaeology of the coast of Eastern Africa is that the Swahili towns were related, and this is true whether or not Kilwa controlled affairs in the whole region between AD 1000 and about AD 1400.

In the later phase, from about AD 1300, or slightly earlier, larger Swahili towns were built by coral stones and lime mortar and roofed by mangrove poles, lime mortar and palm leaves. Archaeology also finds a profusion of many smaller settlements, which were built by mud and wattle; the larger settlements may also have had the majority of its population living in such simple houses (Horton 1996; Pradines 2002; Chami 2002). When Ibn Baṭṭūṭa visited the coast of East Africa in the AD 1330s, contrary to what archaeology suggests today, he did not see many stone houses even in larger towns such as Kilwa and Mombasa (Gibb 1939). Whether this was a personal bias against stone houses if he only saw simpler town places is not yet properly explained (see discussion by Sutton 1998).

It is also not quite certain whether each large Swahili town had its own trade and cultural link with foreign traders or if trade was only controlled by one or two larger towns which collected trade goods and distributed them to other towns. Ibn Baṭṭūṭa seems to have visited only two towns on the Swahili coast, Kilwa and Mombasa, suggesting that those were the larger ones. However, in the same time period a Chinese trip to East Africa led by Zheng He entered a town called ‘Malin’. Some scholars think this place was Malindi on the Kenya coast (Chittick 1975: 21; Wheatley 1975: 90–1); Fuwei (Fuwei 1996: 190) suggests that ‘Malin’ was Kilwa. A support for Fuwei comes from the fact that the wealthy clan at Kilwa at that time was known as Malindi and the most impressive tombs at the water front belong to this clan.

Probably each large town had its own trade abroad or a set of traders visiting particular ports in the Middle East and India. Archaeologists are now finding sites and many Swahili cultural materials in the Middle East, suggesting that the Swahili people sailed to those distant lands (Sutton 1998). It is likely that the profusion of foreign trade goods in all Swahili settlements could also suggest that individual towns engaged in long distant trade at least within the western Indian Ocean seaboard. This is testified by the fact that several towns are now known to have made their own coins and that when Vasco da Gama reached Northern Mozambique he had to get a person from Malindi, on the Kenya coast, to guide him to India. Probably the southern towns were not co-operating with the Portuguese.

The Origin of The Swahili Towns

Scholars had, up to the end of the twentieth century, debated the origin of the Swahili people and their stone town culture. Such debates revolved on the question of who the Swahili people were (Allen 1974, 1983; Nurse and Spear 1985; Pouwels 1987; Horton 1987; and Chami 1994, 1998). The original popular conception was that the Swahili people and their culture originated from the Middle East. These were alleged to have arrived in waves of immigration. Individuals in these waves founded settlements, which later grew into larger Swahili stone towns. Chittick (1974, 1975) used chronicles, particularly that of Kilwa, and archaeology to argue that the earliest immigrants could have arrived on the East African coast not earlier that the ninth century. This view suggested, therefore, that the Swahili people were originally Persians or Arabs who would later have mixed with Africans. Due to their alleged origin in the Muslim world the Swahili people were necessarily Muslims and people of towns.

Archaeologists such as Horton (1987), influenced by Allen (1983), suggested that the Swahili were people of Cushitic origin, from the northeast of Africa, who were originally pastoralists. The pastoralists, who are alleged to have ruled the Bantu speakers in a mythical land called Shunguaya, mixed with Bantu speakers, adopted Islam and spread to the rest of the coast and islands of East Africa. In this theory the Swahili people are seen as Africans who also mixed with the people of the Middle East in the process of adopting Islam and trade. This position was made more prominent in the 1990s (Horton 1990; Abungu 1994–1995; Sutton 1994–1995) in an attempt to quash the discovery that the Swahili people were Africans of Bantu origin, people of the general region of Eastern and Southern Africa who were agriculturalists and fishermen.

That the Swahili people did speak a Bantu language was a point recognised by linguists from the 1980s (Nurse and Spear 1985). Archaeologists had also established settlements of Early Iron Working people near the coast; scholars recognised that they were early Bantu speakers (Soper 1971; Phillipson 1977). Historians also recognised that the people reported by the Romans in the first centuries AD to have inhabited East Africa, then known as Azania, were agriculturalists and probably Bantu speaking (Casson 1989). In the early 1990s this author suggested that the cultural tradition found in the earliest Swahili settlements was culturally related to that of the Early Iron Working tradition (Chami 1994). In some cases settlements of the Early Iron Working people and those of the so-called early Swahili, termed by this author as Triangular Incised Ware tradition, were found in the same location. In some cases the later was found superimposed over the former in the offshore islands and on the coastal littoral of the central coast of Tanzania (Chami 1998, 1999a).

The evidence of cultural continuity from the time of Christ, through the mid-first millennium AD, to the time of the foundation of the Swahili towns in the early centuries of the second millennium AD, has now been recognised by many scholars (Kusimba 1999; Sinclair and Hakansson 2000; Spear 2000). Those who disagreed with the the first set of evidence for this continuity have now revised their ideas (Horton 1996; Horton and Middleton 2000; Sutton 1998). Archaeological findings now prove that the Swahili coast had been settled by an agricultural and trading population from the time of Pharaonic Egypt, 3000 BCE, through the Greaco-Roman period (Chami 2006). Whereas the former was of Neolithic tradition, the latter was an Early Iron Working culture. Throughout these periods the Indian Ocean, just like it was during the time of Islam, had brisk trade with communities of Asia, the Middle East and the Red Sea/Mediterranean worlds. Ceramics and beads as evidence of trade of all these pre-Islamic trading periods have now been recovered from the islands of Zanzibar, Mafia, Kilwa and Rufiji River (for conspectus see Chami 1999b, 2004, 2006).

The most recent thinking that the early Swahili people, or Zanj of the Arab documents, were Indonesians/Austronesians (Dick-Read 2005) is an attempt to disregard the archaeological, linguistic and historical data already established. For this recent thinking to be regarded as scientific at least a discussion of the previous thinking on the subject matter and its flaws should have be debated.

Some Cultural Aspects of the Swahili Towns

General Culture

The culture of the Swahili towns, as already suggested, is African with an infusion of Islamic traits. It is these infused Islamic traits such as religion, law, language, writing and costume which have made many students of the Swahili culture identify the people as Arabs. The people who had adopted this culture themselves wanted to be identified as Arabs or Persians. However, Ibn Baṭṭūṭa identified the people as 'Sawahil' and the earliest European visitors to the Swahili world, the Portuguese, identified the people as 'Moors' or 'Suaili' as opposed to Arabs.

De Barros, as Ibn Baṭṭūṭa did, also identified the Sultans of Kilwa as black people (Chittick 1975: 39). Barbosa, writing in about 1518, wrote, "Of the Moors there are some fair and some black, they are finely clad in many rich garments of gold and silk and cotton." To show that the Swahilis were different from Arabs, the Queen of Kilwa in the mid-eighteenth century wrote a letter calling home her people who had run away from the Arab/Omani domination of Kilwa to Mozambique. This was written in Kiswahili and not in Arabic; a Swahili letter suggesting that it was only the

Cities and Towns in East Africa. Fig. 5 Kilwa friday mosque.

Europeans/Christians who were in conflict with the Arabs, but not the African/Swahili people (Omar and Frankl 1994).

Religion

Most Swahili people are of the Sunni sect of Islam, which suggests an early link with Southern Arabia. Large mosques (Fig. 5) had been built with stones from AD 1300 or slightly earlier in every town of the Swahili coast. Some towns have several mosques, some being smaller for the purpose of a clan or a family. Kiblas/the north of these mosques were elaborately made; probably the one at Songo Mnara in Kilwa (Fig. 3) is the most elaborate of those seen by this author. One very unique religious aspect of the Swahili towns is that of making spectacular burials for the dead. The tombs, which most of them concentrate around the mosques, were built using stones and lime. Walls of some are more than two meters high with various decorative panels including impressed Chinese porcelain. Some tombs have high standing pillars some reaching up to six meters above the tomb.

These aspects of tombs are non-Islamic as they are found nowhere else in the Muslim world. Muslim burials are supposed to be made humbly and no materials or aspect of wealth are supposed to be involved. That these spectacular tombs are also found attached to houses or are located in compounds where people were living suggests that this is an African culture blended with Islam. I have noted elsewhere (Chami 2002) that the African tradition of wanting to live with the spirit of the dead in the same house/compound or within the settled landscape is the one portrayed in this context. Like the ancient Egyptian tradition, the spirit should not be abandoned in the wilderness away from human warmth and food. A failure to observe this rule was/is expected to bring bad omen to the family.

Writing and Arithmetic

Whatever type of pre-Islamic writing that could have existed on the coast of East Africa cannot be known for now. Early Islamic characters found on the Swahili settlements are Kuffic, the earliest known being of the eleventh century tomb of Kizimkazi in Zanzibar (Flury 1921). Later on Arabic scripts were used to write in the Swahili language. These can be seen in many tombs post dating AD 1300.

In daily counting the Swahili people mixed African and Arabic words. Counting may have followed Arabic languages in schools or official places, but in normal cases African counting was used. Today most counting words in Kiswahili are still African with the exception of a few numbers such as twenty, thirty, forty and fifty, which are in Arabic. Probably much more Arabic influence came after the rule of the Omanis from AD 1884.

Architecture

Garlake (Garlake 1966) studied the architecture of the Swahili towns; his interpretation of Swahili architecture has prevailed (Chittick 1984; Sutton 1998). As was noted with the tombs, the architecture of the Swahili buildings is of Western Indian Ocean Seaboard origin. It is the tradition that began and evolved within the region. The architecture is very much conditioned by available resources for building lime coral rubble which is made into walls with lime mortar and then plastered with the same mortar. Rarely were bricks and dressed stones (apart from porites) used. The only dressed stone used for door and window frames, mihrabs [a niche in the wall of a mosque or a room in the mosque that indicates the direction of Mecca] and lamp chambers was porite [coral]. This is a coral cut from underwater while fresh and it is dressed and decorated or inscribed while fresh.

For multi-storey houses floor slabs were made by arranging mangrove or other hard woods across. Lime mortar, sometimes mixed with coral rubble, was spread on top. Some houses, especially mosques, had moulded roofs with decorative arches, domes and vaults. Most houses must have been roofed by wood and palm/grass. Swahili houses had large verandas and corridors for relaxation and cooking. Carved panels decorated the doorframes.

Livelihood

Swahili people engaged in various economic activities. They are traditionally agricultural. They lived in mostly settled communities with vegetable gardens around their compounds and in areas a few hours' walk from towns. Allen (Allen 1983) characterized the Swahili as people who commute from town to the countryside for agricultural purposes. This has been the situation from ancient times. Crops cultivated include rice, millet, beans/peas, banana, coconut, sugar cane, spices and fruits such as mango and oranges. In recent history American crops such as maize, cassava, sweet potato and tobacco have been added to the list.

The Swahili people would have been mixed farmers who would also have domesticated chicken, cattle and ovicaprids (sheep and goats). These are well authenticated from archaeological records dating back to the early Swahili period. They also had dogs and cats and for the northern coast donkeys and camels. Due to environmental variability the northern part of the Swahili coast would have been more pastoral than the south because of the interaction that existed with the nomadic regions of Somalia and Northern Kenya.

Fishing must have dominated the activity of those living near the shore and on the island settlements as it secured the most reliable means of obtaining protein. They fished in the deep and shallower, waters and there is much evidence for times when they consumed a lot of shellfish probably suggesting difficult times (Msemwa 1994). There was also fresh water fishing. There are several large rivers entering the Swahili coast from the deep interior and also few lakes near the littoral which provided fish. Salting and drying fish facilitated transport to the deep interior.

Sailing, not only for fishing, but also for trade was probably the most prestigious activity of the Swahili man. Swahili towns consisted of people who had travelled far for the purpose of trade or prayers. There was a lot of intermarriage between communities. The Swahili people can therefore be seen as a maritime people. Goods to be exchanged with those arriving from abroad had to be collected from the south or interior of the region and this also involved distribution of those imported goods. So the Swahili towns were trade axes providing for the larger part of Eastern and Southern Africa.

Consequently the Swahili people were also involved in building sailing vessels. The Romans found the people of the Swahili coast already making sewn boats and also importing boats from abroad (Casson 1989). This technology grew tremendously and by the time of the stone towns the Swahili people must have been building large dhows used to cross the Indian Ocean to Arabia and India. In most of the Swahili towns today one can find at least one operating dhow/boat building yard, suggesting a continued tradition. Related to this technology was that of metal working, which has passed down since ancient times. This technology was necessary for cultivation and boat making, as wood had to be felled and worked.

Swahili Towns in Ruins

It was noted earlier that the realm of the Swahili culture is in the period between AD 1200 and 1500. After this heyday the Swahili culture entered into a deteriorating moment following the penetration of Europeans into East Africa. They wanted to conquer by destroying the large Swahili towns such as Kilwa and divert trade to the Atlantic Ocean towards Europe. The monopoly of trade was taken from the Swahili traders and put into the hands of European companies and later on, after 1800, into the hands of Oman Arabs and Indians. The Omanis came to East Africa to challenge the Portuguese. It was the Swahili rulers who invited the Omanis to use their Muslim responsibility to assist Muslim brethrens, but the Omanis did not leave after they accomplished the task. Only petty trade was left in the hands of the Swahili. In some towns trade was left to the Swahili people, but they had to cater for the masters of the new order.

In the new order, the Swahili towns, which had not given way to invaders before, were suppressed to the extent that they fell into ruins. This was necessary because other prosperous settlements, mostly controlled by the new Portuguese and Omani powers, emerged and it is here the new elite, whether foreign or local, would move (Chami et al. 2004). As Kilwa and other settlements of its type decayed, with only short periods of renewal, previously unknown towns emerged from about 1700. Such towns included Zanzibar, Bagamoyo and Kilwa Kivinje. Mombasa also grew substantially. These are towns founded by the enterprising British and German colonials. From the 1890s the new colonial towns such as Dar-es-Salaam, Nairobi and Kampala challenged these other towns. See (Chami et al. 2004) for an explanation of the fall and the rise of the Swahili towns.

See also: ►Ceramics, ►Beads, ►Navigation, ►Fishing, ►Agriculture

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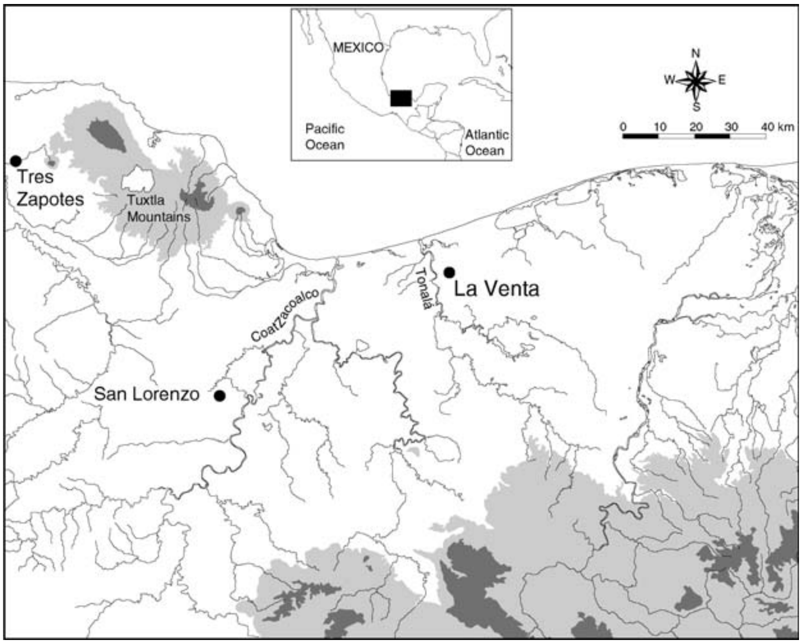
Cities and Towns of the Olmec

JOHN E. CLARK

Mesoamerica's first civilization arose about 3,400 years ago among the Olmecs of the tropical Gulf Coast lowlands of southern Mexico (Fig. 1). Olmec civilization lasted a thousand years and is recognized by its spectacular and unique art style manifested in colossal stone heads and thrones, figurines, carved pottery, and polished and incised jade objects. Among their many accomplishments, Olmecs created the first cities in North America. Many archeological sites are known for this culture, but only two were large and splendid enough to qualify as cities: San Lorenzo and La Venta. As capitals of dynastic societies and habitats of kings, some bureaucratic functions and services were unique to these cities, as evident in their palaces, thrones, royal tombs, ballcourts, temples, observatories, and state art. Scholars expect cities to accommodate 5,000 or more people. By the standards of function and size, San Lorenzo was Mesoamerica's first city. It enjoyed a meteoric but brief history and was succeeded in the same region by La Venta, the last Olmec city. For its part, La Venta represented the first mature manifestation of the quintessential Mesoamerican city, and it was a model of a sacred center copied by other peoples. Key issues in Olmec studies are the historic and formal relationships between San Lorenzo and La Venta. These are most easily appreciated by beginning with La Venta and tracing some of its features back to San Lorenzo.

The Last City, La Venta

La Venta was founded and built about 850 BCE on virgin soil in a special place: a long, 20 m high island in the middle of a vast swamp in western Tabasco, Mexico, just 15 km from the coast. La Venta was abandoned about 400 BCE and never reoccupied. This was a fortunate happenstance for investigators because the city has been preserved as the Olmecs left it



Cities and Towns of the Olmec. Fig. 1 Map of Mesoamerica showing the Olmec region and its principal sites.

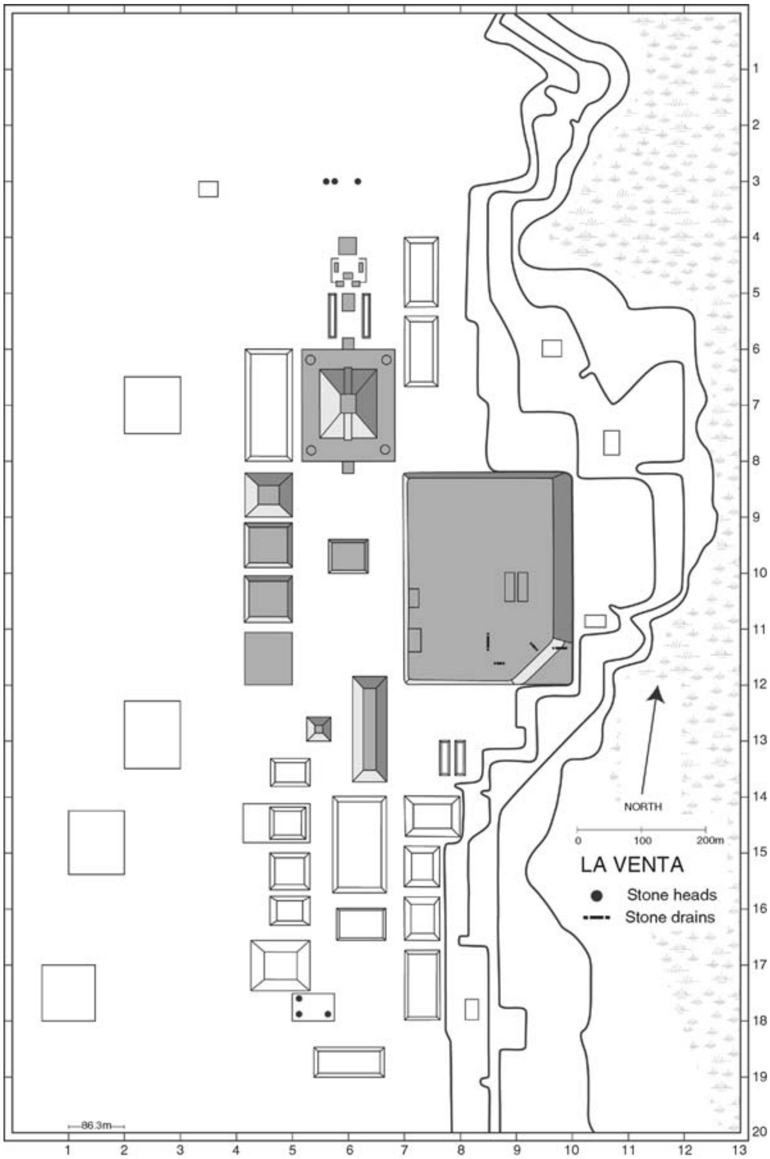
2,400 years ago. The map of the site in Fig. 2 indicates the probable early and final form of this city. At its founding, La Venta was laid out along the eastern edge of the island. This escarpment was cut and terraced to bring it into alignment with the principal axis of the ∴-shaped city. Some of the construction fill used to build the city may have come from these land modification operations.

La Venta was built to a rigid plan, in regular 86.6 m blocks, and along a centerline oriented 8° west of north. The original city center was 10 blocks long and 8 wide. Subsequent additions to the city respected the principal axis and measurement interval. Later mounds encroached on the original mounds in the north. The monumental city center eventually extended 1,482 m, or 17 blocks. Late in its history, stone monuments were set up as boundary markers. Three basalt colossal stone heads were placed at the northern end of the city, and they faced north. Three even larger sandstone heads near the southern end faced south. These monuments were placed 1,300 m or 15 blocks apart.

These building intervals, when translated into native Mesoamerican beliefs and practices, show that La Venta was built as a sacred center. The Olmecs measured this city with the 1.67 m fathom used by the later Aztecs and Maya; thus, the 86.6 m block represented 52 fathoms, the year count for the calendar round. Five such macrounits comprise the number of days in the sacred almanac (260), and seven (364) approximate the solar year. These calendar distances separate critical points in the arrangement of buildings at La Venta. For example, the original city was 10 blocks long, or 2 × 260. Later additions to the site extended it 7 blocks, or a solar year count. Other ritual counts are built into the placement of mounds and monuments. They demonstrate that La Venta was carefully planned and built with marvelous precision.

The city was partitioned and arranged according to function. The original layout shows a long, 6 ha plaza (2 × 4 blocks) with special architecture in each cardinal direction. The plaza was probably for public ceremonies and for viewing rituals performed on the platforms surrounding it. The plaza could have accommodated well over 100,000 standing spectators. Looking north, a spectator would see a 32 m high stepped pyramid made of nearly 100,000 m^3 of dirt and clay. A temple of perishable materials probably graced the top of this artificial mountain. The summit could be accessed from stairs on the south and north faces. The pyramid is the only promontory for over 100 km on this coastal plain and can be seen from over 10 km away. It would have been very impressive close-up in its final form. The pyramid was given a new clay skin several times during the city's history, each time making it slightly bigger and taller. The height of the original pyramid has not been determined.

East of the plaza lies a broad 8 ha platform or acropolis that required nearly twice as much earth and clay to build as the pyramid. This high platform was probably the royal compound: residence of the king, his courtiers, and servants. A ballcourt and an elaborate system of subterranean stone drains have been



Cities and Towns of the Olmec. Fig. 2 Map of La Venta, Tabasco, Mexico. The gray areas indicate the early part of the city.

identified there. In the block south of the plaza lies a long mound flanked on the west by a short pyramid. Together these constituted an astronomical observatory for monitoring the movements of the rising sun through the year, perhaps to coordinate the agricultural cycle and other state rituals. Looking to the west a spectator would see a string of low platforms and their perishable buildings, probably priests' residences or special temples. Axial symmetry is evident in the organization of the original city. Buildings on facing blocks around the plaza were complementary pairs: the pyramid and observatory formed a N–S pair, and the royal compound and priestly residences an E–W pair.

North of the pyramid block a compound was built 1/4 the scale of the rest of the original city. The main complex consisted of five low mounds surrounded by a 2 m high and rectangular palisade of upright, basalt pillars. Spectacular jade and serpentine offerings and royal tombs were found in this sector arrayed along the principal axis, and on both sides of it. Some individual offerings had more than 1,000 tons of serpentine. A pair of offerings depict the abstract face of the earth lord, each on top of 28 layers of carefully placed serpentine rubble. The two images look identical but are color coded to depict an east and west image of the same entity. All rock used in these offerings was imported from over 60 km away, so the massive offerings represented a tremendous burial of wealth. Another expense was the importation of tons of basalt for stone monuments and architectural enhancements.

These were brought in by canoe or raft from over 100 km of inland waterways. To date, 90 stone monuments and hundreds of 1-ton basalt pillars have been discovered in the city. Sculptures include colossal stone heads, thrones, full-figure images of kings, and low-relief carvings on flat slabs, or stelae. The latter depict gods or narrative scenes. The south side of the great pyramid had a line of six stelae facing the main plaza, three on each side of the stairs.

The mounds added to the southern end of the city later in its history are not as logically arranged as those of the original city. Presumably, they were for privileged personnel and state functionaries. With the exception of the six monuments used as boundary markers, large stone sculptures were confined to the northern part of the city, the domain of La Venta's lords and priests. The oldest buildings in the north were rebuilt or refurbished many times during their centuries of use.

In its final form the city center was about 58 ha in extent, and with its residential neighborhoods the whole city covered at least 200 ha. At its height, the city housed 3,000–5,000 people, with many more on small islands and river levees within 10 km of the city. The extent of the La Venta kingdom has not been determined, but the city was the royal capital for towns and villages located over 100 km distant. La Venta kings were depicted as corn gods, indicating that the city was governed by divine kings, or priest-kings. The institution of kingship became fundamental to Mesoamerica statecraft; its beginnings can be traced to San Lorenzo.

The First City, San Lorenzo

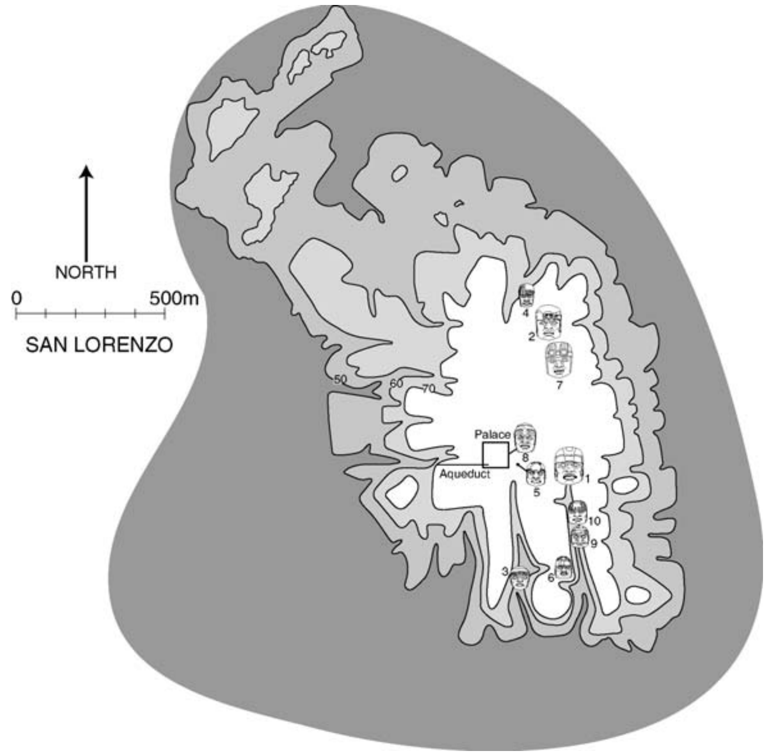
San Lorenzo was occupied off and on from 1750 BCE to AD 1100, but it only functioned as a city from 1300 to 1000 BCE, at which time it reached its maximum extent of 500 ha, over twice the size of La Venta in its prime. San Lorenzo collapsed about 1000 BCE, perhaps due to a shift in the course of the Coatzacoalcos River. The city is located 60 km from the coast and currently lies 7 km west of the meandering Coatzacoalcos, the second largest river in Mexico. Just over 3,000 years ago, this river ran on both sides of San Lorenzo, making the site an island and well positioned to control canoe traffic and commerce. The city core lay atop the summit of a 50 m high natural plateau nearly 60 ha in extent. The surface of the plateau was carved and stretched into a ⊥-shape, with the N–S crossbar being nearly twice as long (1,213 m) as the E–W axis (650 m). Elite houses, public buildings, and special stone statuary were confined to the top of the plateau, with residential terraces encircling the heights and spilling down and across the plain below. San Lorenzo was the capital of a region that extended 40 km up and down river. At least 7,000–10,000 people lived in the city in its heyday, with four times as many in subordinate communities and provinces.

Little is known of the layout of San Lorenzo because the city lies a meter or two beneath the current surface, so its format will only be revealed through excavation. The few mounds on the plateau postdate the Olmec occupation. A striking difference with La Venta is that early San Lorenzo lacked pyramids. Recent research discovered a palace with an inner courtyard; a colossal stone head and throne were on display there, demonstrating that stone monuments were associated with royal architecture and that some were buried in place. Plazas and temples have not yet been identified. Ballcourts are known at a junior center and may eventually be found at San Lorenzo.

Judging from the size and shape of the modified plateau top, and the first level of broad terraces below the summit, San Lorenzo was arranged in the same measurement increments as La Venta. The original cruciform of the plateau was 14 × 9 blocks. Another five blocks are evident in the descending terraces on the western and eastern extensions, making the planned city center a 14 block square, or two solar years on a side.

The shape of the plateau and alignments of stone heads and aqueducts demonstrate that the central part of San Lorenzo was rectangular and aligned to N–S and E–W axes, with the long axis 1° west of true north (Fig. 3). Both cardinal axes at San Lorenzo were important, but the axial symmetry of the city unfolds from the E–W centerline. When Olmecs built La Venta, they rotated the basic San Lorenzo plan 90° counter-clockwise so the most important cardinal direction became north instead of east. San Lorenzo was formally organized and zoned from the center of the plateau outward, and downslope. Residential status decreased as a function of distance from the center. The only palace identified so far was built near the western edge of the city's center (Fig. 3), opposite its placement at La Venta. The San Lorenzo palace was placed near a freshwater spring, and a 171 m long aqueduct ran west from its courtyard to the edge of the plateau. If the colossal stone heads were buried in palace courtyards, their distribution suggests that each king had his own palace and that these shifted during San Lorenzo's history from the west edge of the plateau to the east.

As at La Venta, much engineering and earth moving went into constructing San Lorenzo. The first task in building the city was to level the plateau and extend and straighten some of its edges. The eastern and southern faces appear to have been the most precisely cut, and even after nearly 3,000 years of erosion, their straight, perpendicular edges can be appreciated (Fig. 3). Ramps and causeways were created for hauling



Cities and Towns of the Olmec. Fig. 3 Map of San Lorenzo, Veracruz, Mexico, showing the distribution of colossal heads, the E Group palace, and long stone aqueduct. The heads are shown to scale relative to each other.

the colossal sculptures to the summit. A complex system of stone drains was also installed at their proper gradient.

Many specialized artists, artisans, and bureaucrats resided at San Lorenzo, and they were supported by food brought in from outlying settlements. The clearest evidence of subsidized citizens shows up in the site's 130 stone monuments imported from 60 km away, some of them weighing over 20 tons. The best known are thrones and colossal heads. The latter are thought to be realistic portraits of individual kings. Judging from similarities of facial features, at least three families appear represented in the San Lorenzo king list. These kings were depicted as warriors and heroes rather than gods, as became the subsequent practice at La Venta. Together, the San Lorenzo heads displayed the city's royal dynasty – the first in Mesoamerica. The artistry and labor evident in these monuments, and the organizational requirements for carving and dragging them through the jungle to the city, reveal the presence of other citizens: artisans, overseers, haulers, and probably slaves.

In summary, similarities between San Lorenzo and La Venta include their orientation, cruciform shapes, concentric zoning, size of city centers, standard block sizes, spacing by calendar distances, axial symmetry and complementarity, palaces, and abundant monuments of gods and kings. Significant differences are the presence of pyramids and special monumental architecture at La Venta and the emphasis on north as the sacred sector of the city, the place of the tallest pyramid. The small hamlet at San Lorenzo at 1750 BCE evolved in place into a glorious city in just four centuries. In contrast, La Venta was planned as a special city before the island was occupied. Many later Mesoamerican cities mimicked the formal layout of La Venta rather than that of San Lorenzo. The latter's contribution was getting kingship and city building started, not giving them their final form.

See also: ►Pyramids, ►Calendars

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Cities and Towns in West Africa

Cris Beauchemin, Philippe Bocquier

West Africa, like most regions of the continent, is still largely rural. Even after decades of rapid urban growth and the emergence of cities of 1 million people or more, the majority of the population continues to live in rural areas. However, cities and towns generate higher revenues than the countryside. Urbanisation has brought major changes for both urban and rural dwellers. Large cities, which are often ports, are gateways to the rest of the world. The most traditional practices coexist with the most advanced technology and, in contrast to the negative image conveyed by media about the Developed World, Africans have shown a strong ability to adapt to the global world (see Fig. 1). That said development in West Africa is impeded by a number of problems. This article will address the endogenous and exogenous factors hampering urban development in West Africa. First, we will show that the (long) urban history of West Africa is the result both of indigenous and European influences. Then we will analyse recent urbanisation trends from a demographic point of view before examining the origin and reasons for urban development. Finally we will consider the issue of urban management. For the purposes of this article, "West Africa" is defined as the countries to the west of the line running from Lake Chad to the border between Nigeria and Cameroon.

Cities and Towns in West Africa. Fig. 1 Cotonou, Bénin. Tall, modern buildings are proudly erected next to very crowded places where the informal sector is blooming and yellow and green taxis are waiting clients to transport goods. Note the mobile phone antenna and the satellite dish on top of the blue building; all their offices are connected to the Internet. Some investors are less successful, as can be seen from the unfinished building on the right. © Franck Houndegla.

A Long but Little-Known Urban History

Urbanisation is not only a contemporary phenomenon in West Africa. Urban centres have developed in this region of the world for over 2,000 years (Coquery 1990). In the Middle Ages, some were very prosperous and were known by Europeans as great cultural and commercial places (Timbuktu, for instance). Some were even compared by travellers to European cities such as Amsterdam or Lisbon (Benin City in the seventeenth century).

Still, the history of West African towns and cities is still very incomplete, mainly because this is a new field of research. Urban Africa was only 'discovered' by historians in the late 1970s and until very recently there has been little interest in pre-colonial urbanism other than through the work of archaeologists (Anderson and Rathbone 2000). The scarcity of written sources and the fact that few stone monuments survive may explain why African urban history is still very incomplete. For a long time, towns and cities were only presented as colonial creations. Earlier settlements were not recognised as urban because their features were not similar to those of European towns and cities (often considered as a standard to define urban settlements): there were no stones used in architecture, an abundance of agriculture, and very low population density. But recent research has shown that West Africa has nurtured various forms of settlements quite distinct from simple villages long before the Europeans' arrival.

The first urban settlements in West Africa, as in the rest of the continent, were indigenous creations (Coquery 1990). The most ancient is Jenne-Jeno (distinct from Djenne), located in Middle-Niger, discovered by archaeologists in 1977[1]. It was probably created around 250 BCE, reached its peak between 750 and 1150, declined under Islamic influence and finally disappeared in the fifteenth century. Except for the fact that it had city walls, Jenne-Jeno did not look like a medieval European city. It was quite extended (40 hectares around the tenth century), as opposed to very dense European settlements of the same period. There were no monuments in the centre of the city (such as palaces, churches or markets always present in European towns and cities). And the

[1] For more information and to see pictures of the archaeological site, see: ►http://www.ruf.rice.edu/~anth/arch/brochure/

Cities and Towns in West Africa. Fig. 2 source: ►http://www.sum.uio.no/timbuktu/. The city of Timbuktu: a place of contact between the Sahara and Sub-saharan Africa.

buildings were made of adobe. But Jenne-Jeno was an important commercial centre for its region (fishing and agricultural products) and it was also probably one of the first places of the trans-Saharan trade (salt against copper in the fourth century).

Other towns and cities developed in this region of contact between the Sahara and the Savannah (Fig. 2), where international trade was possible. In the Middle Ages, the succession of great centralised states (ancient Ghana[2], Mali and Songhaï empires) contributed to the development of a network of towns and cities, among which Timbuktu, Djenne and Gao are the most famous. Following the trade Saharan routes, the Islamic and Arabic influences grew in the process of urbanisation. The introduction of Islam gave to the great cities mentioned above their monuments: Sudanese style mosques (Fig. 3). It also gave them a cultural aura (Timbuktu was a famous Islamic intellectual centre). And it played a role in matters of social organization; these cities were cosmopolitan places. Whatever the influence of Islam, their fame in the European Middle Ages is mainly due to the fact that they were the gold providers for the East through the trans-Saharan trade[3]. But they also played an important role in the economy and even in the urbanisation process of southern regions of West Africa. Stopover places, first created to facilitate the exportation of gold and other goods from coastal regions, progressively turned into real towns, such as Begho[4].

Cities and Towns in West Africa. Fig. 3 Djenné, Mali. This town exemplifies early urbanization in West Africa. Situated on the Bani River, Djenné dates back to 250 BCE In the thirteenth century, Djenné was an important market for trans-Saharan trade, particularly between North and West Africa. The most common items of exchange were gold, slaves and salt. Djenné also became an important center for Muslim learning during the seventeenth century. The city's mosque (at the rear of the Fig.) is the largest mud–brick building in the world. © IRD – Jacques Champaud.

Trade, through trans-Saharan routes, was a major factor of urbanisation in medieval West Africa. However it is worth noting that some great urban regions also developed in West Africa, even if they had weak connections with this trade system. It seems to be the case for the Hausa-speaking city-states, the Yoruba towns or the Ghanaian urban system. These urban regions have some common features. They started their development in the Middle Ages and were especially

[2] Ancient Ghana's territory is distinct from contemporary Ghana. It broadly covered the oriental Senegal and Mauritania, the occidental Mali and a part of the current Guinea. The creation date of the Ghana Empire is not precisely known, though an Arab writer mentions it in the eighth century. It finally disappeared in the twelfth century.

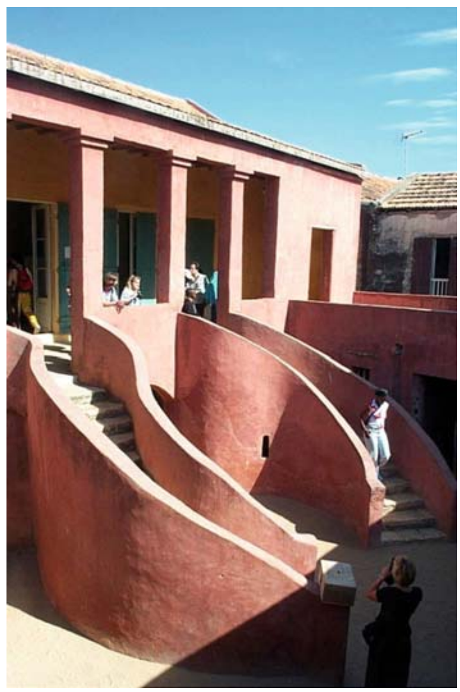
[3] See a map: ►http://www.metmuseum.org/toah/hd/gold/hg_d_gold_d1map.htm

[4] The Dioula merchants were also the actors through which the Sudanese-style mosques spread all over West Africa.

prosperous between the fifteenth and the eighteenth century (their respective peak periods are however not totally contemporaneous). In contrast with the Middle Niger cities, the towns of each of these regions emerged without a centralised state. They shared a common culture (language, religion, social organisation) but they were in competition, and sometimes at war, each one of them trying to extend its influence on the surrounding countries (Fig. 4). Whereas the Middle Niger cities were mainly turned towards international trade, the towns and cities of the Hausa, Yoruba and Ghanaian regions were first engaged in regional trade. Agriculture was sufficiently intensive to produce enough surplus to feed an important urban population. In Ghana for instance, around 30% of the population lived in urban areas and 70% of the urbanites (merchants, craftsmen, the nobility and their families) bought their food in markets (Coquery-Vidrovitch 1993). The rural people were under the domination of urban power; they were sometimes forced to leave their villages in order to settle in the towns (Yoruba region) and also paid important taxes. In the Ghanaian region, rural taxes represented between a quarter and a half of peasants' earnings (Coquery-Vidrovitch 1993). Some cities of these three regions remained famous: Kano and Katsina in the Hausa region, Great Accra in Ghana, Benin City, Old Oyo or Ife in the Yoruba area. They have been described by the first Europeans who arrived in West Africa (Iberian sailors) in the fifteenth century. Till the eighteenth century, Ghanaian and Yoruba towns and cities[5] benefited from the new forms of trade introduced by Europeans. But the launching of the slave trade disrupted these urban networks.

The first European settlements in West Africa were not towns: they were only isolated forts on the coast, whose purpose was to resupply the shipping expeditions. They progressively turned into trading posts and finally into small towns when the slave trade was introduced in the eighteenth century (Fig. 5). Gorée, Saint-Louis or Ouidah, for example, were central places at this time. They were inhabited not only by Europeans but also by African people. And a kind of local bourgeoisie, with a Creole culture, appeared. The overseas trade acted as a new vector of indigenous urbanisation on the coast and also in the hinterland. New states, engaged in the slave trade, emerged and gave birth to new capital cities (kingdoms of Porto Novo and Abomey, Ashanti Empire). For instance, Kumassi, the Ashanti capital city, was a center of the slave economy, but it was also a trade centre for kola nuts, which were exported to the north. It was the heart of a dense road network, quite far from the coast, in

Cities and Towns in West Africa. Fig. 4 Source: ►http://www.uni.edu/gai/Nigeria/Pictures/kano.html. Kano, Nigeria. The old-walled section of Kano is nearly 1000 years old and is enclosed by a mud wall. Located on the edge of the Sahel, Kano is a Muslim city, one of the oldest in West Africa. Kano was the centre of a prosperous Hausa city-state in the seventeenth century, when the Songhaï Empire declined. Under the Sokoto Empire (nineteenth century), it became a very important place of textile production in West Africa. At the end of the nineteenth century, half of the West Sudanese population was dressed with loincloths from Kano.



Cities and Towns in West Africa. Fig. 5 Source: ►http://www.globalgeografia.com/album/senegal/goree.jpg. Gorée, Senegal. This building, built around 1780, may have been the last slaves' house in Goree. The first ones dated back to 1536, built by the Portuguese, first Europeans to set foot on the island in 1444.

[5] Hausa city-states were less influenced because they were far from the coast.

order to escape a too strong European influence. There were 77 neighbourhoods (around 13,000 inhabitants in 1870) separated by large and rectilinear avenues. It remains today an important city in Ghana.

The abolition of slavery, declared in 1815 in all European countries, appears as a shock in African urban history. The cities whose prosperity relied on the Atlantic slave trade declined. New settlements were created to welcome freed slaves from the United States (Monrovia) or from the British territories (Freetown). Some existing towns turned the end of the Atlantic trade to their advantage by using for their own development the workforce of the slaves. For instance, Kano became a great centre of textile production in West Africa (Fig. 4). In 1894, there were 100,000 inhabitants, 50% of whom were slaves. During the nineteenth century, various urban centres emerged as commercial places and/or as capital cities for new West African states (Sikasso, capital city of Kenedougou; Sokoto, capital city of the Fulbe Empire...).

To sum up, it should be clear that the urban history of West Africa started before European colonisation. First contacts with Europeans, from the fifteenth to the nineteenth century, had an impact on the urbanisation process, but they did not totally drive it. When Europeans started to colonise West Africa, they created new cities, mainly ports (e.g., Dakar, Abidjan, Cotonou, Conakry...) and crossroads places (e.g., Bamako) aimed at facilitating natural resources exportation (see Map 1). They also took advantage of the existing urban networks. Indigenous towns and cities happened to be excellent places for the political and economic control of the territories. Colonisation seriously boosted the urbanisation process by creating new urban activities. Labour migration was an important factor in urban development in colonial times when workers were needed for public infrastructure (airstrips, railways and ports), administration (soldiers, clerks) or various private services (maids, etc.). Migration flows to urban centres continued after independence. In sum, colonisation acted as a starter for urban development on a larger scale[6].

Recent Urban Trends in West Africa: Rapid Demographic Change

In terms of the contemporary urbanisation process, West Africa is at once lagging behind (with the exception of Nigeria, it remains one of the least urbanised regions of the world) and at the forefront of change (the region had one of the highest urban growth rates of the second half of the twentieth century). Urban growth has not been linear: after a peak in the 1960s (9.3% per year for West Africa as a whole), it reached a low of 5.6% in 1990–2000 (Fig. 3), and the region remains predominantly rural (see End Notes 1. Definitions and Measures Vagaries). Migration is usually seen as the main contributing factor in the growth of towns and cities. According to a 1988 UN report, almost all governments of developing countries believed that internal rural-to-urban migration was the dominant factor contributing to the growth of cities (United Nations 1998). But urban growth can be generated by any of three mechanisms: natural growth, reclassification and migration. All these components follow a specific pattern in the context of West Africa.

Cities and Towns in West Africa. Fig. 6 A street restaurant in Dakar, Senegal. Women prepare and sell traditional dishes (rice on the left and vegetables on the right). © IRD – Michel Dukhan.

Natural urban growth (i.e., the surplus of births over deaths) in West Africa remains one of the highest in the world: 2.7% annually, versus 1.9% for the developing world as a whole (PRB 2001). (Natural growth rates are nevertheless lower in urban than in rural areas, since mortality and fertility have declined faster in towns and cities than in the countryside). This is one reason why urban growth remains so high in this region compared to the rest of the world. A United Nations study has shown that the contribution of natural growth to urban growth is much higher in Africa than in other parts of the world. On the African continent, natural growth accounted for 75% of urban growth in the 1980s, compared with a share of only 50% in Asia, excluding China (Chen, Valente et al. 1998).

Another feature of urban growth specific to West Africa is the importance of reclassification. Reclassified

[6] Bairoch (1985) estimates that the urbanisation level in Africa as a whole was 5% in 1900, 12% in 1950, and 28% in 1980.

settlements are those that cross a population threshold (10,000 inhabitants in the GEOPOLIS database used in this article; see End Note 1), beyond which they are considered urban instead of rural. These newly-urban settlements contribute to urban population growth, even though their population may not have moved. In Africa as a whole, between 1950 and 1980, the share of reclassification in urban population growth was 26.4%. This means that, in 1980, more than one new African urban dweller in four lived in an agglomeration that had been classified as rural in the previous 30 years. This rate was only 13.4% worldwide, excluding China and Korea for which reliable data are not available (Moriconi-Ebrard 1994). Thus, urban growth in Africa, much more than in the other continents, is due to the proliferation of new small urban centres that had previously been considered rural (see End Note 2. The Urban Future: Mega-Cities or Small Towns?).

Considering the foregoing arguments, the role of migration in urban growth seems to be less important than is commonly assumed. The process of urbanisation, from a demographic point of view, is more complex than a simple rush of migrants from rural to urban areas. Furthermore, the contribution of migration and reclassification to urban growth appears to be decreasing. Indeed, according to the GEOPOLIS database, two-thirds of urban growth in West Africa was due to migration and reclassification in the 1960s, versus only one-third in the 1990s (Bocquier and Traoré 2000). This result is consistent with several other studies (Arnaud 1998; Chen, Valente et al. 1998). To what factor can this change be attributed?

One reason is mathematical. Urban growth due to migration automatically falls as the urban population increases in relation to the rural population, simply because the rural population who could potentially leave their villages becomes smaller. When the majority of people live in villages, net out-migration (i.e., a negative migratory balance) from a rural area means, for the same volume of migrants, a higher net in-migration rate towards urban areas. As the respective proportions of the rural and urban populations balance out, the number of migrants who contribute to urban growth decreases, even though the probability of out-migration from rural areas may remain the same. This is what happens in developed countries; when more than 60% of the population lives in urban areas, urban growth by immigration from rural areas is necessarily low. But is this mathematical equation sufficient to explain the decline in urban growth in the 1980s and 1990s in Africa, where the level of urbanisation is only around 30%?

In fact, the decreasing role of migration in urban growth is largely due to new migratory trends. In sub-Saharan Africa as a whole, several recent sources indicate that rural out-migration has not only subsided, but that its counter-stream (i.e. urban out-migration) has increased. West Africa offers interesting examples in this regard. Côte d'Ivoire, for instance, experienced a migratory reversal between the mid-1980s and the late 1990s[7]; urban-to-rural migration exceeded the opposite flow, causing the level of urbanisation to decline (Beauchemin 2002b). Even though the counter-urbanisation process is still marginal in Africa at national level (Zambia is the only other country where this trend has been identified), many countries are experiencing a decrease in rural-to-urban migration to some extent. A West African network of national migration surveys revealed that secondary towns in seven countries (Burkina Faso, Côte d'Ivoire, Guinea, Mali, Mauritania, Niger and Senegal) recorded a net loss of migrants between 1988 and 1992 (Bocquier and Traoré 2000). Some larger cities are also affected by a decline in migration; Accra, capital city of Ghana, apparently saw significant net out-migration in the mid 1980s (Simon 1997); and Abidjan had no migratory growth between 1988 and 1992, excluding international flows (Beauchemin 2001). Economic decline appears a pervasive explanation for the slowing of urban growth and change in migratory trends. Despite these new migratory patterns, in most West African countries, the urban population continues to grow faster than the rural population. However, due to the slowdown in urban growth, the rural way of life could well remain predominant in West Africa for a long time to come (Bocquier 2003).

The Economic Roots of Urban Development

Although urbanisation is commonly associated with a gradual reallocation of labour from agriculture to industry, which is what happened in the industrialised world in the nineteenth century (Bairoch 1985), urban in-migration in West Africa occurred (and continues to occur) without industrial development. In addition, African countries witnessed a massive migration of the rural population to urban areas despite rising levels of urban unemployment and underemployment (Todaro 1997).

These apparent contradictions in migration and urbanisation were initially attributed to irrational behaviour. A better explanation was found in the concept of economic dualism between the formal and informal urban sectors, first introduced by Lewis (1954) and extended by Todaro (1976). In contrast to the formal sector (geared towards capital-intensive, large-scale modern production), the informal sector is a traditional, unregistered, subsistence sector geared towards labour-intensive, small-scale production. How-

[7] Internal migration has probably evolved since then, due to civil war.

ever, the spectrum of informal activities ranges from the so far predominantly downmarket informal sector to an upmarket informal sector (see Figs. 8 and 7), which is closer to small and medium business type activity, even though it does not comply fully with tax and social security regulations. The existence of the informal sector explains why rural-to-urban migration has persisted—leading to rapid urban growth—despite limited absorption capacity in the urban formal employment sector (see End Note 3. Migration, Urbanisation and Development; A Controversial Issue). Although sometimes discouraged by public authorities because of its illegality and suspected tax evasion, most researchers now recognise that the informal sector has economic advantages; it absorbs surplus labour and provides a safety net in a context of high unemployment and poverty (Becker, Hamer et al. 1994; Snrech 1994). In fact, the sector employs the majority of urban workers and serves the purpose of receiving and integrating migrants and providing them with minimum subsistence. However, this pattern has evolved in the last two decades as a result of the economic crisis.

Cities and Towns in West Africa. Fig. 7 A barbershop in Ouagadougou, Burkina Faso. Female hairdressers usually work at home. © IRD – Marie-Noëlle Favier.

Cities and Towns in West Africa. Fig. 8 Abidjan, Côte d'Ivoire. Informal economic activities range from itinerant micro-commerce to established activities (joinery, garage mechanic...). Here young girls sell plastic bags of fresh water, carried on their head in large baskets. © IRD – Philippe Haeringer.

Since the 1970s, West Africa, still mostly dependent on commodity exports (coffee, cocoa, bananas, petroleum, etc.), has suffered from falling prices on international markets. West African countries first delayed the crisis by maintaining public expenditure. But, as debt became unsustainable, structural adjustment programmes (SAPs) imposed by international organisations and donors focussed on reducing public expenditure via privatisation and staff redundancies (Duruflé 1988; Becker et al. 1994). Employment surveys conducted in 2001–2002 showed that public sector employment in seven West African capital cities was 8% on average, with a higher-than-average rate in Niamey (15%) and Ouagadougou (13%), which is still rather low considering that these cities concentrate most of the public sector activities (AFRISTAT 2005). In the 1990s, urban unemployment reached unprecedented levels, in particular among educated people looking for jobs in the formal sector (Lachaud 1994; Charmes 1996; Bocquier and LeGrand 1998). In 2001–2002, in Cotonou, Bamako and Lome unemployment was relatively low (5% to 8%) compared with Dakar (12%), Niamey (13%), Abidjan (14%) and Ouagadougou (15%) (AFRISTAT 2005). These figures, computed using the ILO's standard measure of unemployment, would be much higher if they included discouraged unemployed city dwellers (i.e. non-working people who have stopped looking for a job after unsuccessful attempts) and 'underemployed' people. Gugler generally defines 'underemployment' as the underutilisation of labour. This occurs when workers are so numerous that at all times a substantial proportion is employed part-time. It is linked to the economic role of solidarity groups that continue to employ all their members rather than laying them off when there is insufficient work to keep them fully occupied (Gugler 1982). As most workers turned to the informal sector, the crisis caused the informalisation of the urban economy. In West African capital cities (Cotonou, Bamako, Lome, Dakar, Niamey, Abidjan and Ouagadougou), about 75% of employment is informal, with little variation (plus or minus 5%) between countries. However, the informal sector itself suffered from worsening economic conditions. Demand from urban households plummeted as standards of living deteriorated. In 2001–2002, more than 55% of workers earned less than the official minimum hourly wage, and average monthly household income ranged from $30 to $70 (i.e. $10 a month per urban dweller on average) across the seven capital cities listed above. Less income in the informal sector is shared by more people as competition was heightened by the arrival of those left out of the formal economy (Arnaud 1998). Urban poverty has increased dramatically in West African towns and cities. Even though the recession affected both urban and rural areas in West Africa, urbanites seem to have suffered more hardship than their rural counterparts. Jamal and Weeks calculated that, in the 1970s and 1980s, the rural–urban income gap in many African countries either disappeared or shifted in favour of the farmers (Jamal and Weeks 1993). The fall in real urban incomes has generated a new urban poor population, who are forced to adopt survival strategies. Households diversify their sources of income; previously non-working members, mainly women, enter the petty commodity sector, and wage earners take on supplementary cash-earning activities. They reduce their expenditure by developing subsistence agriculture within and around the urban area (see Fig. 9), and by adjusting their housing arrangements (some move towards less expensive districts, while others rent out a part of their house). Another coping strategy is to strengthen and adapt rural–urban ties, which includes returning to rural homes. This often involves changes in household composition. Adult members are sent to villages to diversify income in order to cope better with economic hazards, some children are sent back to rural areas where schools are cheaper, while foster children are sent back to their original households (Beauchemin and Bocquier 2004, Potts 1997). These strategies are not marginal and explain why urban out-migration has increased significantly in West Africa.

Household coping strategies would appear to be effective in adapting to the deteriorating urban economy. In West Africa, no riots broke out in response to the implementation of structural adjustment. However, in this context of rising poverty, social and ethnic tensions have been exacerbated in some countries[8]. In other countries, remittances from international migrants might have acted as safety valves. For instance, Senegalese and Malian emigrants are known to play an important role in both rural and urban development in their home countries (Tall 1994; Gueye 2002; Bertrand 1994).

Construction of Towns and Cities

The physical appearance of West African cities and towns is mostly the result of a recent and rapid pace of growth, which public authorities, despite their intentions, have been unable to control. Almost everywhere, governments nationalised land after independence, and public authorities were supposed to become the main—if not the only—actor in urban development. They did indeed draw plans and build housing units to supply demand from urban residents. However, the supply of public housing has only ever met a small proportion of needs, and the dwellings or serviced plots made available are not affordable for the lowest income groups. How did the others—in fact the majority—find accommodation? They relied on the informal sector, by buying a plot from a holder of customary tenure rights and building their own houses, or by renting a place in an unauthorised neighbourhood (Durand-Lasserve 1986; Rakodi 1997).

Cities and Towns in West Africa. Fig. 9 In a context of growing poverty, urban households turn to agriculture within and around urban areas in order to reduce their expenditures. Here, the Figure also shows the progressive building process in West Africa. Construction is usually incremental due to the underdeveloped nature of the housing finance system sector. Therefore, people build as they get money. © IRD – Philippe Haeringer.

As in other sub-Saharan African countries, in West Africa there are overlapping land tenure systems. Although the law imposed public control over land, the customary system has survived informally. Theoretically, in that system, land cannot be owned as private property. It is vested in a community (usually a lineage whose ancestors settled on the land), and administered by the head of the group. In that system, unused land can be allocated to a non-member of the group, especially if he needs it to survive. In that case, in the traditional system, only a token payment to the land chief is required. This is not a sale since the land remains theoretically inalienable. However, in urban areas, as pressures intensify, traditional payments are moving closer to real land prices. Since the 1960s, in all cities, customary authorities have informally sold (i.e. without transfer of title) land for urban development. Since the occupants have no title, public authorities can always contest the use to which the land is put. Until the late 1970s, informal settlements were demolished. Then policies switched to regularisation and upgrading programmes; titles or occupancy licences were delivered to the previously unauthorised occupants and infrastructure was installed (Amis 1989). All in all, states now tolerate informal settlements because they meet popular demand. Building a house is for most households the only source and accessible investment while bank savings are unreliable and poorly profitable. The informal land tenure system has thus become

[8] On the conflict in Côte d'Ivoire, see Beauchemin 2005.

more secure. In 2001–2002, between 50 and 85% of self-declared landowners in seven West African capital cities possessed a land title (AFRISTAT 2005). The urban structure of unauthorised neighbourhoods is also quite similar to that of regular districts; landowners, intermediaries and buyers are adopting urban and architectural standards likely to facilitate subsequent regularization (see Fig. 10).

In West African cities, the majority of houses in both the formal and informal sectors have been built on an individual rather than mass production basis. The typical West African housing unit is the compound house (see Fig. 11). This type of accommodation houses 85% of the population in Abidjan (Côte d'Ivoire) and Bamako (Mali) and three-quarters of households in Accra (Ghana). Even in informal areas, urbanites do not build their own houses; artisan builders are commissioned (Coquery 1990). Construction is usually incremental, mainly due to the lack of title and an underdeveloped housing finance sector (see Fig. 9). According to needs and means, houses are extended horizontally (by filling empty spaces with new rooms, such as by reducing courtyards to corridors) or vertically (by adding more storeys). Most compound houses are permanent structures, built of cement breezeblocks with corrugated iron roofs. Mostly built for rental, compounds usually accommodate several families and various socio-economic and ethnic groups, enabling a mix of the city's population groups and cultures (see Fig. 12). Compared with other cities in the developing world, including the rest of sub-Saharan Africa, most West African cities do not appear to be very segregated, either socially or ethnically.

Cities and Towns in West Africa. Fig. 10 Dakar, Senegal. This neighbourhood is next to the airport area (rear of the Fig.). It was officially declared unsuitable for building development by the Senegalese government. However, this land was sold for construction by customary authorities of the *Lebou* (a local ethnic group). The quality of the houses shows quite well that unauthorized areas do not necessarily become slums. Nowadays, this type of neighbourhood is often regularized after construction (informal owners finally obtain titles from the public authorities). © IRD – Michel Dukhan.

The informal nature of land distribution and housing production has led to under-serviced urban development. There is no legislation governing construction in unplanned housing areas, and consequently there is no tax on the capital gain on land sales and no obligation to service land prior to sale. As for housing, publicly provided services and infrastructure have lagged far behind needs. As a result, a large share of the urban

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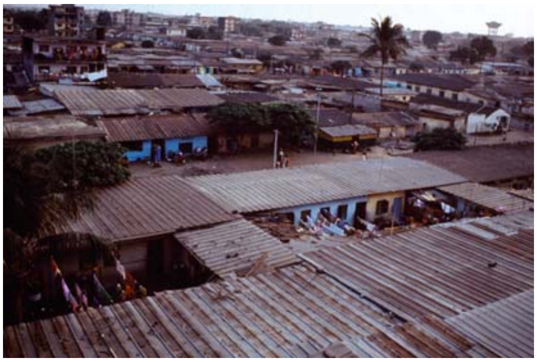


Cities and Towns in West Africa. Fig. 11 Abidjan, Côte d'Ivoire. Except in the downtown center and in some upper-class districts, the city skyline is very low and horizontal. 85% of the Abidjan population lives in compounds such as this. Several households surround the courtyard, usually the center of the plot. Each living unit normally comprises one room or two rooms of approximately 10 m^2, one which is used as a bedroom and the other a sitting room. Three rooms is the maximum number of rooms for this type of housing and that is very rare. Courtyards are progressively filled with new constructions. At the rear, owners have started to build additional storeys. © IRD – Philippe Haeringer.

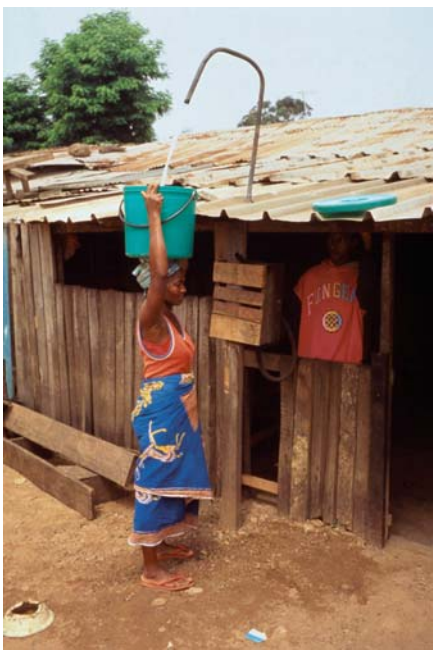
Cities and Towns in West Africa. Fig. 12 Abidjan, Côte d'Ivoire. Courtyards are used for domestic activities and sometimes for economic activities. Here, women sort candies they are going to sell in the street and at the markets. On the right front, notice the collective place dedicated to the dishes and the washing. Barrels (red and blue, on the left rear) indicate that there is no tap water in the compound. Women are in charge of getting the water. © IRD – Philippe Haeringer.

population does not have access to basic services. Access to water, vital for health, is a concern for much of the urban population (see Fig. 13); in 2001–2002, only 43% of all households had access to tap water in the seven capital cities cited above, with the proportion ranging from about one-quarter in Lome, Bamako and Niamey to 41% in Cotonou, 50% in Abidjan and 68% in Dakar (AFRISTAT 2005).

In response to service shortages, urban dwellers have adopted a range of alternative strategies. In Pikine, the largest suburb of Dakar, by taking advantage of political clientelism, residents in the unauthorised area have obtained as many facilities (schools, health centres, water points) as their counterparts in the formal area. For urban dwellers, political pressure has become a potentially powerful lever since decentralisation in the mid-1980s. Do-it-yourself is another strategy; illegal hook-ups to electricity may be a way to access power (Marlard et al. 1999). Informal economic activities have also emerged to compensate for the inadequacy of the public service system. Many people rely on private vendors instead of collecting and queuing themselves for water although prices are more expensive than for public supplies (see Fig. 14). Collective taxis and private minibuses (*gbaka* in Abidjan, *cars rapides* in Dakar, etc.) serve the neighbourhoods with terraced roads bypassed by public transport systems and are usually less expensive (see Fig. 15). A large proportion of the residents of unauthorised neighbourhoods thus have access, to some extent, to the highest-priority services. The situation is nevertheless not very satisfactory. Poor sanitation is a major health issue, water that is expensive and remote encourages drinking of non-potable water, and unregulated transport is dangerous. Furthermore, the privatisation of urban services, in line with structural adjustment recommendations, has worsened the situation since the mid-1980s (Stren and White 1989).

In a nutshell, West African cities and towns face the same problems as other developing regions in terms of access to services and housing. However, due to the informal land tenure and housing systems, squatting[9] and slums are much less extensive than in Asia and Latin America (Peil 1976; Konadu-Agyemang 1991). A regional study found that 'only' (*sic*) 15 to 25% of urban residents lived in precarious housing (shanty towns), a similar proportion in planned districts, and the remainder, i.e. the majority, in structured, albeit informal, neighbourhoods. However, the fact remains that in the poorest neighbourhoods, living conditions are so bad that infant and child mortality rates are sometimes higher than in rural areas (United Nations human settlements programme 2003; National Research Council 2003).

Urbanisation is known to be historically associated with development. In the past, when the developed world



Cities and Towns in West Africa. Fig. 13 San Pedro, Côte d'Ivoire. A woman buys water from a neighbour who is equipped with running water. The scene takes place in the Bardo, the largest informal settlement in Côte d'Ivoire; 90 000 people (about to thirds of the town population) lived there in 1998. San Pedro is the perfect example of the urban planning failure in West Africa. It is a new town, created in 1968 to be the exportation (cocoa, wood, etc.) port of the southwest of Côte d'Ivoire. From the beginning, the Bardo, the unplanned part of the city, started to grow faster than the authorized part. © IRD – Philippe Haeringer.

Cities and Towns in West Africa. Fig. 14 Mopti, Mali. A water street vendor. © IRD – Sophie Martin.

[9] A distinction must be made between squatting (deliberately building on land without permission and against the owner's wishes) and unauthorised settlement (building in areas where the government has not given permission to build, but where customary owners can sell plots for construction).

Cities and Towns in West Africa. Fig. 15 Dakar, Senegal. The official public transport system is not sufficient to serve the whole agglomeration and is too expensive for a large part of the population. Private mini-buses, the so-called 'cars rapides' in Dakar (it means fast buses), compensate for this inadequacy. But since the material is old, they are not always secure and contribute a lot to pollution. © IRD – Michel Dukhan.

experienced its transition from a predominantly rural-agricultural economy to an urban-industrialized one, urban growth was the highest where economic growth was fast. The urbanisation process in sub-Saharan Africa differs to some extent from the process experienced by contemporary developed nations at a comparable stage in their development (Njoh 2003). There is nevertheless a consensus nowadays to recognize that the level of urbanisation (percent urban population) is correlated to various development indicators, such as the GDP per capita or the Human Development Index (Davis and Henderson 2003; Njoh 2003). Therefore recent slow-down trends of urban growth, especially where migratory reversal occurred, may be worrying in terms of development. Actually, these trends reveal a polymorphous crisis, i.e. both a crisis of urban management (unsolved problems of housing, services, infrastructure, etc.) and a crisis of the urban economy (increasing unemployment, insufficient income, high cost of living, etc.). From a global point of view, the peripheral position of the West African countries in the world economy appears to be the main reason for their lagging urbanisation (Simon 1997). West African countries are still excluded from the more profitable production sectors. Their economies are still highly dependent on raw materials and from this end they are not able to control the world markets. In this context, West African states remain highly dependant upon international aid. As a consequence, conditions imposed by the financial institutions weigh heavily on national economic and urban policies. Urban management issues are thus more and more delegated to (new) municipalities, which dispose of fewer means. Public services are often privatized, but the poorest do not have necessarily better access to them. Drastic reductions in public expenditure prevent states to invest in infrastructure (electricity, roads, etc.) that are recognized to be necessary for the population's wellbeing and for the enterprises' prosperity. West African states have to reconcile on one hand the conditions that will allow private informal and formal enterprise to expand in towns and cities in order to generate wealth and employment and on the other hand extend basic services in order to guarantee a better health and education for the poor.

Note 1 Inconsistent Definitions and Measures Vagaries

What is rural? What is urban? There is no global standard to define the line between urban and rural settlements. This issue is not specific to West Africa, but it is particularly relevant there because of frequent discrepancies. For instance, in Côte d'ivoire, the official definition published in 1975, based on population and activity criteria, has never been used in practice (a list of cities has been established without regard for the official definition) (Dureau, 1987). Furthermore, there are often inconsistencies between national official definitions and definitions published in UN reports (practically the only comprehensive source of international urban data available). In the UN's Statistical Yearbooks, definitions are not stated for some countries, even though this information is available in national reports (e.g., Benin, Burkina Faso and Guinea). Definitions for other countries (e.g., Côte d'ivoire, Mauritania and Niger) are even in contradiction with national definitions. Obtaining information on the definition of urban settlements in West Africa is in itself a challenge. In any case, one observation can be made: the definition of 'urban area' varies from one country to another, and can also vary over time, which makes geographical and chronological comparisons problematic. As a result, most publications on urban trends based on UN data are flawed by the inconsistency of definitions (Bocquier 2003).

In order to draw a more accurate figure of urban trends in the world, Moriconi-Ebrard (1994) has created an urban database based on a standardised definition: in GEOPOLIS, settlements with a population over 10,000 are considered urban, regardless of country and period (from 1950 to now). This new definition could have a major impact on national figures. However, in the case of West Africa, using a standardized definition does not produce a very different figure of urban trends on the regional scale. The level of urbanisation measured by official definitions appears to have been slightly overestimated, but trends remain similar. The pace of urbanisation in West Africa slowed sharply in the 1980s and 1990s.

Urban studies in West Africa are not only flawed by definition problems. They are seriously hampered by a lack of reliable and up-to-date demographic data. Census data are the principal sources of information on urbanisation. But censuses tend to be conducted only once a decade and then take several years to be analysed and published. In Africa, deadlines are often delayed due to financial, political or security reasons, so that recent data are rarely available. As a result, figures shown in UN publications are often estimates. Because of the poor quality of available data and an inappropriate projection method (Bocquier 2005), estimates for West African countries in the 1980s and 1990s have overrated urbanisation levels. To conclude, statistics on urban trends should be used with caution!

Note 2 The Urban Future: Mega-Cities or Small Towns?

Contrary to popular perception, most urban dwellers in Africa do not live in the slums of mega-cities. In fact, most African cities are small by international standards. Lagos in Nigeria is the only sub-Saharan African urban agglomeration to be included in the UN list of the 30 largest urban agglomerations in the world. Urban systems in Africa, and more specifically in West Africa, are quite different from those in Latin America or Asia. There are no major metropolises (with the exception of Lagos), but many small and medium-sized towns (as a result of the reclassification process). It is precisely because large cities play a less clear-cut role in urban dynamics than in other parts of the developing world that this is such a controversial topic among academics.

Some authors stress and decry the high degree of primacy, where a large proportion of the urban population lives in a single city. This view is widely shared by policymakers who are concerned by the growth of large cities and who claim to have developed policies to reduce migration to cities (United Nations 1998). Some African cities do clearly predominate in national urban systems (e.g. three-quarters of the urban population of Guinea were living in Conakry in 1994, according to UN data) and have seen spectacular growth, especially in the 1970s (e.g. Abidjan grew by more than 10.3% per year between 1965 and 1975, a record rate of urban growth). Furthermore, several studies have shown an increasing concentration of the urban population in the main cities in recent decades; urban systems seem to have evolved from undersized to oversized capital cities as compared to the world average (Bocquier, Traoré, 2000).

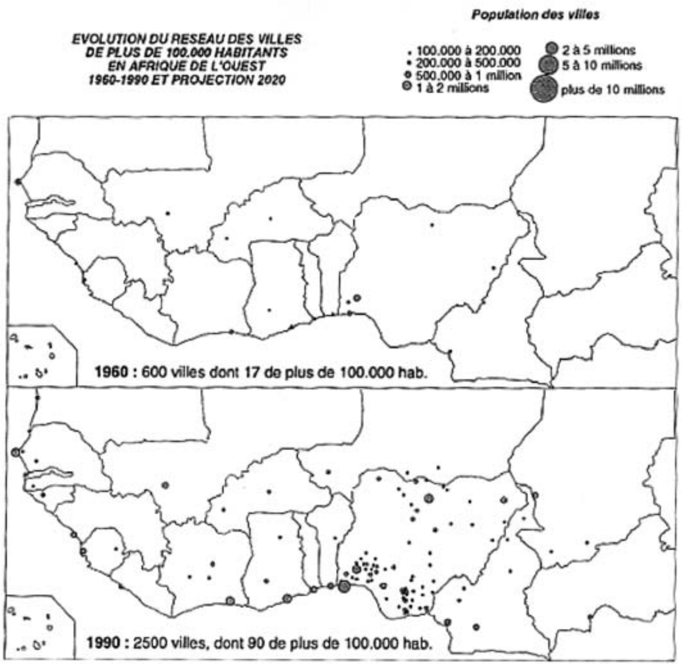
Conversely, some authors argue that urban growth in West Africa is largely due to the development of small and intermediate towns. Using other data sources or other calculation methods, they show that primacy is no greater than in other regions of the world and that it has not increased over time (Cour and Snrech, 1998; Bocquier, 2003). Indeed, in most countries, the principal city's share of the total urban population has not changed much since the 1950s. For instance, Dureau (1987) has shown that Abidjan has concentrated about 40% of the urban population of Côte d'Ivoire since 1936 and that, even when the city saw spectacular growth (1965–1975), 49% of new urban dwellers settled in secondary towns. In fact, in the mid-1980s, West African small and medium-sized towns became a separate subject of research (Hardoy and Satterthwaite 1986; Baker 1990; Dubresson 1996). Several studies stressed the importance of their development. In West African countries, the number of small towns (settlements with a population of 5,000 to 20,000) rose from 150 in 1960 to 400 in 1980 (Giraut and MoriconiEbrard 1991) (see map 1).

What is the urban future? Projections are always hypothetical, especially when they are related to such controversial issues (Bocquier 2005). Nevertheless, a consensus is emerging. Despite popular perceptions to the contrary, West African people will not all be living in mega-cities in the near future. Primacy may increase in some countries, but it may result from regional integration. Cities like Dakar, Abidjan and Lagos are highly cosmopolitan and their share in the urban population would be more accurately assessed at the regional level (West Africa) than at the national level. In any case, small and medium-sized towns will continue to appear (through reclassification) and grow.

Note 3 Migration, Urbanisation and Development: A Controversial Issue

Does rural-to-urban migration (and the resulting urbanisation) favour economic development? This question, which is a matter of policy concern in West Africa is also vigorously debated by scholars. Broadly speaking, there are two main contrasting viewpoints.

An anti-migration viewpoint is that rural-to-urban migration is excessive and should be curbed because it leads to a "less than optimal allocation of labour between the rural and the urban sectors" (Gugler 1982). On the one hand, it exacerbates unemployment and underemployment in African cities. On the other hand, it reduces potential agricultural output, by depriving the rural population of its more innovative and able-bodied members. Furthermore, rural-to-urban migration is criticised as the primary contributor to the uncontrolled expansion of urban areas (Bairoch 1985). Finally, rural-to-urban migration increases the cost of providing for the country's population in two ways. Firstly, new infrastructure is required by the migrants, and amenities (housing, transport, garbage and sewage disposal, etc.) are more expensive in cities or towns than in rural



Cities and Towns in West Africa. Map. 1 Evolution of the West African urban system (1960–1990). 1960: 600 towns and cities, 17 have more than 100000 inhabitants. 1990: 2500 towns and cities, 90 have more than 100000 inhabitants. Source : ►http://www.urbanisme.equipement.gouv.fr/cdu/datas/docs/ouvr16/2020_p1.htm. These maps show the proliferation of towns in West Africa during the second half of the XX[th] century. Most of the larger towns and cities were developed under colonial rule and were founded in coastal regions and along rivers.

areas, where they may not be needed at all (Gugler 1982). Secondly, urban job creation is generally more costly than rural job creation, because most jobs in the industrial sector require substantial complementary resource inputs. For these reasons, rural-to-urban migration is seen "both as a symptom of and a contributor to African underdevelopment" (Todaro 1997). This view is largely shared by policymakers (United Nations 1998).

Taking the opposite point of view, pro-migration authors argue that it is completely inappropriate to regard migration as an undesirable force, which needs to be suppressed (Amis 1989). On the urban side, authors acknowledge that substantial unemployment and severe underemployment characterise most large African cities today, but they point out that, on average, migrants must be better off in urban places, otherwise rural out-migration flows would slow (Becker, Hamer et al. 1994). On the rural side, they argue that there is no labour shortage since emigration has not prevented the rural population from increasing far more rapidly than it has ever increased in the developed countries (except in the United States). On the contrary, rural out-migration is seen as a way of alleviating human pressure on natural resources. In addition, they contend that urbanisation stimulates agricultural activities, since it creates a market for specialised food production with high added value (market gardening and poultry farming). Apart from the impact on rural areas, migration and urbanisation are seen as key components of the development process. Authors argue that, for several reasons, increased urbanisation raises per capita income and other measures of economic welfare. First, when driven by rural-to-urban migration, urbanisation tends to move workers from agriculture to more productive occupations (e.g. urban services, commerce, and manufacturing sectors). Second, urbanisation offers the cost-reducing advantages of economies of agglomeration and economies of scale and proximity as well as numerous economic and social externalities (e.g. skilled workers, cheap transport, amenities, etc.). Finally, urbanisation also contributes to development in more subtle ways. For example, it may lead to lower levels of fertility and mortality, as individuals benefit from improved access to health care. Theory apart, Becker et al. (1994) stress that, from a macro-economic point of view, while less than a third of Africa's population lives in cities or towns, these centres generate over half of the continent's gross domestic product (GDP).

To conclude, one is tempted to agree with Portès, who takes the view that "internal migration and urban growth are intrinsically neither good nor bad. Such assessments depend upon the specific social context, and in particular, on the point of view one adopts with respect to the different classes and institutional actors. A case can be made that, in the short run at least, the present trends of rural–urban migration and urban concentration are functional for a wide assortment of groups" (Portès 1985).

See also: ►Building Construction in Africa, ►Architecture in Africa

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City Planning in Ancient India

PAUL GREGORY

As the birthplace of Indian culture, the towns of the Indus Valley represent an important and rich source of information concerning urban development in the Indian subcontinent. The Indus River is one of the largest and most important rivers in south central Asia. From its source in the Himalayan Mountains to its terminus in the Indian Ocean it traverses a course of over 2,000 miles. For millennia it has been an essential route for travel, trade, and communication and has been the source of much of India's agricultural production. The valley which surrounds the Indus River has witnessed the birth, growth, and death of many cities.

Excavations of Indus towns have demonstrated the most ancient town planning in the world. The grid pattern (straight streets intersecting other straight streets at right angles) is among the most common and universal types of town planning. The discovery and excavation of the most famous of these sites, Mohenjo-daro, by Sir John Marshall (1931) and Ernst Mackey (1938) supported the contention of Dan Stanislovski (1946) that the development of the grid pattern in western societies – Greece, Rome, and Europe in the Middle Ages – can be linked directly to the development of town planning in the Indus valley.

A recent excavation on the Western plains of the Indus – the Rahman Dheri site – reveals a town plan from the early Indus period. This site comprises an area of roughly 22 ha and could have been home to 10,000–14,000 people. Radio carbon-dating of artifacts places development somewhere in the first half of the fourth millennium BCE. Rahman Dheri is built in the classic grid pattern. It is rectangular in shape surrounded by an immense wall and bisected by a major traffic artery which runs roughly southeast to northwest. Perpendicular to this road exists a pattern of regularly occurring laneways which appear to create individual dwelling lots.

The successor to the plan of Rahman Dheri is thought to be the Surkotada site in Kutch which dates to ca. 2500–2000 BCE. Though smaller in scale than its predecessor the Surkotada site is built along the same grid pattern as Rahman Dheri. This settlement was enclosed by a stone rubble and brick fortifications. This produced two separate areas each of roughly 60 m^2.

Similar to Surkotada, only on a larger scale, the Kalibangan site was completely surrounded by an enormous rampart. This site, about 200 km to the southeast of Hirappa on the banks of the (now dry) Ghaggar river, was composed of two mounds. The smaller mound, named the citadel, was to the west and was roughly 240 m by 120 m. The larger mound, named the lower city, was to the east and measured 360 m by 240 m. The lower city demonstrates the grid plan divided into blocks of which the east–west side was roughly 40 m in width. The width of lanes and streets in the lower city ranges from 1.8 to 7.2 m. Interestingly each lane or street is some multiple of 1.8 m. This site is thought to date to the early Indus period, roughly 3000 BCE.

The evolution of Indus town planning reached its zenith at Mohenjo-daro. The town is geographically located on a floodplain of the Indus river; the city occupies about 1 km^2 – over five times larger than Kalabangan. The basic grid of Mohenjo-daro is about 180 m^2, subdivided into 16 sections of about 40 m^2. Mohenjo-daro existed from ca. 2500 to 2000 BCE. During this time it bore the brunt of often severe flooding, and as a result the original grid plan was often modified and transformed. The city itself was originally planned in the same way as Kalabangan: an oblong walled city divided into a citadel and a downtown area divided by an open space. Similar to its predecessor communities, the town plan of Mohenjo-daro indicates the same parallel grid street structure that has come to characterize urban planning in this region at this time.

As this brief history of the evolution of town planning in the Indus river valley demonstrates the grid pattern was commonplace. The importance of the Indus river valley communities to the historical development of culture and civilization in the Indian subcontinent and the East is well known. Stanisloski has suggested that the grid pattern form of town planning has its roots in the Indus valley. Parallel developments in Nepal, Sri Lanka (formerly Ceylon), Burma, Korea, Vietnam, and China also indicate how widespread the influence of the Indus river valleys communities were. It is suggested that this form of town planning was taken up by the Greeks, Romans, and other Western Europeans and eventually became a standard form of urban organization in Europe and the New World.

Excavations at and along the Indus River valley reveal cities strikingly similar in topography to contemporary Western European and North American cities. While some may suggest that the grid pattern evolved in a happenstance fashion without benefit of central planning or administration, substantial evidence exists to support the opposite point of view. First, the grid pattern can be seen in a variety of towns all along the Indus river, which existed and flourished over a several thousand year period. Second, the similarity between these towns and the general division between a lower city area suggests the development of town planning conventions as early as 2500 BCE. Third, there is a remarkable mathematical symmetry in Kalabangan where lanes and streets (which range from 1.8 to 7.2 m in width) all occur in multiples of 1.8 m.

The contribution of this historic period to the development of Western cities should not be underestimated. Much of what we take to be enlightened urban planning was considered over four thousand years ago by planners in south eastern Asia.

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City Planning: Aztec City Planning

Michael E. Smith

The Aztecs were the most urbanized of the ancient civilizations of Mesoamerica. The last in a long line of urban societies, they selected principles of city planning from an ancient Mesoamerican heritage and adapted these to their needs. Most Aztec urban centers were modest settlements best called towns, but the central capital Tenochtitlan was a huge metropolis of a different order.

Most Aztec towns were founded between AD 1100 and 1350 when the Aztec peoples immigrated into the central Mexican highlands. They established new settlements and dynasties leading to a system of autonomous city-states. The construction of a royal palace marked the official founding of a new city or town, most of them city-state capitals. In 1430, three Aztec peoples – the Mexica, Acolhua, and Tepanecs – formed a tributary empire, known as the Triple Alliance or the Aztec Empire. Two of their capitals, Tenochtitlan (Mexica) and Texcoco (Acolhua), became the preeminent cities of the Valley of Mexico. By the time Spanish conquerors arrived in 1519 this empire had conquered much of Mesoamerica, and Tenochtitlan had grown into a city of 200,000.

One of the remarkable features of Aztec urban planning is the extent to which basic buildings and

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City Planning: Aztec City Planning. Table 1 Historical sources of planning principles employed in Aztec cities

Principles of Urban Planning	Aztec Towns	Tenochtitlan
Ancient Mesoamerican Planning Principles:		
1. Inventory of public architecture	x	x
2. Urban epicenter	x	x
3. Central public plaza	x	
4. Astronomical orientations	x	x
5. Unplanned residential zones	x	
Teotihuacan Innovations:		
6. Huge size of the city		x
7. Massive scale of main temples		x
8. Orthogonal planning of entire city		x
9. Layout dominated by central avenue		
10. Lack of central public plaza		x
11. Standardized housing		x?
Tula Innovations:		
12. Formalization of the epicenter	x	x
13. The largest temple on the east side	x	x
14. Circular Quetzalcoatl temples	x	x
Aztec Innovations:		
15. Twin-temple pyramids	x	x
16. Multiple small altars	x	x
17. Walled ceremonial precinct		x

planning principles were standardized among cities throughout central Mexico. This standardization long preceded the formation and expansion of the Aztec empire, and its explanation probably lies in the common cultural origins of the Aztec peoples, coupled with processes of interaction that kept the rulers and nobility of the Aztec city-states in constant contact with one another. This uniformity in urban planning contrasts strongly with other Mesoamerican cultures, such as the Classic Maya, the Olmec, or the Zapotec, whose individual cities show far greater variation in architecture and urban layout.

Historical Development of Planning Principles

The Aztecs drew upon several ancient historical traditions to select principles of urban planning for their cities and towns. Not surprisingly, the two major Aztec urban types – city-state capitals and Tenochtitlan – had somewhat different historical legacies. In this section I outline 17 principles of urban planning employed in central Mexico, grouped into four historical categories based upon their historical origins: ancient Mesoamerican principles, Teotihuacan innovations, Tula innovations, and Aztec innovations. Table 1 lists these principles and their use in Aztec towns and in Tenochtitlan.

Ancient Mesoamerican Principles of Urban Planning

The Aztecs drew on ancient Mesoamerican principles of urban planning in the design of their cities. Five such principles can be identified for the pre-Aztec cities of Mesoamerica, including those of the Classic Maya lowlands, Oaxaca, and other regions (for Mesoamerican architecture and cities, see Hardoy 1968).

1. *The Inventory of Public Architecture.* A basic set of public buildings was used in most ancient Mesoamerican urban centers: large temple-pyramids, smaller temples, royal palaces, ballcourts, and a suite of less-common special purpose buildings that included council halls, sweatbaths, schools, and other structures.
2. *The Urban Epicenter.* Public architecture in Mesoamerican cities tended to be concentrated spatially in a central zone, called the urban epicenter. The locations and orientations of individual buildings often suggest coordination and planning, although strict formal patterns, such as orthogonal layouts, were rare.
3. *The Central Public Plaza.* The basic unit of urban planning was the public plaza, an open rectangular space whose sides were taken up with public buildings. Large cities with multiple concentrations of public buildings often had multiple public plazas of different sizes.
4. *Astronomical Orientations of Buildings.* The ancient Mesoamerican peoples were accomplished astronomers, and key public buildings were often aligned with significant astronomical phenomena, such as the direction of sunrise on the solstice. There is a general tendency for urban epicenters to be aligned roughly to the cardinal directions (most

typically several degrees east of north), a pattern that may also have derived from astronomical considerations (Aveni 2001).

5. *Unplanned Residential Zones.* Most urban housing was located outside of the urban epicenter. Individual houses typically show little or no evidence that their locations, forms or orientations were coordinated or planned by central authorities.

Teotihuacan Innovations

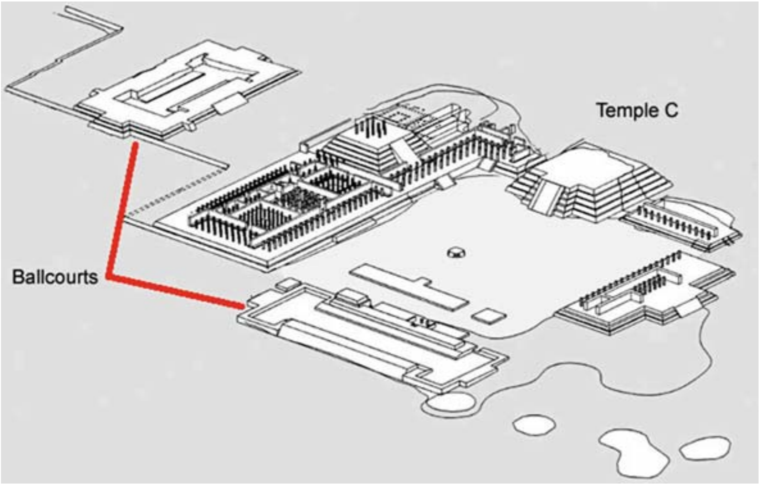
With a population of around 150,000 inhabitants, the huge metropolis Teotihuacan was the largest city in Mesoamerica (and one of the largest anywhere in the world) during the Classic period (ca. AD 150–650). Teotihuacan dominated central Mexico politically, and its economic and cultural influence extended to all corners of Mesoamerica. In its form and size, Teotihuacan was utterly unique in Mesoamerica, and only the later Aztec imperial capital Tenochtitlan can be said to resemble Teotihuacan at all (Cowgill 1997; Millon 1992). Six innovations in urban planning can be identified at Teotihuacan.

6. *The Huge Size of the City.* With an extent of over 20 km^2 and its huge population, Teotihuacan was a city of a different scale from anything seen previously in Mesoamerica (Fig. 1).
7. *Massive Scale of the Main Temples.* Although not the tallest pyramids in ancient Mesoamerica, Teotihuacan's "Pyramid of the Sun" and "Pyramid of the Moon" are among the most massive in volume.
8. *Orthogonal Planning of the Entire City.* The principle of orthogonal city planning was quite rare in ancient Mesoamerica, found only at Teotihuacan, Tenochtitlan, and perhaps Tula. Teotihuacan is remarkable for the consistency of orientation of its buildings.
9. *Layout Dominated by a Central Avenue.* The so-called "Street of the Dead" is a central avenue several km in length that forms the central axis for the layout of Teotihuacan (Fig. 1). This use of a dominant central avenue is not found elsewhere in Mesoamerica.
10. *Lack of a Central Public Plaza.* There is a moderately sized open plaza at the north end of the Street of the Dead, but this plaza differs from typical Mesoamerican central public plazas in several key respects: it is small in relation to the size of the city; only a few of the central public buildings are adjacent to the plaza; and it is not centrally located within the city. Instead, the Street of the Dead at Teotihuacan can be considered a functional analogue of the Mesoamerican central public plaza in terms of urban layout and planning. The major public buildings were arranged along this feature, which gave form to the entire plan of the city.
11. *Standardized Housing.* One of the most remarkable urban features of Teotihuacan was the highly standardized form of commoner housing, the apartment compound. There were more than 2,000 apartment compounds in the city, all aligned to its orthogonal grid.

Tula Innovations

Tula, the next large political capital in central Mexico after Teotihuacan, drew on the layout of Teotihuacan for inspiration in urban planning. Although the rulers of Tula returned to the older Mesoamerican pattern of urban layout around a large public plaza, they employed several of the Teotihuacan innovations (nos. 6, 7, and perhaps 8). Although not as large as Teotihuacan, Tula was much larger than its central Mexican contemporaries, and one of the largest cities in

City Planning: Aztec City Planning. Fig. 1 The "Street of the Dead" at Teotihuacan. Photograph by Michael E. Smith.



City Planning: Aztec City Planning. Fig. 2 Reconstruction of the epicenter of Tula. Modified after Mastache et al. (2002: 90).

Mesoamerica during the Epiclassic and Early Postclassic periods, ca. AD 800–1200 (Mastache et al. 2002). Three urban planning innovations can be identified for Tula.

12. *Formalization of the Epicenter.* The public plaza at Tula established an orientation that was used for all of the buildings in the urban epicenter (Fig. 2). This shows a higher level of coordination and formalization than was typical of other Mesoamerican urban epicenters. The Aztecs later adopted this principle for their urban epicenters.
13. *The Largest Temple on the East Side of the Plaza.* At Tula, the largest pyramid, Temple C, is located on the east side of the central public plaza, a pattern also used by the Aztecs.
14. *Circular Quetzalcoatl Temples.* The cult of Quetzalcoatl, the feathered serpent, spread throughout Mesoamerica in the Epiclassic and Early Postclassic periods. In Postclassic times, circular temples were dedicated to Quetzalcoatl's avatar, the wind god Ehecatl (Pollock 1936). At Tula, a circular temple was built at the El Corral locality, a concentration of public architecture outside of the main urban epicenter.

Aztec Innovations

The rulers of Aztec city-states drew primarily upon general Mesoamerican planning principles and Toltec innovations when they laid out their towns. The rulers of Tenochtitlan, on the other hand, emphasized these principles to a lesser extent, preferring planning principles from Teotihuacan. Three innovations can be identified for Aztec cities.

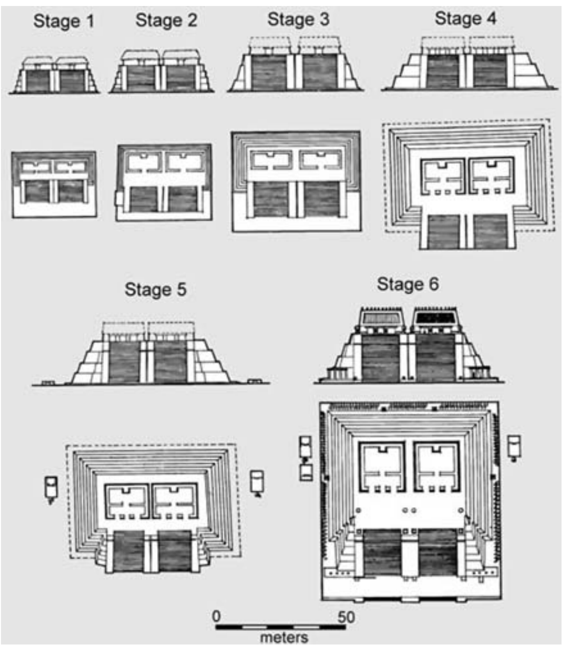
15. *Twin-Temple Pyramids.* Several of the earliest Aztec cities (e.g., Tenayuca and Teopanzolco) used a new form of pyramid with two temples on top and two stairways (Fig. 3). By the Late Aztec period, this form had fallen out of fashion except at the central temples of Tenochtitlan and Tlatelolco.

City Planning: Aztec City Planning. Fig. 3 Aztec twin-temple pyramid at Teopanzolco. Photograph by Michael E. Smith.

16. *Multiple Small Altars.* One of the notable attributes of Aztec cities is the prevalence of small platforms or altars throughout the urban epicenter (Fig. 4). These were often located within the public plazas, and some altars were adjacent to large pyramids.
17. *Walled Ceremonial Precinct.* The central religious architecture at Tenochtitlan was concentrated within a walled compound called the "Sacred Precinct". Although some authors have suggested that this was a regular feature of Aztec cities, Tenochtitlan is in fact the only example with a well-documented walled precinct.

These seventeen principles are listed in Table 1.

City Planning: Aztec City Planning. Fig. 4 Row of small altars at Teopanzolco. Photograph by Michael E. Smith.



City Planning: Aztec City Planning. Fig. 5 Construction stages of the twin-temple pyramid at Tenayuca. From Smith (*The Aztecs* 2003: Fig. 2.8); based upon (Marquina 1951: 169).

Urban Architecture

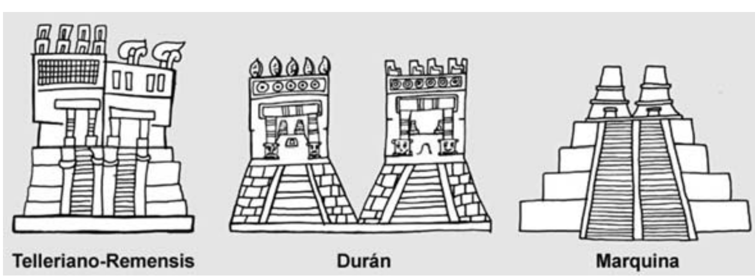
In addition to their use of ancient Mesoamerican traditions of urban planning, the Aztecs also made use of Mesoamerican patterns of monumental architecture. The basic religious structures were temple-pyramids, typically rebuilt and expanded by successive kings. When archaeologists excavate into a Mesoamerican pyramid, they typically find the buried remains of one or more earlier construction stages (Fig. 5). This continual rebuilding of temples in the same location was related to notions of sacred space and the importance of continuity with the past. In addition to temple-pyramids, the Aztecs also used the basic Mesoamerican architectural inventory of palaces, ballcourts, altars, and commoner houses.

Twin-Temple Pyramids

This innovative form of temple-pyramid is found at only five Aztec cities. Two of the major political capitals of the Early Aztec period – Tenayuca and Teopanzolco – employed large twin-temple pyramids for their central state temples (Fig. 3). Excavation of the Tenayuca pyramid revealed a series of enlargements and expansions (Fig. 5), all employing the double temple design. By the Late Aztec period, this style had fallen out of fashion at most Aztec cities, whose main pyramids had only a single temple. But the Mexica peoples at the twin cities of Tenochtitlan and Tlatelolco revived this form for their central pyramids. At the well-known Templo Mayor of Tenochtitlan, the temples were dedicated to Tlaloc (an ancient central Mexican fertility god) and Huitzilopochtli (patron god of the Mexica with associations of warfare and sacrifice). This structure is known both from excavations (Matos Moctezuma 1988) and from pictorial sources (Fig. 6) .

Single-Temple Pyramids

The single-temple pyramid was the standard form of temple throughout most of Mesoamerican history. The extent of its use during the Early Aztec period is hard to judge, but by Late Aztec times this form dominated Aztec cities, serving as both their central temples and as subsidiary temples (Fig. 7).



City Planning: Aztec City Planning. Fig. 6 Native drawings of the Templo Mayor of Tenochtitlan. From Smith ("A Quarter-Century of Aztec Studies" 2003).

Circular Pyramids

Many Aztec cities and towns had circular pyramids dedicated to the wind god, Ehecatl (Fig. 8). These temples were rarely if ever located in central positions in Aztec cities. In some cases (e.g., Tlatelolco and Tenochtitlan) these temples were located within the urban epicenter but somewhat apart from the central twin-temple pyramid (Guilliem Arroyo 1999). In other cases (e.g., Huexotla, Zultepec, and perhaps Calixtlahuaca) the circular temples were located far from the urban epicenter, as at the earlier city of Tula.

Ballcourts

Only a few Aztec ballcourts have been located, but given the prominence of ballcourts and the ballgame in Aztec codices (Nicholson and Quiñones Keber 1991) (Fig. 9), it is likely that these features were integral parts of most city layouts. The restored ballcourt at Coatetelco (Fig. 10) is probably typical of Aztec ballcourts; see also Matos Moctezuma (2001). The Aztecs played a version of the Mesoamerican ballgame, a public performance using a rubber ball that combined sport, ritual, and politics in poorly understood ways.

City Planning: Aztec City Planning. Fig. 7 Small single-temple pyramid at Calixtlahuaca. Photograph by Michael E. Smith.

City Planning: Aztec City Planning. Fig. 8 Circular temple at Tlatelolco. Photograph by Michael E. Smith.

Palaces

Aztec palaces, unlike those of the Classic Maya, were highly standardized in layout. They contained a central courtyard with a single entrance. The courtyard was enclosed by raised platforms, on top of which were arranged a series of rooms, halls, altars, and other features (Figs. 11 and 12). This standard plan was followed for a whole range of palaces, from the sumptuous royal palaces of Tenochtitlan and Texcoco to the modest residences of provincial nobles (Smith *The Aztecs* 2003: 139–146; Evans 1991).

Special-Purpose Buildings

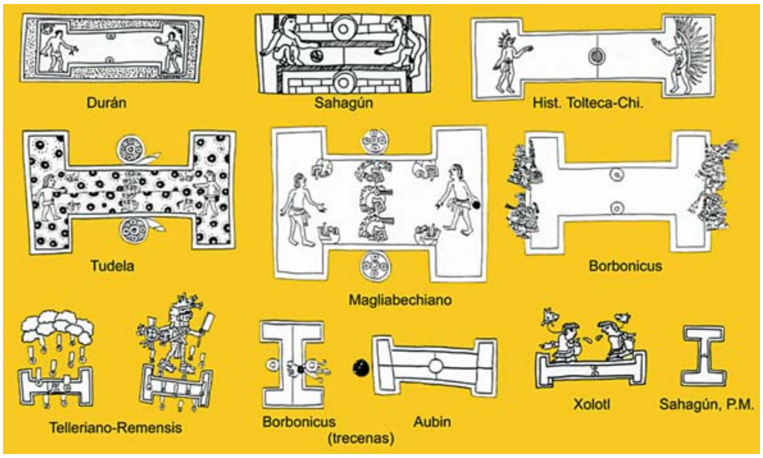
A variety of specialized buildings are known from archaeology and documentary sources. Written sources mention two types of schools, but none have been excavated. Special buildings for elite warriors have been excavated adjacent to the Templo Mayor of Tenochtitlan and in a rock-cut chamber at the hilltop ceremonial precinct of Malinalco (Fig. 13).

Altars and Small Platforms

Among the more intriguing and poorly understood features of Aztec cities are small altars and platforms that typically occur in multiple groups (Fig. 4). There were evidently numerous categories of such altars, dedicated to diverse deities and with a variety of uses in ritual and performance. Two specific functional types have been identified so far: platforms that supported skull racks (for the display of the skulls of sacrificial victims), and altars dedicated to the curing principles of the *tzitzimime* deities (Fig. 14) (Klein 2000). The Aztecs even journeyed to Tula to build a small altar in front of Temple C, perhaps symbolically to convert the ancient structure into an Aztec temple.

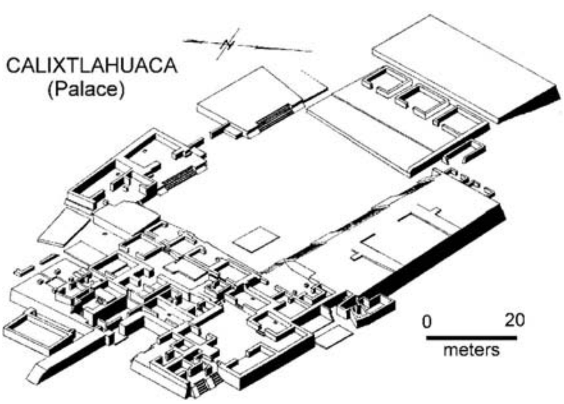
Commoner Housing

Two patterns of commoner housing have been identified at Aztec cities. At Tenochtitlan and other cities in the Valley of Mexico, house compounds enclosed by low walls was the norm (Evans 1988; Calnek 1974). These compounds contained a number of structures and rooms arranged around an open work area (Fig. 15). In the provinces, in contrast, commoners lived in individual adobe houses (Smith et al. 1999). Although often arranged into groups around a central patio, these house groups were never enclosed with walls (Fig. 16). Commoner housing exhibited considerably more variation within and between cities than was found in the palaces of the nobility.



City Planning: Aztec City Planning. Fig. 9 Depictions of ballcourts in the Aztec codices. Modified after Nicholson and Quiñones Keber (1991).

City Planning: Aztec City Planning. Fig. 10 Ballcourt at Coatetelco. Photograph by Michael E. Smith.



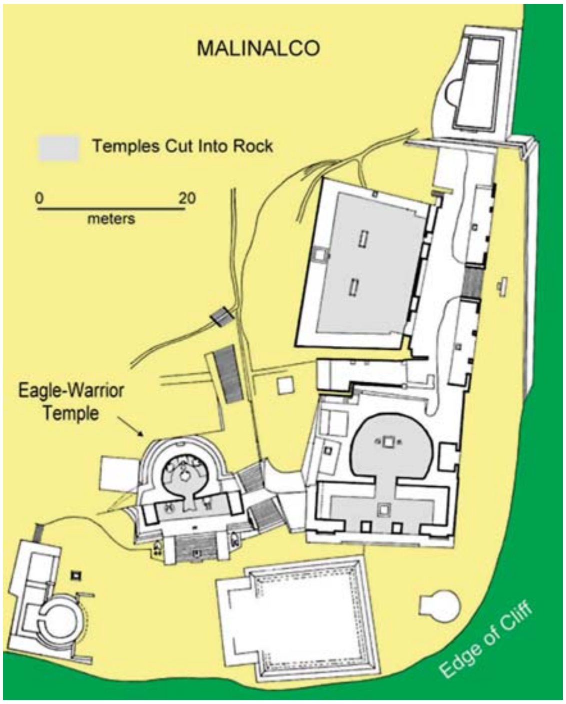
City Planning: Aztec City Planning. Fig. 11 Reconstruction of the palace at Calixtlahuaca. Modified after (Smith *The Aztecs* 2003: Fig. 8.7); based originally upon (García Payón 1981: Fig. 8).

City Planning: Aztec City Planning. Fig. 12 Rooms in the royal palace of Yautepec. Photograph by Michael E. Smith.

Categories of City

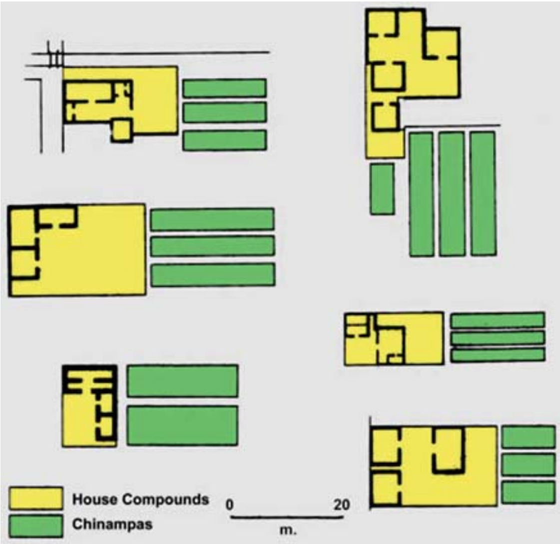
City-State Capitals

As noted above, the designers of Aztec cities and towns drew upon the principle of the formalized urban epicenter as articulated at the ancient city of Tula (Fig. 17). The city of Coatetelco in Morelos (Arana Alvarez 1984) illustrates this pattern (Fig. 18). The central pyramid lies on the east side of the plaza (as at Tula), with the ballcourt opposite. Five small altars or platforms, attached to the exterior wall of the ballcourt, extend into the plaza. The buildings on the north and south sides of the plaza were only partially excavated and their functions are not known. The formal, planned central plazas of Aztec towns are clear even in the overgrown mounds at unexcavated urban sites such as Coatlan Viejo (Fig. 19). Although it is possible that the planned layout of the epicenters and their consistent orientations just east of north related to cosmological principles, there is no concrete evidence to support this interpretation.



City Planning: Aztec City Planning. Fig. 13 Map of the hilltop ceremonial zone of Malinalco. From Smith (*The Aztecs* 2003: Fig. 7.5); based originally upon Marquina (1951).

City Planning: Aztec City Planning. Fig. 14 Altar decorated with carvings of human skulls at Tenayuca used to worship the *tzitzimime* deities. Photograph by Michael E. Smith.



City Planning: Aztec City Planning. Fig. 15 Commoner houses with *chinampa* (agricultural) fields. Modified after Calnek (1972: 112).

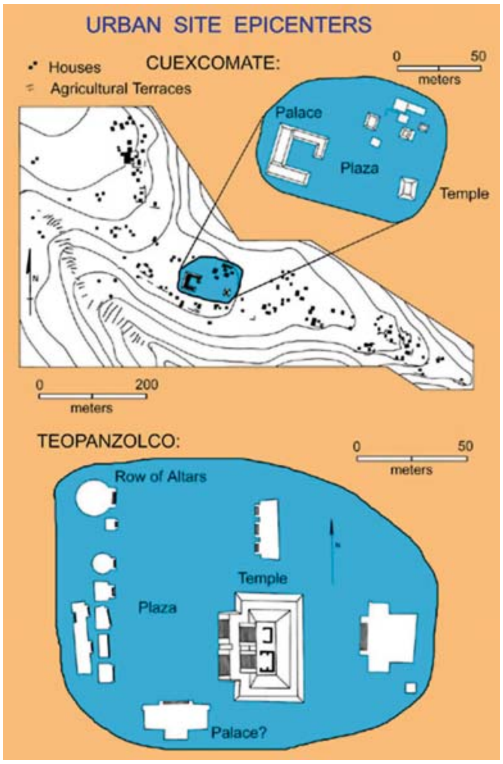
City Planning: Aztec City Planning. Fig. 16 Commoner houses excavated by the author at Yautepec. Photograph by Michael E. Smith.

Outside of the epicenter, the residential zones of Aztec towns exhibited little evidence for planning or coordination. Although only one Aztec town – Cuexcomate – has been mapped in its entirely (Fig. 17, top), residential excavations in other cities and towns are consistent with this interpretation of unplanned residential areas (Smith et al. 1999).

A related type of settlement was the hilltop ceremonial zone, found in a number of Aztec city-states. The rituals carried out at these locations were typically political ceremonies linked to both agricultural fertility and the religious legitimation of kings and dynasties. The best known examples are Cerro Tlaloc in the Valley of Mexico, Malinalco in the State of Mexico (Fig. 13), and Tepozteco in Morelos.

Tenochtitlan

When the Mexica peoples constructed Tenochtitlan on an island in Lake Texcoco in the early fourteenth century (the official date for the founding of the city is AD 1325), they drew more inspiration from Teotihuacan and Tula than from the standard Aztec urban plan already established at many towns in central Mexico (Table 1). The use of orthogonal planning is one of the remarkable features of the imperial capital (Fig. 20). Although few explicit articulations of urban planning concepts have survived, three factors were most likely responsible for creating the form of Tenochtitlan: the city's island location, imperial ideology, and cosmological principles. Most of Tenochtitlan's 13.5 km^2 were reclaimed from Lake Texcoco. Spanish observers were struck by the great number of canals in the city, which they likened to Venice. The canals were used as transportation arteries and for agricultural purposes. Raised fields or *chinampas*, an extremely productive method of farming, were built to cultivate reclaimed swampy land in the outer neighborhoods of the city (Calnek 1972). Families living on their individual small plots worked these fields (Fig. 15). As the city expanded, many of these rectilinear chinampas were converted into dry land, contributing to the orthogonal plan of the city.

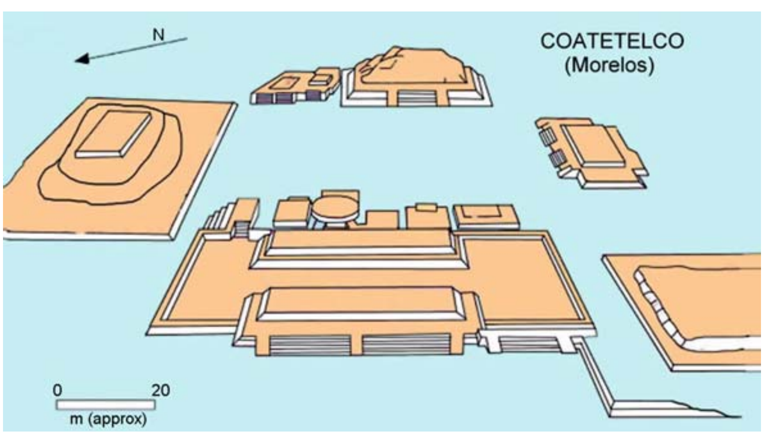


City Planning: Aztec City Planning. Fig. 17 Definitions of urban epicenters of Cuexcomate and Teopanzolco. Modified after Smith (2004: Fig. 2).

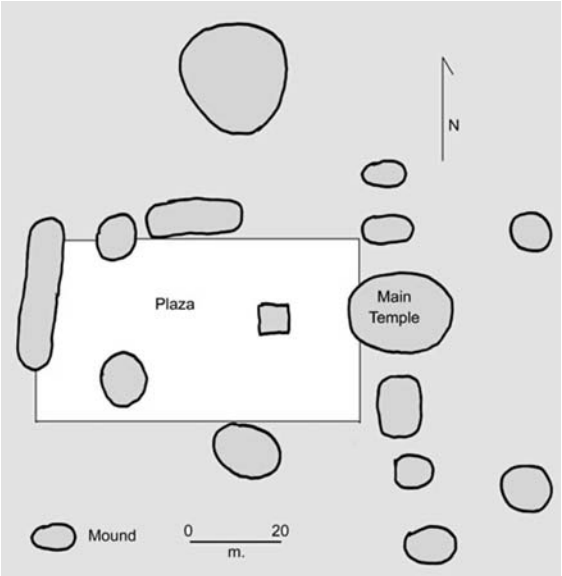
Tenochtitlan's orthogonal layout is seen in the major avenues radiating out from a central ceremonial precinct in the cardinal directions (Fig. 20). The avenues divided Tenochtitlan into four quarters, each with its own smaller ceremonial precinct. Outside of the chinampa areas, houses were packed tightly together. The city of Tlatelolco, with its own impressive epicenter (Fig. 8), was originally a separate town but was later incorporated into Tenochtitlan (González Rul 1998). By drawing on the orthogonal layout of Teotihuacan (Fig. 1), the Mexican rulers proclaimed Tenochtitlan's continuity with the past and its legitimacy as the imperial capital of central Mexico (Umberger 1987).

Cosmological principles also contributed to the form and layout of the capital. The largest structure, the Templo Mayor (Fig. 6), was viewed as the symbolic center of the Aztec empire (Carrasco 1999; López Luján 1994), and it was the setting for elaborate state ceremonies including human sacrifices. The Templo Mayor was built in alignment with sunrise on a key holy day (Aveni 2001), and the entire layout of Tenochtitlan can be viewed as an extension of the sacred orientation of the central temple.

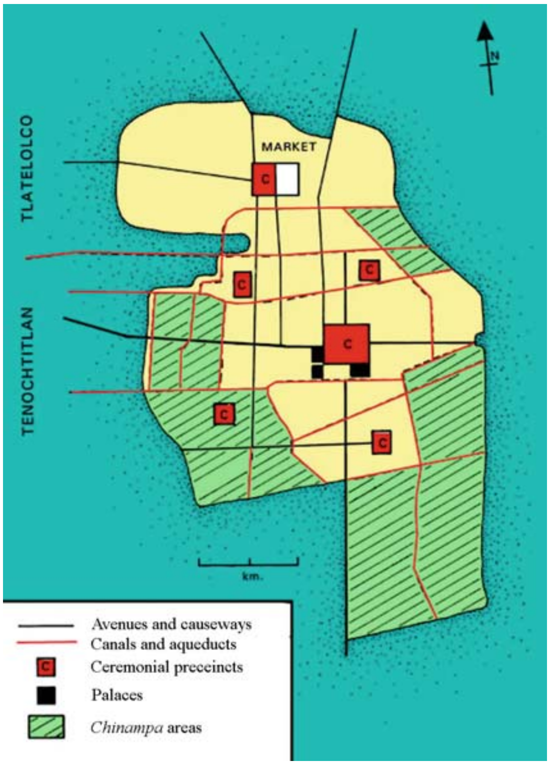
In sum, the planners who laid out Tenochtitlan made radical breaks with past Aztec (and Mesoamerican) norms in two ways. First, they filled the central plaza with buildings. In place of an open plaza is the sacred precinct, a large walled compound packed with temple-pyramids, altars, priests' residences, and other sacred buildings (Fig. 21). The palaces of the Mexica kings



City Planning: Aztec City Planning. Fig. 18 Reconstruction of the plaza at Coatetelco. Modified after Smith (*The Aztecs* 2003: Fig. 8.2); based originally upon Konieczna Z. (1992).



City Planning: Aztec City Planning. Fig. 19 Map of the epicenter of Coatlan Viejo, an unexcavated city-state capital in Morelos. Modified after Mason (1980: 53).



City Planning: Aztec City Planning. Fig. 20 Map of Tenochtitlan. From (Smith *The Aztecs* 2003: Fig. 8.8); based originally upon (Calnek 1972: 108).

City Planning: Aztec City Planning. Fig. 21 The walled "Sacred Precinct" at Tenochtitlan. After Marquina (1951: lámina 55).

were arranged around the outer walls of the precinct. The sacred precinct occupies the place of the public plaza in other Aztec (and Mesoamerican) cities. Second, the imposition of a common grid over the entire city was a radical practice that expressed the power of the rulers to shape their city and differentiate it from other Aztec cities. The orthogonal layout also exemplified continuity with Teotihuacan and resonated with ancient Mesoamerican cosmological principles of the importance of the cardinal directions.

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City Planning: Inca City Planning

Jean-Pierre Protzen

Although the Incas were not great city builders, they redesigned their capital, Cuzco, on a grand scale, and founded numerous new settlements. Ollantaytambo is one such new town. Because it has what "may be the oldest continuously occupied dwellings in South America" (Kubler 1975), and because many parts of the town are well preserved, it would seem the perfect object for the study of the town planning principles of the Incas.

Ollantaytambo is located about 90 km to the northwest of Cuzco at the confluence of the Urubamba and the Patakancha rivers. It is built on a narrow, gently sloping bench of artificially leveled ground squeezed in between Cerro Pinkuylluna to the east and the Patakancha river to the west. It is carefully sited so as not to occupy prime agricultural land, yet to provide easy access to the terraced fields to the north and the south. The glacier-fed Patakancha provides an ample water supply for both agricultural and domestic uses. Tucked in between the high mountains at the mouth of the Patakancha valley, the town is well protected from the fierce afternoon winds which often sweep through the broader Urubamba valley.

The town was laid out on a regular grid, trapezoidal in shape, of four longitudinal and seven transversal streets. The transverse streets, oriented at 110.5° east of magnetic north, are perfectly parallel to each other, suggesting that the Inca were knowledgeable about geometry, and that they had a method of surveying to lay out the streets.

In the time of the Incas, there was a large plaza in the middle of the town. On its north and south sides it was bordered by great halls, long buildings with many openings toward the plaza. If what Garcilaso de la Vega tells us about Cuzco holds for Ollantaytambo, then the plaza was the theater for ceremonies and festivities, and the great halls were the place where the revelers withdrew to pursue their activities on rainy days (Garcilaso de la Vega lib. VII, cap. X; 1976: II,108).

The fifth transverse street manifestly divided Ollantaytambo into two parts with distinct architectural features: the street facing walls in the southern half of town were built of cut and fitted stones, whereas in the northern half they were built of unworked field stones. The blocks in the southern half show a rigorously repetitive block design of two walled-in habitation compounds, called *kancha*, arranged back to back, that is not reflected in the northern half. Cobo stated:

> The Incas imposed in all their kingdom the same division in which the city of Cuzco was divided, Hanan Cuzco and Hurin Cuzco; cutting each town and lordship into two parts or factions called hanansaya and hurinsaya, which means "the upper district" and "the lower district," or the part or faction from above and the faction from below;… (Cobo lib. XII, cap. XXIV; 1964: II,112).

This division, which is a social one and probably has ancient Andean roots, was used by the Incas to control, administer, and inspire their subjects (Cobo lib. XII, cap. XXIV; 1964: II,112). The two moieties were essentially equal, and each was governed by its own leader, with the *hanan* leader having first rank. It is possible, but not demonstrated, that the architectural division observed at Ollantaytambo is a referent to this social division.

Because of the rigor and clarity with which the town of Ollantaytambo has been laid out, one might be tempted to interpret it as an exemplar of Inca town planning. A comparison from a formal point of view with other Inca sites, however, does not sustain this proposition. Outside Ollantaytambo regular grids are only found at Chucuito, on Lake Titicaca, and Calca. The Chucuito grid too is trapezoidal in shape, and that of Calca appears to be strictly orthogonal. It is not known with certainty whether the Chucuito grid is of Inca origin. Calca, on the other hand, is known to have been established by Waskhar, the twelfth Inca. Whether or not the blocks in these two sites were occupied by kancha is not known. Cuzco, the navel of the Inca empire, shows an ordered street pattern, but the grid and the block sizes are not as regular and uniform as those of Ollantaytambo. At least some blocks in Cuzco were built up with compounds very similar to the kancha at Ollantaytambo. Huánuco Pampa, a large administrative center in the central highlands, lacks a regular street pattern, and although there are discernible town blocks, they are quite irregular in size and shape. Many kancha-like compounds are scattered throughout the site, but their design is quite varied and irregular, and the compounds do not define blocks or streets. At Patallaqta, some 20 km downstream from Ollantaytambo, the kancha design is prominently in view. There are two arrangements of kancha; one consists of two kancha, back to back, similar to Ollantaytambo, except that it is not walled in; the other is made of four smaller kancha. Even though the kancha are not walled in, their groupings nevertheless define town blocks and streets. Tambo Colorado, an administrative center in the coastal valley of Pisco, has neatly rectangular compounds, but the center is not built on a grid pattern of streets, and the compounds only remotely recall the kancha design. The only feature common to the sites discussed above appears to be a plaza. At Huánuco Pampa the plaza is huge; it measures about $540 \times 370\ m^2$, is surrounded by buildings on all sides, and is dominated by what must be the largest remaining *usnu*, a ceremonial platform. Two great halls face the plaza on its east side. The plaza, *Hawkaypata*, in Cuzco was also quite large, about $200 \times 250\ m^2$. It too had an usnu, and was bordered with great halls on its north and east sides. Tambo Colorado's trapezoidal plaza is surrounded by buildings on three sides and has an usnu on its fourth side, but no great halls face it. Whether the plaza at Ollantaytambo had an usnu is not established. Thus, if the plaza is a recurrent element of Inca settlements, its configuration is by no means standard.

If no specific town planning rules seem to emerge from the comparison of different Inca settlements with Ollantaytambo, it stands to reason that Ollantaytambo is not representative of Inca town planning. It has been said that the Incas laid out their new settlement in the image of their capital, Cuzco. However, a comparison of the various plans analyzed above does not fare much better; there are no more similarities between Cuzco and the other sites than there are between them and Ollantaytambo. Rowe suggested that Cuzco was laid out in the shape of a Puma. Neither of the plans reviewed can be made to fit this shape. Perhaps similarities between Cuzco and other sites should not be searched for the physical form, but instead, as Gasparini and Margolies (1980) suggested, "in the meaning and the functions of the form." They argue that, if one makes abstraction of the physical form, one will note that certain elements are "repeated with considerable insistence." They list the division into *hanan* and *hurin*, a principal and a secondary plaza, the great halls on the plaza, the *usnu*, the *inkawasi* (house of the Inca), the *aqllawasi* (house of the Chosen Women), the temple of the sun, and the storehouses. In light of the difficulties of attributing specific functions to particular ruins, and the uncertainties regarding a physical referent for the division into *hanan* and *hurin* discussed above, the effort to establish similarities among settlement patterns, and to derive planning canons, is considerably weakened.

The Spanish chronicler Bernabe Cobo described an elaborate set of about 40 lines, called *zeq'e*, radiating out in all directions from the Qorikancha, the holiest of all Inca shrines, in Cuzco. Along each line were arranged a number of sacred places and objects. Each line was the responsibility of a specific royal family of Cuzco. The families were in charge of officiating at the shrines in their care and of providing the appropriate sacrifices on the designated days. Although Tom Zuidema (1964) argued that the zeq'e influenced the plan of Cuzco, and perhaps of other Inca settlements, it is obvious that the radiality of the zeq'e did not affect the city's layout which is orthogonal in its core. As John Hyslop (1990) noted, "it is still uncertain to what degree the Incas are actually portraying zeque systems (even) in radial layouts, or just the principles and spatial relationships found in the system."

Another reason why it may be difficult to extract generally applicable town planning rules is that the various settlements served different functions and were used in different ways. Ollantaytambo, Machu Picchu, and Patallacta discussed above were royal estates, that is the private property distinct and apart from state property, of the ninth Inca Pachakuti, and Calca was an estate of the Inca Waskhar. Cuzco, on the other hand was the all important capital of the Inca Empire, whereas Huánuco Pampa, like Tambo Colorado, was a regional administrative center in a newly conquered territory. The different types of settlements may have operated and functioned along different lines, such that any comparison may be spurious. Little is known about life in Inca settlements. Of Cuzco, Pedro Sancho de la Hoz, Francisco Pizzaro's personal secretary, wrote that it "was so large and so beautiful that it would be worthy of being seen even in Spain," and he added that it was "full of palaces of the lords, for in it there lived no poor people." What Sancho described referred probably only to the core of the city, for it is known that there were people from every corner of the empire also living in Cuzco. Of life in Cusco Protzen and Rowe (1994) wrote:

> Street life was probably limited to the movement of people from one place to another, with a stop perhaps for a bit of gossip, or to fetch water from the canals. There was no mercantile activity in the streets and there were no storefronts. Most residential and religious compounds [or *kancha*] were surrounded by walls with only one doorway giving access to the street. Supplies for sustenance of daily life were delivered directly from the state warehouses to the compounds. All production, weaving, wood and metal working, pottery, brewing, baking, and so forth was carried out within the compounds. On official occasions, civil or religious, the street scene may have been animated by parades and processions: the Inca being carried around town in his litter with the requisite entourage of nobles and bodyguards; the arrival of a dignitary from the provinces accompanied by llama trains loaded with gifts of all kinds; the triumphant return of a war party, with soldiers displaying their loot and parading prisoners; or a solemn religious procession, with priests in colorful attire carrying idols and other paraphernalia.

It is not known to what extent what happened in Cuzco can be extrapolated to other Inca towns. There are very few eyewitness accounts of life in other places of the Inca Empire. Little is known about the organization, function, and operation of royal estates. However, as in the case of Ollantaytambo, one can assume that there was a royal residence for the Inca and his immediate entourage, that there were accommodations for the accompanying nobility and administrators, and that there were quarters for the servants. Yet, the layout of the settlement, its size and its architecture, suggest that it was more than just a rural retreat with its requisite appendices. It has the character of an agglomeration in which a population of perhaps a thousand people was permanently settled.

Discovering general planning principles may be, at least in part, also complicated because the principles, whatever they were, may have been altered to fit the specific features of a site and its topography.

In Cuzco, in spite of colonial modifications, the major features of the Inca plan can still be appreciated. The grid-like street pattern was squeezed and bent into the neck of land between the Watanay and the Tulumayo rivers to conform to the Puma shape. At Patallaqta the street pattern also is grid-like, yet it is shifted and broken to fit the crescent-shaped plateau on which it is built. At Machu Picchu, where the terrain is much more accidented, or broken, than at Patallaqta, the intent of an orthogonal layout can still be detected. Alleyways and staircases generally cross at right angles. The modifications brought to the layout are subtle adaptations to the specific topography. Streets and alleyways, like the terraces, follow the contour lines, and staircases follow the terrain's fall lines. The town occupies two natural ridges, and is completely split into two sectors by a plaza which is molded into the saddle between the ridges. The kancha are squeezed, stretched, and distorted to fit the available space on the terraces, as they do at Wiñay Wayna, about an hour from Machu Picchu.

One of the most striking site planning efforts, and some of the most spectacular adaptations of building forms to suit the particular terrain, are seen at Phuyupatamarka. The buildings literally grow out of the bedrock and espouse the terrain to become one with the site; the man-made world again is inseparable from the natural world.

Today's tourists, arriving at Machu Picchu by train and bus, miss one of the most important features of Inca site planning; they are deprived of the dramatic encounter with the site the ancient traveler experienced when coming through the gate of Intipunku. That encounter involves a succession of open spaces that are scaled from the vast horizons of the Andes to the intimate courtyard in town, strung together by narrow passages over precipitous cliffs, steep staircases, alleyways, and gates. Along this pathway the site is veiled and unveiled in a sequence of vistas that reveal the lay of the land and the setting of the town, and attract attention to details of nature or architecture framed by narrow passages or gates.

The gate of Intipunku affords a distant view of Machu Picchu, still too far away to discern individual architectural features, but close enough to grasp its general layout, and to appreciate its scenic setting and subtle incorporation into the majestic landscape. When one descends the trail from Intipunku, Machu Picchu disappears from view completely only to reappear in a succession of mere glimpses. Only when one rounds the bend in the trail, just below the so-called Watchman's House, does the site reveal itself again in its entire splendor, spread out immediately at one's feet with the sugar loaf peak of Wayna Picchu looming over it. Continuing down the stairway toward the main gate, most of the site vanishes again, and it is not until the very last step before the gate that Wayna Picchu is unveiled again in a dramatic view, perfectly framed by the gate.

Moving on through the site, one's view is alternatingly constrained by high walls bordering the alleyways and broadened as one emerges onto a staircase, a terrace, or an open space. There is a progression from the open and public spaces through narrow alleyways and gates to the enclosed and private spaces. At many junctures, one's attention is drawn to important features in the landscape. Sometimes this is achieved by narrowing one's field of vision, sometimes by widening it. The windows of the Temple of the Three Windows concentrate the view upon the half dome of Putukusi to the east and to the west the plaza, defined by the temple and the two buildings which flank it, opens wide to a sweeping view of the snow-capped Cordillera Vilcabamba and its many sacred peaks.

Machu Picchu is not unique in this; orientations upon features in the landscape are rather common in Inca architecture and can be observed at many other sites.

The rigid street grid of Ollantaytambo was by no means the norm for Inca settlements. Where regularity in the layout of the streets is found, it is probably a by-product of the rectangular design of the kancha, and not so much a reflection of the intent to parcel out the land in a grid. In accidented terrain the kancha and the building forms were "deformed" and modified to adapt to the topography, rather than made to conform to an abstract principle. While some commonalities and the repetition of certain elements can be observed at various sites, there is simply not enough empirical evidence available to induce a set of formal town planning rules by which, if they existed, the Incas laid out their settlements. It may be that the incorporation of views and the orientation on architectural and landscape features was the all-pervasive site and town planning criterion. To support this hypothesis, if it is at all tenable, many more sites will need to be analyzed dynamically; that is, as one moves through the sites rather than by merely investigating their plans.

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City Planning: Maya City Planning

Rubén G. Mendoza

Much of ancient Maya civilization flourished in the period from AD 250 to 900 in the area encompassing the whole of Mexico's Yucatan Peninsula, the Mexican states of Chiapas and Tabasco, and the countries of Belize, Guatemala, western Honduras, and El Salvador. During the course of nearly twenty centuries of development, the distinctive architectural styles of the Maya heartland evolved and collapsed. As with other aspects of the Native American legacy, ancient Maya architecture was once seen as far too sophisticated to have been the product of aboriginal genius, and was long credited to Old World voyagers ranging from Egyptians to Israelites, and from white men or Danes to "great white Jewish Toltec Vikings" (Silverberg 1968).

As scholarly knowledge of Maya architecture, settlement patterns, and city planning has grown exponentially over the course of the last 60 years, so too has our respect and admiration for this ancient American tradition (Morley 1983). Until quite recently, scholars perpetuated the belief that the Maya had neither a literate tradition or history, nor true cities or political economies. They often typecast Maya architecture as inferior, because it did not employ the "true" arch in the Roman sense. And they were unable to demonstrate that Maya centers were planned and constructed under the direction of professional architects with drafted plans. Given the geomantic principles, astronomical alignments, and geometric sophistication inherent in Maya cities, it would be more difficult to demonstrate that the Maya had no such architects or recorded plans. This review will begin with an overview of the role of astronomy, cosmology, and geomancy in Maya architectonic arrangements, and then move to a broader consideration of the question of site planning in the ancient Maya heartland.

Maya Architecture, Sculptural Programs, and Cosmology

Archaeologist and architectural historian H. E. D. Pollock has defined ten primary architectural and planning styles for the lowland Maya heartland. To these may be added another four highland Maya areas that I believe may be distinguished for the Quichean highlands of southern Guatemala, the Cotzu-malhuapan Pacific coastal tradition, the Middle Classic (AD 400–650) styles of Kaminaljuyu and vicinity, and the hybrid regional developments of the present-day state of El Salvador.

Where the Maya lowlands are concerned, Pollock describes the influence of environment and topography on planning and architectural layout:

> The flood plains of Copan and Quirigua; the flat or gently sloping banks of the Pasion River; the steeply rising hills along the Usumacinta River; the mountainous shelf of Palenque and alluvial plain of Comalcalco; the low, wet, but often sharply broken terrain of the Peten; southern Campeche; and southern Quintana Roo; the savannas, valleys, and hills of the Chenes and Puuc regions; and the flat northern Yucatan plain all offered different opportunities and challenges to the ancient builder.

Custom was mediated by local and regional environmental conditions and the adaptive traditions which arose from them. Clearly, civil planning developed well beyond the purely "organic" (Andrews 1974) organization of monuments oriented to topographic and natural features of the immediate environment. Even in the earliest periods of Maya city planning, cosmological, astronomical, ritual, genealogical, and dynastic variables were integrated into site plans and construction programs. Plans were formulated in terms of multiple variables, not the least of which were the mechanistic dimensions of astronomical and cosmological cycles and dimensions, and the organic or topographic, and natural or practical realities of urban planning.

The period immediately preceding the Classic period was a time of great dynamism. According to archaeologist C. Bruce Hunter, "between 600 BCE and AD 250 great activity in city planning was taking place all over Mesoamerica. Cultural areas were defined, ceremonial complexes in the heart of the cities were constructed, and trade routes and luxury goods fostered trade competition between regions." Many of the greatest urban centers were built at this time. By the end of the Preclassic era – ca. AD 100 – Tikal and Uaxactun in the Peten lowlands and Cerros and Cuello in Belize had added to the architectural traditions of the era. The ancient cities of Dzibilchaltun in the northern lowlands, El Mirador in the southern lowlands, and Kaminaljuyu in the Guatemalan highlands defined the ceremonial construction for each of these subregions.

On the basis of recent glyphic transcriptions, we can now say that the iconography and architectural order inherent in the earliest city planning incorporated cosmological, dynastic, ritual, architectonic, and geomantic principles used in the organization of sacred geography and the built environment. My own study of the sculptural program embodied in the architecture and planning of the rock-cut temples of Malinalco, Mexico, and Carolyn Tate's more recent architectural survey of the ancient Maya center of Yaxchilan provides compelling evidence for Mesoamerican site plans based on pre-Columbian solar configurations or cosmograms, as well as the use and deployment of solstice-based axial alignments in city planning (Mendoza 1975; Tate 1992).

Geomancy and Maya City Planning

Geomancy, referred to as "mystical ecology" and as cosmological ecology or sacred geography, was the ancient Chinese practice of situating burials, monuments, and entire towns on the basis of cosmological principles. Because ancient Chinese scholars documented this practice so extensively, it is largely identified with Chinese civilization, although recent studies make clear the use of geomancy in ancient Mesoamerica (Freedman 1969).

Much of the divinatory practice embodied in geomancy is particularly relevant to Mesoamerican, and specifically Maya, city plans. According to John

Carlson, geomancy is “a divinatory art involving the interpretation of local topographical features for the purpose of properly locating and orienting the constructions of man – be they graves, houses, or entire cities.” However, Carlson has redefined geomancy as a:

> profound system of thought, deeply rooted in ancient and fundamental oriental philosophy and involving perception of the dynamic balance of the controlling forces of nature. It is the system in which man divines his own place in relation to the play of these forces, and it is the mechanism by which he can influence them in order to re-establish equilibrium when imbalance is perceived (Carlson 1981).

Maya city centers all provide archaeological evidence for the interpretation that plans were based on cosmological and geomantic models; however, few such sites have been examined with such principles in mind. Recent studies, such as those of William Rust (1992), Jeremy Sabloff and Gair Tourtellot (1992), Wendy Ashmore (1992), Robert Sharer (1990, 1992), and Carolyn Tate (1992), make clear the ancient Olmec connection to Maya ceremonial and settlement planning, the influence of changing economic and demographic patterns on planning, the icons of power, divinity, and divine mandates invoked through creation myths and expressed through architectural vocabularies and sculptural programs, the concentric patterning of civil monuments, and the deployment of solar cosmograms in site planning, respectively. We shall examine one site in detail.

Yaxchilan

The site of Yaxchilan, Chiapas, which overlooks the Usumacinta River separating Mexico from Guatemala, is one site that has been examined from the perspective of world plan as embodied in city plan. The site underwent dramatic transformations in construction during the reigns of Shield Jaguar, his father Bird Jaguar III, and his grandfather. The site was altered to establish “specific axes of solstitial orientation for architecture depending on the function of the building or space or the message of its sculptural program, and was conceived to define ritual areas used by particular rulers” (Tate 1992). Yaxchilan was constructed on an elongated shelf and used terraces, tiers, and elevated plaza-platforms within the context of a larger acropolis-centered pattern. Yaxchilan also incorporated a series of hills into the larger plan of the site, and was situated in a position providing the only unobstructed vantage point from which to observe solstice alignments between major buildings and prominent mountain peaks – serving as clefts in the horizon and as points of astronomical reference. Other recent observations document that major buildings at Yaxchilan were devoted to rites of passage – particularly those pertaining to dynastic accession, succession, calendrically based Period Endings, and to the capture and sacrifice of living kings. Such monument are oriented with respect to the eastern horizon and the summer solstice, whereas funerary chambers and obituary monuments and stelae are oriented along solstitial axes pertaining to the winter solstice at 118° east of magnetic north. Several of the obituary monuments and funerary shrines in question are aligned to 115°–116°, as opposed to the more exacting 118° east of magnetic north; apparently so as to allow for the use of doorways with half-quatrefoil overhead jambs to provide for architectural-solar hierophanies, or light and shadow patterns serving to record the passage of summer and winter solstice events. Such information provides a direct correspondence with ancient Maya identifications of the summer solstice with royal and/or divine renewal and the planet Venus, and the cosmological association of the southern horizon with caverns as the portals to the underworld, the moon, and the land of the dead. The fact that Yaxchilan’s southern precinct skirts the mouths of two prominent caves is cosmologically significant. According to Carolyn Tate, the caves “must have played a role in Bird Jaguar’s decisions on how to shape the ritual landscape” (Tate 1992).

Major buildings, monumental stelae, altars, and ritual markers from Yaxchilan all bear orientations that speak to political and ritual events. Buildings were aligned horizontally, and “situated from high to low vertically” (Tate 1992). By employing “alignments of stelae that conceptually linked the reigns of successive rulers,” the architects and planners coordinated the organization of the royal house of that era.

Recent studies at the sites of Tikal and Quirigua (Guatemala), Cerros (Belize), and Kohunlich (Mexico) provide dramatic examples of the means by which Maya world view and the realm of the supernatural were incorporated into city planning in a manner reminiscent of Christian, Muslim, Buddhist, and Hindu towns and cities of the Old World. While the sites of Cerros and Kohunlich provide architectural arrangements centered on monumental depictions of solar, lunar, terrestrial, and venusian cosmograms, the sites of Tikal and Quirigua incorporate these same dimensions in addition to those iconographic vocabularies and Twin Pyramid groups and precincts intended to symbolize the Classic Maya conception of the cosmos. Maya city planning has only recently undergone scrutiny with an eye to the larger mechanistic and organic dimensions and concepts of time and space inherent in Maya planning and design of the built environment. Wendy Ashmore has recently identified what she deems the five principle components of the Maya pattern pertaining to Tikal and related sites, these are (1) north–south axial arrangements, (2) complementary and paired functions of buildings centered along the main axes that serve to demarcate supernatural and celestial from underworld or terrestrial dimensions, (3) subsidiary eastern and western monumental arrangements within precincts providing for a triangulation with monuments located on the northern perimeter of individual precincts – and identified with the celestial vault and the cosmic tree of the north, (4) ball courts as transitional zones between north and south, and (5) the construction of causeways and paved roads linking precincts into a symbolically coherent cosmogram. To this listing I would add specific buildings that embody solar cosmograms and cosmic templates, as well as sculptural programs and iconographic vocabularies deployed across whole sites to imbue them with a sacred geography and cosmological ecology (Mendoza 1977). We can no longer assume that the Maya built in a random and largely organic fashion – by accretion and accommodation as opposed to design and structure. Primitivist and eurocentric portrayals of the ancient Maya have eroded in recent years under the onslaught of a new world order reinterpreted on the basis of surviving hieroglyphic stairways, monumental texts, commemorative stelae, funerary shrines, frescoed murals, painted ceramics replete with textual information, and pre-Columbian and contact period codical documents and screenfold books. These sources are now providing a revolutionary perspective on the Maya (Schele and Freidel 1990).

See also: ►Geomancy in China

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Clocks: Astronomical Clocks in China

Christopher Cullen

Timekeeping was a necessary preoccupation of the Chinese imperial state from its inception in the third century BCE. It was essential to the effective performance of ritual, which required the selection of auspicious hours as well as days, and to the proper interpretation of the astrological portents carefully recorded by the Astronomical Bureau. In addition it underpinned the fine tuning of increasingly elaborate systems of mathematical astronomy. The earliest devices used by astronomers were simple outflow or inflow waterclocks (clepsydras), which depended on the flow of water from a vessel to a small orifice. A graduated float indicated the time elapsed. Several later sources mention the Han dynasty scholar Zhang Heng (AD 78–139) as having succeeded in rotating an armillary sphere by means of "flowing water" so that it kept time with the heavens.

More detailed accounts survive of a similar project under the Tang dynasty in the eighth century AD, when the Buddhist monk Yixing and his colleague Liang

Lingzan made a water-powered armillary sphere, which incorporated jack-work to announce the hours and quarters by bells and drums. In neither case we have enough data to begin to reconstruct the mechanism involved. However, in AD 1086 the high official and scholar Su Song was commissioned to construct an astronomical timekeeper which was to be much more complex than any of its predecessors, and a detailed illustrated description of this device has come down to us in his monograph entitled *Xin yixiang fa yao* (Description of a New Astronomical Instrument or New Design for an Armillary Clock).

From this book we learn that the device Su Song constructed was in effect a clock-tower more than 10-m high, surmounted by a great bronze armillary sphere automatically rotated, with a rotating celestial globe in an inner chamber. On the front of the tower was a complex array of jacks and annunciators to mark the passage of time. The mechanism which turned the shafts was based on a great water-driven scoop wheel, with a weighbridge and trip-lever movement which allowed the wheel to advance one step each time a standard weight of water had run from a constant-head tank. This happened once every hundredth of a day, about 15 min, so that the correspondence with the heavens was somewhat jerkily maintained. While the utility of this device to astronomers can only have been moderate, its possession must have been seen as a considerable enhancement to imperial prestige. Su Song's tower fell out of use when the capital fell to invaders in AD 1126.

See also: ►Zhang Heng, ►Divination in China, ►Calendars in China

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Clocks and Watches

Donald R. Hill

There was a long tradition in the Hellenistic world for the construction of large water clocks. Vitruvius, writing in the first century BCE, mentions the water clocks constructed by an Alexandrian engineer called Ctesibius (ca. 300 BCE) which incorporated gearing, automata, and audible time signals. The Alexandrian writer Hero, who flourished around AD 60, is known to have written a book on water clocks. The Byzantine historian Procopius described a monumental water clock constructed at Gaza in the sixth century AD. It is almost certain that the inspiration for the construction of water clocks in the Islamic world came from this Hellenistic tradition.

Islam

Monumental water clocks are described in detail in two Arabic treatises. Al-Jazarī in his machine book *Kitāb fī maʿrifat al-ḥiyal al-handasiyya* (The Book of Knowledge of Ingenious Mechanical Devices), completed in Diyar Bakr in 1206, describes two such machines. Riḍwān ibn al-Saʿātī, in his treatise *Kitāb ʿamal al-sāʿāt wa ʻl-ʿamal biha* (Book on the Construction of Clocks and on Their Use) dated 1203, describes the water clock built by his father Muhammad at the Jayrun gate in Damascus. It fell into disrepair after Muhammad's death and was restored to working condition under his son's supervision. It was a large construction, having a timber working face about 4.73 m wide by 2.78 high, built into the front of a masonry structure. The clock had several design defects which undoubtedly caused the breakdown that Riḍwān undertook to repair. Moreover, Riḍwān himself was not an engineer and his description, though containing some valuable information, omits to deal with some important constructional details.

Al-Jazarī's two clocks, on the other hand, were manufactured and constructed in a very workmanlike manner. Although very similar in principle to al-Saʿati's they did not incorporate any design defects. The first and larger of the two was described in such careful detail that it was possible to construct a full-size working facsimile from al-Jazarī's instructions and illustrations for the World of Islam Festival, in the London Science Museum in 1976.

The working face of the clock consisted of a screen of bronze or wood about 225 cm high by 135 cm wide set in the front wall of a roofless wooden house which contained the machinery. At the top of the screen was a zodiac circle about 120 cm in diameter, its rim divided into the 12 signs. It rotated at constant speed throughout the day. Below this circle were the time-signaling automata which were activated at each hour. (The clock worked on "unequal" hours: i.e., the hours of daylight or darkness were divided by 12 to give hours that varied in length from day to day.) These included doors that opened, falcons that dropped balls on to cymbals and the figures of five musicians – two drummers, two trumpeters, and a cymbalist. The musicians were operated by the discharge of water from an orifice, whereas all the other automata were operated by a heavy float that descended at constant speed in a reservoir. A cord tied to a ring at the top of the float led to a system of pulleys that activated various tripping mechanisms.

The speed of descent of the float was controlled by very ingenious water machinery that included a feedback control system and a flow regulator, the latter for varying the rate of discharge daily in order to produce the "unequal" hours. The same system was used by Riḍwān and both writers attribute its invention to Archimedes. There is a treatise that exists only in Arabic and is attributed to Archimedes. The treatise almost certainly contains Hellenistic, Byzantine, and Islamic material but its first two chapters describe water machinery that is essentially the same as that used by Riḍwān and al-Jazarī. There is every likelihood that these chapters were indeed the work of Archimedes.

Al-Jazarī's book also contains descriptions of four other water clocks, two of which embody the principle of the closed-loop, and four candle-clocks which, on a small scale, are as impressive from an engineering point of view as the water clocks.

Other Arabic works add to our knowledge of Islamic hydraulic timekeeping. A certain Ibn Jalaf or Ibn Khalaf al-Murādī worked in Andalusia in the eleventh century. Unfortunately, the unique manuscript of his treatise on machines is badly defaced, but it is possible to determine the essential details of the automata and water clocks that are described in it. The most important feature that they incorporate is complex gear-trains which include segmental gears (i.e., gears in which one of the wheels has teeth only on part of its perimeter, a device that makes intermittent action possible).

Al-Khāzini's justly famous book on physics, *Kitāb Mīzān al-Ḥikma* (Book of the Balance of Wisdom) was completed in 1121–1122. In the eighth treatise two steelyard clepsydras are described. On the short arm of the beam was a vessel that discharged water at a constant speed from a narrow orifice. Two sliding weights were suspended to the long arm, which was graduated into scales. At a given moment the weights could be moved to bring the beam into balance and the time could then be read off from the scales.

A number of noteworthy references to water clocks can be found scattered among the works of Arabic writers. For example, we read of one such device in the works of the Anadusian poet ʿAbbās ibn Firnās (d. 887). Two water clocks were constructed by the famous astronomer al-Zarqallu in 1085 on the banks of the river Tagus at Toledo. The remains of two large water clocks still exist in Fez, Morocco. One of these is in the street opposite the Bu'ananiyye Madrasa and was built in 1357. According to the historian of Fez, Al-Jazna'ī in *Zahrat al-Ās*, at each hour pellets fell onto a gong and a pair of door leaves opened. The door openings and the brackets for the gongs still exist. A second clock was constructed in 1361. It had an astrolabic dial and it also released pellets and had doors that opened. It is in the minaret of the Qarawiyyīn mosque. The doors and the dial still survive, but in neither of the Fez clocks does any trace of the water-machinery remain. Another North African water clock, in Tlemcen, was mentioned by Abū Zakariyyā Yaḥyā ibn Khaldūn in *Bughyat al-ruwwād*.

In 1276–1277 a work entitled *Libros del Saber de Astronomia* was produced in Castilian under the sponsorship of Alfonso X of Castile. This consists of various works that are either translations or paraphrases of Arabic originals. It includes five timepieces, one of which is of significance in the history of horology. This consisted of a large drum made of walnut or jujube wood tightly assembled and sealed with wax or resin. The interior of the drum was divided into 12 compartments, with small holes between the compartments through which mercury flowed. Enough mercury was enclosed to fill just half the compartments. The drum was mounted on the same axle as a large wheel powered by a weight-drive wound around the wheel. Also on the axle was a pinion with six teeth that meshed with 36 oaken teeth on the rim of an astrolabe dial. The mercury drum and pinion made a complete revolution every 4 hours and the astrolabe dial made a complete revolution in 24 hours.

This type of timepiece had been known in Islam since the eleventh century.

China

The commonest method of timekeeping in China, for many centuries, was the inflow clepsydra. In its simplest form this consisted of two vessels: a reservoir and a receiver below it. The reservoir had an overflow pipe near its top and an orifice in its underside. The water supply ran into the reservoir and the overflow pipe ensured that the water level remained constant. The rate of flow from the orifice into the receiver was therefore also constant as was the rise of the water in the receiver. A float in the receiver was used to activate various time-recording mechanisms.

The inflow clepsydra was used extensively in China from the Han period (202 BCE to AD 221) onwards. Two main types were developed. The first type involved the introduction of one or more compensating tanks between reservoir and receiver. At each successive stage the retardation of flow due to diminishing pressure head was more and more fully compensated. The introduction of at least one compensating tank can be dated to the second century AD. As many as six tanks are known to have been used. In the second type an overflow or constant head tank was placed in the series, a practice that began in the middle of the sixth century AD. There can be no doubt that this type of water clock was widely used in China throughout the medieval period.

The most notable achievement of Chinese horologists was the clock described by Su Song in *Xīn yixiang fa yao* (New Design for an Armillary Clock or Description of a New Astronomical Instrument) begun in 1088 and completed in AD 1094. This was a monumental clock, 30–40 ft (9–12 m) in height, having a rotating armillary sphere and celestial globe, together with numerous jack-work figures with both audible and visible effects. These devices were driven, through a complex system of gearing, by a water-wheel 11 ft (3.35 m) in diameter carrying 36 scoops on its perimeter. Water stored in an upper reservoir was delivered to a constant-level tank by a siphon, whence it was discharged on to the scoops of the wheel, each of which had a capacity of 0.2 ft^3 (.6 cm). The wheel was provided with a very ingenious escapement system, in essence two steelyards upon each of which the scoops acted in turn. When a scoop was full, its weight overcame the balancing system and it fell freely for a given distance until checked, without recoil, by a locking device. The next scoop then came under the delivery jet and the cycle repeated itself. There is no evidence that the system of escapement used in Su Song's clock was ever transmitted westward.

The mechanical clock was invented in western Europe toward the end of the thirteenth century. Almost certainly its inventor came from the ranks of the makers of water clocks. The verge escapement made the mechanical clock possible, but all its other features – weight-drive, automata, gear-trains, and segmental gears – were present in Islamic water clocks. It is highly probable that these ideas were transmitted from Islam to the European makers of water clocks. An Islamic influence on the genesis of the mechanical clock may therefore be postulated.

Several of Taqī al-Dīn's writings are concerned with timekeeping, and one of these, *Al-kawākib al-darriyya fī al-binkāmāt al-dawriyya* (The Brightest Stars for the Construction of Mechanical Clocks), written about 973/1565, has been edited with Turkish and English translations.

In this he described the construction of a weight-driven clock with verge-and-foliot (an early form of balance) escapement, a striking train of gears, an alarm, and a representation of the moon's phases. He also described the manufacture of a spring-driven clock with a fuzee [a conical pulley or wheel] escapement. He mentions several mechanisms invented by himself, including, for example, a new system for the striking train of a clock. He is known to have constructed an observatory clock and mentions elsewhere in his writings the use of the pocket watch in Turkey. This is a surprisingly early reference to the use of watches in Turkey; the manufacture of watches began in Germany about 1525 and in England about 1580.

Taqī al-Dīn's descriptions are lucid with clear illustrations, showing that he had mastered the art of horology. Clockmaking did not, however, become a viable indigenous industry and Turkey was soon being supplied with cheap clocks from Europe. Taqī al-Dīn himself commented on the low price of these European clocks, which entered Turkey, he said, from Holland, France, Hungary, and Germany.

See also: ►Al-Jazarī, ►Al-Khāzini, ►al-Zarqallu, ►Ibn Khaldūn, ►Alfonso X, ►Su Song, ►Taqī al-Dīn

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Coir in India: History of Technology

K. T. Rammohan

Coir, a natural fibre used extensively to make brush, spin yarn, twist rope, and weave carpets, is obtained from coconut. The coconut tree (*Cocus nucifera*) grows in many tropical countries but chiefly in India, Thailand, Sri Lanka and the Philippines. Within India it grows best on the southwest coast of Malabar, especially in the state of Kerala. Europeans and Arabs used to refer to it as the Indian Nut. One of the earliest references to its production in Kerala appears in a temple inscription of tenth century, which refers to the fruit as *tengai* and lists it as a major source of revenue to the temple. *Ten* means the south, probably indicating its arrival from South Sea Islands and/or Sri Lanka by the sea. While there is inscriptional evidence of coconut groves from this period, really large-scale cultivation – turning almost the whole region into a vast coconut grove – begins from the sixteenth century. For the people of Kerala, the coconut tree is what the reindeer is to the Eskimos; it fulfils many needs.

The coconut tree with its long trunk – very rarely branched – stands tall on sandy tracts adjoining the sea and backwaters. It yields fruits – coconuts – about three-quarters the size of a football. These are green on the outside when tender, turning into brown as the coconut ripens. Coconuts are usually plucked by a male worker climbing up the tree using a loop grip-chord at the ankles. Sometimes, to ease labour, a single bamboo (*Dendrocalamus strictus* or 'male bamboo') is leaned against the tree and used to gain the first long ascent from the ground – the branches extending from the nodes of the bamboo serving as steps – while the rest of the climb is completed using the loop grip-chord. On reaching the top, the climber cuts off bunches of coconuts with a knife and drops these to the ground. The nuts are picked from the ground, collected and carried in bamboo and reed baskets, mostly by women.

Only male workers of specific castes group engage in plucking coconuts. Usually they do not take up other work. The collecting women could be of any caste and are not restricted solely to this activity. Even today the wages of the climber and the collectors are paid partly in coconut. Over the past two decades semi-mechanical devices for tree climbing have been introduced but these have not gained popularity as experienced climbers do the job much faster.

A hard shell with an outer cover of fibrous mass protects the coconut kernel. The coconut is first removed of its husk with an iron spike or a knife. To obtain the kernel the inner shell is cracked, yielding two, fairly hemispherical pieces, brown on the outside and white inside. The coconut kernel is an important component of the everyday diet of the people of Kerala and is their chief source of oil for cooking and anointment. It is the coconut husk obtained while cutting up the coconut for kernel that yields fibre. Coir is thus the product of a by-product obtained in coconut cultivation.

Yet, of the several industries associated with the coconut tree in Kerala, the coir industry is the most important in terms of employment and investment. The use of Malabar coir yarn and rope for maritime purposes internationally has a history that may be traced to the thirteenth century or even earlier. Coir yarn was used to stitch together the planks of a ship and ropes were used to tie the sails to the mast. Coir ropes were also used in fishing. Weaving of coir matting or carpets on the Malabar Coast dates back to the nineteenth century. For the poor in Europe, coir matting substituted for expensive carpets, while for the rich it served as an underlay for expensive carpets. Coir fibre was used in upholstery and in making brush mats. While coir yarn was widely used locally for agricultural purposes, mat and matting were woven primarily for the world market.

Initially, coir fibre and yarn were exported from Kerala to Great Britain where these were woven into brush mat and matting. As coir fibre is bulky, transport over long distances was uneconomical. Baling presses could not gain wide acceptance because baled fibre was hard to tease. From the mid-nineteenth century, carpet weaving factories were set up in Kerala's port towns, initially under the initiative of British capital and subsequently by local entrepreneurs – although

Drawing: T. Anil

Coir in India: History of Technology. Retting.

Coir in India: History of Technology. Defibering.

export of fibre and yarn and its processing elsewhere continued. The expansion of the coir matting industry and the consequent rise in demand for raw material yarn prompted changes in the scale and technology of spinning. Unlike weaving, which was conducted in factories spinning was household production. It continues to be so even today.

To produce fibre, the coconut husks are first treated in saline water (retting) and the fibrous mass removed from its semi-hard shell by hand (ripping). That is beaten with a rod to yield tufts of fibre (defibering), and finally cleaned by throwing up in the air. The husks are carried by big, country canoes along canals to the backwater for saline water soaking. To soak the husk, a big, circular net of coir is stretched across the water surface and stacked with husks. A worker standing on the backwater bank throws husks into the net. Workers standing waist-deep in the backwater arrange the husks in layers, one over another, in the net. Usually, 10,000 husks are stacked in a net. The stacked husks are covered with plaited coconut leaves and tied together on the top, crisscrossed with coir strings. The husk mass is then punted to the interior of the backwater and covered with mud and stones dug out from the backwater bed. The plaited coconut leaf cover and mud ensure that the husks do not dry up in the sun. As the husks absorb water, since they are burdened with heavy stones, the husk mass sinks a little. To distinguish between husk mass sunk by different owners, small metal discs bearing the initials of the owner or a number code are inserted into the husk mass.

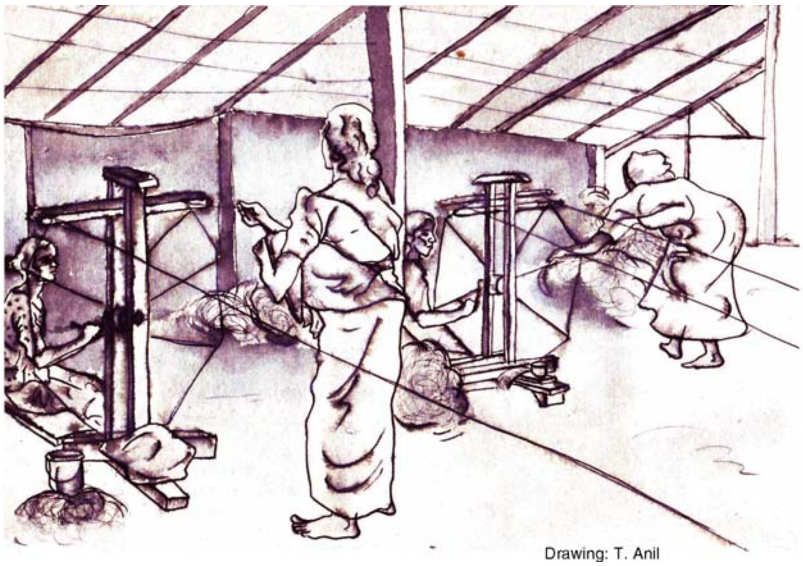
The husk mass remains in water for a period ranging from six to eight months or even more. Flushing washes away tannin and facilitates bacterial action that decomposes the fibre-binding pectin. Salinity lends strength to the fibre. The husk mass becomes heavy after retting and has to be brought back to the backwater bank in a canoe. Workers standing waist-deep in the backwater untie the retted husk mass and throw the husks into the canoe. The retted husks are unloaded at the defibering sites that are usually located on the bank. Women workers carry these as head load to the work spot. Male workers, usually drawn from subordinate caste groups, do the entire retting operation.

In certain parts of Kerala retting is carried out by burying the husks under the beach sand. Retting in small ponds in the homestead is also in vogue. Unlike backwater retting, which is a male preserve, women undertake retting in beach sand and ponds. The defibering mills that have been built in the past few years do away with the retting operation and defiber the green husks. The fibre so produced has to be soaked for a few days in saline water later. Even then, its quality is inferior to that produced by retting.

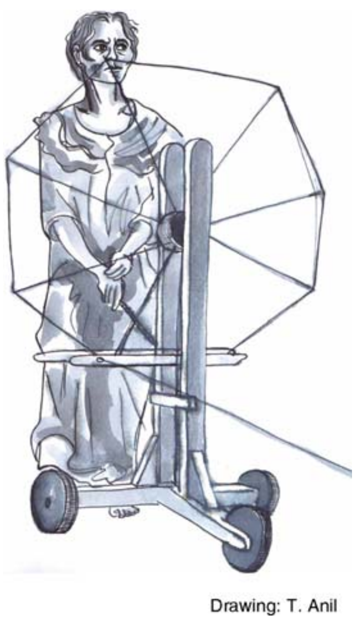
Defibering or separating fibre from the retted husk is done entirely by women, mostly of subordinate caste groups. The worker squats on the ground and rips off with her hand the loosened fibrous mass from its semi-hard shell. She then places the fibrous mass on a flat stone or wood and gently beats it with a small iron or metallic rod. A few beatings and the black, retted husk turns into a tuft of golden brown fibre.

A large quantity of fibre dust or pith is produced in defibering. Accumulated pith makes small hills on the backwater side. This is occasionally removed and used as a saline input or as ash in coconut groves and vegetable gardens. More recently pith has been put to new uses. It is baled into pith bricks for use in indoor gardening or into pith logs to block soil erosion. Like other coir products these also enjoy global demand.

Defibering work is backbreaking. The long working hours, continuous exposure to sun and rain, the uncomfortable squatting posture, contact with fibre particles and dust, and lack of a balanced diet because of the very low wages often cause women's health to deteriorate. There had been attempts to mechanise the defibering operation beginning from the nineteenth century, but these were given up as employing labour was cheaper and capable of producing better quality fibre as compared to the mechanical process. Attempts at mechanisation occurring in the latter half of the twentieth century were defeated by workers who were faced with the threat of unemployment. Over the past decade, however, defibering mills that can process large quantities of raw husks have been established.



Coir in India: History of Technology. Spinning.



Coir in India: History of Technology.

As with defibering, only women workers and mostly of subordinate castes spin coir yarn. Traditionally the fibre was spun into yarn by rolling between the palms. With the expansion in international demand for coir carpets and therefore for yarn for weaving in the mid-nineteenth century, spinning wheels were introduced. A woman worker – most often a child or an old woman – rotates the fixed wheel while two other women workers walk backwards feeding fibre and drawing out a strand of yarn. The workers then walk forward, twisting the two strands into one by pushing a moveable wheel and by running a triangular wedge. The spun yarn is counted and bundled and delivered in the market or sent to the weaving site by country canoes, carts, and trucks.

Spinning is laborious. By the end of the workday, a spinner, walking forward and backward between the two spinning wheels, would have covered a distance of about 8 km. The spinners often tend to develop body disorders, especially the outward curving of their feet from walking backwards. For centuries, the low wages of spinners has been a disincentive to entrepreneurs in experimenting with mechanised processes. During the past decade, coir workers' cooperatives have sought to increase productivity and reduce labour by introducing electrically operated spinning wheels. These have not been very successful. The yarn tends to break too often in mechanised spinning and the final output is not of a quality that matches the yarn spun on hand-rotated wheels.

Spinning yarn by rolling it between the palms still continues in parts of Kerala. Rope making is also done by hand. One end of the yarn is tied to a coconut tree and the other end passed through the eye of a coconut shell. A small stick is then tied to the other end and briskly rotated. This draws the yarn and gives it a hard twist. After toughening each yarn, these are plaited to make rope. Depending on the strength required, four or more yarns may be plaited.

Certain kinds of coir yarn are used in agriculture, packing, and house construction. Certain other kinds are raw material for weaving carpets. Traditionally, entirely and even today, mostly, coir yarn is woven into matting on wooden handlooms. In contrast with defibering and spinning done only by women, weaving is exclusively male labour. While a mat is woven on relatively small looms worked by a single worker, matting is made in large looms with six to eight persons working in unison. Power looms have led to a substantial rise in productivity and a widened range of products – sometimes in combination with jute and latex – but some of the designs may be worked only on handlooms.

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C

Colonial Medicine in India

Ranès C. Chakravorty

Ancient India

The Indian subcontinent was well inhabited by the first millennium BCE. The inhabited territory extended west into areas that today are in Pakistan and Afghanistan. These ancient Indians had a well-developed system of medicine termed Āyurveda (The Science of Life). Ayurvedic physicians practiced medicine and to a lesser extent, surgery. The system and its practitioners were held in high regard and Indian physicians are known to have been in the courts of the Muslim rulers. Some of the Ayurvedic texts were translated into Arabic early in the history of Islam.

The basic thrust of Colonialism is to exploit the colonized for the benefit of the colonizers. Usually after a long period of colonization the two groups come to a situation of better parity. Both these phenomena are well illustrated in the colonization of India.

Muslim Invasion

From the early eighth century, India was invaded by the Muslim kings ruling in the west across the Himalayas. Initially these Muslim pockets were small and often short-lived. By the twelfth century, a Muslim kingdom had been established in Delhi, though the ruler(s) recognized their western center outside India as the capital. By the thirteenth century Muslim occupation in India had become permanent, and ultimately the Muslim rulers assimilated into the Indian culture. The Turk, Babur, established his capital in Delhi in 1526, though it was not until his grandson, Akbar (1556–1605) ruled, that the Mughals considered themselves Indians. The Muslims had brought with them the Islamic system of medicine, Unani or Tibbi, based largely on translations of Greek

Medicine. However, Āyurveda was also in use, not only in the Hindu population, but also among the Muslims.

With the arrival of the Europeans, European physicians also practiced in India though in small numbers. From the time of Shahjehan, Akbar's grandson, some European physicians are known to have practiced in royal courts. Thus, Niccolo Manucci (1639–1717) was an artilleryman to Shah Jahan's eldest son Dara Shukoh. He later took up the profession of medicine (even though untrained) and practiced both professions (!) in various royal courts. Manucci's memoirs name some other European physicians practicing in India. François Bernier, a Frenchman with a medical degree from Montpellier, served Dara Shukoh and later his brother, the Mughal emperor Aurangzeb (Majumdar et al. 1994).

European Colonization

Portuguese

From the middle of the sixteenth century, European nations turned their eyes eastward for territorial expansion and trade. The Muslims had established themselves in the Middle East from today's Syria southwards to Egypt and across North Africa to the southern half of Spain. Trade with India and further East had become dangerous and expensive. There was also the need to spread Christianity.

The first to arrive in India was the Portuguese Vasco da Gama who landed at Calicut (now Kozhikhode) in southwest India on 20 May 1498. By 1510 the Portuguese had an established presence in Goa on the west coast. Goa remained a Portuguese possession until 1949 when it joined the Republic of India. In the 450 years of its association with Portugal, Goa became a medical center of sorts. It had the oldest European-style hospital and medical school in the East.

The Royal Hospital was started in 1510 and by about 1546 western medicine was being taught. The Hospital was fully supported by the Portuguese rulers and was a showpiece in its time. The continuing rivalry between the Dutch and the Portuguese, however, caused a decline in Goa's prosperity and the Hospital started to decline by the mid-seventeenth century. In order to have a cadre of assistant physicians, non-Portuguese natives were taught the rudiments of medicine.

Some Portuguese physicians and apothecaries traveled to Goa and some even stayed behind. The most prominent among them was Garcia d'Orta. A converted Jew, Garcia d'Orta was born to Jewish parents who had been expelled from Spain in 1492. They were converted to Catholicism but were always looked down upon. D'Orta studied medicine in Spanish universities and returned to Portugal in 1523. He then joined the faculty at the medical school in Lisbon. In 1534 he left for Goa with his friend, who was to become the Governor-General of Goa and the Portuguese territories in India.

D'Orta became a very successful practitioner, not only for the rich Portuguese in Goa, but also for the rulers of neighboring Hindu and Muslim kingdoms. (Other Portuguese physicians also became court physicians and many rich Indians came to Goa for treatment.) D'Orta is remembered today for his book *Coloquios dos Simples e Drogas da India* – an Indian materia medica, which was published in 1563, in the first printing press in India. The book gained great renown and was very popular in Europe. D'Orta died in 1568, probably quite poor as the Catholic hierarchy had turned against him. His bones were burnt at an auto-da-fe in the cathedral in Goa some years after his death. D'Orta remains the first author of a western-style medical book from India.

A woman medical doctor, Dona Juliana, came to Goa and later on moved to the court of the Great Mughal Akbar. Nicolau Manucci, mentioned above, came and practiced in Goa for a short while but was then thrown out by the authorities.

Around 1842 a formal medical school, Escola Medico-Cirurgica de Nova Goa was established in Goa. The number of graduates (strictly limited to Christians) from this school was never very high, though many of them went on to achieve professional distinction in Goa, in India and in the Portuguese territories elsewhere (Pandya 1982). The school was discontinued at the time of Goa's admission to the Republic of India.

Following the Portuguese, the French, the Dutch, and the Danes established trading centers in India. The latter two countries had undistinguished and short stays in India. The French remained in Chandernagore, Pondicherry, Mahe, Yaman, and Karikal, all isolated enclaves until Indian independence in 1947. During this period they had no significant medical establishments either as medical schools or hospitals.

British

Starting with small trading posts in the seventeenth century, the British ultimately occupied all of the Indian subcontinent and the history of colonial medicine in India is almost exclusively that of the development of medicine during British rule (1857–1947).

Medical practices under the British will be described in two phases. The first was under the East India Company, the next under the British crown as a part of the Empire.

Phase 1: The East India Company

The East India Company was a profit-making body administered by local administrators in India. In theory the Board of Governors in England were responsible for the supervision with some generally minimal oversight by the British Parliament. Under the Company, fortune making and profiteering were rampant and generally tolerated. Only a very few people were ever brought to justice in the courts or impeached in the Parliament. The entire western-style medical setup was for the British, largely the armed forces; the native population depended upon the indigenous medical systems.

Each ship coming to India had a (naval) surgeon on board.[1] They sometimes deserted (often without punishment when captured), settled as surgeons to the trading settlements on land and not infrequently fought as soldiers in the many and frequent battles between the British, the French (the Carnatic and Mysore Wars),[2] and the native Indians.

While a number of the naval surgeons were of great service to the British, two are of special interest, signifying different aspects of the duties of the navy surgeon. William Hamilton of Dalziel in Scotland is hardly remembered today Fig. 1. However his epitaph (still to be seen in the graveyard of St John's Church in Kolkata, India) states "…his Memory ought to be dear to this Nation for the Credit he gained ye English in curing FERRUKSEER the present king of Indostan… by which he made his own name famous at the court of that great monarch; and without doubt will perpetuate his Memory in Great Britain as well as in all other Nations of Europe." Hamilton was apparently trained as a surgeon and did not have a university degree in medicine. He was attached to the small Company trading post in Calcutta. The Company had been trying to get a *firman* or permit to carry on trading with the local populace under advantageous terms and lowered customs duties. The Company sent a delegation to the Surman Embassy to the court of Farrukhshiyar, the reigning Mughal monarch in Delhi. On arrival at Delhi, the delegation found that Farrukhshiyar was seriously ill with infected lymph nodes in the groin. He had been treated by the court (native) physicians unsuccessfully. Hamilton treated the emperor (apparently lancing the boils) which resulted in rapid recovery. The emperor also had an anal fistula that Hamilton successfully treated.

Colonial Medicine in India. Fig. 1 The tombstone and epitah (in English and Arabic) of William Hamilton in St. John's church, Kolkata, India (Photograph by author).

The grateful monarch issued a firman in favor of the British, munificently rewarded the young surgeon, and wanted him permanently in his employ. Hamilton died soon thereafter and was buried in the Company cemetery in Fort William, Calcutta (Wilson 1911).

John Zephania Holwell (1711–1798) was quite a different type of physician. Born to well-established parents (his father was a timber merchant in London) Holwell studied in England and Holland and trained as a surgeon in Guy's Hospital, London. He came to India in 1732 and to Calcutta, which had the most important British factory in India, in 1736.

In 1756 the British settlement in Calcutta was attacked by Siraj-ud-Dowlah, the ruler of Bengal. The Governor left the Fort with all the ladies and most of the men for a safe refuge on the river Ganges. Holwell remained as the governor of the fort, put up a stiff fight, was defeated and captured. He with the 156 other captives was put in a small chamber termed the "Black Hole." Only 23 survived the night (Holwell's description of this event has been seriously criticized. Probably the numbers reported were exaggerated though the confinement did happen. A monument erected by Holwell to recall the event was later removed but can still be seen at the back of St John's Church.)

Holwell became the temporary Governor of Bengal after Robert Clive's return to England and finally returned to England in 1761. He wrote a number of books on his experience, knew a number of languages including Arabic, and was one of the first to study Hindu antiquities.

Phase 2: The British Raj

In 1857, there was a revolt by some of the Indian regiments and Indian rulers against the East India Company. Known variously as the Sepoy Mutiny

[1] The training and career of a naval surgeon of the times are well detailed in *The Adventures of Roderick Random* (1748) by Tobias Smollett (1721–1778) who was himself a physician trained at the University of Aberdeen.

[2] The Carnatic and Mysore Wars were fought in the latter half of the eighteenth century by the British against the Marathas, rulers of Mysore, and the French to establish British power in southern India.

(by the British) and the First War of Independence (by the Indians) the immediate result of this conflict (which the British won) was the takeover of the Indian territories by the British Government. The Government sent representatives of the Crown (Governor Generals) to rule over the Indian territories.

Even though the Government was mainly geared to British interests, there was some beginning interchange between the Indians (mainly the Hindus) and the British rulers. Calcutta remained the capital and the seat of government (until 1911) so most of the action occurred there (Bala 1991; Arnold 2000).

With the establishment of the Raj, the early British officials were very interested in native customs and learning. In 1776, (Sir) William Jones, a superb linguist, and a Judge of the Calcutta High Court, established the Royal Asiatic Society of Bengal with the support of the Government specifically for oriental studies and research. Both he, Warren Hastings, and other high-ranking officials encouraged the study of the Indian systems, and this helped establish the Calcutta Madrassah for the study of Arabic and Persian and the Sanskrit Colleges of Calcutta and Benares for the study of Arabic (Majumdar et al. 1979).

Because of the lack of practitioners trained in Western medicine, the local British physicians would train their assistants for 1 or 2 years and then certify them as being capable of practicing western medicine independently. In order to increase the number of better-trained medical practitioners and the number of assistants to the European physicians, the Government started a Native Medical Institution in 1824 in Calcutta (and later in Bombay) mainly to produce assistants, dressers, etc. Auxiliary Medical sections were also established at the Sanskrit College in Calcutta where Āyurveda was taught together with some western medicine. (A hospital with 30 beds was started for these students in 1830.) At the Calcutta Madrassah, rudiments of western medicine were taught together with Unani or Tibbi – the Arabic medical system. The western system had a therapeutic armamentarium that was possibly inferior to the native systems. Its nosology (classification of diseases) was different but not much better; the main difference was in the study of human anatomy by dissection and surgery (without anesthesia).

A Bengal Medical Service had been started in 1763 – similar provincial services started in Madras and Bombay. Membership was limited to the British for many years and when Indians started to be admitted to the Indian Medical Service they were usually assistant or subassistant surgeons. Created to serve the needs of the Empire, the IMS had a prime responsibility to the armed forces and military matters; service to civilians was secondary.

Arrangements for the institutionalized treatment of the employees of the East India Company and the soldiers and sailors had existed from the beginning at the three main British centers – Calcutta, Madras, and Bombay. Madras had a hospital since 1664. A hospital for Europeans was started near St John's Church in Calcutta in 1707. In 1768 a General Hospital for other Europeans (including indigents) and visiting European sailors was started in Calcutta. This Presidency General Hospital still exists.

Lord William Bentinck was the Governor-General from 1828 to 1835. He was convinced that education was to be Europeanized. In 1835 the Native Medical Institution and the medical sections of the Sanskrit College and Calcutta Madrassah were abolished. The Bengal Medical College was opened in Calcutta with three British and one Indian faculty (Anon 1935). The Indian, Madhusudan Gupta had been a student (and later a teacher) of the Vaidyaka Sreni or medical section of the Sanskrit College. A remarkable person in all respects, Gupta initiated cadaver dissection in 1836 (Chakravorty 1997) Fig. 2. In 1857, with the establishment of the University of Calcutta, the College changed its name to the Calcutta Medical College. The Madras Medical College also started in 1835. Amongst other achievements, this institution was the first to formally train women in medicine. The Grant Medical College of Bombay was started in 1845.

Colonial Medicine in India. Fig. 2 Painting by Madhusudan Gupta by Mrs. Belnos in the Anatomy Department, Medical College, Kolkata, India (Photograph by author).

Women

The first special attention paid to native women by the British physicians followed a law enacted in Britain. From 1805 to 1833 and again from 1868 to 1880, venereally infected prostitutes and soldiers were kept in "lock hospitals." Christian women missionaries from the west played a large role in looking upon native women's health, although the main object was probably conversion to Christianity (Balfour 1929). The first was Clara Swain, who in 1869 established the American Methodist Episcopalian Mission in Bareilly. Here she also trained Indian women in nursing and midwifery. Many women missionaries came from Great Britain, Canada, and the United States to render service to native women and men.

Ida Scudder, an alumna of Cornell University Medical School, opened a medical college and hospital for women in Vellore, Madras Province. In 1945 the college was opened to men also. Today it is the biggest Christian hospital in the world and one of the best-teaching institutions in the country. India was a haven for women medical graduates from the British Isles. They had problems in being accepted in Great Britain but had much better opportunities in India.

A specialized case was that of Lady Dufferin's Fund (Lal 1994). Initiated by the wife of the Viceroy, Lord Dufferin, this organization collected donations to start hospitals for women and train nurses and midwives. Though always short of funds, the Fund played a significant role in women's health care. It also helped establish the Lady Hardinge Medical College for Women in Delhi in 1916.

As in all other countries, women had difficulty in receiving formal education in medicine. Among the first woman physicians of India was the English woman (Dame), Mary Scharlieb who was the wife of a prominent lawyer of Madras. Her husband's family was well known to the Governor and the Superintendent of the General Hospital in Madras. She first took courses in midwifery but later with three other Anglo-Indian ladies was allowed to attend classes and sit for the final Licentiate examination in 1878. Of her colleagues, Dora White became a physician to the Nizam's Government in Hyderabad and D'Abreu (who had come to Madras as she had not obtained admission in Calcutta) became a medical missionary. She later returned to England and became very well known as a physician.

The first Indian woman to graduate was Kadambini (Basu) Ganguli (1861–1923). She was the first woman to get the Bachelor's degree at Calcutta University (together with Bidhumukhi Bose). She obtained her licentiate from Calcutta University in 1886. Later she went to Great Britain and obtained degrees from Glasgow and Edinburgh. She was a very successful practitioner of medicine, obstetrics and gynecology, and surgery.

Anand(a)ibai Joshi of Pune graduated from the Women's Medical College of Pennsylvania in 1886. She returned to practice in India in charge of the Female Ward of the Civil Hospital in Kolhapur, Maharastra, but died of tuberculosis soon thereafter.

Diseases, Public Health, and Research

India has its own spectrum of diseases, many of which were unknown to westerners. I will discuss only three of the most devastating.

Malaria had been a devastating disease in India and the countries around the Mediterranean for centuries. Because of the lethality of malarial fever, the British Indian authorities had established a Fever Commission (of which Madhusudan Gupta – see above) was a member. Later "Burdwan fever" – a malignant febrile illness, generated a great deal of discussion, without any effective resolution of its nature and treatment. The use of Jesuit's Bark, Cinchona (quinine), was known and in fact had been used by Ayurvedic physicians since 1860. However it was not until Ronald Ross (1857–1932) working in the Presidency General Hospital in Calcutta established the life cycle of the malarial parasite in the mosquito that the disease was finally understood. Born in India and educated in England, Ross joined the Indian Medical Service in 1881. He was awarded the Nobel Prize in 1902. He left India for England in 1901 and died there in 1932.

In 1859, the prevalence of infectious diseases and a high mortality amongst Europeans in India had resulted in the formation of a Royal Sanitary Commission with Dr John Snow (who had written the book *On the Mode of Communication of Cholera* in 1855) as its chairman. In 1863 a Commission was setup to inquire into the Cholera Epidemic of 1861 in Northern India. With Robert Koch's identification of the causative organism in the water of a reservoir in Calcutta in 1884, the possibility of controlling cholera through sanitary measures became practicable. (Koch became a Nobel Laureate in 1905.)

Smallpox had been a devastating disease all across the world for centuries. Variolation – the introduction of live smallpox from a patient to a healthy person by scarification had been used for immunization for centuries. The Indian Medical Service accepted and used this method till the discovery of vaccination (the introduction of cow pox by scarification) by Edward Jenner (1749–1823) in 1796. Both variolation and vaccination were used in India for immunization for a while until the Smallpox Commission in 1850 stated that the latter was superior and safer than the former.

Research

Though Ronald Ross was the physician to get the highest accolades, the members of the Indian Medical Service carried on investigations into common local diseases. In later years some Indians (outside the IMS) also became well known for their research findings. Thus Sir U. N. Brahmachari discovered the cure for Kala-Azar (Leishmaniasis), and Sir K. N. Das was a pioneer obstetrician who wrote a classic text on the discovery, development, and use of the obstetric forceps.

In the 190 years of British occupation of India, the relationship between the colonizer and the colonized had equalized considerably. In 1887, Dr R. G. Kar and colleagues started the Carmichael Medical College as the first non-Government Medical College in the country. Today the R. G. Kar Medical College is one of the prime teaching and research institutions in the country. In the earlier half of the twentieth century, the medical programs in the country were more and more in the hands of the Indians, though postgraduate education abroad, especially in the British Isles was almost mandated for a teaching position and even for successful private practice. Indian physicians today occupy many prestigious chairs outside India, especially in English-speaking countries. This is one of the legacies of colonial medicine in India.

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[3] A number of publications in Bengali have significant information on this subject. They have not been mentioned here.

Colonialism and Medicine in the Malay Peninsula

Hairudin Bin Harun

The history of British medicine in the Malay Peninsula is synonymous with the history of tropical medicine. It is also a history of colonial medicine, which is a chapter of the history of British colonialism and imperialism in the East.

Three factors were crucial in determining the outcome of the struggles by colonial powers to expand and consolidate their empires in the East: sea-power, colonial settlers, and diseases. The nation that controlled the sea could occupy distant lands with ease. If there were conflict, sea-power enabled a colonial nation to intercept and prevent vital supplies from reaching rival colonies. Colonial settlers were important for political and economic reasons. A claim for the motherland could easily be made over an area well settled with colonial immigrants. Economic exploitation and control could be established by a network of colonial settlements, which also functioned as buffers against economic challenge and security threats from natives or rival powers. Finally, disease was of immense importance in moderating colonial expansion. Diseases could exact a heavy toll on the army, officials, colonial settlers, and their laborers or slaves. Malaria and yellow fever reportedly wiped out some of the British colonies in the tropics and Africa.

British colonial rule over the Malay Peninsula and Borneo Island (now Malaysia) lasted for more than a century. Their use of medicine as a strategic, diplomatic, and political tool to enhance their grip on the indige nous people and resources of the Malay Peninsula is well-documented. Medicine was also an instrument of colonial conscience, one aspect of which was the call to discharge "the white man's burden," including the task of "civilizing" the natives. In the Peninsula this entailed, among other things, the aggressive promotion of tropical medicine, and it contributed to Malayan negative perceptions of colonial medicine. Indeed, colonial medicine came to be perceived as a ruthless campaign to stamp out their traditional medicine.

In spite of that, colonial medicine could still claim success among the colonial laborers and urban dwellers, although among the natives and villagers the campaign seemed to have failed. There are several reasons for this. One was the preexistence of an elaborate traditional medical system. Second, the natives enjoyed better health than the imported colonial laborers, and even the colonial masters, many of whom were afflicted either with beriberi or malaria. Third, local traditional medicine was far more effective in treating some forms of tropical diseases.

The effectiveness of Malay medicine, however, was generally overlooked. It was difficult for colonials to accept that a primitive medical tradition could be equal to or better than colonial medicine. The official attitude further institutionalized such prejudices, as Malay medicine was officially perceived with contempt.

Since the beginning of British colonialism in the Malay Peninsula, combating tropical diseases was a priority. Initially, it was important to the officials and indentured colonial laborers, and it assumed a strategic and political dimension.

If one were to put a date on the genesis of British colonialism in the Malay Peninsula, it is likely to be 1786. This was when the East India Company took possession of Penang from the Sultan of Kedah. By 1830 the Company had added Singapore and Malacca to its inventory list, and by 1895, four of the richest Malay states in the Peninsula were under British influence. Throughout the period, the number of Britons sent to the area increased tremendously. The Peninsula's climate and geography, however, were harsh, and many of the early colonialists succumbed either to the heat or diseases. The large-scale importation of foreign indentured laborers, known then as *coolies*, was a significant feature of the period. They were crucial for economic and political reasons, but they were also decimated by diseases, especially malaria and beriberi. The result was a loss of productivity and a forced suspension of many economic projects. Thus, disease, or its absence, among officials, settlers, and coolies acquired an economic imperative; while health or the lack of it among natives acquired a strategic and political dimension.

During the colonial period, the course of events in the Peninsula was inevitably intertwined with that in England. The 1870s saw the emergence of a new political figure in Britain, Joseph Chamberlain (1836–1914). In 1893 he was appointed Secretary of State for the Colonies. He reorganized the Office from an ill-equipped, almost forgotten, department to one of the best around. Indeed, colonial appointments before he took office were seen as more akin to polite exile than glamorous jobs. Chamberlain changed that. He was able to infuse a new attitude, as well as a new policy, so that the colonial jobs gained the same respectability as home appointments.

As far as the history of colonial medicine is concerned, Chamberlain's most significant political act was his appointment of Dr Patrick Manson (1844–1922) as the Medical Advisor to the Colonial Office. Dr Manson was then the most distinguished authority in tropical medicine, which was then a marginal subject within mainstream medicine. The main concern of British medicine was the diseases of Europe, not of the tropics, and health policy was geared to serve home needs and rarely those of the colonies. Under Chamberlain, with Manson as the medical advisor, there was a reorientation of policy and priorities. The medical problems and health policies of the colonies were given serious attention. Soon Chamberlain's name became synonymous not only with the development of British colonialism but also with the development of tropical medicine. Indeed, under his stewardship, Britain's colonial fortune took a positive turn; so too did the health of Britons and the state of medicine in the colonies.

Chamberlain was forthright about the fact that British lives were more important to him than native lives. The participation of his ministry in the development of British tropical medicine was solely to ensure their welfare. The welfare of the natives was looked upon only in terms of Britain colonial interests, if ever. This policy was reflected in the establishment of the London School of Tropical Medicine in 1899. Its purpose was to foster research and development of the "new" British tropical medicine. The school was backed up by a number of research stations in the colonies, the biggest and most important of which was the Kuala Lumpur Pathological Institute, located in the Federated Malay States (British Malaya). The Institute was formed a year after the London School. Indeed, the rapid development of British tropical medicine in the early part of the century owed much to the linkages of the London School with the Kuala Lumpur Institute.

The Institute's founder was Sir Frank Swettenham (1851–1945), a charismatic colonial official who knew a lot about colonial and local politics but next to nothing about medicine. Swettenham's tenure coincided with the period of intensive colonial economic activities in the Malay States. These were sustained mainly by the extensive importation of coolies from abroad, particularly from China and India. As indicated earlier, this importation was important for both economic and political reasons. It showed the native Malays that the British could easily handle any boycott by local labor; but the importation soon hit a snag. Many of them were decimated by unknown diseases, one of which was later identified as beriberi.

Owing to the epidemic, the local colonial administration was burdened by thousands of sickly and unproductive coolies. A search for a beriberi cure was imperative. Swettenham had come to know about the interest at the Colonial Office regarding tropical diseases, and about the plan to set up a school of tropical medicine in London, but he also knew that the

School's priority was research on tropical diseases afflicting European communities in the tropics. In the Peninsula, however, beriberi was a non-European disease. Swettenham was aware that it was extremely difficult, if not impossible, to persuade the Colonial Office to allow it to devote a portion of its research time and money to beriberi. It was at this stage that he toyed with the idea of a local institution modeled after the school, which would facilitate the search for beriberi's cure.

In London, luck seemed to be on his side. Swettenham's plan for a local medical research institute was received positively. It was seen as simply the compliance of a colonial official to London's policy on tropical medicine. Such plans from distant colonies normally received an impersonal go-ahead signed routinely by nameless individuals on behalf of the Secretary. Instead, Swettenham's plan came to the attention of Chamberlain, who personally signed the authorization papers for the Institute. At home, Swettenham did not bother to wait for the official go-ahead; he had made arrangements to set up the Institute even before Chamberlain had signed the order.

Perhaps owing to the excellent staff, the Institute lived up to its expectation. It was able to come up with the cure for several tropical diseases, including beriberi. The riddle to the latter was conclusively resolved exactly 9 years after the founding of the Institute. Thus it succeeded in alleviating the colonial authorities from one of the major causes of the local economic and social problems. The Institute was a bastion of colonial medicine, and far removed from the practices of traditional medicine. Notwithstanding that, some of the major breakthroughs of the Institute were affected directly or indirectly by the latter. For instance, in the search for the cure of beriberi the Institute's scientists looked to traditional cures for clues, and indeed found a lead in Malay medical practices. Colonial pharmacologists examined and benefited greatly from the Malay materia medica, particularly in the search for new drugs and alkaloids. Institute authorities still were extremely reluctant to acknowledge any hint of contribution by native medicine, especially in advancing tropical medicine.

To understand the events that followed, it is necessary to take a brief look at the prevailing colonial health policy, particularly with regard to the natives. There were several discernible phases. The initial phase placed the emphasis on the health of the officials and laborers with no regard to the natives. The second phase involved the missionary zeal to promote colonial medicine among the natives and other non-European inhabitants of the colonies. The *Ordinance to Provide for the Registration of Medical Practitioners in the Colony* (1905) was passed to control the practice of medicine, by stipulating minimum qualifications for those who wanted to practice medicine in the Malay States. On the face of it, the Ordinance seemed to spell a blow to traditional medical practitioners, particularly the natives and the Chinese, but interestingly, the Ordinance carried with it an exclusion clause:

> Nothing contained in this Ordinance shall be construed to prohibit or prevent the practice of *native* systems of therapeutics according to Indian, Chinese or other Asiatic method.

Throughout the British rule the native Malays relied extensively on traditional medical systems for their medical needs. The backbone of the traditional system was the medicine man, *bomor*, or *pawang*. They did almost everything, from preparing herbal medicines, setting dislocated bones, and delivering babies, to variolation and minor surgery like circumcision. Occasionally, Europeans sought treatment from the *bomor* and claimed that they were cured of their ailments by the Malay medicine man.

Evidently, colonial medical officials were intrigued by the ability of the native Malays to live a healthy life in the tropical climate. Many noticed that the native Malay view of nature was totally different from theirs. Nature or the land was treated by the Malays with respect, regarded more as a living or spiritual being than a thing, and more like a member of their family than an artifact of convenience. The Malays maintained a relationship with their land in what one would describe now as balanced ecological relationship. In fact, the need to seek harmony and equilibrium was central to their view of disease and health. Nature was multidimensional and hierarchical, having both a metaphysical and physical dimension – reflecting the spiritual and physical constitution of man. Their doctrine of diseases and health reflected the belief that health was a manifestation of the harmony of human's inner constitution and nature's constitution; disease was the result of a lack of harmony.

The complexities and intricacies of the Malay medical doctrines were left much to themselves. Occasionally they became objects of anthropological curiosity by colonial scholars. However, this attention was academic; no medical officials or policy makers seemed interested in knowing more about Malay medicine or the Malay medical system. It was not until the later stage, the missionary zeal phase, that they began to take notice of Malay medicine. At this stage, however, Malay medicine was seen more as a rival than a complement.

The effort to introduce colonial medicine to the Malays was apparently a frustrating task to the majority of the colonial officials. Frequently, they expressed their frustrations at what they alleged was the Malays' indifference to "superior medical treatments." For instance, the Colonial Resident Councillor of a Malay State remarked:

> If a Malay thinks he is going to be kept in a hospital, he will not apply for medicine as an outdoor patient and will prefer to remain in his own house and be treated by a Malay doctor on simple herbs, together with a judicious supply of still simpler incantations. (Harun, 1989)

The Colonial authorities also took active steps to restrict the practice of Malay medicine men. This perhaps can be best seen in the checking of the traditional inoculation or variolation practice. Variolation was widely practiced whenever smallpox broke out in a village. It involved the direct inoculation of smallpox virus treated with certain medicinal herbs. Colonial doctors described it as "a barbarous practice," and the practice was targeted for curtailment. In 1905, when smallpox broke out in the eastern Malay state of Kelantan, the Government enforced a law banning variolations. In their place, they introduced large-scale vaccinations. The authorities also recruited some traditional inoculators as "assistant vaccinators," although the actual task of vaccination was undertaken by the colonial medical department.

To the Malays, the inoculation rituals sanctioned by their traditional culture were much preferable to vaccination. Their acceptance of colonial medicine lagged behind official expectation. In fact, the authorities noted a decrease in the number of natives seeking medical treatment at colonial clinics. They realized that the campaign to promote colonial medicine among the Malays would fail unless their confidence was won over.

The new campaign strategy perhaps can be best seen in the work of Dr Gimlette. He was a colonial medical officer best known for his sympathetic and detailed study of Malay medicine which was originally part of the new campaign. By the time he finished, it had taken an unexpected form. For all practical purposes, it had become a crusade for the preservation of Malay medicine. Gimlette, probably to the displeasure of his superiors, openly urged the colonial authorities to soften their attitudes toward the *bomors*. Indeed he argued that "it would be unfair to damn him [the *bomor*] as an accursed sorcerer who poisons honest folk to gain his private ends." Gimlette even drew parallels between the practice of colonial doctors and that of the medicine man:

> It is too much to say that the work of the bomor in clinical medicine is merely fanciful; he endeavors to prepare a *penawar*, that is to say a "neutraliser," for every kind of poisonous principle; this idea of neutralization distinctly anticipates modern science. His knowledge of local materia medica is often profound, and after all, some of his theories as to the etiology of tropical diseases are conceptions now known to modern science in the form of animal parasites (protozoa, spirochaetes, etc.), which are invisible except under high powers of microscope.

Gimlette also claimed that Malays knew mosquitoes were the cause of malaria, evidently earlier than Manson. According to Gimlette, Malays' apparent resistance to malaria was largely owing to their knowledge of mosquitoes. For instance, the Malay traditional ritual of smoking their homes and villages through the burning of *padi* (paddy) straw during harvest season effectively expelled mosquitoes in their homes or in the surrounding area. Malays also bred fish in their *padi* fields during the flooding period. This practice was akin to a form of biological control of pests, since the fish preyed on small organisms and thus destroyed all the mosquito larvae breeding in the *padi* fields. The Malays also practiced selective clearing of jungles as another form of mosquito control. Gimlette was convinced that the secret of Malays' resistance to malaria or "harmony" with mosquitoes, lay in their practice of such rituals.

It is not known what the actual reaction to Gimlette's views was, particularly within the colonial medical establishment. It is likely that his views would have caused some uneasiness among officialdom. Gimlette assigned a common level of legitimacy to Malay medicine and colonial medicine. It is interesting to note that soon after the publication of his book on *Malay Poison*, Gimlette retired in 1921 from the Colonial medical service. He returned to England and embarked on a project to compile a dictionary of Malay folk medicine. Because of ill health, the project was not completed. However, his friends, Thomson and Skeat, took over the project and completed the manuscript, which was posthumously published in 1934 as the *Dictionary of Malayan Medicine*.

The official version of the development of colonial or tropical medicine was no different from the history of medicine. The motives were Hippocratic idealism and the fanatical dictum that there should be no mention of nonscientific or nonmodern contributions to the development of modern medicine. Understandably, the Malay's contribution to the development of colonial medicine in the Peninsula was largely ignored.

The prevailing colonial view stereotyped native medicine as nothing more than primitive panaceas or "snake-oil cures." However, studies like Dr Gimlette's challenged established prejudices and institutionalized misconceptions. They established that native medicine was a storehouse of perennial wisdom, and collection of empirical observations of scientific significance. Still, Malay medicine was often referred to contemptuously in colonial discourse.

No branch of modern science can be said to have developed almost exclusively under colonial ideological and political impetus than tropical medicine.

See also: ►Colonialism and Science

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Colonialism and Science

Michael Adas

From the very first decades, scientific advances played essential roles in European overseas expansion. Improved astronomical instruments and calculations and an array of new navigational devices and cartographic techniques made the Portuguese voyages into the uncharted South Atlantic possible. Subsequent voyages of exploration and (for the Europeans) discovery led to further refinements of both instruments and navigational data and stimulated the introduction of ever more sophisticated ways of measuring time, distance, and location. Scientific curiosity was among the main motives of Europeans who planned or led expeditions of discovery and conquest. Astronomers and cartographers often sailed with explorers and merchants for the express purposes of testing new instruments, taking astronomical or meteorological readings from distant latitudes, and charting regions that had hitherto been unknown to the Europeans. The application of the data gathered on these voyages to improving maps, to compiling more accurate navigational charts, and to devising new instruments greatly enhanced European advantages over other peoples in navigation, trade, and warfare by sea.

As European armies and administrators advanced inland, first in the Americas and the outlying island of Africa and Asia and later throughout the globe, botanists and geologists followed, collecting "exotic" specimens to carry home to the gardens and cabinets of their rulers and national scientific societies. European savants examined and classified the bewildering mass of information and objects that flowed in from the rest of the globe, and struggled to fit it into the preexpansion world picture; or, more commonly, used it to build a new vision of both the earth and the cosmos. A host of self-appointed, usually amateur, ethnologists also reported extensively on the diverse peoples and cultures they encountered overseas. Their observations became the basis for elaborate, allegedly scientific, and invariably hierarchical classifications of human types. These classifications in turn provided evidence to support highly contentious theories regarding the relationships among human groups, usually termed races, and between humans and other species, particularly different varieties of apes.

Both in Europe itself and increasingly (but on a much reduced scale) in colonial enclaves overseas, scientific institutions – such as the Hortus Botanicus in Leiden, Kew in London, and the Sibpur botanical gardens in Calcutta – served as clearing houses for flora and fauna collected from around the globe and focal points for taxonomic inquiries and experimentation in procreation and hybridization. The elected members of Europe's scientific societies, most notably London's Royal Institution and the Académie des Sciences in Paris, provided the backing to mount scientific expeditions, certified that what were regarded as scientific procedures had been followed by the explorer or naturalist in question, and made the findings of overseas investigations available to the educated public of their respective nations and the European scientific community as a whole.

From the outset the scientific side of the process of European overseas expansion was all but monopolized by one of a number of approaches to the natural world that had jostled for supremacy in the medieval era and coexisted in the West since ancient times. The predominance of what recent scholars have characterized as the Baconian or mechanistic strain of scientific thinking in European colonial enterprises was of special importance. It meant that other options, such as the organic approach to nature and the cosmos, which might have been more compatible with and accommodating toward non-Western epistemologies, were excluded or relegated to marginal roles in this critical area of interaction between European and non-Western peoples and cultures.

The key attributes of the dominant Baconian or mechanistic strain of Western science rendered European colonial observers and policy-makers particularly unreceptive to non-Western ways of thinking about and interacting with the natural world. The underlying assumptions of the Baconian approach also strengthened the resolve of those among the colonizers who were ironically the most concerned with the well-being of the subjugated peoples to impose Western epistemological presuppositions and standards and procedures of investigation on colonized peoples. Though there were important differences among those scientists who adhered to the Baconian mode, it is possible to distil a number of key attributes that most colonial theorists and administrators would have agreed characterized the proper, or Western, approach to scientific thinking. Though developed in the West and shown by recent research to have been vitally affected by the social and cultural milieux in which it arose, the science carried overseas by European colonizers was seen to be value neutral, objective in its procedures, privileging abstraction and reason, empirically grounded, and somehow transcending time and space and thus universally valid. These attributes gave the practitioners and advocates of Western science confidence that the spread of this epistemology – and the institutions and procedures associated with it – to the rest of the peoples of the globe was both beneficial and inevitable.

This view is, of course, still held today by many scientists as well as development specialists, social theorists, and assorted intellectuals with an interest in the so-called Third World. Its champions among the colonizers viewed the diffusion of Western science as part of a larger campaign to rationalize the world and conversely to banish what they viewed as superstitious or subjective, intuitively oriented epistemologies. Although only the most reflective and outspoken colonial observers would have acknowledged it, Western science was also aggressively expansive and intolerant of rival non-Western epistemologies – just as it had been of alternatives in Europe itself. By the early nineteenth century, it was also inextricably linked to the great technological advances that drove the Industrial Revolution, and the market-oriented, fossil fuel intensive, interdependent global order that was associated with the resultant transformation of the West. Thus, the Western scientific approach proved to be quite compatible with prevailing Western hegemonic ideologies, such as the *mission civilisatrice*.

Despite attempts to develop general paradigms for the diffusion under the aegis of European colonial domination of Western science, its role in the process of colonization and its impact on non-Western peoples and cultures varied widely by time and place. Important differences can be seen, for example, in the scientific fields and types of investigations that were prominently associated with overseas colonization before and after the Industrial Revolution. In the early centuries of exploration European scientists overseas were mainly preoccupied with astronomy, zoology, and botany. As Western Europe's need for markets and raw materials grew with the spread of industrialization, fields like meteorology, geology, chemistry, and applied mathematics became increasingly integral to the colonial enterprise. As European colonizers came to administer much of Africa and Asia directly, more sophisticated techniques of surveying, codifying, and statistical gathering became essential for activities as diverse as revenue collection and the formulation of legal codes. Recent scholarship has also shown that the relationships between colony and metropolis in terms of scientific investigation and exchange also shifted dramatically after World War I. These transformations were accelerated in the interwar years and after World War II by the process of decolonization, and a concomitant shift from an emphasis on extraction to a fixation with the rhetoric of development, which became enshrined in modernization theory after 1945.

The process by which Western science was diffused and its impact on overseas societies also differed greatly depending on the timing and nature of European interaction with non-Western cultures, the colonizers' assumptions about the level of sophistication of indigenous epistemologies and material cultures, and the actual attainments of colonized peoples in science and technology. The process of Western scientific diffusion, for example, in settlement colonies such as Australia and Canada, that had relatively small and scattered autochthonous populations, followed a very different course than in densely populated areas, such as South Asia and China, where small communities of European administrators, missionaries, and merchants encountered highly developed scientific and technological traditions with ancient links to their own.

Even within the different types of colonial societies there were critical variations. Thus, for example, the New World colonies in both Latin and North America, which were the first areas of extensive European conquest and large-scale settlement, were the sites of significant scientific investigations and developed their own scientific societies as early as the eighteenth century. By contrast, Australia and New Zealand were not settled until the following century and were not integrated into the scientific networks of their European metropolis, Great Britain, until the late 1800s. In addition, from as early as the late seventeenth century, the pursuit of science was stunted in much of Latin America, as compared to Canada and the United States, due to Spain's long political and economic decline and its increasing marginalization as a center of scientific learning.

None the less, in all of the settlement colonies, indigenous learning, and epistemologies were pushed to the periphery. Ethnologists studied "aboriginal" beliefs and traditions for their folkloric or antiquarian value, not because they had anything to teach the colonizers about the ecology or topography of the lands they occupied, much less because they might stimulate major modifications in European understandings of the natural world. The research agendas of all of the settlement colonies were also largely dictated by the savants of scientific societies and institutions of higher learning in Europe itself. Though the size and the close links of the elite in the United States to Europe made original work by colonial scientists, such as Benjamin Franklin, more likely than in other settlement areas, until the early twentieth century settler colonists were primarily engaged in applied field research, heavily focused on the collection of local flora and fauna samples. Much of this work was directly linked to efforts to uncover and extract the great natural wealth of settlement areas. The empirical findings of New World botanists, geologists, or ethnologists, who were often merely temporarily transplanted Europeans, were mainly funneled to scientists in European centers for interpretation and theoretical elaboration.

After about 1900, scientific connections between European centers and settlement areas – both those still formally colonized and those, such as the United States, long independent – were radically transformed. Dominions, such as Canada and Australia, were accepted as partners, rather than assistants, in international scientific inquiry. The settlement areas more generally emerged as important centers of scientific research and theoretical innovation in their own right – as evidenced, for example, in Frederick Banting's discovery of insulin in Canada and Macfarlane Burnet's work on immunology in Australia. This was particularly true of the United States, where the already substantial growth of an internationally recognized scientific community early in the twentieth century was greatly accelerated in the 1930s by the forced migration of leading scientists from Europe, such as Albert Einstein. By the 1940s, this former colony and settlement area had taken the lead in many areas of scientific endeavor, from the most abstract theory to applied research.

In comparison with the tropical dependencies, where small numbers of Europeans ruled large and ancient African or Asian societies, the diffusion of Western science to the settlement areas met with little serious resistance. To begin with, the transfer was overwhelmingly to settler populations of European origins and heritage. This meant, on the one hand, that questions of racial ability with regard to the development of scientific communities and institutions in colonized areas did not arise, even though the arrogance of metropolitan savants was often a source of considerable discomfort for the colonials. On the other hand, because the dominant settlers despised and marginalized or discarded altogether the epistemologies of the indigenous peoples, there were no alternative thought systems or ways of doing to rival or provide foci of resistance to hegemonic Western scientific approaches.

Scientific friction between metropolis and settlement colony arose from personal and institutional rivalries, but scientists in both locales shared epistemologies, methodologies, and presuppositions about the place of humans in the natural order. Local resistance came not from subjugated indigenous peoples defending their own, very different traditions, but from the poorly (or un)educated majority of the settler population. The latter were not so much opposed as indifferent to the endeavors of a rather isolated scientific elite, whose labors appeared to be wasted unless they could be turned to some immediate practical advantage. Thus, the key challenge for the scientific communities in the settler colonies was expanding popular understanding of and approval for scientific research, and winning government funding for scientific institutions and projects. Evidence of practical application was key to success in these endeavors, and thus a premium was placed on applied research, at least until the middle of the twentieth century.

The linkages between science and colonization in nonsettler areas of Africa, Asia, and Oceania, where small numbers of Europeans dominated large and diverse colonized populations, were markedly different than in Australia or the United States. Here it is important to distinguish between areas that the Europeans conquered outright and ruled directly, such as India and much of sub-Saharan Africa and Southeast Asia, and those they dominated indirectly or "informally" through military threats and periodic interventions, economic influence, and the manipulation of indigenous leaders. The latter areas would include most of the Islamic Middle East, Persia/Iran, China, Siam/Thailand, and Japan – until it became a Western-style scientific and technological power in its own right in the early twentieth century. Even within these two general categories of nonsettlers, critical distinctions need to be taken into account. Colonial policies regarding the diffusion of scientific learning and investigation, for example, were quite different in British India or French Indochina than in most of sub-Saharan Africa or the islands of the Pacific, even though all of these areas were formally colonized. Within the indirectly controlled areas in the informal spheres of influence, the European approach to Islamic societies in scientific matters differed in important respects from their interaction with China, Japan, or Thailand.

In some ways the diffusion of Western science in some formally colonized areas like India shared more with informally controlled areas, particularly China and the Islamic Middle East, than with Africa or the Pacific, which were ruled directly. In India, China, and the Middle East, the European colonizers recognized not only that the indigenous peoples had produced ancient and sophisticated civilizations – which usually meant that they had certain key attributes, including writing, specialized elites and cities – but that they had long nurtured scientific traditions of their own. Informed European observers even acknowledged that the West owed a large debt to Islamic peoples both for the recovery of much of classical Greek learning that had been "lost" to European civilization after the fall of Rome, and for original scientific advances made by Muslim peoples and transmitted to Europe through Arab and Jewish scholars in Spain and Italy. A handful of European observers also recognized that Islamic civilization had served as a vital conduit of scientific learning and inventions from civilizations further east, particularly India and China.

Recognition of the earlier scientific achievements of selected non-Western peoples informed the attitudes of European colonizers towards the diffusion of science in the societies so designated in important ways. In the early centuries of European overseas expansion, it fed mutual curiosity and ongoing interchange. The first Jesuit missionaries in China, for example, evinced a strong interest in Chinese astronomy, chemistry, and medical techniques. In India, Portuguese and later Dutch merchants and officials routinely consulted Indian physicians well into the eighteenth century. European physicians not only studied the prescriptions and techniques of Indian *vaidas* and *hakims*; they readily conceded the superiority of indigenous specialists in treating tropical diseases.

By the early decades of the eighteenth century, most European observers had concluded that even the most advanced, non-Western scientific traditions were hopelessly outdated and encrusted with superstition and quackery. If it survived at all, recognition of non-Western achievements was focused on the distant past. In the accounts of European authors who concerned themselves with matters scientific or technological, the stagnation of Indian or Chinese learning, in stark contrast to the ever-changing and highly progressive advance of Western knowledge, was a constant refrain. In areas that escaped direct colonization, particularly China and Japan, scientific knowledge and technological expertise had been and remained the most effective ways for gaining access to Asian rulers and impressing Asian elites with the efficacy of Western ways, which seemed otherwise dubious, if not crude. None the less, the sense that peoples like the Chinese and Japanese had long been civilized and had once excelled in science and technology deeply affected the educational policies pursued by Christian missionaries, when they were permitted to proselytize in these areas, and the trading policies and diplomatic exchanges of the great powers. Japan as a whole closed in on itself after 1600, but Dutch traders at Deshima continued to make the latest European scientific treatises available to an emerging Japanese literati. Christian educators in China frequently pushed advanced training in the sciences (particularly medical) and mathematics. By the late-nineteenth century, regionally based segments of the Chinese scholar-gentry were avidly importing Western technologies in "self-strengthening" campaigns designed to ward off the imperialists' partition of the Middle Kingdom.

From the mid-nineteenth century similar patterns of diffusion can be found in other non-Western areas, which the Europeans regarded as long civilized but where they increasingly exercised informal sway. French missionaries strove to impress their Lebanese students with the superiority of Western scientific learning, while Siamese rulers strove to educate an elite corps in the engineering skills of the West. Because their own scientific traditions shared much with those of the Europeans – not the least a common, extensive borrowing from the ancient Greeks – the approach of the Muslim peoples of the eastern Mediterranean to these interchanges was somewhat different from that of the Siamese or, most critically, the Chinese. Having given so much to the West in the sciences, Arab and Turkic reformers could claim that it was in no way demeaning for Muslim peoples to borrow back in order to catch up to their European rivals. Though not all accepted this argument, it made the introduction of Western scientific learning palatable for those who supported advocates of forced "modernization," such as Muḥammad ʿAlī in Egypt and the Ottoman ruler Mahmūd II. Unable to make a convincing argument for such historical precedents, the Confucian literati of China vehemently resisted the introduction of Western learning or reluctantly conceded its necessity in the name of China's survival.

Although similar tensions were present in formally colonized areas that had longstanding scientific traditions, such as India, decisions about how much and what sort of Western scientific and technological diffusion should occur were taken out of the hands of the indigenous peoples. Colonization resulted in a growing influx of European scientists, engineers, and medical practitioners, and a great expansion in their activities and influence. The collection of flora and fauna that antedated colonial rule continued and in

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some respects expanded, but trained scientists and technicians were now employed by colonial administrations for massive and systematic geological and land tenure surveying operations. Statisticians oversaw census counts; botanists tested new plant varieties in state supported gardens; and hydrologists directed the overhaul and expansion of irrigation systems. As these activities suggest and scholars from formerly colonized areas have recently argued, science was a central pillar of the European colonial order.

Colonial science was also field-oriented, overwhelmingly applied, and devoted primarily to enhancing efforts to maximize the extractive potential of conquered areas. Its diffusion to the colonized peoples was consciously channeled and often constricted out of security concerns or fears of future economic competition. Rather than an abstract, objective and dispassionate concomitant of colonial expansion, Western science was the linchpin of rationalizing offensives that sought to reshape the thinking of colonized peoples, reconfigure the spatial relationships in colonized areas, and remake institutional frameworks and social relations in ways that accorded with Western epistemologies and presuppositions about the logical order of things.

Much of the literature on the diffusion of Western science in the colonial empires has concentrated on the biographies and activities of European scientists and on the policies pursued by European colonial administrators. As a consequence the varied and critical roles played by the colonized peoples in the dissemination of Western scientific learning and techniques have been obscured. At a range of levels, their contributions were essential. In the era when naturalists were dominant, the collection and identification of specimens would have been difficult, if not impossible, without Javanese or Indian guides and assistants, and villagers who were vital repositories of local knowledge about animal life or the rain forest. Working in the celebrated miniaturist tradition that peaked under the Mughals, Indian artists sketched flora and fauna in the field and often illustrated the published collections on these subjects that remain standard references to the present day.

As the grip of colonial administrations tightened from the middle of the nineteenth century, subjugated peoples found new ways to become involved in the scientific enterprises that buttressed the new order. Indian surveyors, engineers, and medical practitioners served in colonial administrations both in South Asia and British colonies in Africa and Southeast Asia. Indian chemists, physicists, and biologists worked for British firms, traveled to Europe for advanced study or to take up research positions, and increasingly taught in one of a growing number of universities in India itself. Indian doctors and surveyors set up private practice in colonial towns.

The assumption of many of these roles depended on the spread of higher educational opportunities open to Indians in the sciences and mathematics. The very existence and steady expansion of these opportunities underscores a vital difference between India and most of the other colonized areas. Here again, the colonizers' recognition of precolonial scientific attainments proved critical. The work of Sir William Jones and other "Orientalists" in the late-eighteenth and early nineteenth centuries left little doubt that ancient Indian civilizations had excelled in many of the sciences and mathematics. Though increasingly disdainful of these achievements and impressed with contemporary Indian backwardness in matters scientific and technological, key colonial officials who strove to reform Indian society premised their educational initiatives on the assumption that Indians could master the most advanced Western scientific learning and mathematical techniques. This assumption and the policy decisions regarding higher education that followed gave Western-educated Indians much greater agency in the process of the diffusion of Western science than was enjoyed by any other colonized people. By the last decades of the nineteenth century, racist objections to these policies were raised by both prominent officials and private individuals. However, the path breaking work done by such Indians scientists as Ray and Bose made a shambles of the racists' aspersions, and bolstered the demands of Indian nationalists for greater opportunities in higher education, particularly in the Western sciences.

With the partial exception of colonies like French Indochina and the Netherlands Indies, opportunities for advanced training in the Western sciences in much of the rest of Asia, sub-Saharan Africa, and the Pacific islands were minimal or nonexistent. In these areas, scientific work was the monopoly of the European colonizers. As in settlement areas, such as Australia and the United States, indigenous epistemologies and local knowledge were dismissed as irrational, ignorant, and superstition-bound. These might be studied in order to understand the "native mind" to control the colonial populace better. However, they had nothing to contribute to Western scientific learning or methodology. Thus, in most nonsettler colonies, which the Europeans deemed devoid of scientific traditions of their own, racist assumptions regarding the mental capacity of the indigenous peoples insured that little or no advanced training in science or mathematics was available. These policies in turn left most colonized peoples ill-prepared for a postcolonial world where Western scientific knowledge and skills have proved vital for successful economic competition, development planning, and many aspects of intellectual discourse.

The colonizers' disdain for indigenous epistemologies and approaches to the natural world has also obscured a number of other important patterns involving the interaction of science and colonialism. However extensive or limited the volume of Western science diffused to different colonies, in all there was a persistence of indigenous scientific thinking and practices. In some cases the colonizers themselves were complicit in this process, as when the British made use of Indian *hakims* and *vaidas* in their campaigns to eradicate epidemic diseases, such as smallpox and cholera in India, or when merchants or officials in Africa resorted to local cures for snakebite or dysentery. In some colonies, most notably India but also in Kenya, Senegal, Indonesia, and other areas, the defense of indigenous epistemologies and procedures was explicitly linked to the nationalist assault on the European colonizers. In the thinking of visionary leaders, such as Mohandas Gandhi, the restoration and reworking of these traditions posed what well may be viable alternatives to the approaches to economic and social development championed by the industrial West.

In virtually all of the formerly colonized societies, non-Western approaches to science in areas as diverse as medical practice, preservation of soil fertility, and care for the emotionally disturbed have persisted. In view of the clear limits in terms of resource exhaustion, environmental degradation, and social inequity of both major Western development alternatives – market-capitalist and socialist command economy – this persistence may ultimately prove critical. It may be that the predominant direction of scientific diffusion will be reversed; that approaches to work, resource use, social organization, and economic well-being pioneered by Gandhi and other non-Western thinkers will have much to offer the beleaguered societies of the postindustrial world.

See also: ►Knowledge Systems: Local Knowledge, ►Ethnobotany

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Colonialism and Science in Africa

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By 1914, most of the African continent had been subordinated to colonial rule, with 36% of African territory seized by the French, 30% by the British, and the remaining 34% dominated by Belgium, Germany, Italy and Portugal. This of course was not done without bloodshed. Millions of Africans died in the process of resistance against the invasion of the continent, waging guerrilla warfare for as many as 30 years in some cases. Colonialism was essentially a process of administration which denied Africans political and economic autonomy while subordinating them to the dictates of an evolving global capitalist ethic and world market controlled by a Euro-American elite. Indigenous science and technology were adversely affected by it. Ironically though, institutions such as the British Imperial Institute, through its Scientific and Technical Department, actually aided in the transfer of existing scientific and technical know-how from the colonies to the metropole.

One of the major effects of colonialism was the subordination of science and science education to the logic of colonial production and class structures. Science and technology development in most cases ceased to emanate from the womb of African civilization and indigenous problem-solving and experimentation. A new set of norms, values and relations of production was introduced and superimposed on existing precapitalist structures. In so far as colonialism was an exploitative system geared toward the redeployment of resources in the form of mineral and agricultural wealth, from the periphery to the center, it necessarily led to the destabilization of existing processes of accumulation of knowledge and technique. Colonial capitalism was geared primarily toward the export of surplus from the continent, and colonial education was to focus primarily on the creation of a new collaborative, nonthreatening elite supportive of the colonial agenda and committed to the running of the colonial (and neo-colonial) machine. It was less geared to innovation and creativity than to servile complicity.

References to glass-making and iron fabrication may illustrate the extent to which indigenous capability was undermined. As a consequence of the relatively cheap glass products from Europe dumped on the Nigerian market, indigenous glass producers ceased to produce glass from local raw materials such as silica and potash and proceeded to simply re-smelt and refashion imported European glass objects. In the case of iron there was a deliberate attempt to undermine indigenous initiative by the introduction of the “scrap iron policy” whereby metal designed as “scrap” was imported into the region from Britain. It has been argued that this policy was a deliberate attempt on the part of the British to replace iron products with those from European factories. The policy succeeded in strangulating the local metallurgical industry and arrested the further development of indigenous technology in this field.

The Scientific and Technical Department of the British Imperial Institute, located in London, was aimed at the acquisition of knowledge with respect to various indigenous technologies through experimental research, technical trials, and commercial valuation from within the vast colonial domain, including African colonies. The Institute consisted of a series of well-equipped research laboratories, and a supporting staff of trained scientists and researchers kept active in the analysis of natural and manufactured products from the colonies. Specific attention was placed on medicinal plants and it was explicitly stated that the numerous plants held in high repute as medicinal agents in the colonies should be investigated both as regards their active ingredients and their medicinal value. The above guidelines led to experimentation on *Khaya senegalensis* and a variety of Guinea corn, amongst others, plants held in high repute by indigenous experts. Traditional medicinal knowledge, integrated into the British scientific laboratory, was in fact a contributing factor in pharmaceutical development in the metropolitan center in the first three decades of the twentieth century. Research activity was not confined to medicinal plants, however, and one of the areas of investigative research was textile, specifically silk. Loni or Boko silk from Bauchi, Nigeria was one of those products analyzed. An up-to-date display of the various research findings was kept in the Galleries of the British Imperial Institute, London, and was of particular interest to merchants and industrialists on the look out for new products. Details were provided on application to the Commercial Information Office of the Institute or other authorized officers.

It is clear therefore that colonialism had far reaching implications for both the colony and the metropole. It weakened indigenous African capability with respect to experimentation, problem-solving and the creation of indigenous utilitarian objects and processes. At the same time though it facilitated the transfer of knowledge from Africa and other colonial dependencies while leaving in return an education system more geared to the reproduction of Christian religious norms and values and alienation than the further development of scientific and technological capability.

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Colonialism and Science in the Americas

Ubiratan D'Ambrosio

When the Europeans arrived with Christopher Columbus, they found that the set of explanations and dealings with natural realities that constituted the scientific knowledge of the peoples of the newly found lands absolutely novel. They marveled at the constructions, urban organization, clothing, and ornamentation of these peoples, mistakenly called Indians. To explain and understand what they were witnessing, European knowledge was not appropriate. The surprise was total.

Viking traders, and probably some other European, Asian, and African navigators, had previously visited these lands. There is evidence of this in or about the tenth century, but the records of these visits did not reach what we call the official literature.

The Portuguese were the most advanced people in Europe in navigational knowledge. People interested in navigation would study at the court of King Dom Joào II, in Lisbon, and frequent the entourage of the Infante Henrique, his son in charge of the navigation projects. Astronomers, ship builders, and pilots from all over the world were there. Among them was Martin Behaim, who, upon returning home to Nürnberg in 1490, was asked by his city authorities to produce a report on his studies abroad. He presented this in the form of a model of the Earth: a globe which he called the *Erdapfel*. There, between Europe, Asia, and Africa, shown in a detailed picture, lay a vast mass of water.

Surely views like this convinced Christopher Columbus, also a student in the court of Dom Joào II, of the possibility of reaching Cipangu and the domains of Grand Kahn. He convinced the King and Queen of Spain, Fernando and Isabel, who financed a fleet of three ships, which left Palos, near Seville, on 3 August 1492. On 12 October 1492 they landed on an island called Guanahani in the language of its inhabitants. They did not recognize where they had landed; Columbus and the others believed they had reached Asia. The early days of the conquest and first encounters with the natives are related in descriptions of the conquest, by Columbus himself and by other chroniclers.

What the Spaniards encountered, as far as science and technology are concerned, is described in the article on "Americas: Native American Science" in this encyclopaedia. The centuries preceding the arrival of Columbus saw a political process very similar to the one which took place in Europe in the Middle Ages, when principalities and other smaller domains were uniting into larger organizations such as kingdoms and nations. The Spanish conquerors were able to destroy the emergent power elites and replace them with the power of the conqueror, based on a well-balanced State-Church structure controlling the means of production.

In Central America there was a tax system based on collecting products, while in the Inca Empire tax was paid in labor. We can identify something that approaches private property and commerce in the Aztec model, while among the Incas the State is all powerful in the economy. Recent research reveals important commercial development in the coastal area of Peru and the beginnings of economic uses of sea resources. Although by and large the economic practices are similar to those in Europe, there is no indication at all of something that resembles capitalism. Maybe these are examples of noncapitalist economies. It is important to note the relatively low use of technology in agriculture. For example, they had no plowing devices and practically no fertilizers. Thus, production relied more on human factors, such as a more attractive division of lands with well-coordinated forms of cooperation and control of distribution, than on the intensive use of technology. At the same time, a considerable intervention of the state in major infrastructures such as irrigation and roads, associated with a rather efficient tributary system, indicate economic models which differ from those in the Old World (Europe and Asia). This is an important area of scholarship.

This was the situation the conquerors encountered when they met the highland civilizations. Before that two of colonial settlements had been created in the Dominican Republic: Isabela in 1494, and Santo Domingo in 1496. In the beginnings of this process, with agriculture depending on Indian slave labor, local tribes were exhausted. This caused slave-hunting expeditions to the other islands of the Caribbean. To the South, the arrival of the Portuguese Pedro Alvares Cabral in Brazil led to an exploratory mission by Amerigo Vespucci, in 1501, under the Portuguese crown. The establishment of colonial settlements waited until 1532, when Martim Affonso de Sousa founded Sào Vicente in coastal Brazil. In 1534 the Portuguese king divided Brazil into large areas, the *capitanias*, mostly coinciding with the current coastal states of Brazil, and with the right of property to be inherited. This family distribution of the lands of Brazil established much of the style of land possession in the Portuguese colony.

Meanwhile, the search for slaves led the Spaniards to found Puerto Rico in 1508, Jamaica in 1509 and Havana in 1511. From there to Florida was a small step for Juan Ponce de León in 1513. The exploration of the coast of the Gulf of Mexico by Alonso de Pineda was completed in 1519. Also, Vasco Nuñez de Balboa led the remnants of the failed expeditions of Alonso de Ojeda and Diego de Nicuesa to Colombia and Panama to the Pacific Ocean and the founding of Panama in 1519. From there the exploration of the Central America and Mexico and incursions to South America were obvious steps. Founding several cities, the conquerors approached the heart of the Aztec and Inca empires.

The recognition of high civilizations in the region approached by the Spaniards led to political, religious, and philosophical disputes. Under instructions by the King of Spain to establish trading relations, Hernán Cortés contacted the Aztec King Moctezuma. Attracted by the richness of the Aztecs, Cortés joined with peoples conquered by the Aztecs against Moctezuma, and ingeniously used Aztec mythology as a war strategy to defeat him. Cortés completed the conquest of the region and established the Kingdom of New Spain. In 1539, he was recalled to Spain, leaving behind an empire stretching from the northern part of South America to the southern part of the United States, up to the Colorado River.

The successes in Central America led to efforts to conquer South America. In 1530 Francisco Pizarro reached Peru and won over the Inca Atahuallpa, who was killed after being baptized. Resistance to the conquerors lasted until 1572, with a prolonged siege of Cuzco, the old Inca capital, ending with the capture and beheading of the last Inca, Topa Amaru. From Peru, the conquest was carried on to the South and North. Founding of the cities of Quito (1534), Lima (1535), Buenos Aires (1536), Asunción (1537), Santa Fé de Bogotá (1538), Santiago de Chile (1541), Potosí (1545), La Paz (1549), and Caracas (1562) completed the period called "the Conquest." All of Latin America, with the exception of the Amazon Basin, was in the hands of the Spanish and the Portuguese. Attempts by the French and the Dutch to conquer regions in Brazil did not succeed.

In the colonial times that followed, we see the exploitation of the lands and resources and of the peoples of the conquered regions. The colonizers brought with them traditional European agricultural and mining techniques with which they exploited the native production, mainly in metallurgy. The colonizers changed the means of production. This was done to a great extent indirectly. The native religions were simply destroyed. Food habits were also considerably modified. Wheat, rice, coffee, citrus, sugar cane, and bananas were all grown for export. This had severe consequences for the nutrition of the natives. Famine, never known in pre-Columbian times, became a major concern for Latin America. Urbanization, again following the styles of Europe, led to the development of architectural styles unsuitable to the weather and geological conditions of the conquered lands. This can be traced to the current inadequacy of the cities in the face of natural disasters such as earthquakes, floods, and high winds.

In the sciences in general, Latin America was the recipient and not the producer of scientific advances. The peripheral status of the countries was maintained throughout independence. Indeed, the colonial style and submission of the native population, with land distribution determined by the conquerors and colonizers, was kept after independence. Independence was for the *criollos*, never for the native populations, throughout the three Americas. Even after independence, education was modeled on the former imperial system.

Colonial science, considered as contributing to the mainstream of scientific development, is at best very modest. It is very important to recognize isolated cases, but they do not add to universal scientific development. Native contributions are almost exclusively in medicine, particularly in pharmacology.

The development of Native American science and philosophy was interrupted with the conquest and colonization. Remnants of pre-Columbian forms of knowledge are limited, and research today only begins to reveal their depths.

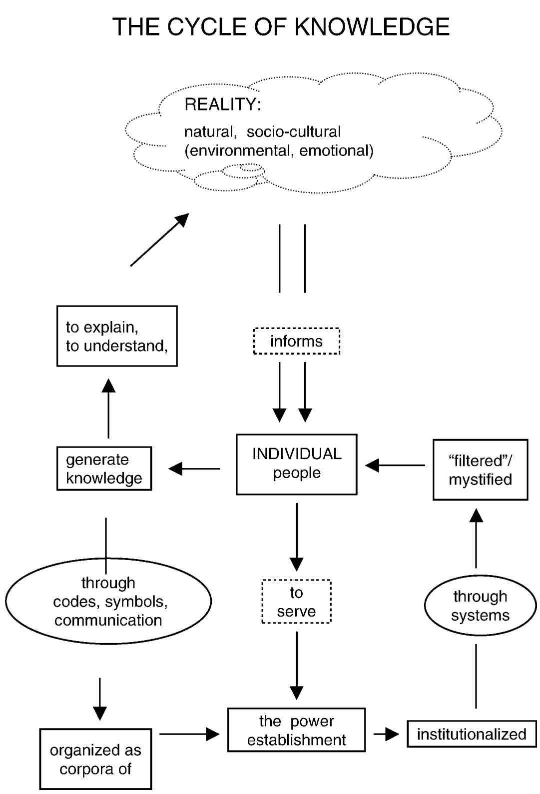
An explanatory note: this article is a critical appraisal of science, technology, and society in the Americas. It deals primarily with the social support for science, technology, and mathematics in colonial Latin America. Other forms of knowledge come naturally in the exposition. They are mutually interdependent and cannot be separated. The frequent references to mathematics reflect the perception that modern science relies, after the success of Newton's *Principia*, on Mathematics. Hence, there is sometimes a confusion between science and mathematics, as well as between science and technology. Most of the times we refer only to science, but the reflections imply technology and mathematics. This is characteristic of the research program, which underlies this paper, called Ethnoscience or Ethnomathematics.

Every culture generates knowledge as a response to mystical, environmental, and economic demands. The major challenge is to understand the human condition, which aims for survival and transcendence. Survival of the individual and of the species depends on the encounter with nature as a whole, which includes others of the same species capable of cooperation for procreation. The encounter is in the moment, is present. Transcendence results from backing survival by searching the past, trying to understand birth and creation, and by probing into the future, questioning death and posthumous influences, and this determines behavior.

Individual knowledge, as well as behavior, is the response to these drives, which implies gregariousness. Individuals are organized in groups, in the broad sense, as families, tribes, communities, and societies in general, and develop communications strategies. These strategies allow for exchanging individual knowledge and generating group knowledge, and agreeing on compatible behavior. The culture of a group may be defined as shared knowledge and compatible behavior of the group.

How is knowledge shared and how is behavior made compatible? In other words, how are they generated, intellectually and socially organized, and diffused? These questions are closely related and schematized in Fig. 1.

Science, as well as language, religion, arts, astronomy, mathematics, and techniques, are corpora of knowledge that have been generated, organized and diffused in a particular context, with specific motivations. Eventually, the corpora of knowledge become unsatisfactory and subject to criticism and revision. This



Colonialism and Science in the Americas. Fig. 1 The Cycle of Knowledge.

may be the result of internal cultural factors, or, what is very common throughout the history of mankind, as a result of exposure to other cultures. Both the internal and external factors are present in cultural dynamics.

Science in History

The great navigations since the sixteenth century mutually exposed forms of scientific knowledge from different cultural environments. The several ethnosciences involved in the encounters, which obviously include European science, have been subjected to great changes as a result. Ethnosciences, as a research program, focuses on corpora of knowledge established as systems of explanations and ways of doing, which have been accumulated, through generations, in specific cultural environments. This program, typically interdisciplinary, brings together and interrelates results from the cognitive sciences, epistemology, history, sociology, and education. An essential component is the recognition that science and mathematics are intellectual constructs of mankind, in response to the needs of survival and transcendence.

The need for an intellectual framework to organize the corresponding systems of explanations and codes, norms and practices gave rise to many aspects of science and Mathematics (D'Ambrosio 1994). In this research program, particular attention is given to those dimensions of knowledge which bear some relation to what became known as science and mathematics in European civilization after the fifteenth century.

Today, many of the weather explanations and predictions, agricultural practices, culinary, production systems and commerce, dressing and institutional codes, such as the legal system, processes of cure, languages, religion, philosophy, which, as a complex, constitute science, come from the European tradition developed in the Middle Ages and the Renaissance. They were imposed, after the sixteenth century, to much of the world, in the processes of conquest and colonialism. But we see, all over the world, extant practices performed in various levels of intensity and in very distinctive ways. These practices, which have their origins in native communities, have been, and continue to be, significantly modified as a result of mutual exposition of cultural forms. For example, it is common to see indigenous peoples in the Americas using Indo-Arabic numerals, but performing the operations from bottom to top, explaining that this is the way trees grow. In the more advanced nations, it is not difficult to identify the influence of this mutual exposition in priorities and even styles of scientific action.

Priorities and styles of intellectual action are the substrata upon which new knowledge is built. Thus, new knowledge reflects the individual and cultural history of the agent, and reveals the diversity of extant cultures. This is the essence of a multicultural historiography, which is the framework in which we discuss the history of science in Latin America. A new educational posture depends on a new historical attitude which recognizes the contribution of past cultures in building up the modern world and modern thought, and which avoids omissions and errors of the past treatment of cultural differences.

We easily identify two categories of scientific knowledge (1) academic science, sometimes called formal or scholarly science, generated by a restricted professional community, organized as specialties or disciplines, according to a convenient epistemology, and shared with peers through an elaborated language, and diffused through strictly controlled institutions, academic or governmental and (2) traditional science, also called cultural science, popular science, practical science, street science, resulting from everyday practices and common knowledge.

These names are challenged. Many scholars do not agree with using the word "science" with a qualification, reserving the word only for the former and using simply "traditions" for the latter. The main distinction refers to criteria of rigor and truth and to the nature, domain and breadth of its pursuits. Science is subjected to a concept of truth supported by criteria of rigor, and organized in disciplines. The criteria of rigor, hence the concept of scientific truth, are changeable in the light of new evidence. In other words, permanence is not strict in science, which led to scientific evolution or revolutions. This is the main issue behind the Popper–Kuhn controversy. In the traditions the focus of concern and the methods are, necessarily, holistic. Traditions reveal, sometimes explicitly, mystical features, characteristic of revealed truth, giving a sense of permanence to their fundamental principles. Thus, scientific knowledge tends to be skeptical, while traditional knowledge is more prone to fundamentalism.

Indeed, sciences and traditions are closely related and influence each other. Skepticism and fundamentalism are the consequences of the resistance to recognize the mutual influence. The Ethnoscience Program is the recognition of this mutual influence. Its main objective is to understand, through a concept of cultural dynamics, this influence.

For example, pre-Columbian cultures had different styles of doing their measurements and computations, and these practices are still prevalent in some native communities (Closs 1986). Most Amazonian tribes have counting systems that go, "one, two, three, four, and many." And that is all, since with these numbers they can satisfy all their needs (do Salvador 1965: 89–90). We also see important ways of dealing with pottery, tapestry, and everyday knowledge with strong mathematics characteristics in several cultures. The people from these cultures have no problems at all in assimilating the current European number system and deal perfectly well with counting, measurement, and money when trading with individuals of European culture demands it. Land measurement, as practiced by peasants in Latin America, comes from ancient geometry transmitted to medieval surveyors since land property and measurement (geo-metry) is strange to pre-Columbian cultures.

The high prestige of science comes mainly from its recognition as the basic intellectual instrument of progress. Modern technology depends on science and the instruments of validation in social, economic, and political affairs, mainly through storing and handling data, are based on science and mathematics. Particularly important in this respect is statistics, which brings to science an aura of essentiality in modern society. There is a general feeling that there are practically no limits to what can be explained by science. Many of the applications which give science such a prestigious position are part of various forms of cultural conflict (D'Ambrosio 2000).

Some Remarks on Historiography

History, as a major academic discipline, carries with it an intrinsic bias which makes it difficult to explain the ever-present process of cultural dynamics which permeates the evolution of mankind. This paves the way for paternalism and arrogance, for intolerance and intransigence. This interferes with the understanding, by a cultural group, of the processes of building up cultural realities which respond to the need for survival and transcendence of another cultural group.

This is seen in the encounter of the two worlds, Europe and America, in the processes of conquest and colonialism. The origin of the interference may be related to distinct views of nature. A scientific conceptualization, which resulted from the medieval intertwining of Judaic, Christian, and Greco-Arabic thought in Europe, led man to look at nature and at the universe as an inexhaustible source of richness and to exploit these resources with a mandatory drive toward power and possession, ignoring native cultural, economical, spiritual, and social diversities. Man was created, in the Biblical tradition, to obey the Creator and to be the master of all the creatures.

In the history of science, these biases have been methodological, as well as ideological. The fact that to pursue historical analyses one talks about the sciences, such as physics, chemistry, or mathematics, as distinct from religion, art, or politics, is an obstacle to understanding the processes of evolution of ideas and methods, of reflection and action, which underlie man's struggle to find explanations and to understand and cope with his environment, as well as to find means of conviviality with nature.

One of the main difficulties in doing the history of science in Latin America concerns the chronological division. In what follows, geographical divisions and historical periods are defined according to the general chronology associated with the conquest and colonization of the Americas.

Geographic divisions are defined following the administrative organization in Viceroyalties (1) New Spain (roughly what is today Mexico, Guatemala and upper Central America) (2) New Granada (roughly what is today southern Central America, Costa Rica, Panama, Colombia, Venezuela, Ecuador); (3) Peru (roughly what is today Peru and Bolivia); (4) La Plata (roughly what is today Chile, Paraguay, Argentina, and Uruguay); and the lately created Viceroyalty of (5) Brazil, under the Portuguese crown. Since the independence movements, which began early in the nineteenth century, the cultural map has remained roughly the same.

With respect to periods, it is misleading to adopt, for the New World, the same division as in the history of science in Europe. I propose five major periods:

1. Pre-Columbian era
2. Conquest and early colonial times
3. Established colonies
4. The rise of independent countries
5. The twentieth century (which will not be dealt with in this essay)

These periods reflect the established societies before the conquest, the emerging classes of Creoles, the definition of production and political systems, and international geopolitics, which have, mainly in the twentieth century, major influences in the sciences and technology in Latin America. Of course, there are specificities. While recognizing important attempts of French and Dutch settlements in the Americas, the main colonial role was played by Spain, Portugal, and England. It is important to understand the different styles of these three colonial empires.

Portugal, since its early consolidation as a kingdom, in the thirteenth century, recognized the Atlantic as its essential link to its commercial interests. The limited means of production led Portugal to develop a potent scientific and technological establishment focused on the navigations. The European navigators of the end of the fifteenth and early sixteenth centuries reached all of America, Africa, India, and China. In the case of Africa and in Asia, there had been previous contacts with civilizations which had many encounters among themselves and with Europeans. Thus the encounters of the fifteenth and early sixteenth centuries were amplifications and deepenings. Meeting the "new," the unknown, the unexpected, was experienced by Columbus and the Spaniards, in 1492 and in the subsequent voyages to the New World.

Visions of the World

Earlier contacts with the Americas are known, but the motivations and behavior of earlier navigators was completely different from the Spanish and Portuguese, and afterward the English, French, and Dutch.[1]

The influence of the navigators and chroniclers, particularly Portuguese, in building up the mode of thought which underlies modern European science is noticeable. In the words of Joaquim Barradas de Carvalho, "the authors of the Portuguese literature of the navigation made possible the Galileos and the Descartes" (Carvalho 1983: 13), essentially through the development of "objective and serene curiosity, rigorous observations and creative experimentation" (Correia 1940: 468).

Particularly important as chronicles are the *Crónica dos feitos de Guiné* of Gomes Eanes de Zurara (1453) and the *Esmeraldo de situ orbis*, by Duarte Pacheco Pereira, written between 1505 and 1508. These, particularly the latter, are probably the earliest major scientific works reporting on what was observed and experimented in the newly "discovered" environments.

The voyages themselves allowed a broader view of the world. For the Portuguese, to venture into the Southern Hemisphere demanded two major enterprises: the construction of the caravel, an extremely versatile ship built by the Portuguese in the fifteenth century as the result of a remarkable engineering project[2]; and novel navigation techniques, relying on tables constructed from systematic recorded observation carried on by the commanders of those ships. As the first European looking at "different skies," they were responsible for recording what they saw. The contributions of Gil Eanes crossing the Bojador Cape in 1434, Nuno Tristão reaching in 1443 the coast of Mauritania, and the major achievement of Diogo Cão crossing the Equator line in 1483, all paved the way for Bartolomeo Dias to cross the Cape of Hope in 1488 and for Vasco da Gama to reach Calicut in India, in 1498. Together with Columbus reaching the Western lands in 1492, the vision of the World changed. All lands and peoples were within the reach of the navigators. It was the beginning of a new phase in the history of mankind.

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[1] See the interesting study of Ivan Van Sertima. *They Came Before Columbus*, New York: Random House, 1976 and the reports on the voyages of the Chinese monk Huei Shen in the fifth century to Mexico. See the communication of Juan Hung Hui: "Tecnologia Naval China y Viaje al Nuevo Mundo del Monje Chino Huei Shen, III Congreso Latinoamericano y III Congreso Mexicano de Historia de la Ciencia y la Tecnologia, Ciudad de Mexico, 12–16 Enero 1992.

[2] See Antonio Cardoso, As Caravelas dos Descobrimentos e os mais Ilustres Caravelistas Portugueses, Monografia n° 7 do Museu de Marinha, Lisboa, 1984.

Conquest and Early Colonial Times

America, and to some extent Africa, were more surprising to Europeans than the lands which had been reached before by land routes, in the so-called Old Continent. Particularly, America showed peoples with new systems of explanation, of rituals and of societal arrangement. Reflections on natural philosophy or the physical sciences, particularly astronomy, were part of the overall "Cosmo" vision of the pre-Columbian civilizations.

The scientific establishment and native scientists, surely present in the society of the conquered cultures, were not recognized as such by the conquerors. One of the earliest registers of these cultures, Fray Bernardino de Sahagún (1499–1590) writes that "The reader will rightfully be bored in reading this Book Seven, [which treats astrology and natural philosophy which the naturals of this New Spain have reached]… trying only to know and to write what they understood in the matter of astrology and natural philosophy, what is very little and very low" (Sahagún 1989: 478). This important report explains much of the flora and fauna, as well as the medicinal properties of herbs of Nueva España. But he does not give any credit to indigenous formal structured knowledge. This is typical of what might be called an epistemological obstacle of the encounter.

In the vision of the conquered, a great impression was caused by the arms, tools, and equipment in general, as seen in pictures, for example in the *Codice Florentino*. Much research is needed on the science of the encounter. But this needs a new historiography, since names and facts, on which current history of science heavily rely, were not a concern in the registry of these cultures. A history "from below," which might throw some light on the modes of explanation and of understanding reality in cultures, has not been common in the history of science.

Mexico, in itself, has a very rich colonial history. Developments in Central and South America reveal the important and strategic position of Mexico in the New World.

To acquire fluency in the language of the conquered peoples was a priority. Grammars are a major contribution to this. As early as 1547, Fray Andrés de Olmos (ca. 1485–1571) published the *Arte de la Lengua Mexicana*. Fray Domingos de S. Thomas (ca. 1505–1570) published in 1560 the *Grammatica o Arte de la Lengua General de los Indios de los Reynos de Peru*. The need for this understanding of the culture of the conquered, where much of the mining was taking place, is also seen in numeracy. A description of the number system of the Aztecs was written by Juan Diaz Freyle: *Sumario compendioso de las quentas de plata y oro que en los reinos del Pirú son necessarias a los mercaderes y todo genero de tratantes. Con algunas reglas tocantes al arithmética.* Printed in Mexico in 1556, this is the first arithmetic book printed in the New World. This is a clear indicator that the successful elimination of basic communicative instruments supporting the means of production and the religion of the conquered, such as language and numeracy, had to be mastered by the conqueror. Soon after the consolidation of the conquest, this book disappeared from circulation and Aztec arithmetic was replaced by the Spanish system; the Spanish language also became dominant.

Printing of scientific books in Mexico reveal the intellectual atmosphere of Nueva España. Alfonso [Gutierrez] de la Veracruz published, in 1954, *Recognitio Summularum* and *Dialectica Resolutio*, and, in 1557, *Phisica Speculatio*. The first book contains an exposition on Aristotle's theory of syllogisms, including modal logic, and the second contains Aristotle's "Categories," with commentary, and includes numerous examples drawn from geometry, such as parallel lines, triangles, and the incommensurability of the diagonal of the square.[3]

It is interesting to observe that the registration of space location did not have the same importance as language and numeracy. Maps, essential in European actions, were not known in these cultures, while time measurement was done with remarkable precision. This has much to do with the differences in what I call Cosmo vision.[4]

Although different production systems and societal organization prevailed in the Atlantic Coast, under Portuguese rule, efforts to master the language were also important. In 1595, José de Anchieta S. J. (1534–1597), published the *Arte de Grammatica da Lingoa Mais Usada na Costa do Brasil*, and in 1640, when Spanish interests grew in the Eastern South America, mainly focused on the Jesuitic Missions in Paraguay, Antonio Ruiz de Montoya S. J. (1585–1652) published the *Arte y Bocabvlario de la Lengva Gvarani.*

In early colonial times, the Spanish and the Portuguese tried to establish schools, mostly run by Catholic religious orders. The effort to impose the language of the conqueror was responsible for considerable advances in linguistics. The demand for science and mathematics was essentially for economic purposes related to trade, but there was also an interest in science and mathematics related to astronomical observations. Reliance on indigenous knowledge was limited, but there was some interest in the nature of native knowledge. The *Historia Natural y Moral de las Indias*, published in Seville in 1590 by Joseph de Acosta S. J. (1540–1600),

[3] I owe this information to Bruce S. Burdick.

[4] An important study of these differences is Fernando Flores Mirador: *Tierra firme antecipada. El descubriiento de América y las raices arcaicas de Occidente* (to appear), Lund, 2003.

is representative of the trend to write comprehensive studies of society, history, religion and science.

Already in the first century after the conquest, there were practical books published in Mexico, such as the *Arte menor de arithmetica,* by Pedro de Paz, in 1623, and *Arte menor de arithmética y modo de formar campos,* de Atanasio Reaton, in 1649. It is also to be noticed the book *Nuevas proposiciones geométricas,* written by Juan de Porres Osorio, in Mexico.

There are some sources for the history of the natural and the health sciences in the general books of the chroniclers. In the conquest, there was a high level of scientific curiosity to observe and understand new diseases and new cures. Indeed, Felipe II (1527–1598), of Spain, sent his personal physician, Francisco Hernandez (ca. 1514–1597), to Mexico, to learn and record new practices and drugs which might be useful in improving health care in the cities. Unfortunately, all of his manuscripts were destroyed in a fire at the Escorial Library.

It is important to remember that social medicine was more developed in Portugal and Spain, as well as in England, than in the rest of Europe. Upon the arrival of ships to and from the New World, it was necessary to provide medical care for the travelers, in many cases subjected to new and unknown diseases. The *Santas Casas* (holy houses), founded in Lisbon in 1498, were built with this purpose. In 1543, Bras Cubas founded a *Santa Casa* in Santos, near São Vicente, one of the earliest urban settlements in the Portuguese colonies, founded by Martim Afonso de Souza. Soon there was concern about creating formal medical classes in the colonies. In 1653, a Chair of Medicine was established in Nueva Granada, in the Colegio Mayor de Nuestra Señora del Rosario, in Bogota. This lasted until 1865 and was replaced by the Facultad de Medicina de la Universidad Nacional, in 1867.[5]

Astronomy was a major area of interest in Latin America in the seventeenth century. There are important discussions on the meaning of comets. Many of the interpretations related to the purpose of such strange phenomena: to convey divine messages to mankind. Surely, these were searches for scientific explanations. Several polemical exchanges of letters and papers are known from these times, with important epistemological arguments. The figure of Don Carlos de Sigüenza y Góngora (1645–1700), of Mexico, towers. His works focus on astronomical observations and calculations. His most important book, considered one of the most important works of Latin American science, is *Libra astronómica y filosófica,* written in 1690. In it, Sigüenza y Góngora refutes prevailing astrological arguments about comets.

In Brazil, research on comets was also of major importance. We can see the same tone of the reflections of Sigüenza y Góngora in the work of Valentin Stancel S. J. (1621–1705), a Jesuit mathematician from Prague who lived in Brazil from 1663 until his death. His astronomical measurements are mentioned in Newton's *Principia.* A polemic, which includes another Jesuit, Antonio Vieira S. J. (1608–1697), reveals how important was the discussion about the nature of comets in building up modern scientific ideas.

In the Viceroyalty of Peru, we have the same concerns. The first to be recognized as a mathematician in Peru was Francisco Ruiz Lozano (1607–1677), who wrote *Tratado de los Cometas,* essentially a treatise of medieval mathematics explaining the phenomenon.

The Established Colonies

The death of Carlos II (1661–1700), of Spain, resulted in a turbulent period in Europe, known as the War of the Succession of Spain (1701–1714). An important consequence was the intellectual movement known as the Enlightenment [*Ilustración*], which had important consequences for the Americas, mainly the intellectual revival, which began in Spain under Carlos III (1716–1788) and in Portugal under José I (1714–1777) and his strong minister, the Marquis of Pombal (1699–1782) (Maxwell 1995).

Religious orders were not immune to the new ideas coming from Europe, and several descriptive treatises of the world were written. A general geography of the continent, the *Geographia Histórica de la América y de las Islas Adyacentes, y de las Tierras Arcticas y Antárcticas, y Islas de los Mares del Norte y del Sur*, authored by Pedro Murillo Velarde S. J. (1693–1753), was published in Madrid, in 1752, as volume IX of a monumental 10-volume *Geographia Histórica del Mundo.* This important and comprehensive presentation of the New World is a remarkable source of the history of the development of the colonies, revealing the political struggles and cultural differences.

As a result of the War of the Succession of Spain, relations with other European nations were intensified, and, as a consequence, a number of foreign scientific expeditions, with mixed scientific and commercial interests, came to the region during the eighteenth century (Weinberg 2000: 497–515). This contributed to shaping scientific development in Latin America. Great repercussions were caused by the scientific expeditions of Amedée Frézier (1682–1773), published in 1716 as *Relación del viaje por el mar del Sur a las costas del Chile y del Perú realizada durante los años 1712, 1713 y 1714,* and of Charles Marie de la Condamine (1701–1774), whose main results were

5 A detailed history of this chair of medicine is the book by Emilio Quevedo and Camilo Duque, *História de Cátedra de Medicina, 1653–1865*, Centro Editorial de la Universidad del Rosario, Bogota, 2003.

published as *Relation abrégé d'un voyage fait dans l'intérieur de l'Amerique méridionale*. Alejandro Malaspina (1754–1809) organized one of the most important expeditions. In 5 years, they visited practically all the Spanish possessions and collected precious materials.

A good number of expatriates and Creoles played an important role in creating a scientific atmosphere in the colonies. As a result of the emergence of modern science, following the publication of Newton's *Principia*, mathematics was central in the emerging scientific community. A number of intellectuals, well versed in a variety of areas of knowledge, were responsible for introducing mathematics to the colonies. These include Juan Alsina and Pedro Cerviño in Buenos Aires, who lectured on infinitesimal calculus, mechanics and trigonometry. In Peru, Cosme Bueno (1711–1798), Gabriel Moreno (1735–1809) and Joaquín Gregorio Paredes (1778–1839) are best known. In Brazil, José Fernandes Pinto Alpoim (1695–1765) wrote two books, *Exame de Artilheiros* (1744) and *Exame de Bombeiros* (1748); both focused on what we might call military mathematics, and both were written in the form of questions and answers.[6]

A distinguished figure from the period is José Celestino Mutis (1732–1808), who was responsible for an unpublished translation of Newton, but also for the introduction of modern mathematics in Colombia, mainly relying on the books by Christian Wolff. He was the founder of the *Observatorio de Bogotá* in 1803. His most distinguished disciple, Francisco José Caldas (1771–1816), became the director of the Observatory. Caldas was deeply involved in the Independence War and was shot by the Spaniards.

In Chile, the Universidad Real de San Felipe, which was inaugurated in 1747 in Santiago, was provided with a "catedra" of Mathematics. Fray Ignacio León de Garavito, a self-instructed Creole mathematician, was responsible for this chair.

Again we have to mention Mexico, where the most important developments of mathematics in Latin America at that time, took place. In the first half of the eighteenth century a number of textbooks on geometry, arithmetic, and astronomy were in use in Mexico, written by local scholars. These were mostly minor scientific works. In the second part of the century, there were publications with more scientific value. Particularly notable are the *Lecciones matemáticas* of José Ignacio Bartolache, published in 1769. In 1772, an unkown person built a "calculating wheel," capable of performing the four basic operations for numbers up to 10^8 digits. Also in 1772, Benito Bails published the *Elementos de matemáticas*, which treated infinitesimal calculus and analytic geometry.

A special kind of applied mathematics was developed, stimulated by the complexity of problems related to water and to mining. These two constitute the most important problems in the technological development of the country. "Subterraneous geometry" became a major theme in Mexican science. The needs of mining led to the creation of mining schools, such as the Real Seminário de Minería, founded in Mexico City by the Spanish mineralogist Fausto de Elhuyar in 1792. Particularly important were the efforts for urbanization, which took place in all the colonies (Catalá 1994). The book *Comentarios a las Ordenanzas de Minas*, by Francisco Javier Gamboa, published in 1761, is most representative of these developments.

Let us move to the South. In Guatemala, which included Costa Rica, the most renowned scholar was José Antonio Liendo y Goicoechea (1735–1814). He taught at the Universidad de San Carlos de Guatemala. This had already become a very important academic center after a new plan of studies published in 1785, written in Latin in the form of 25 theses, under the title *Temas de Filosofia Racional y de Filosofia Mecánica de los sentidos, de acuerdo con los usos de la Física; y de otros tópicos físico-teológicos según el pensamiento de los modernos para ser defendidos en esta Real y Pontificia Academia Guatemalteca de San Carlos*…. This was, essentially, a medieval proposition. Goicoechea was responsible for modernizing this plan of studies, incorporating experimental physics into the project, and introducing modern mathematics based on the texts of Christian Wolff.

Independence: The Basin Metaphor

The independence of the Viceroyalties of Nueva España, Nueva Granada, Peru, La Plata, and Brazil was achieved in the first quarter of the nineteenth century. The political division in countries, following independence, was practically the same as today. The pattern of cultural dynamics since colonial times did not change much, except for the fact that other empires replaced Spain and Portugal as central nations.

There is no way to deny that (Western) science and mathematics are essential in the modern world. Public opinion is ready to support investment in scientific and mathematical research in spite of being absolutely unable to guess what kind of research is being supported. For example, peers and society in general regard those that get good grades in mathematics as potential geniuses, while those that do not do well in mathematics are regarded as potentially stupid. Socially, this has been instrumental in the selection of the elite. The attitude regarding sciences in general is not different. The

[6] Brazil was different from the Spanish colonies; she did not have presses. These two books, although written in Brazil, focusing on Brazilian interests, were printed, in Portuguese, in Spain and Portugal.

appropriation, by larger strata of society, of scientific and mathematical terminology and even results, is reprehended and even derided. Those who do well in the arts or in sports, but fail in mathematics, are considered less intelligent. The references to "hard sciences" subtly reveal contempt for the humanities and social sciences. The best illustration of this is what became known as the "Science Wars," exposed by Alan Sokal's hoax.[7]

Let me introduce some concepts and reflections that result from what is now called Social Studies of Science or Science Policy. This is basically the study of the politics of scientific development, the backbone of funding agencies. It is very interesting to analyze the substitution of the colonial discourse by the discourse of aid – both multilateral, like UNESCO, and bilateral, like ORSTOM, the British Council and others. The nature of the deprived populations in colonial times and after independence, following WWII, did not change. Neither did basic needs. But the strategies to keep them as faithful consumers had to change.[8] But let us not deviate from the main objective of this paper, which is the production of scientific and mathematical knowledge.

When deciding on investments in science and technology, it is natural to expect social benefits. These investments have been substantial, both through funding agencies, either governmental or through aiding agencies, either bi- or multilateral. The outcomes in the so-called Third World have not been encouraging, as recently mentioned by the Director-General of UNESCO. "The gap between rich and poor countries is a gap of knowledge," said Federico Mayor (1994). Over 80% of the benefits of scientific and technological research are available only to the populations of the First World. But the gap between central nations and peripheral nations in the production of scientific knowledge is widening. Scientific productivity is related to the cultural atmosphere and self-esteem. Evidence from research shows that both individual and social creativity are enhanced by self-esteem. Self-esteem can hardly prevail among a population deprived of its history.

The most efficient strategy to consolidate colonial control was to deprive the conquered peoples of their systems of explanation and the instruments for survival and transcendence. This was achieved with a subtle deprivation of the history of the conquered and the production of a history "favorable" to the conqueror. This prevailed after independence. Today, Cardinal Richelieu and D'Artagnan are themes of history and literature in former colonies. Hernán Cortez is better known than Montezuma. Local heroes are ignored or labeled as evil criminals. For example, in Brazilian history books, Zumbi (1655–1695) was regarded as an outlaw and although recognized, more recently, as a hero, the space reserved to him in books and classes is negligible.[9]

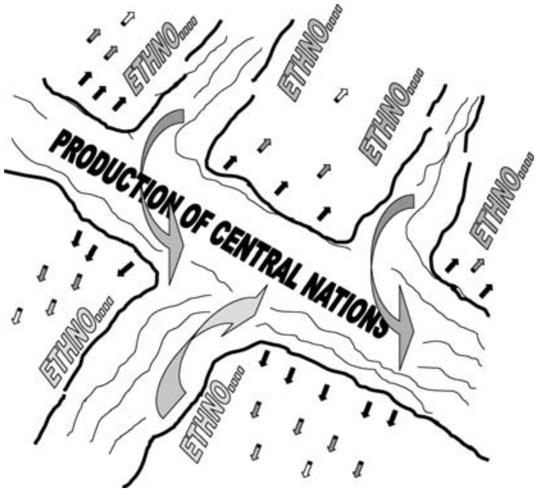
We may consider, as it is frequent in discussions of policy, especially in the United Nations and other national and international agencies, the production of scientific, technological, and mathematical knowledge as something measurable. Scientometrics relies on several indicators and the studies of quantitative history allow us to speak of the central nations as those who produce new knowledge, and the peripheral nations as those who absorb new knowledge. Production and absorption of knowledge are clearly distinguishable. The sad situation is that the peripheral nations have been slow in absorbing new knowledge. The lack of infrastructure acts as a barrier for this process (D'Ambrosio 1975: 94). The Basin Metaphor helps us to understand the process. The main producers of knowledge (Central Nations) are represented by the main stream. Water always fertilizes their margins. They will produce their effect in the margins of the tributaries (Peripheral Nations) much later, when the waters have already flown along the stream (thus producing the gap or obsolescence of knowledge). The water (knowledge) does not flow upstream of the tributaries (Fig. 2).

The water of the tributaries fertilizes their margins, and also adds and contributes to the volume of water of the main stream. For example, expropriation of "popular" knowledge – so common in the pharmaceutical industry – and cooptation strategies, particularly the brain drain, encourage this. A strict school system was

[7] See the issue devoted to the theme "Science Wars" in *Social Text*, 46–47, Spring/Summer 1996. The issue has very interesting papers. Regrettably, attention was given only to the hoax of Alan Sokal. As a consequence there was a renewal of attacks on Afrocentrism, warnings against a "new dark age of irrationalism" and other controversial disputes going on in the academic world. All this, that might be interpreted as a form of intellectual fundamentalism, is nothing but a defensive posture against the challenge of the current epistemological order.

[8] These topics have in the postwar period drawn much attention and generated important studies whose results throw some light on the production of scientific knowledge throughout history. Particularly interesting is the historiography adopted by Harold Dorn in his exciting book, *The Geography of Science*, Baltimore: The Johns Hopkins University Press, 1991.

[9] Zumbi is the leader of the "Quilombo dos Palmares," a republic created by runaway slaves in the Northeast of Brazil, which lasted for about 100 years. It was destroyed in the late seventeenth century. But other such republics lasted and some were contacted only recently. Their economy and production systems, particularly agriculture and mining, are as yet to be studied. See more on the communities of runaway slaves in the Americas in Richard Price, org., *Marron Societies: Rebel Slave Communities in the Americas*, 2 vols. Baltimore: The Johns Hopkins University Press, 1972.



Colonialism and Science in the Americas. Fig. 2 The Basin Metaphor.

responsible for this strategy in colonial times. This is manifest in the emigration of academics and, worst, in the subordination of laboratories and research institutions of the peripheral nations to the priorities of their major homologues in the central nations (D'Ambrosio 1979: 223–229). This strategy plays out, for example, in the valuation of foreign academic degrees over local degrees. Now, it is quite revealing to see the efforts to entice research institutions in the peripheral nations to join major biotechnology research plans.

The cooptation of scientists in the periphery is normally done by sending experts, in many cases scientists with high reputations, to the periphery for short visits and conferences, by offering fellowships, by giving stipends higher than the current national salaries, by sending equipment (in many cases obsolete or already heavily used) and offering international travel to seminars and congresses. This is true in academics and, in the more developed peripheral nations, also in industry. Particularly in mathematics, we have numerous examples of such practices in the postwar period. The presence of monies of the US Army, Navy, and Air Force research agencies, as well as of the NSF, the CNRS, the British Council, the DAAD and other agencies, following the pattern mentioned above, is remarkable.

These cases have not been studied in detail as yet. They have the common feature of producing human resources and results without any analysis of the capability of the peripheral countries to absorb and to make these resources and results useful for their needs. Normally this is the result of a lack of qualitative directives in science policy of the peripheral nations. Practically every scientific development plan in the periphery is a program entirely based on quantitative goals. The World Bank, the UNDP and other financing agencies rely on, indeed stimulate, plans based on quantitative goals. Clearly, they are easier to check. But the benefits for the poor populations of the peripheral nations are practically nil.

In the basin metaphor, the sources of the rivers, both the main stream and the tributaries, correspond to ethnomathematical knowledge. Ethnomathematical knowledge, like the waters, flows fertilizing the margins of the tributary and eventually mixes in a major stream, contributing to this flow. Waters of the main stream do not go upstream through the tributaries.

The notion of progress carried on by the main stream will benefit the margins of the tributary after a long way through difficult land paths – which correspond to the acquisition of knowledge from other sociocultural and environmental sources. The needs of the margins – peripheral cultures – are met by the water of the tributaries, and only later receive the benefits coming from the main stream. But these can be useful only if the grounds are fertile. To make them fertile requires long, deep, and very complex educational reforms.

In this metaphor, an alternative to main stream and tributaries would be to have a large lake, where all the sources contribute equally to the main body of water. Each source produces according to its environmental history and all the waters of the lake fertilize all the margins. The creation of the great lake – the deterioration of the current world order – is identified with a sensible globalization, leading to a new planetary order.

Developments in the Newly Independent Countries

The independence of Guatemala, in 1821, decreased the influence of Mexico in Central and South America. The establishment of new universities and the renewal of old ones, immediately preceding and after independence, generated open attitudes with respect to sources of knowledge on which to build up the newly established countries of Latin America. Formerly restricted to an almost exclusivity of influences coming from Spain and Portugal, the new countries attracted considerable attention from the rest of Europe, and a new wave of scientific expeditions came to South America. They had great influence in creating new intellectual climates throughout the region. This new source is seen very strongly in the building of large and diversified libraries, both public and private, and the acquisition of modern literature.

In Costa Rica, colonial authorities established the Casa de Enseñanza de Santo Tomas in 1814, in which the most influential teacher was Rafael Francisco Osejo, born in 1780. In 1830, he wrote *Lecciones de aritmética*, written in the form of questions and answers, a common feature in that period, as shown above when referring to Alpoim in Brazil. In 1843 the Casa de Enseñanza was transformed into the Universidad de Santo Tomas, where courses in Engineering were established. But there were no courses in pure sciences and mathematics.

Colombia soon attracted foreign mathematicians. The Frenchman Bergeron introduced Descriptive Geometry in the country, and the Italian Agustín Codazzi (1793–1859) was influential in creating the Colegio Militar. Lino Pombo (1797–1862), who was particularly influential in founding the Academia de Matematicas de Venezuela, wrote a complete course of mathematics.

In Brazil, the transfer of the royal family of Portugal, who were escaping the Napoleonic invasion, in 1808, was decisive in changing cultural life in the colony. The Portuguese court settled in Rio de Janeiro, where it was necessary to create an infrastructure to run, from a colonial town, the vast Kingdom of Portugal. They founded a major Library and an Escola Militar (Military School), the first institution of higher learning in the colony. Both were influential in the development of mathematics in Brazil. In the school, a doctorate in mathematics was established and a number of theses were submitted and defended (da Silva 1992). Translation of the textbooks of Lacroix, of Legendre and others, were quite important in generating what we might call a mathematical style in Brazil.

Particularly interesting is the case of Joaquim Gomes de Souza (1829–1863), known as "Souzinha," the first Brazilian mathematician to appear in Europe. He presented his results in the Académie des Sciences de Paris and in the Royal Society. Only short notices of the papers were given,[10] and they were posthumously published as *Mélanges du Calcul Intégral*, as an independent printing by Brockhaus of Leipzig in 1889. This work, dealing mainly with partial differential equations, is permeated by very interesting historical and philosophical remarks, revealing access to the most important literature then available. This was possible due to the existence of important private collections in Maranhão, his home state in the Northeast.

Argentina, independent since 1816, experienced a remarkable intellectual development. In 1822, the ephemeral Sociedad de Ciencias Físicas y Matemáticas was founded in Buenos Aires (Nicolau 1996). There was an emergence of private libraries. Particularly important is the private library of Bernardino Speluzzi (1835–1898), which listed the main works of Newton, D'Alembert, Euler, Laplace, Carnot, and several other modern classics. Another intellectual, Valentin Balbin (1851–1901), while Rector of the National College of Buenos Aires proposed a new study plan, in 1896, which included history of mathematics as a distinct discipline. This is probably the first formal interest in the History of Mathematics in South America, which eventually led to an important school of History of Science in Argentina.

In Peru, there was an interest in Statistics, beginning with the book *Ensayo de estadística completa de los ramos económico-políticos de la provincia de Azángaro…* by José Domingos Choquechuanca (1789–1858), published in 1833.

In Chile, the Universidad de Chile was created in 1842, with a Faculty of Physical and Mathematical Sciences. A most distinguished member of the Faculty was Ramón Picarte, a lawyer, who had his paper, "La división reducida a una adición," accepted and published by the Academy of Sciences of Paris in 1859.[11] Much emphasis was given to teacher training. An agreement with the government of Germany provided the pedagogical support to reform education in the country. Fifteen German mathematicians, most with a doctorate, immigrated to Chile in 1889.

The influence of Auguste Comte (1798–1857) toward the end of the century was very important in all of Latin America, particularly in Mexico and in Brazil. Although the main reason was the demand of the emerging political elites to build up the ideological framework of the new countries, Comtian ideas influenced a considerable development of mathematics and the Sciences in general.[12]

Conquest and colonization had an enormous influence on the course of development of civilization. The chroniclers of the conquest tell of different ways of explaining the cosmos and the creation and of dealing with the surrounding environment. Religious systems, political structures, architecture and urban arrangements, sciences and values were, in a few decades, suppressed and replaced by those of the conqueror. A few remnants of the original behavior of these cultures were and still are outlawed or treated as folklore. But they surely integrate the cultural memory of the peoples descending from the conquered. Much of these behaviors are easily recognized in everyday life.

Mathematics, as an human endeavor, is not different. This is one focal point of the research program known as Ethnomathematics, which deals with the generation, the intellectual and social organization and the diffusion of different ways, styles, modes (*tics*) of explanation, understanding, learning, coping with and

[10] *Comptes-Rendus de l'Académie des Sciences de Paris*, tomes XL, p. 1310, and XLI, p. 100 and *Proceedings of the Royal Society*, 1856, pp.146–149. It is quite interesting to read the referee's reports and the reaction of Gomes de Souza to the fact that Liouville did not give an appraisal of the paper, according to Gomes de Souza, because of "la petite jalousie." A thorough study of the scientific works of Gomes de Souza has still not been done.

[11] I did not have personal access to these papers and to the records of Picarte's presence in Paris.

[12] See the important doctoral dissertation of Circe Mary Silva da Silva, Positivismus und Mathematikunterrichte: Portugiesche und franzsische Einflüsse in Brasilien im 19. Jahrundert, IDM, Bielefeld, 1991.

probing beyond (*mathema*) the immediate natural and sociocultural environment (*ethno*). This clearly results from the mutual exposition of different cultures and the dynamics of this process is a major problem we face in doing the history of ideas in every region of this world.

The conquest paved the way to colonization. In the Americas, the early colonizers, the Spanish and the Portuguese, paved the way for the French, the English and the Dutch colonizer and later on for Africans, Europeans, and Asiatic immigrants. With them came new forms of coping with the environment, of dealing with daily life, and new ways of explanations and learning. The result was the emergence of a synthesis of different forms of knowing and explaining which were generated by and available to the different communities, to workers and to the people. We recognize the emergence of new religions, cuisine, music, arts, and languages, particularly in the Americas – the Creoles. All of these interrelated as a synthesis of the cultural forms of the ancestors.

Science and Mathematics, as cultural forms, are not different. The emergence of new cultural behavior is another focal point of the research programs known as Ethnosciences and Ethnomathematics.

Particularly in the Americas, the variety and peculiarity of the expositions of cultures and the specificity of the population migrations reveal an effort of the colonizer to transfer, with minor adaptations, the forms of social, economical and political organization and administration prevailing in the metropoles, including schooling and scholarship (academies, universities, monasteries). The new institutions in the Americas were based on the styles prevailing in the metropoles, mostly under the influence, and even control, of religious orders.

All this, which took place during most of the sixteenth, seventeenth, and eighteenth centuries, occurred while new philosophical ideas, new sciences, new ways of production and new political arrangements were flourishing in Europe. The cultural artifacts produced in Europe were assimilated in the Americas under specific, mostly precarious, conditions. There is a clear coexistence of cultural goods, particularly knowledge, produced in the Americas and abroad. The former were consumed mostly by the lower strata of society, the people and workers, and the latter by the domineering classes. These boundaries are not clearly defined and the mutual influences of the resulting intellectual productions are evident.

This poses the following *basic question*: What are the relations between the producers and consumers of cultural goods?

This guides my proposal for the historiography of science and mathematics and what I have called "the Basin Metaphor." Although this is a question affecting the relations between academia and society in general, hence between the ruling elites and the population as a whole, it is particularly important for understanding the role of intellectuality in the colonial era. Thus ethnoscience and ethnomathematics are fundamental instruments of historical analysis (D'Ambrosio 1995; 1996).

Curiously enough, the main factor influencing the consumption of what we might call academic science and mathematics produced in an alien cultural environment – sometimes inside the same country – depend basically on what the "outsiders" – that is, the people, not learned in science and mathematics – have to say about science and mathematics. This factor has not been given attention in the prevailing historiographies (D'Ambrosio 1993). This broader look, suggested by new historical scholarship, comes under severe attack, in what became to be known as the Science Wars (D'Ambrosio 2000). My proposal incorporates to the History of science and Mathematics, in an essential way, the views of aliens, in the sense of strangers to the specific knowledge fields or strange to the cultural environment, about science and Mathematics.

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Colonialism and Science in India

DEEPAK KUMAR

Colonization was not merely a political phenomenon; it had far-reaching economic and cultural ramifications. It was an exercise in power, control, and domination. Scientific and technological changes greatly facilitated this progress. Techno-science and colonialism are closely linked and to some extent share a cause and effect relationship. In recent years a good deal of work has been done on the nature, course, and consequence of this relationship in different geographical and culture areas. Some scholars see in it utilitarian and developmental images; many others find it utterly exploitative, while some prefer to opt for a middle path and emphasize both the regenerative and retrogressive aspects of the science and colonization nexus. So the debate continues, and several works have appeared with case studies on Africa, Latin America, and Asia. India, being a prime example of classic colonization, has also received considerable attention.

The fact that India has a very long techno-scientific tradition and a rich cultural heritage is fairly well known. It was, however, during the seventeenth to eighteenth centuries, the post-Renaissance epoch (that of Descartes and Newton) that Europe began to outdistance India in scientific and material advancement. The rise of modern science in Europe profoundly disturbed the balance of scientific development among traditional societies. It is also possible that the various sciences and technologies were on a decline in India around 1790. There was definitely no "conscious" spirit of technological innovation and scientific enquiry to match the spirit of Europe. The result was colonization.

The advancing European trading companies became deeply involved in political and military rivalries, culminating in the establishment of the British paramountcy over the Indian sub-continent. A new empire was in the making. The colonizers were out to collect the maximum possible information about India, its people and resources. They reported what was best in India's technological traditions, what was best in India's natural resources, and what could be most advantageous for their employers. The English East India Company, for its part, was quick to realize that the whole physical basis of its governance was dependent upon the geographical, geological, and botanical knowledge of the areas being conquered. The colonizers fully recognized the role and importance of science in empire building.

The most interesting feature of this early phase of colonial science lies in its highly individualistic character. State followed the trade, and certain individuals on the spot would largely determine what was advantageous for both. These colonial scientists would try their hands at several fields simultaneously, and were in fact botanist, geologist, zoologist, physicist, chemist, geographer, and educator – all rolled into one. As data gatherers they had no peers, but for analysis and recognition, they had to depend upon the metropolitan scientific culture whose offshoots they were and from which they drew sustenance. The colonial government quickly patronized geographical, geological, and botanical surveys; after all these were of direct and substantial economic and military advantage. Medical or zoological research did not hold such promises. Research in physics and chemistry was simply out of the question, for there were no laboratories, equipment, or specialized training. The reigning spirit remained that of exploration. Systematization or analysis of its results had to wait for some time, but then, even disjointed and often haphazard studies served some purpose.

Other positive achievements were the establishment of scientific bodies and museums. Pre-British India never had anything like as scientific society, not to say a journal, which could provide some sort of a platform for scientific workers. William Jones was the first to realize this and founded the Asiatic Society in Calcutta in 1784. This society soon became the focal point of all scientific activities in India. It was followed by the Madras Literary and Scientific Society (1805), the Agricultural and Horticultural Society of India (1817), Calcutta Medical and Physical Society (1823), and the Bombay Branch of the Royal Asiatic Society (1829). Trigonometrical and topographical surveys were organized under the Great Trigonometrical Survey of India (1818), and a Geological Survey was established in 1851. Scientific research thus for a long time remained an exclusive governmental exercise, and this largely determined the nature and scope of scientific research in India. Colonial science primarily implied “natural history” and its star (if not sole) attraction was the exploitation of natural resources. It was basically plantation research with emphasis on experimental farms, the introduction of new varieties, and the various problems of cash crops. Next came surveys in geology and meteorology. Another major area of concern was health. The survival of the army, the planters, and other colonizers was at stake. The importance of medical research was always recognized, but the quantum of emphasis varied from time to time. In any case, however, research was not to be a curiosity-oriented affair. Financial considerations were invariably there. The colonial administrators consistently held that scientists in India should leave pure science to Britain and apply themselves only to the applications of science. They would goad the various organizations to work along only economically beneficial lines. Colonial researchers often found themselves unable to distinguish between basic and applied research. This was particularly true of the geologists and the botanists. Their problem was how to discover “the profitable mean course” in which scientific research, having a general bearing, would at the same time solve the local problems of immediate economic value. The dilemma was fairly acute.

In the field of education, science was unfortunately never given a high priority. In 1835 Thomas Macaulay not only succeeded in making a foreign language, English, the medium of instruction, but his personal distaste for science led to a curriculum which was purely literary. A few medical and engineering colleges were opened, but they were meant largely to supply assistant surgeons, hospital assistants, overseers, etc. What India got was some sort of a hybrid emerging out of a careless fusion between literary and technical education. What is more, adoption of English as the sole medium of instruction in science rather hampered its percolation to the lower classes. Colonial education widened the social gulf and accentuated the age-old divide. Even in government institutions, growth was kept under a self-regulatory check. The Tokyo Engineering College was established in 1873, much later than the Engineering College at Roorkee, and by 1903 it had a staff of 24 professors, 24 assistant professors, and 22 lecturers. The Massachusetts Institute of Technology was established in 1865 and by 1908 it had 306 teachers. And Roorkee, even after 100 years of its existence (i.e., in 1947), had only three professors, six assistant professors, and 12 lecturers.

Colonialism involved not only exploration and classification but also coding and decoding cultures. Its cultural projects showed deeper penetration and greater resilience than its economic forays. With the help of schools, universities, textbooks, museums, exhibitions, newspapers, etc. local discourse was influenced and colonized. Modernity was presented as a colonial import and not something intrinsic to humanity’s rational nature. Colonial rule, with its sharp tools, dissected and bared differences and was not inclined to synthesize. Colonialism usually stalls the possibilities of exchange and prefers one-way traffic. One may talk of transfer – transfer of knowledge, systems, or technologies – but it was a transfer restricted or guided to achieve certain determined objectives. As education and awareness grew, several Indians participated in the official scientific associations and institutions, but very often they searched for a distinct identity and established institutions, scholarships, and facilities of their own.

In the first half of the nineteenth century, Bal Gangadhar Shastri and Hari Keshavji Pathare in Bombay, Master Ramchandra in Delhi, Shamhaji Bapu and Onkar Bhatt Joshi in Central Provinces, and Aukhoy Kumar Dutt in Calcutta worked for the popularization of modern science in Indian languages. In 1864 Syed Ahmed founded the Aligarh scientific Society and called for the introduction of technology to industrial and agricultural production. Four years later Syed Imdad Ali founded the Bihar Scientific Society. These societies did not live long. In 1876 Mahendra Lal Sarkar established the Indian Association for Cultivation of Science. This was completely under Indian management and without any government aid or patronage. Sarkar’s scheme was very ambitious. It aimed not only at original investigations but at science popularization as well. It gradually developed into an important center for research in optics, acoustics, scattering of light, magnetism, etc. In Bombay, Jamshedji Tata drew up a similar scheme for higher scientific education and research. This was opposed by the then Governer-General, Lord Curzon. Yet it finally led to the establishment of the Indian Institute of Science at Bangalore in 1909. There was thus greater awareness by the turn of the century.

In the first quarter of the twentieth century, those who put India on the scientific map of the world were J. C. Bose, who studied the molecular phenomenon produced by electricity on living and nonliving substances, Ramanujan, a mathematical genius, and P. C. Ray who analyzed a number of rare Indian minerals to discover in them some of the missing elements in Mendeleef’s Periodic Table. C. V. Raman’s research on the scattering of light later won him the Nobel Prize in 1930 and gave the name to Raman spectroscopy. Meghnad Saha pioneered the field of astrophysics, while S. N. Bose’s collaboration with Einstein led to what is known as the Bose–Einstein equation. These were great sparks, individual and sometimes lonely, yet imbued with both scientific and national spirit. They thought over what role science and technology would play in building modern India, and they dreamt of freedom. The colonial government was aware of its limitations and discomfiture, and gradually permitted greater indigenization of its scientific institutions and cadre. In the wake of the First World War the government realized that India must become more self-reliant scientifically and industrially. It appointed an industrial commission in 1916 to examine steps that might be taken to lessen India's scientific and industrial dependence on Britain. However, few of the Commission's recommendations were actually implemented. Discontent continued to grow. India's national leaders appreciated the importance of science and technology in national reconstruction and worked closely with the scientific talent of the time. A National Planning Committee was formed in 1937 for this purpose, in which several leading Indian scientists and technologists participated. In 1942, the Council for Scientific and Industrial Research was established. The end of colonial science was pretty near. With the A. V. Hill Report in 1944 on Scientific Research in India, the curtain dropped.

The foregoing analysis illustrates that in a colonial situation field sciences may have been developed through imported scientists as an economic necessity, but little fundamental research was possible. A few colonial scientists made important contributions that no doubt enriched science in general, but their activities hardly succeeded in introducing science to the Indian people or in ameliorating their condition. Colonial science did, on the whole, support and help sustain exploitation and underdevelopment.

See also: ►Western Dominance, ►Ramanujan

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Colonialism and Science in the Malay World

Hairudin B. Harun

By the sixteenth century, the legends of the Golden Chersonese, about the distant land having more gold and exotic treasures than people, were well established among the sea going nations of Europe. Legend had it that the Golden Chersonese was geographically located midway between India and China. The Golden Chersonese description apparently fit the Malay Peninsula very well. Indeed, it came to be known among the early Europeans by that very name until it was replaced by another, Malacca. By whatever name the Peninsula was known, it was a major focal point of Eastern trade. Indeed, Malacca – actually a tiny coastal city-port situated in the middle of the Malay Peninsula – was not only a commercial Mecca, but also a cultural center and meeting point for the major civilizations of the time.

In 1575, Louis De Roy, writing on the virtues of the new knowledge and inventions spurned by the Renaissance spirit, made a special note about the meeting of Magellan and the King of Malacca. According to De Roy, the meeting was made possible by the new knowledge of the seas and the use of the magnetic compass for navigation. Malacca, to the Europeans then, as not just a reference to the city-port but rather to the whole Malay Archipelago, including the Peninsula and Islands of Indonesia that were under Malaccan rule. By the time De Roy's article was published. Malacca had actually been under the annexation of Portugal for 65 years, since the Portuguese defeated the Malays in 1511. Some scholars have suggested that the downfall of Malacca also marked the decline of Eastern scientific and technological superiority *vis-à-vis* the European. Others have cautioned against making simplistic conclusions, pointing out that the reasons for the downfall of Malacca were far more complex than those that have been suggested.

The Portuguese ruled Malacca until the mid-seventeenth century. In 1614 the Dutch successfully wrested Malacca from the Portuguese. By the mid-eighteenth century Dutch power in the Malay Archipelago declined, giving way to the British. The British were relatively latecomers to the region, but they were none the less regarded as the best prepared – intellectually, militarily and economically – among the colonizers of the region. They were poised for a long stay.

There were two major factors that were crucial to the expansion and consolidation of the Crown's influence: the colonial economy and the health of officials, colonialists, and *coolies* (colonial laborers). In the early phase of British colonialism, spices, timber, and other agricultural products were the backbone of the colonial economy. Knowledge of economically and medicinally useful plants of the East was indispensable both for the sustenance of the economy and the maintenance of health. This knowledge was to be found in the new discipline of plant science, later known as *economic botany*, and much later as *agricultural science*.

The cultivation of spice trees, and the transfer of economic plants like rubber trees from the Amazon to the Malay Peninsula, was some of the colonial activities made possible by the new plant science and its scientific institutions. Indeed, apart from medicine, no branch of science was regarded as so crucial to the sustenance of colonialism as economic botany. Before the advent of synthetic drugs, herbs and plants were the main source of medicines. For instance, quinine, an extract from the chichona tree that grew wildly in the Peruvian jungle, was extensively used to cure malarial fever. Hence, knowledge of the indigenous plants was important not only for economic reasons, but tot health as well. Health and diseases also assumed an economic and political significance. They were moderating factors in the colonial expansion and exploitation of the East, especially in the tropics. Tropical diseases like malaria were a menace to the health of colonial officials and then laborers. Indeed, malaria reportedly wiped out some of the remote British colonies and military bases and was blamed for slowing down colonial campaigns in the Far East and Africa. In the following discussion we will see how the development and history of British colonialism and science in the Malay Archipelago became intertwined.

Botany and British Colonialism

As early as the seventeenth century there were attempts to grow exotic and foreign food crops away from their natural habitats. The first attempt to grow pineapples in England was reportedly made during the reign of Charles II (1660–1685). The colonization of the New World and later, Asia, led to the introduction of many new crops to Britain. Maize, a staple crop of the Native

Americans, which yields ten times more than wheat, was among the crops that revolutionized European tastebuds. Another imported high yielding crop, that reportedly saved Ireland from starvation, was the potato. However, there were still many food crops that resisted local cultivation and therefore had to be brought over from the colonies. Supply was notoriously irregular and rarely adequate to meet demands. It was not until the nineteenth century that supply became more reliable. This reliability owed much to the active colonization of new fertile lands in the East and the new discipline of economic botany.

In the nineteenth century, the political ideology of the times, the botanic gardens, and the colonial office functioned as an integrated framework, enforcing an economic structure whereby the East became the producer of raw materials for the West's industries. Indeed, this framework was a characteristic description of colonialism which involved, among other things, the establishment of plantations and the large-scale cultivation of economic plants, and the systematic transfer of economic plants from an area less productive or less conducive (either politically, economically, or scientifically) to a more productive and conducive one. Colonialism also entailed the need to coordinate and transfer labor from one colony to another in order to ensure the viability of a plantation or an agroeconomic project. Underwriting the success of the colonial plantations and agriculture-based economic projects were the many research oriented botanic gardens established throughout the colonies. The most prominent of these botanic gardens were the Calcutta Garden in India, the Peradeniya Gardens in Ceylon (Sri Lanka), and the Penang, Malacca, and Singapore Gardens in the Malay Peninsula, known then as *British Malaya*.

The Royal Botanic Gardens at Kew in London was the center for scientific research and coordination of the work of the botanic stations in the colonies. Kew's role was very well illustrated in the case of the discovery and cultivation of the cinchona tree – the medicinal tree from which the malarial medicine, quinine, was extracted. The discovery of cinchona involved a large army of field workers and researchers collecting and gathering seemingly irrelevant bits of information and materials, from every remote corner of the British Empire and beyond. The information and materials were sent to Kew for analysis. The discovery and eventual successful extraction of quinine, which turned out to be the most potent antidote for malaria, was a credit to Kew and its network of botanic gardens in the colonies. Indeed, quinine was not just an important scientific discovery; it also had important demographic and political effects. Through the control of malaria it saved the lives of countless colonial officials and their *coolies* (laborers) and made possible the large-scale colonial exploration and exploitation of Africa and the Far East.

Colonial Botany in the Malay Peninsula

Colonial botany came to the shores of the Malay Peninsula in the year 1822 with the establishment of the botanic garden in Singapore by Sir Stamford Raffles. The staff of the botanic garden was instrumental in overseeing the introduction and improvement of spice cultivation in the Straits Settlements. Indeed, in the Malay Peninsula *botany* was almost indistinguishable from *economy*. Whether the relationship between botany and colonial economy in the colonies had any influence in the formalization of economic botany back in the motherland is a difficult question to answer with certainty; but what is certain is that the colonial economy benefited much from the knowledge and expertise provided by economic botany.

Back in Britain, botany was given a boost following several developments, one of which was the appointment in 1841 of Joseph Hooker (1817–1911), far more widely known as a colonialist than as a botanist, as head of the Royal Botanic Garden at Kew. Kew was responsible for coordinating and supervising all the scientific research on economic plants and agriculture within the British colonial empire. It was under Kew's supervision that in 1858 new botanic gardens were established in Singapore superseding the one established by Raffles. In 1887 botanic gardens were also established in Penang followed soon after by another in Malacca.

Nowhere is the importance of Kew to British colonialism so clear as in the case of the transfer of the wild Brazilian rubber plant from Latin America to the Malay Peninsula. Initially, various species of wild rubber seeds were collected from the Amazon jungle and sent to Kew Gardens for study and analysis. Eventually a species, *Hevea brasiliensis*, was identified as promising and was transferred to the botanic gardens in Singapore. Under the supervision of the Singapore gardens which H. N. Ridley headed, politically backed by the colonial office, and heavily financed by the Crown companies, experimental plantations were set up in various parts of the Malay Peninsula. The plantations turned out to be experimentally successful and, as anticipated, destined to become commercially successful too. At the turn of the twentieth century, with the advent of motor vehicles industry in Europe and America, rubber became one of the most important raw materials for the new industry. Rubber planting indeed became one of the most profitable colonial commercial ventures. Most importantly, rubber could only be found in abundant quantity and of high quality within the British Empire.

The transfer, identification, and eventual cultivation of economic plants would not have been successful without colonial botany equally recording a success in another related activity: taxonomical works. Indeed, one of the main tasks of the botanic gardens was taxonomical work closely associated with identifying economically and medically useful plants. The varieties of plant life in the tropics became a testing ground for the new system of classification. In the Malay Peninsula, the colonial taxonomical campaigns of identifying and naming tropical plants soon turned out to be an enormous task that almost overwhelmed the colonial scientists and their machinery. The variation of plant life in the tropics rendered it practically impossible for their taxonomists and the new taxonomy to start fresh from scratch. However, starting from scratch was the last thing that they had to do. Long before the arrival of the British, the natives had already classified most of the plants, especially the economically useful ones. More often than not, all the colonial taxonomist had to do was to refer to the local taxonomy and be creative. They eventually discovered that the local folk taxonomy was almost encyclopedic, encompassing the encounter of many generations of indigenous wisdom with the local flora.

Colonial Botany and Malay Ethnobotany

The encounter of the colonialists with Malay ethnobotany probably went as far back as the arrival of the first Europeans to the area. Tome' Pires, a Portuguese scholar and explorer, who visited Malacca during the Portuguese rule, noted the existence of a botanical tradition among the Malays. The Malay botanical tradition was described as being composed of a complex system of plant taxonomy and knowledge as well as the cultural–educational rituals associated with teaching and imparting the knowledge to successive generations.

The majority of the colonial botanists, with very few exceptions, were genuinely intrigued by the sophistication and mechanics of Malay plant taxonomy. They seemed to agree that the Malay taxonomy was much more than a fanciful accidental uttering of a primitive tribe oblivious to any sense of rationality or systematic thinking. In fact, in many ways it was comparable to the modern colonial system.

In the colonial scientific taxonomy, plants having the same kind of flower and fruit but which differ in details of size, shape, and color of the flowers, fruits, or leaves constituted a *genus*. A specific name came after the generic name either as an adjective qualifying it or as noun in the genitive case if the species was in honor of some person.

Colonial botanists noted that Malay folk taxonomy, on the other hand, was based on either the use or morphological characteristics of the plants, or at times both. Most economically useful plants were classified by their use, whilst medically useful plants and others were often classified by the morphology of their niche, leaves, fruits, or flowers. What was found as a pleasant surprise to many of the colonial botanists was the discovery that in many instances the colonial scientific taxonomy and Malay taxonomy shared common grounds. There were also considerable numbers of Malay taxonomical names that found no equivalents whatsoever with the colonial names. Names like *kedundung*, *Tinjau Belukar*, and *Puding* were morphological names referring to the chief characteristics of the respective plant. They could be either a reference to their growth habit, shape of leaves, flowers, fruits, or combinations of any of those. They did not correspond neatly to the modern colonial taxonomy. However, in spite of that, Malay ethnotaxonomy was a tremendous aid to the colonial reclassification of plants in the tropical Peninsula to modern taxonomy.

Many of the taxonomical and other scientific findings were published in the *Kew Bulletin*. The Bulletin was not only important academically, but it was also a medium of communication and instruction between Kew and the imperial network of botanic stations. It played the dual role of a scientific medium and a channel for colonial interests, reflecting faithfully the nature of colonial scientific activities.

Colonial scientific activities in the Malay Peninsula, especially the botanical and the taxonomical exercises, were not just scientific per se; they were first and foremost an integral part of the colonial activity to sustain British colonialism. In short, they were by and for colonialism.

See also: ►Ethnobotany

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Combinatorics in Indian Mathematics

Takao Hayashi

Having prescribed the rule

$$C_n^r = \prod_{k=1}^{r} \frac{n-k+1}{k}$$

for the number of combinations of r things taken at a time from n things, Bhāskara II (AD 1150) remarked:

> This [rule] has been handed down [to us] as a general [method], being employed [for their own purposes] by the experts [of specific fields of study], namely, for the tabular presentation of possible meters in metrics, for the number of ways of opening ventilating holes, etc., and the diagram called Partial Meru in arts and crafts, and for the varieties of tastes in medicine. [But], for fear of prolixity, they are not explained here (*Līlāvatī* 113–114).

It is impossible to tell exactly when and by whom this rule was formulated, but from ancient times Indian peoples have had a keen interest in arranging things in order in various aspects of human life, and in theorizing in various areas of study.

The *Bhagavatī*, one of the 12 canonical books of the Jainas, counts by enumeration the number of all the possible cases when one person, two persons, three persons, etc., are distributed in the seven nether worlds.

Most books of Sanskrit and Prakrit prosody, such as the *Chandaḥsūtra* of Piṅgala (ca. AD 200?), *Vṛttajātisamuccaya* of Virahāṅka (between the sixth and the eighth centuries), *Jayadevacchandaḥ* of Jayadeva (before AD 900), *Chando'nuśāsana* of Jayakīrti (ca. AD 1000), *Vṛttaratnākara* of Kedāra (before AD 1000). *Chando'nuśāsana* of Hemacandra (ca. AD 1150), etc., devote one of their chapters (usually the last one) to "six kinds of ascertainment" (*ṣaṭpratyaya*), namely:

1. Spread (*prastāra*), to spread a list of all the possible variations of a given type of meter consisting of short and long syllables according to a certain method.
2. Lost (*naṣṭa*), to find out a lost variation when its serial number in the list is given.
3. Mentioned (*uddiṣṭa*), to calculate the serial number in the list when a particular variation is mentioned.
4. Short- (and-long-) calculation (*laghukriyā*/*galakriyā*), to calculate the number of the variations in the list that have a given number of short or long syllables (for this purpose, a diagram called the Mount Meru-like spread (*meruprastāra*), equivalent to the so-called Pascal's triangle, is constructed).
5. Number (*saṃkhyā*), to calculate the number of all the variations in the list.
6. Way (*adhvan*/*adhvayoga*), to calculate the space of writing materials required for writing down the list.

A chapter on prosody in the *Nāṭyaśāstra* of Bharata (before AD 600), a dramaturgical work, and one in the *Agnipurāṇa* (ca. AD 800), a work on sacred traditions, also contain a section on these topics.

Four out of the six kinds of ascertainment, namely: spread, lost, mentioned, and number, were applied to the melody (combinations of seven notes) and the rhythm (combinations of a half, one, two, and three beats) in Indian music (Śārṅgadeva's *Saṅgītaratnākara*, ca. AD 1250), for which a diagram called Partial Meru (*khaṇḍameru*) was employed. This was also the case with the combinations of five subcategories taken severally from five categories of "carelessness" (*pramāda*) when they contain different numbers of subcategories, in Jaina philosophy (Nemicandra's *Gommaṭasāra*, ca. AD 980).

Medical treatises such as the *Carakasaṃhitā* (ca. AD 100) and *Suśrutasaṃhitā* (ca. AD 200) treated combinations of the six basic tastes (*rasa*), and of the three humors (*doṣa*) of the body. Varāhamihira dealt with the problem of combinations of nine and sixteen basic perfumes in the *Bṛhatsaṃhitā* (ca. AD 550).

Indian mathematicians prior to Bhāskara, too, are known to have been interested in these problems of combinatorics. Brahmagupta devoted one whole chapter consisting of 19 (or 20) stanzas of his astronomical work, *Brāhmasphuṭasiddhānta* (AD 628), for combinatorics related to Sanskrit prosody. The problem of tastes was taken up by the mathematician Śrīdhara in his *Pāṭīgaṇita* (ca. AD 750). Mahāvīra treated the six kinds of ascertainment of Sanskrit prosody as well as tastes in his mathematical treatise, *Gaṇitasārasamgraha* (ca. AD 850).

In addition to the traditional rule for combination mentioned above, Bhāskara gave six rules for permutations concerning sequences of numerical figures in a chapter called "nets of numbers" (*aṅkapāśa*) of his famous *Līlāvatī*. However, it is Nārāyaṇa who for the first time treated various problems of permutation and combination, including the system of "spread-lost-mentioned," of different areas systematically from the viewpoint of mathematics with the help of variously defined sequences of numerals. Chapter 13 entitled "nets of numbers" of his mathematical treatise, *Gaṇitakaumudī* (AD 1356), consists of about 100 stanzas for rules of combinatorics and 45 for examples.

See also: ►Bhāskara, ►Brahmagupta, ►Śrīdhara, ►Varāhamihira, ►Mahāvīra, ►Nārāyaṇa

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Combinatorics in Islam

Ahmed Djebbar

Among the factors which influenced mathematics in Arab-Islamic civilization was a cultural life which fostered, particularly between the ninth and twelfth centuries, rich interaction between the different intellectual activities of the time.

Taken in a general sense as a study of configurations in one-, two-, or three-dimensional spaces, combinatory analysis had its beginnings in early studies in music, chemistry, astrology, and especially in metrics and Arabic linguistics. From the ninth century on combinatory processes asserted themselves in truly mathematical disciplines like algebra, astronomy, and trigonometry.

Combinatory Practices in Nonmathematical Fields

In music, many works contain a study of the combinations of sounds and rhythms, for example, the *Rasāʾil* (Epistles) of the Ikhwān al-ṣafāʾ (Brethren of Purity, tenth century) and the *Kitāb al-mūsīqā al-kabīr* (Great Book on Music) of al-Fārābī (ninth century). In the field of chemistry, as early as the eighth century, Jābīr ibn Ḥayyān introduced combinatory arguments in his theory of balance, which was based on the principle that everything is a combination of numbers. Jābir goes so far as to identify the language, i.e., the combination of words, in chemistry which he considers to be a morphology of metals.

In astronomical astrology, the conjunctions of the seven planets known at that time played an important role in predicting events. One needed to know the number of conjunctions which corresponded with the number of combinations of seven elements two times 2, three times 3…seven times 7. There was a great need to construct configurations by manipulating numbers or letters. Many mathematicians worked on this problem trying to invent processes of construction and new types of magic squares, for example, Thābit ibn Qurra (d. 901), Abū'l-Wafāʾ (d. 997), Ibn al-Haytham, Ibn Munʿim (d. 1228), and Ibn al-Bannāʾ (d. 1321).

In the field of Arabic poetry, it was al-Khalīl ibn Aḥmad (d. 791) who originated research on meter. He began by deriving a superficial structure of Arabic verse (which also serves for prose). Then he derived an underlying structure based on ten measures which, in combination, provided the five fundamental meters. In turn, these meters provided other meters to Arabic poetry thanks to a purely combinatory operation, circular permutation.

In the field of Arabic prose, there is even more interesting information about combinatory practices. As early as the eighth century, al-Khalīl undertook an analysis of the structures of the Arabic language and attempted to develop a theory based on the results of his investigations by studying the constitution of the roots of the language from the 28 letters of the alphabet, and then the composition of words from those roots. To that end, he calculated combinations, without repetitions, of letters two by two, three by three, four by four, and five by five, in order to determine the numbers of roots of two to five letters in the language. The results of his calculations, without any explanation, appear in his book *Kitab al-ʿayn*. After him, a long tradition was established in this field, but the combinatory aspects have not been systematically studied.

That being said, the examples cited above are really too sparse and isolated to prove any continuity in combinatory practices. In particular, we have not yet found anything which demonstrates the beginning of the mathematization of these combinatory practices in the Muslim East or in Andalusia before the twelfth century.

Combinatory Practices in Mathematics

Combinatory practices in the field of mathematics prior to the twelfth century were relatively modest and concerned only two disciplines, astronomy and algebra.

In astronomy, for example, there is the book of Thābit ibn Qurra, *Al-shakl al-Qaṭṭāʿ*, in which combinations occur, two by two, in six sizes occurring in the formula fixed for the secant figure. In his book, *Maqālīd ʿilm al-hay'a* (Keys to the Science of Astronomy), al-Bīrūnī also uses small combinatory results for the purpose of determining the unknown elements of a spheric triangle as a function of the known elements.

In algebra, there are two works which contain certain aspects of combinatorics. The first, the *Kitāb al-ṭarāʾif fi'l-ḥisāb* (Book of Rare Things in the Art of Calculation) by Abū Kāmil (d. 930), deals with the resolution of certain systems of indeterminate equations, stated in the form of problems of birds, the aim being to enumerate, for each system, all the possible solutions. The second work is the *Kitāb al-Bāhir* by as-Samaw'al (d. 1175) on algebra, its objects and its instruments.

We have, as yet, no way of proving that these combinatory practices from within the mathematical tradition gave rise to any real research in the field between the ninth and the twelfth centuries, and in instances where research did occur, we do not know the results. In any case, it was not the combinatory elements encountered in mathematical problems which inspired the mathematicians of the Maghreb who became involved in combinatorics. It was the tradition of linguistics and lexicography which was the basis of their research.

Ibn Munʿim

The oldest mathematical work from the Maghreb which deals with combinatory problems is the *Fiqh al-ḥisāb* of Ibn Munʿim, a scholar originally from Andalusia, living in Marrakesh in the Almohad era. To our knowledge, his book was the first in the entire history of mathematics to have devoted a whole chapter to this type of problem and to have stated them and solved them according to a common procedure.

Combinatorics After the Thirteenth Century

In the second half of the thirteenth century or the beginning of the fourteenth, another Maghrebin mathematician, Ibn al-Bannāʾ, took up some of the results of Ibn Munʿim in at least two of his works, the *Rafʿ al-ḥijāb* and the *Tanbīh al-albāb*. In the latter work, he notes only a table of combinations from Ibn Munʿim without giving exact references, but he explicitly lays claim to the demonstration of a result long attributed to Pascal (d. 1662) which gives C_n^p as a function of C_n^{p-1}, thus allowing the calculation of the combinations two times 2, three times 3, etc., of a certain number of objects, using the arithmetical formula:

$$C_n^p = \frac{n(n-1)\cdots(n-p+1)}{1\cdot 2\cdot 3\cdots p\cdot(p-1)}$$

which today takes the form of

$$C_n^p = \frac{n!}{p!(n-p)!}.$$

In the same spirit, he deduced the expression of arrangements without repetition of a certain number of objects, after having calculated the number of their permutations.

It is important to point out that, at the same time, in the East, the mathematician al-Fārisī (d. 1321) identified the values of the different combinations of the elements of the arithmetic triangle of al-Karajī and used them to establish a theorem of the theory of numbers such that one can determine the number of divisors belonging to a certain whole. Unfortunately, we do not know if this contribution of al-Fārisī spread throughout the East nor can we affirm that it was known in the Muslim West.

However that may be, we can discern two significant processes from Maghrebian writings after Ibn Munᶜim. First, there occurred the extension of the field of application of formulas and of combinatory reasoning. This field was no longer concerned just with the elements of an alphabet, since that became an abstract model operating in different mathematical fields: in astronomy, with the reformulation and enumeration of compound ratios occurring in spheric trigonometry; in geometry, with the classification of figures and the enumeration of all the equations one can deduce; and finally in algebra, with the enumeration of systems of equations (the work of Ibn Haydūr (d. 1413) and of equations of a certain degree greater than three (the work of the Egyptian Ibn alMajdī, d. 1447, in his commentary on the *Talkhīṣ* (Summary) of Ibn al-Bannā˒).

In the second place, there was a taking account of enumeration in general, in very different fields not always related to mathematics. The most typical case is that of Ibn al-Bannā˒, who devoted part of his work *Tanbīh al-albāb* to these types of problems: the enumeration of different cases of possible inheritances when the heirs are *n* boys and *p* girls, the enumeration of prayers to be said according to the exigencies of Malekite ritual in order to compensate for having forgotten other prayers, and the enumeration of all the possible readings of the same sentence according to the rules of Arabic grammar.

The presence of the same combinatory vocabulary in the works of different authors and the fact that none of them laid explicit claim to their results reinforces the characters of continuity of combinatory practices, a continuity made possible, probably, by the persistence of this new chapter in the teaching of certain professors of that time.

However, if to our eyes this new material and these new instruments seem objectively to be of a piece, we do not know to what degree those who contributed to their formulation were conscious of them or what importance they held in *their* eyes.

The reasons for this are to be found in several places at once: the state of the society itself and the nature of its activities and preoccupations which did not allow for the significant development of combinatorics; the absence of local or regional institutions responsible for renewing programs and imposing, and then perpetuating, the teaching of new ideas; and the imprint of certain specialists whose authority influenced at certain moments the content of scientific teaching, fixing it or simplifying (or deleting) certain theoretical developments and certain chapters. At least that is what Ibn al-Bannā˒ implies in his *Rafᶜ al-ḥijāb* and what Ibn Khaldūn confirms in his *Muqaddima* (Prolegomena), writing about the abandonment of theoretical problems and the perpetration of a more utilitarian mathematics.

See also: ►Ibn Munᶜim, ►Magic Squares, ►Algebra, ►al-Karajī, ►Number Systems, ►Ibn al-Bannā˒, ►Ikhwān al-ṣafā˒, ►Ibn Khaldūn

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Comets and Meteors in the Islamic World

David Cook

Comets and meteors in the classical Muslim world were viewed through the prism of Ptolemaic science as anomalies that broke the rules governing the fixed stars and the seven orbiting planets visible to the naked eye. For this reason, comets and meteors were viewed as portents and frequently noted in the history books and commented upon by the population viewing them. Rulers saw them as negative omens and feared the appearance of comets, while revolutionaries used the awe and terror engendered in the common people to foment change.

The terms used in the Arabic and Persian books are difficult to define with precision. All the most common terms for comets – *najm dhū dhū'aba/dhūa'ib/dhanab* (a star with a lock, locks or a tail) or *kawkab* (a star or a planet) with the same group of suffixes – indicate an association with the fixed or orbiting stars and not an independent existence. Frequently other terms are used that have even less precision, such as *nayzak* (a spear), a "sword" in the sky or other terms (among the

Christian sources, a "cross" for example). But at all times the comet attracted attention because it was sharply differentiated from the fixed stars and the orbiting planets, and merits notice in early books of astronomical folklore (e.g., al-Thaqafī [d. 1012]: 36–37). It seems that many nonscholarly observers of comets believed that they were seeing the selfsame comet that returned on a regular basis.

More scholarly writers were puzzled by the appearance of comets, but they relied upon the classical heritage to explain them. An example of this tendency is the famous Spanish Muslim scholar Ibn Rushd (d. 1198), who wrote that the Greeks and the Romans saw comets as unstable parts of the orbiting planets, and that the "tail" was just the light that appeared as a tail to the eye (Ibn Rushd: 43). Others saw the tail as an integral part of the comet, however. Ibn Rushd further cites Hippocrates and his disciples who stated that the "tail" of the comet was the result of the vapors that were pulled by the sun as it passed by. However, Ibn Rushd was critical of theories proposed by Democritus that comets occurred at the time of planetary conjunctions or were related in some way to the planets (a view he ascribed to the Romans, unnamed). He responded to Hippocrates by stating that if the tail of the comet was the result of vapors, then the comet should be seen with a tail sometimes and without it at other times (Ibn Rushd: 44–45).

Ibn Rushd also pointed out that it was fallacious to state that comets only appeared from the north, and cited personal observation to refute this claim. He stated categorically that comets were not to be grouped with the other stars at all. In the end he proposed that both the comet and the tail were burning with flame, and that the comet interacted with the effluvium, which created the illusion of a long tail (Ibn Rushd: 47–48). In conclusion, similar to popular observers of comets, Ibn Rushd noted that they portend high winds and dryness. Not everyone, however, considered comets to be ill omened. For example, "Ṣāliḥ…al-Wāsiṭī said: Ghazwān told me: A comet rose and so my father sent me to Ziyād b. al-Rabīa to ask him [about it]. He said: Say to him that this comet rises every thirty years and when it rises that year will be fruitful, and it was as he said" (Bahshal: 173, cited in Cook 1999).

There are a large number of observations located in Muslim texts, primarily in Arabic and Persian. Cook (1999) and Rada (1999) have gathered most of the relevant material; however, new comets and meteors continue to be found, and there are great many subsections of Muslim literature that have yet to be surveyed for comets and meteors. The information contained in these observations is eclectic in nature. On occasion it is highly precise in terms of times, dates and angles of observation, but for the most part it is casual and anecdotal, often related to the ominous nature of the comet's appearance. All of the appearances of Halley's Comet (appearing approximately every 71–74 years) can be reconstructed after the 684 appearance, with the exception of the 1,301 appearance, can be attested from Muslim sources.

However, it is not until the 837 appearance of Halley's Comet that we find regular notices in the Arabic language historical materials concerning comets. Prior to this time a great many of the appearances are to be found in problematic materials (apocalyptic, literary) or are indistinct either as to the date and time of the sighting and often as to the phenomenon being witnessed. From 837 the quality of the material is considerably higher, and the dates are often exact with sufficient details that the historian can identify the orbit of the comet. For example, in 905, "a star with locks appeared in Capricorn, toward the north, near Ursa [Minor or Major]" (Cook 1999: 139). Gradually measurements in degrees appear inside the texts. In 947, "there appeared in the heavens a star with a tail whose length was about four degrees on Friday night, August 29, in the year 947 and it disappeared after ten days from its appearance" (Cook 1999: 141). Many other sightings are available. However the quality of the material drops off sharply after 1400, and it is difficult to find precise astronomical descriptions of comets in the Persian historical materials (with the exception of the text published by Kennedy). After the 1830s Arabic historians ceased to note the appearance of comets.

Meteors are a completely different matter from comets, and need to be divided into two groups: meteor showers observed in the heavens and meteorites that have fallen to the earth, often with a substantial impact. In contradistinction to comets, the appearance of meteors is attested in the *Qur'ān* and received an accepted place within the framework of popular Muslim cosmology. *Qur'ān* 72 records that *jinn* (beings made of fire) used to sit on *shihāb*s (meteors) and listen to heavenly conversations (cf. also *Qur'ān* 15: 18, 37: 10). God would periodically throw them down and this action generated the appearance of fireballs (Ṭabarī XXIX: 110–111). This view of the heavens is in close accord with other popular beliefs, such as the belief that the Milky Way galaxy was the sweat of a snake that supported the Throne of God (al-Suyūṭī: 32–33), and is not mentioned in the more scientific discussions.

Falling stars and meteor showers are attested regularly from approximately the beginning of the ninth century, just as with the comets above. But the earliest attestation of an actual meteorite in the Muslim sources is from 852, when "Ṭāhir b. 'Abdallāh [ruler of eastern Persia] sent a stone which fell from the heavens in the region of Tabaristan [northern Iran] to al-Mutawakkil [the caliph]. Its weight was 840 *dirhems* (approximately 253 kg), and they said that its fall was heard at a distance of four leagues, and that it came down to earth in five pieces" (al-Ḥarīrī, I: 181). From this point onward meteorites are regularly recorded in the sources, and are often related to the appearance of meteor showers. Usually the sound of the entry of the meteorite into the atmosphere is described as that of loud thunder, and often columns of light or a flash are mentioned as well. Earthquakes are noted to have followed these events after a short time.

Of course, the only meteorites that received close attention were those that fell upon inhabited areas. Meteorites are said to have fallen on Qayrawan (Tunisia) in 951–952, in Aleppo (1025), in the Yemen (1084, 1154, 1384), Tripoli (1117) and a number of other places. In 1110–1111 a meteorite hit Lake Van (today in eastern Turkey) and emptied the lake and killed all of the fish in it (Matthew of Edessa: 206–207). However, as with the materials on comets, there are few records of meteor showers or meteorites in the extensive Mamluk historical literature (1250–1517) or the Persian history books. Peripheral regions of the Muslim world, such as Morocco, Yemen, India, and Jirba (today in Tunisia), continued to note large numbers of meteorites until the end of the seventeenth century after which it is difficult to find any notices of their appearance.

The Muslim materials on comets and meteors are abundant and have yet to be thoroughly researched. It seems reasonably clear that as long as comets were viewed as portents they merited mention, but meteor showers and meteorites were of lesser import. Gary Kronk in his authoritative *Cometography* has commented on the importance of the Muslim astronomical materials, which have served as a corrective for the lack of European materials during this period, and can be usefully compared with the plethora of Chinese and East Asian observations.

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Compass

Julian A. Smith

The origin of the magnetic compass is obscure. Medieval and Renaissance European compasses have been analyzed in detail, but until recently little work has been done on their history in non-Western cultures. Most modern accounts place the birth of the magnetic compass in ancient China, but its inventors are unknown, its development unclear, and historians are divided over whether its later appearance in the West was independent, or borrowed from China through overland or Arabic maritime intermediaries.

The Chinese compass seems to have been derived from a "south controlling spoon" (*si nan shao*) carved from lodestone (magnetite) and used in the early diviners' boards the Han Dynasty (202 BCE–AD 220). Just as in ancient Greece, Chinese philosophers were first aware of magnetic attraction; the ability of the lodestone to pick up iron was mentioned in the *Lü Shi Chun Qiu* (Master Lu's Spring and Autumn Annals, third century BCE), the *Lun Heng* (Discourses Weighed in the Balance, AD 83), and a host of other Chinese annals between the third century BCE and the sixth century AD. The discovery of magnetic directivity (the tendency of magnets to point north and south) made the lodestone particularly important in geomancy and divination. Historian Joseph Needham argued that this was known publicly by the first century AD, and may have been a secret of court magicians as early as the second century BCE.

Between the first and sixth centuries AD, Chinese scholars discovered that magnetic directivity could be induced in small iron needles by stroking them on lodestones. These needles, when floated in bowls of water (sometimes hidden inside carved wooden fish), would then guide Chinese navigators by pointing to the north and south; these early "wet compasses" were the first type. The second variety, a "dry compass" consisting of a needle mounted on a pivot (often concealed inside a wooden turtle), was developed much later (early twelfth century). Chinese encyclopaedias such as the *Taiping Yulan* (Taiping Reign-Period Imperial Encyclopaedia) also mention "dry" compasses made by suspending a magnetic needle on a silk thread.

Chinese physicists may also have been first in discovering magnetic declination. The fact that the compass does not point exactly to the geographic north, but rather to the magnetic north a few degrees away, was mentioned in philosopher Shen Gua's *Meng Qi Bi Than* (Dream Pool Essays) in 1088 AD. He says the compass needle "always inclines slightly to the east." Knowledge of this effect was extremely important for ocean navigation. Chinese knowledge of declination goes back to the late Tang period (eighth–ninth centuries AD).

The development of the magnetic compass in India is highly uncertain. According to some scholars, the compass is mentioned in fourth century AD Tamil nautical books; moreover, its early name of *maccha-yantra* (fish machine) suggests a possible Chinese origin. In its Indian form, the wet compass often consisted of a fish-shaped magnet, floated in a bowl filled with oil.

The earliest references to the magnetic compass in Europe appear in the grammatical and philosophical treatises *De Nominibus Utensilium* and *De Naturis Rerum* of English monk Alexander Neckam (1157–1217), French poet Guyot de Provins' (fl. 1184–1210) *La Bible*, and the *Historia Orientalis seu Hierosolymitana* of French preacher Jacques de Vitry (ca. 1165–1240). Based on these sources, historians have dated the European appearance of both dry and wet compasses to the middle of the twelfth century.

Among Arabic sources, the earliest descriptions of the magnetic compass occur in the thirteenth century. A Persian collection of stories, the *Jāmiʿ al-Ḥikāyāt* (ca. 1232) of Muḥammad al-ʿAwfī says that sailors navigate using a piece of iron rubbed by a magnet, and the 1282 lapidary of Bailak al-Qabajaqi, the *Kanz al-Tijar*, mentions a wet compass seen in 1242. Some of these early treatises discuss the use of fish-shaped compass needles among Islamic navigators in the Indian Ocean, suggesting a possible borrowing from Indian sailors; but it is also possible that Arabs got the compass from Europeans (scholars arguing this hypothesis often point out the Arabic word for compass, *al-kunbas*, appears to come from Italian roots). Much more research needs to be done before this argument can be settled.

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Computation: Chinese Counting Rods

Lam Lay Yong

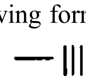
The basic questions in the study of arithmetic in any civilization are: how did the people add, subtract, multiply, and divide, and what were the notations and media that were used to perform these operations.

The ancient Chinese used bamboo sticks or animal bones to count. The first five numbers were tallies in the following form:

The representations for six, seven, eight, and nine were as follows:

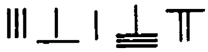
The horizontal rod represented the quantity five.

It is easy to imagine how these rod numerals were handled for the addition or subtraction of small numbers such as two plus five or nine minus two. In the case of the addition of, for example, six and seven, the three vertical rods were grouped together and the two horizontal rods representing two fives were replaced by a single rod positioned horizontally to the left of the three vertical rods. The sum, thirteen, was expressed in the following form:



In this manner, a place value notation was created; the tens' place was to the left of the units' place. The nine numerals that could occupy this place were similar in idea to the nine numerals shown above but had a significant difference: the vertical rods were turned into horizontal ones and the horizontal rods were turned into vertical ones. They were of the following form:

The notion of place values was then extended to express larger numbers. The first set of nine numerals occupied positions whose place values were units, hundreds, ten thousands, and so forth; the second set of nine numerals occupied positions whose place values were tens, thousands, hundred thousands, and so on. For example, the rod numeral for thirty six thousand one hundred and eighty-seven appeared as



and the rod numeral for thirty thousand one hundred and eighty-seven appeared as

which revealed that the thousands' place was empty.

Any number, however large, thus could be represented by the rod numeral system, which used a place value notation with ten as base. The rod numeral system was essentially a computing mechanism; the results of the calculation were recorded in the written numbers.

The rods were used for reckoning in the fifth century BCE. According to *Qian Han shu* (Standard History of the Western Han Dynasty), they were cylindrical bamboo sticks, 0.1 *cun* (approximately 0.231 cm) in diameter and 6 *cun* long. They were carried in a hexagonal bundle made up of 271 pieces. Computation was performed on a flat surface such as a table or a mat. By the sixth century AD, the rods were shorter in length and square in cross-section. During the Tang Dynasty (AD 618–907), it was quite common for officials, astronomers, engineers, mathematicians, and others to carry their bundles of rods wherever they went. Besides animal bones and wood, the rods could be carved from horn, ivory, or jade.

Sun Zi suanjing (The Mathematical Classic of Sun Zi) written aiiiuiul AD 400 is the earliest existing work to have a description of the rod numerals. It also gives detailed descriptions of how multiplication and division were performed. The step-by-step procedures are the same as the earliest known methods of multiplication and division using Hindu–Arabic numerals, which were described by Muḥammad ibn Mūsā al-Khwārizmī in his book on arithmetic and by Abū al-Ḥasan Aḥmad ibn Ibrāhīm al-Uqlīdisī in *Kitāb al-Fuṣul fī al-Ḥisāb al-Hindī*. This fact together with other evidence supports the thesis that the Hindu–Arabic numeral system has its origins in the Chinese rod numeral system.

Just as the Hindu–Arabic numeral system provided the mainstay and impetus for the growth and development of our arithmetic and algebra, the rod numeral system provided the same support for the development of mathematics in ancient and medieval China.

The process of division with rod numerals resulted in an important notation for the expression of a fraction. For example, the notation for four-fifths is

This is the same as the notation for the common fraction in Hindu–Arabic numerals which also originated from the earliest method of division with numerals. The use of this notation enabled an extensive study on operations with fractions – a subject with which other ancient civilizations had difficulties that were frequently insurmountable.

With the concept of the rod numeral system ingrained in their minds and using the rods as the medium of expression, the ancient Chinese developed arithmetic and algebra. The problems in *Jiu zhang suan shu* (Nine Chapters on the Mathematical Art) (ca. AD 100) show that they were able to solve problems involving fractions, the Rule of Three, proportion, areas and volumes, square roots and cube roots, the Rule of False Position, sets of simultaneous linear equations, and negative numbers.

For numerous centuries the rod numeral system played a dual role: in calculation and in the development of mathematics. It aided the progress of the Chinese civilization till the Ming Dynasty (1368–1644) when it was gradually replaced by the abacus as an instrument for computation. Mathematics flourished from the firm foundation depicted in *Jiu zhang suan shu* and reached its peak in the thirteenth century. When the rod numerals became outmoded and fell into disuse, mathematics also underwent its period of decline and transition.

See also: ►Sun Zi, ►al-Khwārizmī, ►al-Uqlidīsī, ►*Jiuzhang Suanshu*, ►Abacus, ►Algebra in China

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Computing Science in Ancient India

SUBHASH KAK

India's romance with numbers can be seen in the mention of large numbers up to 10^{19} in the Black Yajurveda. The sources for mathematical computing in India in the early phase are the Vedic books including the Brāhmana texts, the *Śulbasūtras* (texts on altar geometry), *Jyotisha* (astronomy), the *Chandahśāstra* (Pingala's book on prosody), Pānini's grammar, the *Nātya Śāstra* (Bharata Muni's text on music, drama, and dance), and nonmathematical texts such as the *Mahābhārata* and diverse *śāstras* (scientific and philosophical texts).

The Indian approach to the world was classificatory and computational. In astronomy, an attempt was made to reconcile the motions of the sun, the moon, and the planets that required periodic corrections. In grammar, the most economical rules for different constructions were sought. Not only the sign for zero, but also the binary number system, infinity and its operations, the ideas of metarules, algebraic transformation, recursion, hashing, mathematical logic, formal grammars, and high level language description arose first in India.

The *Śulbasūtras*

The *Śulbasūtras* belong to the *Vedāngas*, or supplementary texts of the Vedas that deal with construction of geometric altars. Their contents, written in the condensed *sūtra* style, cover geometrical propositions and problems related to rectilinear figures and their combinations and transformations, squaring the circle, as well as arithmetical and algebraic solutions to these problems. The root *śulb* means measurement, and the word *śulba* means a cord, rope, or string.

The extant *Śulbasūtras* belong to the schools of the Yajurveda. The most important *Śulba* texts are the ones by Baudhāyana, Āpastamba, Kātyāyana, and Mānava. They have been generally assigned to the period 800–500 BCE of which Baudhāyana's text is the oldest. Baudhāyana begins with units of linear measurement and then presents the geometry of rectilinear figures, triangles, and circles, and their transformations from one type to another using differences and combinations of areas. Approximations to the square root of 2 and to π are given next.

In the methods of constructing squares and rectangles, several examples of Pythagorean triples are provided. It is clear from the constructions that both the algebraic and the geometric aspects of what we call the Pythagorean theorem were known. Several geometric constructions in these texts are based on algebraic solutions of simultaneous equations of linear and quadratic types. It appears that geometric techniques were often used to solve algebraic problems.

Jyotisha

Recent researches have established that the altar geometry of the *Śulbas* was used to represent astronomical facts related to the knowledge of the lunar and the solar years. The solution to these problems involved solution to indeterminate linear equations. Lagadha's *Vedānga Jyotisha* (1300 BCE), a book on the motions of the sun and the moon, presupposes knowledge of such equations.

Pānini's Grammar

Pānini's *Ashtādhyāyī*, "The Eight Chapters" (fifth century BCE), provides 4,000 rules that describe the Sanskrit of his day completely. The great variety of linguistic ideas used in the text mirrors the complexity of cognitive relationships that is the secret of its power and success. It is remarkable that Pānini set out to describe the entire grammar in terms of a finite number of rules. Scholars have shown that the grammar of Pānini represents a universal grammatical and computing system.

The *Ashtādhyāyī* ostensibly deals with the Sanskrit language. However, it presents the framework for a universal grammar that can apply to any language. Two important early commentaries on this grammar are by Kātyāyana and Patanjali. Bhartrihari examined its philosophical basis in an important work in the fifth century AD.

Pānini's grammar begins with metarules, or rules about rules using a special technical language, or metalanguage. Several sections follow on how to generate words and sentences starting from roots, as well as rules on transformation of structure. The last part of the grammar is a one-directional string of rules, where a given rule in the sequence ignores all rules that follow. Pānini also uses recursion by allowing elements of earlier rules to recur in later rules. This anticipates in form and spirit by more than 2,500 years the idea of a computer program.

In Pānini's system, a finite set of rules is enough to generate an infinity of sentences. The algebraic structure of Pānini's rules was not appreciated in the West until about 50 years ago when Noam Chomsky proposed a similar generative structure. Before this, in the nineteenth century, Pānini's analysis of roots and suffixes and his recognition of ablaut led to the founding of the subjects of comparative and historical linguistics.

Pānini took the idea of action as defined by the verb and developed a comprehensive theory by providing a context for action in terms of its relations to agents and situations. This theory is called the *kāraka* theory. These *kārakas* are:

1. That which is fixed when departure takes place
2. The recipient of the object
3. The instrument, or the main cause of the effect
4. The basis, or location
5. What the agent seeks to attain, deed, object
6. The agent

These *kārakas* do not always correspond to the nature of action; therefore, the *kāraka* theory is only a *via media* between grammar and reality. It is general enough to subsume a large number of cases, and where not directly applicable, the essence of the action/transaction can still be cast in the *kāraka* mold. To do this, Pānini requires that the intent of the speaker be considered. Rather than a structure based on conventions regarding how to string together words, Pānini's system is based on meaning.

Chhandahśāstra and *Nātya Śāstra*

The *Chhandahśāstra* of Pingala (400 BCE according to tradition) describes the binary number system. The idea of mathematical zero is also implicit in some of Pānini's rules. The *Nātya Śāstra* presents important results on permutations and combinations. Further results are to be found in later books on musicology such as the *Brihaddeśi* and the *Sangīta-Ratnākara*.

The Siddhāntic Age

Āryabhaṭa (born 476) presented the first general solution to the linear indeterminate equation using the method of *kuttaka*. Brahmagupta (seventh century) solved the quadratic indeterminate equation $Nx^2 + 1 = y^2$. Brahmagupta's expressions for the diagonals of a cyclid quadrilateral are considered most extraordinary.

Virahānka (eight century) gave an explicit rule for what we call the Fibonacci sequence. Vīrasena (ninth century) knew the logarithm to base 2 and its properties. Jayadeva of the same period developed the *chakravāla* (cyclic) method which, according to Hankel, is the "finest thing achieved in the theory of numbers before Lagrange (18th century)." Bhāskara (born 1114) made further advances to trigonometry and analysis.

Navya Nyāya

Navya Nyāya (New Logic) began in Mithila under the leadership of Gangeśa Upādhyāya (twelfth century). The scholars of this school developed an elaborate technical vocabulary and logical apparatus that came to be used by philosophers and writers on law, poetics, aesthetics, and ritualistic liturgy. In their technique of analyzing knowledge, judgmental knowledge was analyzed into three kinds of epistemological entities in their interrelations: "qualifiers"; "qualificandum," or that which must be qualified; and "relatedness." Further abstract entities used were qualifierness, qualificandumness, and relatedness. The knowledge expressed by the judgment "This is a blue pot" may then be analyzed into the following form:

> The knowledge that has a qualificandumness in what is denoted by 'this' is conditioned by a qualifierness in blue and also conditioned by another qualifierness in potness.

At its zenith during the time of Raghunātha (1475–1550), this school developed a methodology for a precise semantic analysis of language. Its formulations are equivalent to mathematical logic.

Kerala Mathematicians

The Kerala school of mathematics flourished during 1200–1600 in South India. One of its great figures, Mādhava (ca. 1340–1425), also provided methods to estimate the motions of the planets. He gave power series expansions for trigonometric functions, and for π correct to 11 decimal places.

A very prolific scholar who wrote several books on astronomy, Nīlakanṭha (ca. 1444–1545), found the correct formulation for the equation of the center of the planets and his model is nearly a true heliocentric model of the solar system. In it, the planets go in eccentric orbits around the mean Sun, which in turn goes around the Earth. He also improved upon the power series techniques of Mādhava.

These mathematicians made truly fundamental advances in analysis including infinite series and calculus. Almeida and his collaborators have suggested that Jesuit missionaries brought this work to Europe and it may have provided the spark for the European mathematical revolution.

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Conics

Jan P. Hogendijk

The theory of conic sections was discovered in Greece around 350 BCE. The most comprehensive ancient treatise on the subject was the *Conics* of Apollonius of Perga (fl. ca. 200 BCE). This treatise consisted of eight Books, of which only the first four have come down to us in Greek. Apollonius considered an arbitrary cone with a circular base, whose apex is an arbitrary point not in the plane of the base. He obtained the conic sections as intersections of this cone by a plane not through the apex. Apollonius distinguished three types of conic sections: the ellipse, the parabola, and the hyperbola.

The story of the translation of the *Conics* into Arabic is interesting, because it shows the difficulty of translating a technical mathematical text. The first Arabic geometers with an interest in the *Conics* were the three Banū Mūsā ("sons of Mūsā," fl. ca. AD 830). At first they possessed only one poor Greek manuscript, containing the first seven Books, and they were unable to understand the very technical contents. Then one of the brothers, al-Ḥasan, decided to develop the theory of the ellipse as the intersection of a cylinder and a plane. He believed that the cylinder was easier than the cone, and he hoped that the theory might be more accessible this way. Al-Ḥasan wrote a book on his discoveries, entitled *Al-shakl al-mudawwar al-mustaṭīl* (The Rounded Elongated Figure). This work is lost.

After the death of al-Ḥasan, his brother Aḥmad obtained a second manuscript of the first four Books of the *Conics* in Syria, together with the commentary of Eutocius of Ascalon (ca. AD 500). This manuscript was much better than the other one, and with the help of the book of his deceased brother, Aḥmad was able to make sense of the contents of the Greek text. He then inserted cross-references in the Greek in order to make the text more comprehensible. Now that he understood the first four Books, Aḥmad was able to make sense of Books V–VII on the basis of the other manuscript. He then had the Books translated: Books I–IV by Hilāl al-Ḥimṣī, Books V–VII by Thābit ibn Qurra. Aḥmad supervised and corrected the translation. Thus Aḥmad ibn Mūsā and Thābit rescued one of the most interesting mathematical works of antiquity, namely Books V–VII of the *Conics*. Book VIII of the *Conics* seems to have been lost altogether. It was reconstructed around 1000 by Ibn al-Haytham, and around 1700 by Edmund Halley.

By the ninth century, geometers in the Arabic tradition had already written treatises on conic sections. Thābit ibn Qurra authored a work on plane sections of a cylinder, which is extant. A popular subject was the determination of the surface areas of segments of conic sections and the volumes of solids obtained by revolving a segment of a conic section about one line (such as the axis or the base). The Arabic geometers knew that Archimedes had solved this problem for the parabola, but they did not know his method of solution. The treatises on this subject by Thābit ibn Qurra, and by the tenth-century mathematicians al-Qūhi and Ibn al-Haytham, are among the highlights of Arabic mathematics.

The Arabic geometers applied conic sections in the solution of a group of problems (trisection of the angle, construction of two mean proportionals, construction of the regular heptagon, etc.) which could not be solved by means of ruler and compass. In the tenth century AD, most geometers in Iraq and Iran considered straight

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lines, circles, and conic sections the only legitimate means of construction in geometry. The reason was that these objects belonged to fixed (immovable) geometry (*al-handasa al-thābita*), whereas all other curves and instruments were believed to be created by motions and instruments, which did not belong to mathematics but to mechanics.

Conics were also used in the solution of the "Problem of Alhazen" (named after al-Ḥasan ibn al-Haytham, mentioned above). In this problem, the positions of the eye, the object, and a convex or concave spherical, cylindrical, or conical mirror are given. One asks for the points of the mirror at which the object is reflected to the eye. Ibn al-Haytham constructed these points of reflection, and he showed that the object is reflected at no more than four points on the mirror. His solution is very intelligent but also extremely complicated, and several seventeenth-century European mathematicians complained about its difficulty. Earlier, the solution had been simplified by al-Muʾtaman ibn Hūd, the king of Zaragoza (d. 1085), but this simplification was unknown in Christian Europe.

In the tenth century, al-ʿAlāʾ ibn Sahl studied reflection in parabolic lenses (which had been studied before) and refraction in hyperbolic lenses (this topic was new). He showed that rays parallel to the axis are refracted to one of the foci of the hyperbola. The reasoning implies knowledge of what we now call Snell's law of refraction, but it is unclear how al-ʿAlā discovered this law.

An important field of application of conic sections was the theory of cubic equations. A cubic equation is an equation of the form $x^3 + ax^2 + bx + c = 0$, for a, b, c given numbers. The Arabic geometers were unable to solve this equation algebraically, i.e., to say, by expressing the root x in terms of a, b, and c. However, they learned to solve it geometrically. The history of the theory is connected with a certain division of a line segment mentioned by Archimedes in Proposition 4 of Book II of *On the Sphere and Cylinder*. Archimedes used the divided line segment but he did not show how it could be divided. In the ninth century, al-Māhānī showed that the division of the line segment, which Archimedes uses, depends on a cubic equation of the form $x^3 + c = ax^2$ (a and c are positive). However, he was unable to solve this equation. Abū Jaʿfar al-Khāzin (tenth century) knew the work of al-Māhānī and also a commentary by Eutocius of Ascalon (ca. AD 500), who shows how the line segment can be divided by means of conic sections. Apparently, Abū Jaʿfar realized that one could use Eutocius' construction using conic sections to find the root x of the equation $x^3 + c = ax^2$ to which al-Māhānī had reduced the problem. Soon other Arabic geometers discovered that conic sections could also be used to solve other "types" of cubic equations. (Because they only worked with positive coefficients, they distinguished different types of equations, e.g., $x^3 + c = ax^2$ is of a type different from $x^3 + ax^2 = c$, etc.) In the eleventh century, ʻUmar al-Khayyām gave in his *Algebra* a geometric solution (by means of conic sections) of all types of cubic equations. His theory was considerably improved by Sharaf al-Dīn al-Ṭūsī around 1200.

The Arabic mathematicians developed an instrument, the perfect compass, with which conic sections could be drawn, but this does not seem to have been much used and no examples have survived. Ibn al-Haytham used conic sections for mosaic constructions.

See also: ►al-Muʾtaman ibn Hūd, ►Ibn al-Haytham, ►Thābit ibn Qurra, ►Banū Mūsā, ►al-Qūhi, ►ʿUmar al-Khayyām, ►Sharaf al-Dīn al-Ṭūsī, ►al-Māhānī, ►Ibn Sahl

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Consciousness in Ancient India

Subhash Kak

The Vedic texts from ancient India (approx. 3000–1000 BCE) claim to be *ātmavidyā*, "science of self" or "consciousness science." The most ancient of these is the cryptic *Ṛgveda*. But prose commentaries, called the *Brāhmanas* and the *Upanishads* that appeared in the centuries following the *Vedas*, provide a framework to decode its narrative, establishing its central concern with consciousness.

Until recently, the question of consciousness was considered to lie outside of the scope of science and, consequently, the Indian texts on the subject were not properly examined. Scientific attitudes toward consciousness have changed due to the recent advances in neuroscience and because modern physics and computer science must confront the question of the observer.

In the Vedic view, reality is unitary at the deepest level since otherwise there would be chaos. This reality is called *Brahman* (neuter gender). Brahman engenders and, paradoxically, transcends the mind/matter split. It is identical to consciousness at the cosmic scale and it informs individual minds. Turning focus to the very nature of the mind provides insight about consciousness.

Limitations of Language

Since language is linear, whereas the unfolding of the universe takes place in a multitude of dimensions, language is limited in its ability to describe reality. Because of this limitation, reality can only be experienced and never described fully. All descriptions of the universe lead to logical paradox, and Brahman is the category transcending all oppositions. Vedic ritual is a symbolic retelling of this worldview.

Knowledge is classified in two ways: the higher or unified, and the lower or dual. The higher knowledge concerns the perceiving subject (consciousness), whereas the lower knowledge concerns objects. The higher knowledge can be arrived at only through intuition and meditation on the paradoxes of the outer world. The lower knowledge is analytical and it represents standard sciences (*śāstra*) with its many branches. In addition, *darśana* represents philosophy where the problem of self is taken together with some aspect of outer reality. There is a complementarity between the higher and the lower, each being necessary to define the other. This complementarity mirrors the one between mind and body.

Recursive Reality and Mind

The Vedic texts present a tripartite and recursive view of the world. The universe, viewed as three regions of earth, space, and sky, is mirrored in the physical body, the breath (*prāna*), and mind. This connection is a consequence of a binding (*bandhu*) between various inner and outer phenomena.

The universe is understood to be a living organism and therefore subject to cycles of life and death. The universe evolves according to cosmic law. Since it cannot arise out of nothing, the universe must be infinitely old. Since it must evolve, there are cycles of chaos and order or creation and destruction.

In the Vedic discourse, the cognitive centers are called the *devas*, deities or gods, or luminous loci. Thus the *Atharvaveda* calls the human body the city of the *devas*. Each *deva* reflects primordial consciousness and one can access the mystery of consciousness through any of these.

Mind in Indian Philosophy (*Darśana*)

The six systems of Indian philosophy are paired together in three complementary groups: logic (*Nyāya*) and physics (*Vaiśeshika*); cosmology (*Sāmkhya*) and psychology (*Yoga*); and language (*Mimāmsā*) and reality (*Vedānta*). Although these philosophical schools were formalized in the post-Vedic age, we find the basis of these ideas in the Vedic texts. In each of these, the question of the experiencing self is included.

The objective of the Nyāya is *anvīkshiki*, or critical inquiry. Its beginnings go into the Vedic period, but its first systematic elucidation is given by Gautama in his *Nyāya Sūtra* (third century BCE). The text begins with the nature of doubt and the means of proof, considering the nature of self, body, senses and their objects, cognition, and mind. The Nyāya is also called *pramāna śāstra* or the science of correct knowledge. Knowing is based on four conditions:

1. The subject or the *pramātri*
2. The object or the *prameya* to which the process of cognition is directed
3. The cognition or the *pramiti*
4. The nature of knowledge or the *pramāna*

Gautama mentions that four factors are involved in direct perception: the senses (*indriyas*), their objects (*artha*), the contact of the senses and the objects (*sannikarsha*), and the cognition produced by this contact (*jnāna*). The five sense organs – eye, ear, nose, tongue, and skin – have the five elements – light, ether, earth, water, and air – as their field, with corresponding qualities of color, sound, smell, taste, and touch.

Manas or mind mediates between the self and the senses. When the *manas* is in contact with one sense organ, it cannot be so with another. It is therefore said to be atomic in dimension. It is because of the nature of the mind that our experiences are essentially linear, although the quick succession of impressions may give the appearance of simultaneity.

Objects have qualities which do not have their own existence. The color and class associated with an object are secondary to the substance. According to Gautama, direct perception is inexpressible. Things are not perceived as bearing a name. The conception of an object on hearing a name is not direct perception but verbal cognition.

According to the atomic doctrine of Vaiśeshika ascribed to Kanāda, there are nine classes of substances: ether, space, and time that are continuous; four elementary substances (or particles) called earth, air, water, and fire that are atomic; and two kinds of mind, one omnipresent and another which is the individual. The conscious subject is separate from the material reality but he is, nevertheless, able to direct its evolution.

The Sāmkhya and the Yoga systems take the mind as consisting of five components: *manas*, *ahamkāra*, *chitta*, *buddhi*, and *ātman*. *Manas* is the lower mind which collects sense impressions. *Ahamkāra* is the sense of I-ness that associates some perceptions to a

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subjective and personal experience. Once sensory impressions have been related to I-ness by *ahamkāra*, their evaluation and resulting decisions are arrived at by *buddhi*, the intellect. *Chitta* is the memory bank of the mind. These memories constitute the foundation on which the rest of the mind operates. But *chitta* is not merely a passive instrument. The organization of the new impressions throws up instinctual or primitive urges which create different emotional states. This mental complex surrounds the innermost aspect of consciousness, which is *ātman*, the self.

Yoga psychology of Patanjali is a very sophisticated description of the nature of the human mind and its capacity. It makes a distinction between memory, states of awareness, and the fundamental entity of consciousness. It puts the analytical searchlight on mind processes with clarity and originality.

Mīmāmsā and Vedānta consider the analysis of language and reality, respectively. Mīmāmsā ideas became a part of the grammatical tradition and Vedānta became a vehicle to consider consciousness in the most abstract sense.

Parallels with Cognitive Science

There are intriguing parallels between the insights of the early Vedic theory of consciousness and those of quantum mechanics and neuroscience. To express Vedic ideas in modern terms, one might say that individual minds emerge out of the reflection that the brain provides to the underlying illuminating consciousness. Therefore, senses of awareness, such as vision and hearing, may be separated from the person who obtains this awareness.

The human brain represents the clearest structure to focus the self, which is why humans are able to perform in ways that other animals cannot. Self-awareness is an emergent phenomenon which is grounded on the self and the associations stored in the brain.

From a modern scientific viewpoint, living systems are dynamic structures, defined by their interaction with their environment. Living systems may also be defined recursively in terms of living subsystems. Thus, for ants, one may consider their society, an ant colony, as a living superorganism; in turn, the ant's subsystems are also living. Such a recursive definition appears basic to all life. Machines, on the other hand, are based on networking of elements that create a well-defined computing procedure, but they lack a recursive self-definition.

The Vedic system, which was an earlier attempt to unify knowledge, was confronted by paradoxes similar to that of contemporary science. It is noteworthy that Schrödinger, the co-creator of quantum theory, admitted to having been inspired by the Vedic texts. According to his biographer Walter Moore, there is a clear continuity between Schrödinger's understanding of Vedānta and his research:

> The unity and continuity of Vedanta are reflected in the unity and continuity of wave mechanics. In 1925, the world view of physics was a model of a great machine composed of separable interacting material particles. During the next few years, Schrödinger and Heisenberg and their followers created a universe based on superimposed inseparable waves of probability amplitudes. This new view would be entirely consistent with the Vedantic concept of All in One (Moore 1989: 173).

The similarity between the Vedic system and quantum mechanics and the fact that quantum mechanical models of consciousness are being attempted leads us to ask how far the Vedic thinkers took their classificatory models of consciousness. We find both hierarchical and distributed cognitive centers listed in the Vedic texts.

Further Universal Categories

If the categories of the mind arise from pattern recognition of shadow mental images, then how are these categories associated with a single "agent," and how does the mind bootstrap these shadow categories to find the nature of reality?

These questions are examined in the later Vedic tradition both within the frameworks of Vaishnavism and Shaivism. Of the latter tradition, the later Kashmir Shaivism of Vasugupta (AD 800) has in recent years received considerable attention (Shiva is the name for the absolute consciousness).

According to Sāmkhya, reality may be represented in terms of 25 categories. These categories form the substratum of the classification in Kashmir Shaivism. The Sāmkhya categories are:

1. Five elements of materiality, represented by earth, water, fire, air, and ether
2. Five subtle elements, represented by smell, taste, form, touch, and sound
3. Five organs of action, represented by reproduction, excretion, locomotion, grasping, and speech
4. Five organs of cognition, related to smell, taste, vision, touch, and hearing
5. Three internal organs, mind, ego, and intellect
6. Inherent nature (*prakriti*) and consciousness (*purusha*)

These categories define the structure of the physical world and of agents and their minds.

Kashmir Shaivism enumerates further characteristics of consciousness:

7. Sheaths or limitations of consciousness, being time (*kāla*), space (*niyati*), selectivity (*rāga*), awareness (*vidyā*), creativity (*kalā*), and self-forgetting (*māyā*)
8. Five principles of the universal experience, which are correlation in the universal experience (*sadvidyā*, *śuddhavidyā*), identification of the universal (*īśvara*), the principle of being (*sādākhya*), the principle of negation and potentialization (*śakti*), and pure awareness by itself (*śiva*)

The first 25 categories relate to an everyday classification of reality. The next 11 categories characterize different aspects of consciousness that are to be understood in a sense different to that of mental capacities (categories 21–23). One of these mental capacities is akin to artificial intelligence, which is geared to finding patterns and deciding between hypotheses. On the other hand, categories 26–36 deal with interrelationships in space and time between these patterns and deeper levels of comprehension and awareness.

Deterministic science cannot explain free will. If consciousness is seen as emerging from the ground of the classical world, then scientific laws again remain incomplete. On the other hand, we do not know why the brain-machine has awareness whereas computers never will. Nor do we understand the mechanisms behind psychoneuroimmunology or the astonishing abilities of savants.

The Indian approaches to consciousness seem to have anticipated many difficulties of contemporary science. The classificatory systems developed in the Indian tradition define categories, such as that of universal experience, that can be seen to explain the "complementary" nature of human experience. These categories clearly assign a central role to selectivity, or context, and change. The Vedic system takes the mind to be emergent on the ground of the brain, but this emergence is contingent on the principle of consciousness.

The ancient Indian texts of consciousness were long limited to philosophical analysis alone, remaining an unexplored frontier in the history of science. Further advances in a scientific understanding of mind will lead to a better appreciation of these texts.

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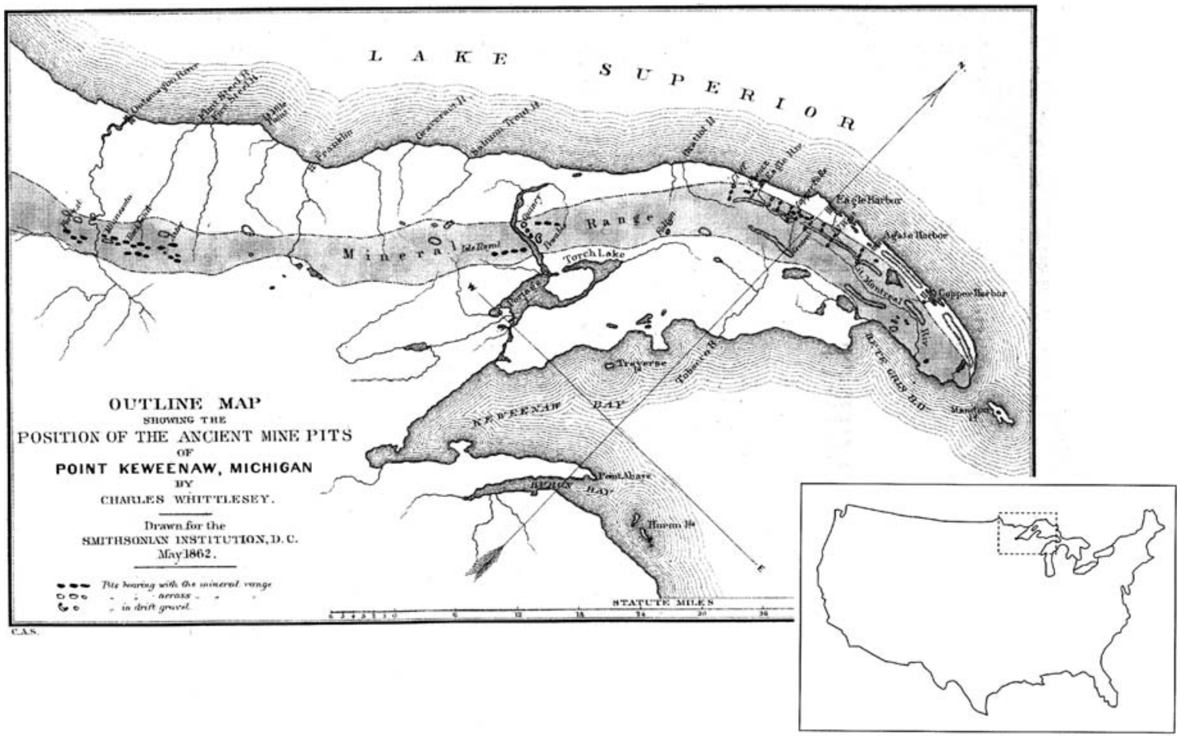
C

Copper Mining in the Great Lakes (USA)

SUSAN R. MARTIN

The roots of indigenous metal mining are ancient in eastern North America. Evidence for early metal mining in North America comes from the copper-bearing regions of the western Lake Superior Basin in the central part of the continent. Here are to be found veins of elemental copper dispersed within sandstone and basalt bedrock, lying relatively close to the surface. In addition, pieces of loose elemental copper lie scattered in the glacial drift that is to be found in many streambeds and riverbanks. These pieces of useable copper and their parent veins were discovered and exploited by Native American people as early as 7,000 years ago. Though the first metalworking technologies of North America derived from the same technologies that people worldwide universally applied to reducing and using stone for tools, this long tradition of using copper for tools and ornaments is the product of native North American ingenuity. Moreover, the traces of this industry of copper mining and working (spoil piles, pits, discarded hammers, and other tools) were visible to the first capitalist American mining entrepreneurs of the Lake Superior basin who established their own mines on the same old ground that had proved itself first via native mining efforts (Foster and Whitney 1850). Archaeological research in the Lake Superior Basin and other copper-bearing areas documents the long-standing importance of copper technologies in the lifeways and practices of the indigenous people of the continent (Fig. 1).



Copper Mining in the Great Lakes (USA). Fig. 1 Map of the keweenaw Peninsula, Lake Superior, USA, indicating locations of prehistoric copper mining pits. Source: Whittlesey 1863.

The bedrock geological history of the Lake Superior region is fairly well understood (LaBerge 1994); its basement of pre-Cambrian bedrock, part of the Canadian Shield, is very ancient. The deposition took place around 1,100 million years ago (MYA), initiated by a period of roughly 25 million years during which a series of enormous movements of magma broke through a cross-continental rift and laid down some 200 extensive lava flows. This activity was intermittent, and followed by long periods of erosion and sedimentary deposition. The resulting strata are deformed by faulting and subsidence to a broad syncline that underlies Lake Superior and its drainage basin.

Gases trapped in the cooling lava, especially at the tops of flows, created porous structures in which later precipitation of minerals took place. Fissures in the lava and interspersed sedimentary rocks provided places where deposition of elemental copper occurred. The copper itself “was likely leached from volcanic rocks deep within the rift by hydrothermal solutions and was then deposited in these same rocks at relatively shallow levels closer to the surface. The timing of the widespread deposition of copper postdated the formation of the bedrock strata by about 20–30 million years and occurred from about 1,067 to about 1,047 MYA” (Martin 1999: 27–28). The result of this activity comprises the largest body of elemental copper known on earth, and its relatively shallow and accessible position allowed people to recover it. The copper-bearing strata outcrop in a narrow band about 3–6 km wide lying in a southwest to northeast direction along the Keweenaw Peninsula and Isle Royale on the western shores of Lake Superior; the beds also outcrop at the northern and eastern shores of the lake, and extend, deeply buried, further to the west into Minnesota. In other areas, native (elemental) copper is a common though irregular constituent of copper ore deposits in Tennessee, Georgia, New Jersey, Nova Scotia, and elsewhere (Levine 1999).

The Lake Superior deposits are quite variable in actual copper content and in form. In sedimentary bedrock deposits, the copper is finely dispersed; in the basalt bedrock the copper is more likely to be found in fissures, veins or nodules of varying sizes. Masses of copper weighing several thousand kilograms were occasionally encountered. The most useful deposits for prehistoric people were of two kinds: thin veins that yielded sheets of copper, or fist-sized nodules of copper. Reducing very large pieces to useable sizes was somewhat beyond the reach of native technologies, but smaller pieces of both kinds could be rendered into tools and useful objects relatively easily. Useful nodules were sometimes found as constituents of the local late Pleistocene glacial drift or in redeposited gravel banks along streams and rivers. This copper-bearing drift is also widely dispersed across the central portions of the North American continent, where glacial ice flows carried copper and other detritus far from their points of geological origin.

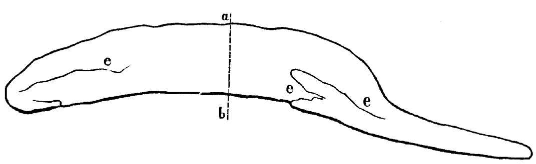
The simplest and least-effort way to acquire copper in elemental form was to search and dig through the many beds of glacial drift in the rivers and streams surrounding the Lake Superior and adjacent regions. Based upon the many pitted areas observed and mapped by Whittlesey during the mid-nineteenth century (Whittlesey 1863), these beds of glacial drift were systematically explored for copper nodules. The glacial drift with copper as a constituent was/is widespread across the central part of North America (Salisbury 1885), and occurred south and west of Lake Superior as far as Iowa and the Dakotas.

In addition to such areas, the bedrock veins were also systematically visited and mined over many thousands of years. Finding the buried veins was a simple matter of being observant. In the western Lake Superior basin, the veins of metal are visible in some surface basalt bedrock outcrops, particularly those that were scoured by glacial action. In other areas, erosion and water action revealed buried veins and nodules. In still others, companion minerals marked the probable occurrence of copper veins. Mining pits on Isle Royale investigated by the University of Michigan in the early 1960s dated to ca. 2470 BCE ± 150 radiocarbon years (Fitting 1975: 238). The early geologists Foster and Whitney described the pattern of such mining pits on the south shore of Lake Superior; observing that along “a distance of nearly 30 miles, there is almost a continuous line of ancient pits along the middle range of the trap (sic), though they are not exclusively confined to it” (Foster and Whitney 1850: 161). The typical pit was rather shallow and followed the course of a vein of copper in a small-scale simple excavation. Alvinus Wood described one that he observed during his excavations on the Keweenaw Peninsula in the late nineteenth century. “It was shown to be 14 ft. deep, having been filled up by the sliding-in of material composed largely of broken rock, taken out in sinking the ancient shaft, and left near its mouth” (Wood 1907: 288). According to Wood, the pit measured about 7 ft. in diameter. In scale, these pits were most comparable to quarrying a face of exposed rock, similar to the mining of flint that had been done for millennia, as opposed to the burrowing or tunneling more typical of recent hard rock mining.

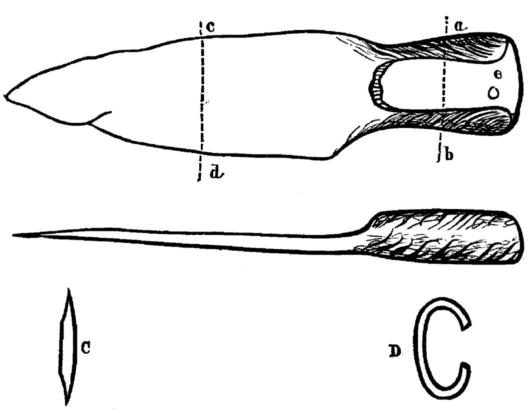
The ancient mining was done with stone hammers that people used to crush the bedrock surrounding a copper-bearing vein. The hammers were, for the most part, unaltered impromptu tools found in the local glacial gravel. Mining pits are sometimes most readily identified by the appearance of many of these expended (shattered) hammers. The hammers were of various sizes and materials; most were of basalt or gabbro and weighed about 2–4 kg, although larger ones were also used, especially early in the mining sequence. Some of the hammers had minor surface modifications, such as a partial or full groove pecked into the circumference to allow a withe or handle to be attached. Pry bars of wood or copper were probably also used to loosen the copper within the vein, and there is some suggestion, especially borrowed from other primitive mining locations around the world, that fire might have been used to weaken the trap rock so that freeing the copper took less mechanical effort. Experimental work on Lake Superior prehistoric mining methods demonstrated, however, that such methods did not measurably improve the efficiency of removing copper (Bastian 1963). Additional artifacts, including copper tools, wooden bowls, wooden ladders, paddles, and other accoutrements of mining were reported to be found in the mining pits investigated by Whittlesey (1863). The size of the mining pits and their conformation suggests that one or two persons could work comfortably within a pit, and experiments showed that ca. a cubic foot of trap rock per hour could be removed from a pit face simply by stone hammering (Bastian 1963: 24).

The native people of central North America fashioned myriad forms of elemental copper artifacts, using simple techniques of repeated cold-hammering and annealing. Despite a search that has already lasted for more than 150 years, there is no unequivocal evidence for intentional melting, smelting or casting of metal artifacts in the Lake Superior region or elsewhere in the eastern United States. All known artifacts were produced in much the same way: careful repeated hammering and heating to recrystallization temperatures. The finished copper objects ranged from weighty woodworking tools to finely crafted ornaments and decorative objects. It is probable that the basic knowledge of elemental metal-working was more or less common across North America, because many elemental metal deposits were known and exploited: at multiple localities in the eastern United States, in Mexico, in the southwestern US, and along the western rivers of Canada. The region around the Lake Superior basin with its large numbers of copper artifacts from local sites allows the researcher a fairly comprehensive look at how specific artifacts were designed and manufactured. Modern researchers established, via experimental replication as well as microscopic studies, the basic outline of prehistoric metalworking techniques (Clark and Purdy 1982; Leader 1988; Vernon 1990). Using the methods of cold or hot-hammering and annealing, the artifacts were carefully fashioned by repeated cycles of heating, hammering, and cooling, with carefully directed blows from a stone hammer creating the final form. Annealing, or reheating to recrystallization temperatures (in excess of ca. 250–300°C), restores malleability and was an essential part of the process; otherwise the hammered copper quickly became brittle and cracked under additional stress. Metallographic inspection of hammered copper revealed “the hammering technique, although primitive in itself, was carried out with assurance and skill; the sheet metal is often of fairly uniform thickness even though laminations are sometimes present” (Wayman et al. 1992: 133–34). Larger artifacts, such as wood-working tools, were hammered and annealed to render a nodule of copper to a desired form. Or, copper sheets were hammered to an even thickness, rolled and then rehammered to consolidate the copper into a thicker artifact form. Final annealing was frequently done, and annealing temperatures may have exceeded 600°C for some artifacts. Ornaments (such as beads) and sheets of copper were sometimes hammered around wooden forms, or mandrels, to produce a final artifact shape. Other artifacts, such as Hopewellian earrings and decorative ornaments of some Mississippian cultures, were composite artifacts of wooden cores clad with a thin cover of fine sheet copper (Fig. 2 and 3).

Finishing touches sometimes included additional limited cold-hammering to harden work edges of tools such as knives and projectile points. Grinding or beveling of work edges was also fairly common, and some artifacts such as harpoons or projectiles were perforated



Copper Mining in the Great Lakes (USA). Fig. 2 Sketch of copper implement, Keweenaw Peninsula, Lake Superior, USA. Source: Whittlesey 1863.



Copper Mining in the Great Lakes (USA). Fig. 3 Sketch of socketed implement with rivet hold ‘e’ and cross sections ‘C’ and ‘D’. Source: Whittlesey 1863.

to enable the securing of a wooden shaft or handle via a copper rivet. Hopewellian and Mississippian cultures used elaborate finishing techniques on their ornaments. Decorative items were embossed, cut out, and perforated in a wide variety of forms depending upon the particular cultural traditions of the artisans producing the artifacts. Some were finished with a high gloss or polish produced by systematic rubbing with ashes and abrasives such as sand. There is some experimental evidence that prehistoric metal workers were able to draw thin strands of copper wire (Cushing 1894).

There is ample evidence derived from the study of the physical distribution of worked and unworked copper to claim that prehistoric people surrounding the Great Lakes communicated with one another, in part, through the exchange of raw and finished copper materials. In addition, overall close similarities in finished copper artifact forms that occur among and within regions close to bedded sources suggest active contact between people of different areas, and at least the copying of each other’s artifact forms, if not direct/indirect exchange of finished materials. This pattern is well documented for areas east and south of the Lake Superior basin (Brose 1994; Goad 1979; Walthall et al. 1982). It is also apparent from research conducted in the northern Plains, where Lake Superior copper may have been exchanged for locally derived lithics such as obsidian and catlinite (Vehik and Baugh 1994). Other raw materials reported from the western Great Lakes region that may have been involved in regional and interregional trade *vis a vis* copper include hornstone (Pleger 1996), Hixton orthoquartzite (Clark 1991), galena (Ritzenthaler 1957), Burlington chert (Pleger 1996), Knife River flint (Salzer 1986), and marine shell (Hruska 1967). Many authors agree that copper was likely widely distributed via trade over vast distances (Brose 1994; Goad 1979; Winters 1968). Other authors add that trade in perishable items, invisible for the most part in the archaeological record, was certainly part of the picture; meat, skins, shells, reed mats and tobacco are suggested as important commodities, especially in the seventeenth century (Smith 1996). Other less tangible commodities and/or motivators to trading activities may have been related to social status, ethnic differentiation, information exchange, and ritual knowledge (Martin 1999). There is, at least by the seventeenth century AD, a solid body of first-hand reporting that documents the connection between native ideologies and copper materials, which were sought after because they were believed to hold the ritual power to bring good fortune, health, wealth and hunting success (Kellogg 1917: 105).

The use of copper was widespread in prehistory and was an important part of the cultural adaptations of the native peoples of eastern North America, beginning by the seventh millennium BP and extending until the advent of European-influenced cultures. The earliest and strongest evidence for the importance of copper mining in native American technologies and lifeways comes from the region adjacent to the bedded copper deposits of the Keweenaw Peninsula, the southwestern shore of Lake Superior, and Isle Royale, Michigan. Here there is material evidence of systematic collecting for copper within surface glacial deposits as well as extensive evidence of the activities of hard rock mining and quarrying by native Americans. The technologies of mining and cold-hammering elemental copper have become well understood through the efforts of experimental (replicative) research and metallurgical studies. Copper was an integral part of the technological, social and ideological experiences of the region's first people, and was equally significant as a material from which to fashion a tool, a social interaction or a ritual transaction. Copper's significance included social reckoning as expressed in burial and in decorative contexts among peoples of many regions and cultures, as well as social interactions as expressed through trade contexts, and finally within religious representation as expressed in elaborate beliefs about its ritual power.

See also: ►Pueblo Indian Adaptations of Spanish Metallurgy

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Cosmetic Surgery in Ancient India

Richard L. Nelson

Cosmetic operations form a special corner in medicine – much in demand and yet often much maligned for being unnecessary or frivolous. This assumes a clear-cut division between a narcissistic desire for an improved appearance, the correction of a disfigurement or injury that altars appearance in an alarming way without altering physiologic function, and the real disability and danger caused by a disease. Whatever the clarity of the division, the demand persists and also reaches back into antiquity. The undisputed father of the field of cosmetic surgery is Suśruta, a surgeon, educator and compiler who lived probably around the sixth to eighth century BCE, though his possible dates vary greatly from 1200 AD. to well before 1000 BCE. No original texts of his great work, the *Saṃhitā*, exist today. It has been edited and revised throughout its history, the most significant contributions made by Nāgārjuna, who lived most probably in the second century BCE.

The *Suśrutasaṃhitā* is a remarkable work in its originality and scope. Though Suśruta is remembered as a surgeon, and division of medical specialists was practised at his time (into surgeons, physicians, poison curers and demon-doctors), the Saṃhitā covers a very broad range of medicine as well as surgery, from discussions of the origins of disease, to the treatment of post-partum depression, to the causes of obesity. Remarkable detail is presented on the pre-operative preparation of patients and the post-operative care of their wounds. Methods of intra-operative anaesthesia and post-operative pain relief are discussed. Over 760 medications are described, 1,120 medical conditions including 76 of the eye alone, more than 125 surgical instruments and 300 surgical procedures in over 1,000 pages of text and 186 chapters. A broad scope of surgery is also presented, including intestinal repair (with black ants) and Cesarean section. Methods of medical education are discussed including cadaveric and animal dissection for the purpose of learning surgical anatomy; only the bodies of children less than two years old could be dissected. Physiology, medical botany, hygiene and public health are discussed, and Suśruta embraced the Ayurvedic (the science of life) approach to medical care.

Yet it is as a cosmetic surgeon that Suśruta is remembered, at least outside of India. And largely for a single operation and even more specifically for a single aspect of the technique for that operation: that of flap formation for the reconstruction of a severed nose. Here is a selection from the 1907 complete (first) English translation of the *Suśrutasaṃhitā* by K. K. Bhishagratna:

> Rhinoplastic Operations: Now I shall deal with the process of affixing an artificial nose. First the leaf of a creeper, long and broad enough to fully cover the whole of the severed or clipped off part, should be gathered; and a patch of living flesh, equal in dimension to the preceding leaf, should be sliced off (from down upward) from the region of the cheek and, after scarifying it with a knife, swiftly adhered (sutured) to the severed (base of the) nose. The cool headed physician should steadily tie it up with a bandage decent to look at and perfectly suited to the end for which it has been employed (Sadhu Bandha). The physician should make sure that the adhesion of the severed parts has been fully effected and to insert two small pipes into the nostrils to facilitate respiration, and to prevent the adhesioned flesh from hanging down. After that, the adhesioned part should be dusted with the powders of Pattanga, Yastimadhuka and Rasanjana pulverised together; and the nose should be enveloped in Karpasa cotton and several times sprinkled over with the refined oil of pure sesamum. Clarified butter should be given to the patient for drink, and he should be anointed with oil and treated with purgatives after the complete digestion of the meals he has taken, as advised. Adhesion should be deemed complete after the incidental ulcer had been perfectly healed up, while the nose should be again scarified and bandaged in the case of semi- or partial adhesion. The

Cosmetic Surgery in Ancient India. Fig. 1 Suśruta pictured performing a rhinoplasty.

adhesioned nose should be tried to be elongated (or trimmed) where it would fall short of its natural and previous length, or it should be surgically restored to its natural size in the case of the abnormal growth or its newly formed flesh. The mode of bringing about the adhesion of severed lips is identical with what has been described in connection with a severed nose with the exception of the insertion of the pipes. The physician, who is conversant with these matters, can be alone entrusted with the medical treatment of a King.

The innovation that made Suśruta's reputation is the skin flap to make a nose. It involved cutting three sides of a rectangle on the cheek, elevating the skin, while maintaining a blood and nerve supply from the fourth side of the rectangle, thus assuring the viability of the skin flap, which could then be slid over and formed into a new nose. Once healing was complete (and a new blood supply formed through the suture line), the fourth side of the rectangle may have been (Suśruta does not actually say he did it) divided and the donor site freed from the new nose. This is a technique used all over the body to replace skin defects today. Later editors changed the donor site to the forehead, but otherwise the technique remained largely unchanged for the next 2,000 years. Nasal reconstruction was an important part of medical practise in ancient India because nasal injury was common, sometimes through disease, but more often due to amputation, a form of punishment for many offences, including adultery.

Yet in one manner of speaking, this is not a frivolous cosmetic operation, but a reconstructive one, replacing a severed or damaged part. The Oxford English Dictionary defines 'Cosmetic' as 'Of surgery: improving or modifying the appearance. Of prosthetic devices (like grafted noses): recreating or imitating the normal appearance.' In that regard the nasal, ear lobe, lip and eyelid reconstructions described by Suśruta are certainly cosmetic.

Cosmetic Surgery in Ancient India. Fig. 2 Drawings of surgical instruments described by Suśruta.

The technique of rhinoplasty is quite briefly described with much less detail than a surgical trainee would want today before tackling this operation for the first time. Much is made today about length/width ratios of the flap or flap thickness to assure viability of the mobilised skin. Too narrow or too thin a flap would not have enough blood flow to the mobilized tip to remain viable. The graft would then die and sluff off leaving the unrepaired defect. The width and depth of stitches, the distance from the flap to the recipient site, the degree of rotation and the time before safe detachment are all left for one to guess in the *Saṃhitā*. Much more space is devoted to the problem of severed (or bivalved) ear lobes, caused by downward pressure and erosion of earrings worn in pierced ears. Suśruta describes skin flaps again (mobilised from the nearby neck), or debridement and primary closure of the lobe if the amount of tissue was sufficient. Reconstructive procedures are also described for repair of defects, sometimes caused by surgical excision of tumors or ulcers of the eyelid and, as stated above, the lip.

See also: ►Suśruta, ►Āyurveda

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Cosmologies of India

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From the viewpoint of modern astrophysics, cosmology is the study of the history, structure, and dynamics of the universe. Many of the traditional cosmological concepts of Indian culture have general counterparts in astrophysical cosmology. For example, the parallelism of the macrocosm and microcosm is an important concept for both approaches; our terrestrial physics is mirrored in the stars, galaxies, and distant quasars. Gravity and other long range forces thread the entire universe. The geometry of Indian temples, cities, and pilgrimage landscapes often replicates the larger cosmos.

Modern physical science relies heavily on quantitative measurement, and according to the architectural traditions of India, the structure of home, temple, and city are based upon a shared religious symbolism, which involves the bringing of cosmic order out of primordial chaos partly through the act of measurement (Zimmer 1946; Malville 1992). Measurement as *cosmogenesis* is asserted in many texts of Indian philosophy and mythology. Puruṣa, the architect of the universe, "bears the measuring rod, knows division, and thinks himself composed of parts" (Vāyu Purāṇa 4: 30–1: Kramrisch 1946: 131). The universe was created as Puruṣa was divided into parts, many of which are the measured and ordered features of our current world such as verses, chants, social orders, time, and temples, and cities.

The universe is understood to have spread outward from a primordial center into the four cardinal directions forming a square (Kramrisch 1946, Vatsyayan, 1983; Malville 1991). The geometric structure of the universe, as described in the sixth century AD *Bṛhat Samhitā,* was represented by the *vāstu-maṇḍala*, usually consisting of 64 or 81squares or *padas,* which was also the fundamental plan for houses, palaces, and cities. The *Bṛhat Samhitā* was primarily a treatise on astrology and astronomy, which provided instructions for determining auspicious dates for laying out the foundation *maṇḍala* of a building or city as well as instructions for its precise orientation to the cardinal directions using shadow casting by gnomons. Major features of the *vāstu-maṇḍala* are (1) true cardinality, i.e., parallelism to the fundamental directions in the celestial realm, (2) a center, out of which creation has emerged, (3) mathematical division of interior space into squares or *padas*, (4) the organization of space according to socioreligious rules, assigning specific *padas* to gods, kings, and social classes, and (5) a boundary that represents the barrier between internal order and external chaos.

As organized by the *vāstu-maṇḍala*, the religiously planned city was meant to be a geometrically exact copy of the macrocosm with its pantheon of gods. The symbolism of the city and temple included the point source of creation, the *garbha gṛha* (womb chamber) of the temple, the cosmic tree separating heaven and earth, the *axis mundi*, and the surrounding squares were assigned to 44 Vedic gods, of whom eight were the all-important protector guardians of the cardinal points. The royal palace was to be constructed on one-ninth the total town area to the north of the center. A few of India's ancient cities have achieved the ideal of the *vāstu-maṇḍala* in their design, such as the excavated sites of Sisupalgarh near Bhubaneswar and Vaisali in North Bihar (Chakrabarti 1997; Krishna Deva 2000; Joshi 2000). Often the ideal *vāstu-maṇḍala* was compromised by local topography, as, for instance, the construction of the city on the irregular banks of a river such as Pataliputra (modern Patna) on the Gaṅgā and Ujjain on the Sipra (Krishna Deva 2000). Furthermore, prominent geographic features often created symbolic forces that drew the orientation of structures toward them and away from cardinality. In the case of the great city of Vijayanagara natural features of its dramatic landscape such as hills, caves, and river played major roles in its organization (Fritz 1985; Fritz and Michell 1991). The most powerful organizing feature of the city was the precise north–south axis that cuts through the center of the Royal Center and passes over the local manifestation of the cosmic mountain, Matanga Hill (Malville and Fritz, 1993a, b; Malville 1994a, b, 2000).

Cosmology as Illustrated in the Hindu Temple

The Hindu temple can be used as a mnemonic for a wide range of cosmological concepts of India. Manifesting the parallelism between microcosm and macrocosm, it contains in its center the chaos out of which the universe emerged. Spreading outward along cardinal and inter-cardinal directions, the stones of the temple are the cosmos into which the universe has transformed itself. The temple is set upon the *vāstu-puruṣa-maṇḍala*, the geometric yantra symbolizing the sacrifice and dismemberment of Cosmic Man, Puruṣa, and the re-establishment of cosmic order. The idea of primordial chaos, which is structured into the center of the temple, is found in many of the cosmological mythologies of the subcontinent and is a well-established feature of the early universe. Creation through disruption of equilibrium, expansion of space-time, and separation of parts are shared concepts of myth and modern cosmology.

The living Indian temple is both a model of cosmos carved in stone and a participatory cosmology. The devotee who enters the temple can travel backward in time by moving from the world of the present, which lies beyond the temple compound, to its center where space and time are collapsed. At the center of the temple, enshrouded by a darkness pierced by only a few lamps, lies the *garbha-gṛha*, the womb chamber symbolic of the chaos, potentiality, and undifferentiated wholeness out of which the universe emerged (Karmrisch 1946). Spiraling inward in space and backward in time, one proceeds from brightly lighted exterior space of the ordinary world to darkness. The large open spaces of the entrance are replaced by the confined small center; the extravagant richness of carving and decoration turn into the simplicity of the unadorned center. Space is focused like a converging beam of light upon the center, becoming ever more constricted and confined as the garbha-gṛha is approached. It is the center, which provides personal renewal and rebirth, paralleling the renewal and rebirth of the universe itself.

Chaos and Equilibrium

"In the beginning was darkness swathed in darkness; all this was but unmanifest water" *Ṛgveda* 10.129.3

The birth of the universe from primordial chaos is one of the most fundamental creation mythologies of our planet (O'Flaherty 1975). In Hindu cosmology, the metaphors for chaos are water, darkness, disorder, lawlessness, and potentiality. Chaos in the center of the temple is protected by massive stones, priests, and doorway guardians. The garbha-gṛha is the cave in the side of the cosmic mountain, Mount Meru, which is the axis mundi, connecting heaven and earth. The cave is the womb out of which the world and life have emerged. The small cubical space of the garbha-gṛha is symbolic of the primordial seed of creation. Chaos, as a source of creation, is thus contained, protected, preserved, and intensified in this dark space. The energy of the cosmic cycle is contained in the temple, and is available each day of the year for the purposes of cleansing, symbolic death and rebirth, and rejuvenation.

Indra and Vṛtra

The conversion of chaos into cosmos is described in two well-known Hindu myths, the battle of Indra and Vṛtra and the churning of the cosmic ocean. Vṛtra, the Restrainer, held the dark waters of creation tight within his coils and had to be destroyed by Indra in order for the waters of time and creation to flow. The battle between the Aryan war god Indra and his archenemy Vṛtra is rich in thermodynamic meaning. The universe was initially imprisoned as dark and unmoving waters held tightly within the coils of Vṛtra. Actualization of potential inherent in the universe was thus prevented; time could not flow and space could not expand. This metaphor addresses one of the great mysteries of existence: what initiated expansion of space-time? As the god of lightning and thunder, Indra slew Vṛtra with his thunderbolt, the *vajra*. The death of Vṛtra symbolizes the victory of change over stasis, time over eternity, light over darkness, as well as summer over winter. One interpretation of the slaying of Vṛtra is that it is a depiction of the transformation of winter ice into summer waters as the light and heat of the sun destroy the darkness and frozen immobility of winter; the mountain streams, which are held fast in winter's coils, are released to flow to the ocean when winter is conquered by the springtime sun.

The initial symmetry, quietude, and perfect balance of the cosmos was broken when the circular coils of Vṛtra were forced open, and, like the escaping contents of a broken pot, the imprisoned waters of time and change were allowed to flow. The sun and moon, locked as embryos in the dark waters, were born with the death of Vṛtra. The transformation from the state of stasis to that of change involved violent activity, disruption of tranquility, and death of the old.

Churning of the Cosmic Ocean

Thermodynamic elements abound in the story of the churning of the primordial ocean for the purpose of obtaining *amṛta*, the elixir of immortality (O'Flaherty 1975). Primordial equilibrium, symbolized by the undifferentiated cosmic ocean, was disturbed by the outside agent of the inverted Mt. Mandara, used as a churning stick. In a manner similar to that of the patterns of convection in a heated pot of water, structures hidden in the water were evoked. The cooperation of all aspects of creation was needed for such transformation of chaos: *asuras, devas*, Viṣṇnu who as the cosmic tortoise provided support for Mt. Mandara, Śiva who drank the poison which emerged before the *amṛta*, the cosmic mountain, and the cosmic serpent, Vasuki. The transformation of equilibrium required extraordinary actions, and the inversion of the cosmic mountain seems to symbolize that ordinary, traditional action was inadequate for such an endeavor. Ordinary action can not bring about major transformation when powerful self-maintaining cycles, i.e. negative feedback, suppress perturbations. The old standards and ordinary behavior were inverted: Mt. Mandara was converted into a stirring stick, the *asuras* and *devas* cooperated, and the serpent as the churning rope became the agent for change rather than the traditional agent for eternity and stasis. The consequences of the churning were violent: fire, loud noises, upsetting of nature, death of many creatures. Polar opposites emerged from the waters such as poison and the elixir of eternal life, *amṛta*. All beings and gods were protected from the poison by Śiva who acquired a blue throat while drinking it. Out of the disrupted equilibrium of the ocean emerged the embryonic sun and moon.

Rescue of Earth from the Waters

The story of the rescue of Mother Earth from the waters involves one of the ten incarnations of Viṣṇu as the boar and is a member of the worldwide class of earth diver creation myths (Long 1963; *Taittirīya Saṃhita*, *Viṣṇu Purāṇa*: O'Flaherty 1975). In each of these stories, a creature dives to the bottom of the ocean to retrieve mud which, when brought to the surface, grows to become the planet on which we live. In one version of the Hindu story, there is a violent battle between the cosmic boar and the demon of the waters who, like Vṛtra, has held the earth prisoner, preventing thereby the flow of time. The recurrent symbols of creation in these Hindu myths are again present: formless, rich, and fertile primeval material locked in the eternal, changeless dark waters is released only after a violent struggle. Another important aspect of this myth involves Viṣṇu in his role as expander and extender. After bringing Earth to the surface of the waters, he spreads her out into a flat disk so that, like a lotus leaf, Earth can float on the waters and not sink back to the oblivion of the dark waters and the death of equilibrium. In the astronomical universe, it is the continuing expansion of space-time which causes departures from equilibrium and prevents structures from sinking back into equilibrium.

Primordial Incest

The stories associated with Prajāpati and his daughter, Rohiṇī, form a highly complex collection of symbols involving both sexual and astronomical allusions (Kramrisch 1981). Back in the timelessness which existed before the creation of our world, the "first created," Prajāpati, desired a second. Instead of a wife he acquired a daughter with whom he sexually united. The on-looking gods were so outraged by such an unthinkable violation of a fundamental law of nature that they created Rudra, the archer, to prevent and punish the incest of Prajāpati. The arrow shot by Rudra struck Prajāpati, too late, causing him to withdraw from his daughter and spill his seed on the ground. From such an unlikely sequence of actions human life sprang from the impregnated soil.

> Meant to prevent the act, the flowing of the seed, the shot failed to prevent its consequences. The failure in timing at the dawn of the world was due to time itself, for the latter had not set in as yet; it was just about to begin. The transition from an integer without dimension of space and time into existence is a danger zone between eternity and the passing moment… Had the timing been perfect, the flying arrow of Rudra would have prevented the coming into existence of man and the flowing down on the earth of the substance of the Uncreate." (Kramrisch 1981: 26)

The sequence of events can be described in thermodynamic terms as follows. Primordial equilibrium contains within itself processes which may become unstable and grow out of control; the result can be a destruction of the old system and the production of something entirely new. As already mated, an equilibrium system has self-maintaining processes built into it designed to prevent such destruction of equilibrium and stability. Incest as a violation of equilibrium was present in the original plenum of creation. In order to prevent change, a negative feedback loop was created in the form of Rudra to suppress the perturbation. Ironically, the consequence of Rudra's action was the opposite of the original intent. The incestuous act was not punished in a manner such that the original equilibrium could continue, but, quite the contrary, the initial instability grew, life on the earth appeared, and the unchanging primordial state was replaced by time and change.

The Prajāpati myth may have astronomical implications concerning a very early discovery of the precession of the equinoxes. Between 4500 BCE and 3500 BCE at the time of vernal equinox the constellation which we know as Orion rose heliacally just ahead of the sun. Prajāpati was identified with that constellation (Tilak 1972; Kramrisch 1981). Prajāpati was also the year (*Śatapatha Brāhmaṇa 3.2.2.4*) which, exhausted from his labors, needs to start afresh at the time of the vernal equinox. The rejuvenation and rebuilding of Prajāpati, the year, was accomplished symbolically by the construction of the Vedic altar, the bricks of which symbolized the days and seasons of the year. The death of Prajāpati, the old year, was necessary for the continuation of the annual cycle of vegetative life. The symbolism of Orion-Prajāpati rising heliacally on the morning of the vernal equinox may have had great ritualistic significance, announcing by its presence in the equinoctial dawn the time for the rebuilding of the sacrificial altar and the rejuvenation of the exhausted year.

For over a millennium, following 4500 BCE, the constellation of Orion-Prajāpati had provided that announcement. But around 3000 BCE Prajāpati no longer appeared briefly in the ruddy dawn of vernal equinox, having been replaced due to precession by his daughter, Rohiṇī, the red star Aldebaran, the eye of the modern constellation of Taurus the Bull. The shock of this change in the makeup of the heavens may have been considerable. No longer was the start of the year announced by the heliacal rising of the grouping of stars which had symbolized the year, no longer was there a synchronization of the heavens with terrestrial phenomena and human affairs, no longer could the heavens be viewed as eternal and unchanging. The astronomical language which is used to describe this event is extraordinary in its allusion to the forbidden act of incest. Prajāpati as the beginning of the year had moved into Rohiṇī due to the process of precession.

A complex variation on the Rudra-Prajāpati-Rohiṇī myth is the story of Dakṣa, the antagonistic and jealous father-in-law of Śiva. The wife of Śiva, Satī, was the first born daughter of Dakṣa. He had 27 other daughters who had been given to the moon in marriage; these are the Nakṣatras, the asterisms through which the moon passes each month in his journey along the sky. Dakṣa performed a great sacrifice but did not invite Śiva nor did he reserve a portion of the sacrifice for Śiva. Dakṣa's jealousy toward Śiva at one level of the myth may symbolize the desire to preserve primordial equilibrium. Satī reproached her father for not having invited her husband. In anger and shame she committed suicide by throwing herself into the sacrificial fire ignited by her father. Śiva, outraged at the consequence of Dakṣa's insult, came in the form of Vīrabhadra, a fierce manifestation of Śiva. He cut off Dakṣa's head with a sacrificial knife, and replaced it with the head of a ram. Vīrabhadra picked up the corpse of his wife and performed a wild and agonized dance with it over the face of the earth. In his dance, his arms flailing to the far reaches of the universe, the stars were scattered by the sweep of his hair. Fearing that the wild dance, the Tāṇḍava, would destroy the earth, Viṣṇu cut the body of Satī into pieces, and where each piece of flesh dropped to earth a shrine was built (*Devībhīgavata Purāṇa*: O'Flaherty 1975). Here again, we encounter the use of horrible and unthinkable mythic deeds to dramatize the consequence of the disruption of cosmic equilibrium and consequent creation in the form of the establishment of shrines and temples across the land.

The Waters and Fires of Chaos

Though structureless themselves, water and fire are infinitely creative (Eliade 1967). Everything which possesses form has separated itself from water. The gods of chaos must be sacrificed in order for life to appear. When form emerges beyond water there is a dying of potentiality, and form becomes subject to limitation by the laws of time, change, and decay.

In the temple tank, fed by deep underground springs, lie the dark and murky waters of chaos, reinforcing the meaning contained in the dark sanctum of the temple. Water is a transformational symbol, both life-giving and life-threatening, the source of vitality and creation as well as the agent for destruction. The waters of the *pralaya,* the cosmic flood at the end of time, provide the source for new creation and new birth. Life is born out of these dark, destroying waters which periodically sweep the earth.

In the city of Vārāṇasī, also known as Kāśī, one finds the intensified symbols of water and fire (Eck 1983). In the center of Kāśī in the Viśvanātha Temple is the Jyothir liṅga, the great pillar of fire connecting heaven and earth. Near the center is the Maṇikarṇikā *kuṇḍ,* the place of the very first dawn of the world at the beginning of time. In an interesting twist, the *kuṇḍ* associates water in the form of sweat with the act of creation. The *kuṇḍ* was excavated by Viṣṇu using his discus and filled by his sweat before he created the world. Viṣṇu symbolizes the activity, expanding power, and movement of the sun as it traverses the sky with great strides. The discus, which is carried in one of his hands, is a sun symbol (Begley 1973). Glowing brilliantly, yet terribly dangerous, it is called *sudarśana,* "beauteous sight". The chaos of the earth has thus been disturbed by the sun disc. The water so necessary for creation has come from god himself. Maṇikarṇikā is also identified by local tradition with the jeweled earring of Satī, fallen to the ground while Śiva was performing his dance after her death by fire.

A central theme of Hindu cosmology is the homology of universe and human body, i.e., the body is a microcosm, a model both of the universe but also for the universe. The universe is the dismembered body of Prajāpati and Puruṣa, the Cosmic Man. It is a complex cosmological homology as, in this view, the human body is both a description of how the universe behaves and a model *for* the universe, i.e., how it should behave. The significance of these "of" and "for" models in cultural symbols has been explored extensively by Geertz (1973). The equality between the sun and the *ātman* which lives in everyone's heart is one such homology. Another homology, suggested by Parry (1981), relates the process of creation and destruction of the universe to the constant stream of sacrificial cremations staged at the Maṇikarṇikā *ghāt*. Parry argues that the human body has been so "cosmicized" in India that the cyclic movement of the entire universe relies upon the unceasing human acts of cremation at Maṇikarṇikā.

The Hindu temple with chaos in its center is surrounded on all sides by the chaos of the profane world; the walls of the temple serve as ramparts against the threatening flood of chaos. Such a flood of chaos can be creative as well as destructive. The devastating flood may be followed by a creative flood as described in the myth of the temple town of Kumbakoṇam:

> When the time of the universal deluge drew near, Brahmā came to Śiva and said, 'Once the world has been destroyed how will I be able to create it anew?' Śiva instructed him to mix earth with *amṛta*, fashion a golden pot, and put the Vedas and other scriptures into the pot along with the Seed of Creation. Brahmā made the pot and decorated it with leaves, and, when the flood began to rise, he put the pot in a net bag and sent if off on the waters. Pushed by the wind and waves, the pot floated southwards; the leaves fell off and became holy shrines, and the pot came to rest at a spot proclaimed sacred by a heavenly voice… Śiva took the form of a hunter and shot an arrow, which hit the pot and let loose a flood of *amṛta*. When the waters of the deluge receded, Brahmā fashioned a *liṅga* from earth mixed with *amṛta*, and Siva merged into the lingam in the presence of the gods (Shulman 1980).

Creation thus follows the flood of *amṛta.* The creative flood flows because Śiva has broken the restraining pot. Creation thus results from the violent disruption of equilibrium. He repeated the archetypal act of Indra when he slew Vṛtra with his thunderbolt, the *vajra*, and allowed the waters of time and creation to flow. The arrow of Śiva was a shaft of light and time entering the darkness of the watery chaos that existed before creation; the pot was the womb, which releases life.

Other Tamil temple myths echo this theme in which a moving shaft such as a spear plays a crucial role of creation following a flood (Shulman 1980:73). In over seventy Śaiva temples of Tamil Nadu, the sun penetrates the centre of the shrine at sunrise or sunset on a few days of the year near the equinoxes. There are numerous interpretations of the event celebrated as a Sūrya *pūjā*. A popular myth is that Sūrya has become afflicted with leprosy and is requesting that Śiva relieve him of the disease. The reference to leprosy may have been associated with an unusually high level of sun spot activity that we know occurred in the thirteenth century. Another interpretation of the event is that the horizontal shaft of sunlight lighting the Śiva *liṅga* in the otherwise dark *garbha gṛha* is symbolic of the first shaft of light that destroyed the darkness of chaos (Malville 1985, 2006; Malville and Swaminathan 1998, 2006).

The temple doorway, through which pass shafts of light, arrows of time, priests, and devotees, contains symbols of chaos and water: the marvelous water creature the *makaram* with wings of a bird, body of a crocodile, and snout of an elephant, yawns widely on either side. Out of the opened mouth of the *makaram* flow the forms of creation to be reabsorbed at the end of the world age by the opposite *makaram.* Intertwined about the doorway are stalks and leaves of water plants and river goddesses. To pass through the doorway from the profane to the sacred world requires transformation which water provides. The priest when he enters the *garbha-gṛha* experiences a transmutation "promoted by the (water) divinities on the door jambs" (Kramrisch 1946: 313–314). Coormaraswamy (1980) has written extensively and creatively on the symbolism of this "water cosmology" of India. Upon murky waters floats the white lotus, unpolluted by the mud, a symbol of separation of creation from the waters of chaos. Out of the waters it climbs on a stalk which is the *axis mundi,* connecting primeval mud with the light of the sun. The earth, the sun, or Brahma is carried by the lotus, suspended above chaos, protected from sinking back into oblivion by the lotus raft. The lotus is also the characteristic symbol of Sūrya, always carried in his hands, expressive of the separation of creation from chaos provided by the light of the sun.

Expansion, Separation, and Differentiation

Nonequilibrium in the universe is the consequence of the expansion of outer space. Portions of the universe were thrown out of equilibrium following the Big Bang as the initially homogeneous matter clumped and hot stars separated from cold space. Expansion is the fundamental dynamic of our universe, constantly forcing matter and energy out of equilibrium and allowing structures to form and complexity to grow.

Viṣṇu as the expanding dwarf who tricked the demon Bali into giving him all the space he could cover in three steps is an oft-repeated allusion to cosmic expansion (*Viṣṇu Purāṇa* 2.36.74–86). As an expanding fish, Viṣṇu saved Manu from a return to chaos through the flood (*Śatapatha Brāhmaṇa* 1.8.1.1–6). When Viṣṇu as the Boar rescued Earth from the bottom of the waters of chaos, he expanded Earth and spread her out, to prevent her from sinking back again into chaos. The infinitely expanding *liṅga* of fire which confounded Brahmā and Viṣṇu during the darkness before creation as it rose from the cosmic ocean, reproduces these resonating symbols of dark waters and expanding form (Zimmer 1946).

The central tower of the temple, the *śikhara*, the "mountain peak," is another *axis mundi*, which pillars apart heaven and earth and lets creation proceed. In Vedic terms, to separate is to create, and to merge and reabsorb is to dissolve and destroy (O'Flaherty 1975: 125). The myth of the triumphant destruction of the triple cities of the demons by Śiva, as Tripurāntaka, again resonates with the insight that to separate is to create, and, conversely, that which causes polar opposites to unite and lose their separate identities is to reverse the course of creation and return to chaos (O'Flaherty 1975). The triple cities symbolize heaven, earth, and sky and their reabsorption returns the universe to formless equilibrium and chaos.

The symbolism of chariots and wheels is found both in the temple architecture itself and in *ratha* festivals. The temple of Konārak has been fashioned into huge chariot of the sun with 24 wheels pulled forward into the east by seven horses (Malville 1989). The wheel is a pre-eminent symbol of time with stillness at its center, which allows movement and change. It is also a symbol of sustained separation of the earth and the heavens. The wheels of the sun's chariot are supported and separated by the axle tree, which performs the same function as the *axis mundi*, holding apart the turning wheels of earth and sky. Creation is possible only because of the separation provided by the axle. The wheels are those of Kāla, time, bringing life out of darkness and returning life to darkness and death.

A frequent icon in many temples is that of Kirttimukha, the "face of glory," another image expressive of creation emerging from separation. Kirttimukha represents both the awesome destructive power of Shiva and the creative powers of the cosmos. Creation flows from his open mouth only so long as it is open; once his jaws close, creation ceases. Fortunately, since Kirttimukha lacks a lower jaw, the mouth of creation can never be closed (Kramrisch 1946).

The sacrifice of Puruṣa, Primal Man, contains the three primary cosmological symbols of chaos, separation, and differentiation (*Ṛgveda* 10.90.1–16). Primal man represents chaos and infinite potentiality. He must be sacrificed before in order for creation to occur. Like water and fire, chaos and creation, equilibrium and ordered structures are mutually exclusive; once water becomes structured it is no longer water, but it is plants, fish, and people. The strongest image of the sacrifice of Puruṣa is that of differentiation of the original parts of primordial chaos. Various parts of the body became the infinite variety of the cosmos: the atmosphere, the heavens, and the earth, the creatures of the earth, and the social classes, waters. Prajāpati, also the primal man, "fell apart", separated and dispersed to become our cosmos: his semen became sun and heaven, his breath became wind and atmosphere, his body became food and earth (*Śatapatha Brāhmaṇa* 7.1.2.1–6).

Symbols of Expansion, Separation and Differentiation

1. Lotus: separation from mud and water; suspended above chaos
2. Śikhara: separation of earth and sky; expansion upward
3. Tree: expansion downward and upward
4. Gopuras: expand outward and upward from centre
5. Wheels: separated by axle tree
6. Vishnu as dwarf: expanded to step across three worlds
7. Viṣṇu as fish: expanded to save Manu
8. Viṣṇu as boar: expanded earth to prevent it from sinking into chaos
9. Kirttimukha: open mouth allows continuing creation
10. Indra: separates earth and sky by expanding
11. Puruṣa: separation and differentiation
12. Tripura: separation of the three worlds

Return to Chaos

At the end of a thousand world ages, a day of Brahmā, a Kalpa the world becomes barren of life. Siva scorches the earth with his eye, drying up the oceans and rivers. The earth catches fire and burns until it is as bare as the back of a turtle. Then the rains come and pour water on the earth for a 100 years, converting the earth into a shoreless ocean. At that time, when only the ocean exists, all creation is absorbed and united into Vishnu who sleeps on his bed of coils of Ananta, meaning infinite, in the darkness of cosmic night (*Viṣṇu Puraṇa*: Dimmitt and van Buitenen 1978). Over and over, this sequence is repeated without end. Life appears and vanishes as passing days and nights. As in the story of the cities of Tripura which were destroyed when they are brought together by the arrow of Siva, union and absorption mean equilibrium and death.

Our astrophysical understanding of the end of the universe involves death by fire in the collapse of space

Cosmologies of India. Hindu Cosmochronology (Dimmitt and van Buitenen 1978; O'Flaherty 1975)

Yuga	Duration (years)
Kṛta	1,728,000
Tretā	1,296,000
Devāpara	864,000
Kali	432,000
1 Mahāyuga: breath of Brahma	4,320,000
1 Kalpa: day of Brahma	4,320,000,000

into a cosmic black hole or death by cold of unlimited expansion. In death by expansion, gravitational collapse may well dominate as stars eventually fall into black holes in the centers of galaxies and the universe becomes a dark and cold system of galactic black holes, silently, and darkly revolving one around the other. Even black holes are subject to change, and matter and energy will eventually evaporate from them to produce a return to chaos in the form of a vast photon ocean of thin, cold light. Lurking somewhere in the immensity of future time there must be other universes waiting to be born.

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Indra slays Vritra: *Ṛgveda* 1.32.1–15.
Prajāpati commits incest: *Ṛgveda* 10.61.5–7; 1.71.5; 1.71.8; 1.164.33; Śatapatha Brāhmaṇa 1.7.4.1–8.
Śiva destroys Dakṣa's sacrifice: *Mahābhārata* 12.274.2–58.
Shiva destroys the Triple City of the Demons: *Mahābhārata* 8.24.3–44, 52–124.
The churning of the cosmos ocean to obtain amṛta: *Mahābhārata* 1.15.5–13; 1.16.1–40, 1.17.1–30.
The corpse of Satī is dismembered: *Devībhāgavata* 7.30.27–37, 40–50.
Viṣṇu as a dwarf takes three strides: *Ṛgveda* 1.154.1–6; Vāyu 2.36.74–86; Vāyu 2.36.74–86.
Viṣṇu becomes a boar to save Earth: Viṣṇu 1.4.3–11, 25–9, 45–9.
Vishnu becomes a fish to save Manu from the flood: *śataphatha Brāhmana* 1.8.1–6; *Matsya* 1.11–34; 2.1–19.

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Cosmology of the African San People

Sven Ouzman

Using words to capture and convey our beliefs and experiences may seem precise and comprehensive, but such omniscience is illusory (Mitchell 1994). It may, however, be possible to fragment the totalising influence of words and concepts like 'cosmology' – knowledge of the world – by using historically specific texts, images, sounds and sensoria to promote epistemological diversity. This approach works well within a culture. I can, for example, distinguish between Southern Baptist and Greek Orthodox as two heterodox forms of Christianity. But what about other people, in other places, at other times? The people on whose behalf we interlocute – in this case the San or Bushmen of southern Africa (Endnote 1) – have histories marked by imperialism, colonialism, missionisation and Apartheid (Fig. 1). How then do we know when our information about these people draws on their remembrances of original traditions or when it embodies recent histories of violence? Despite ethnography's ethical problems (Clifford and Marcus 1986), we can use multiple strands of evidence to produce working knowledge that tacks between absolutism and hyper-relativism (Benhabib and Fraser 2004).

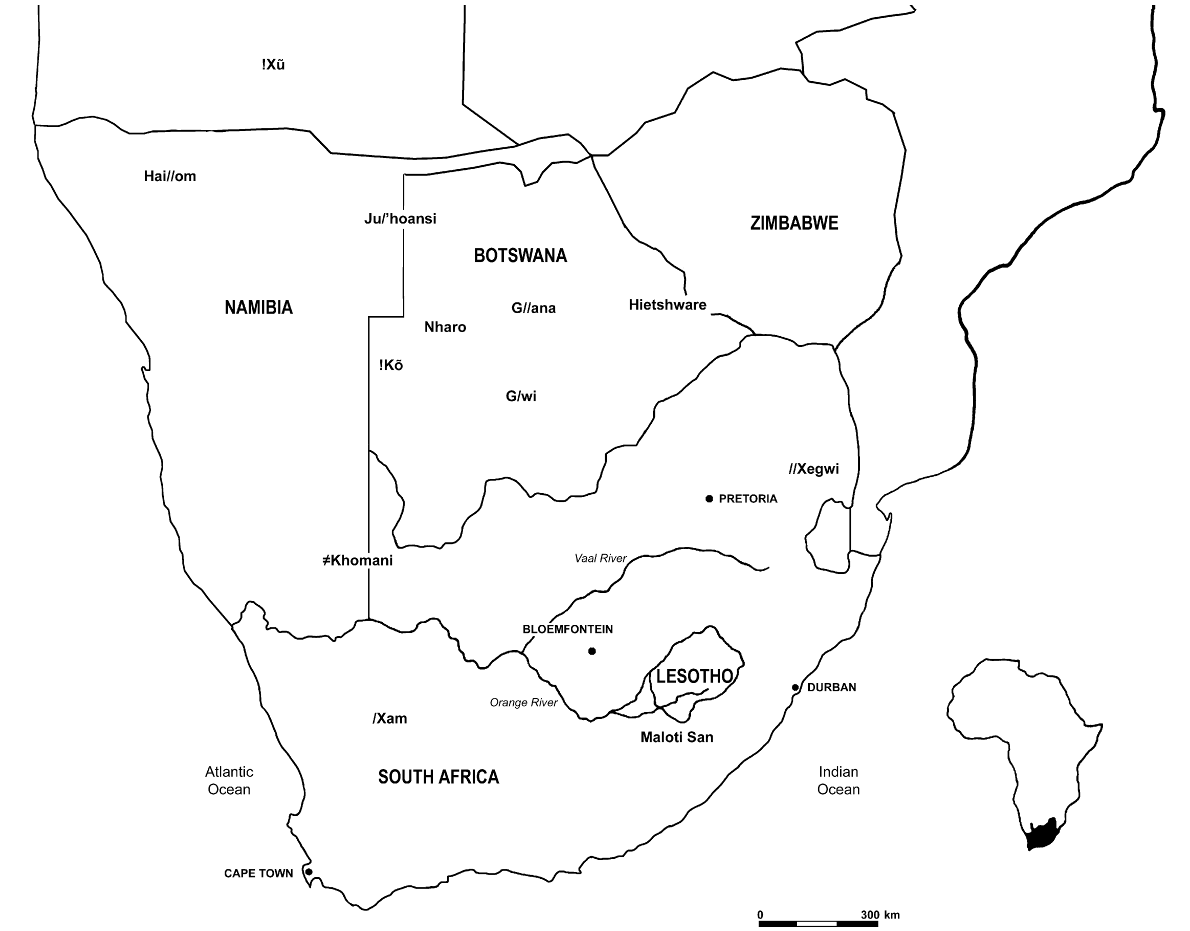
Cosmology of the African San People. Fig. 1 Bushman group, colonial South Africa, 1884. From Bleek and Lloyd (1911: 99).

A First People

The San of southern Africa (Fig. 2; Hyperlink 1) are the most studied people on earth because of their perceived uniqueness as models of original humanity. Such study has not always been accurate. In 1719 the German astronomer Peter Kolb published the statement that Hottentots worshipped the praying mantis (*Mantis religiosa*), generating the Mantis God myth (Marshall 1999: 242–245). In fact, this insect worship was San genuflecting to the powerful trickster, Kaggen, in one of his many corporeal forms (Barnard 1992: 84–85). Even today myths endure. San contextual egalitarianism, shamanic healing and environmental stewardship are often represented as timeless and apolitical, ossifying the dynamic and idiosyncratic flow of San life in which individual action and cosmological constants combine to create a flexible matrix for being in the world (Endnote 2). San groups present and past do, however, show remarkable congruence in "territorial organisation, gender relations, kinship, ritual, and cosmology" (Barnard 1992: 3). For example, colonial ethnographies suggest a common origin realm inhabited by "People of the Early Race" (Bleek and Lloyd 1911: 55–57, 175–199), who both created the cosmological order and delight in transgressing its boundaries. This primal time relies less on personnel, location or temporality than on the relationships between these components (Katz et al. 1997: 47–62). What we comprehend as separate Spirit and Ordinary worlds constantly intersect.

A Connective Cosmos

The Ordinary World has nodal topography studded with campsites, hunting grounds and what Ju/'hoansi call *n!oresi* – bundles of relationships and obligations between animals, beings, people, places, plants and things (Katz et al. 1997: 16, 50). Material traces of these relationships date back millennia, appearing as artefacts archaeologists classify on a continuum between functional and symbolic. Thus, artisanal artefacts such as stone tools and bone points grade into non-utilitarian items like ostrich eggshell beads and decorations, which intensify into symbolic crystals and rock art (Figs. 3 and 4). Some say functionality is easier to prove than symbolism. Yet our best evidence of San life is symbolic rock art present at over 30,000 sites (Ouzman 1998; Endnote 3). What



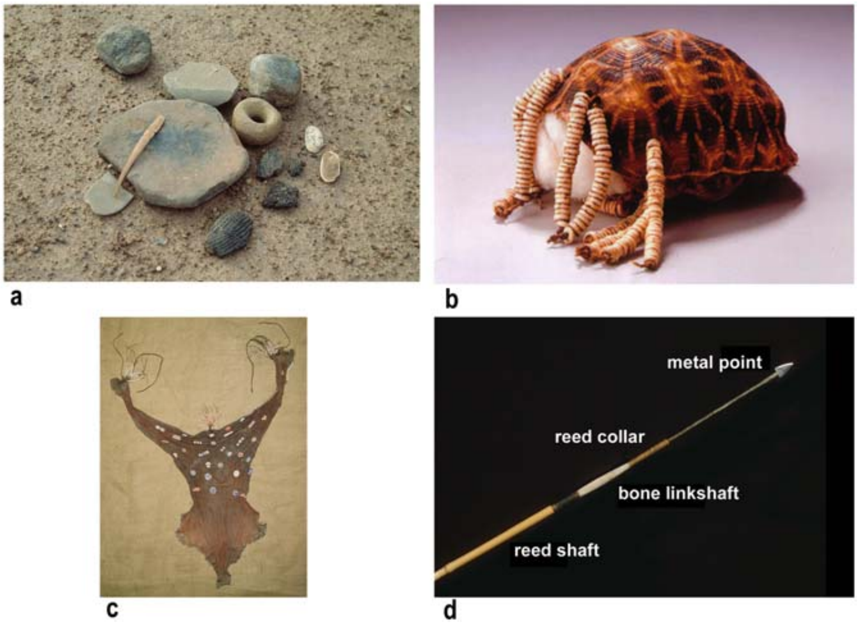
Cosmology of the African San People. Fig. 2 Distribution of San language groups.

we call images were for San actual apocalypse dogs, Beings, cynosuric animals, rain-animals, supernatural potency and part-human therianthropes emergent from an inner Spirit World behind the rock face.

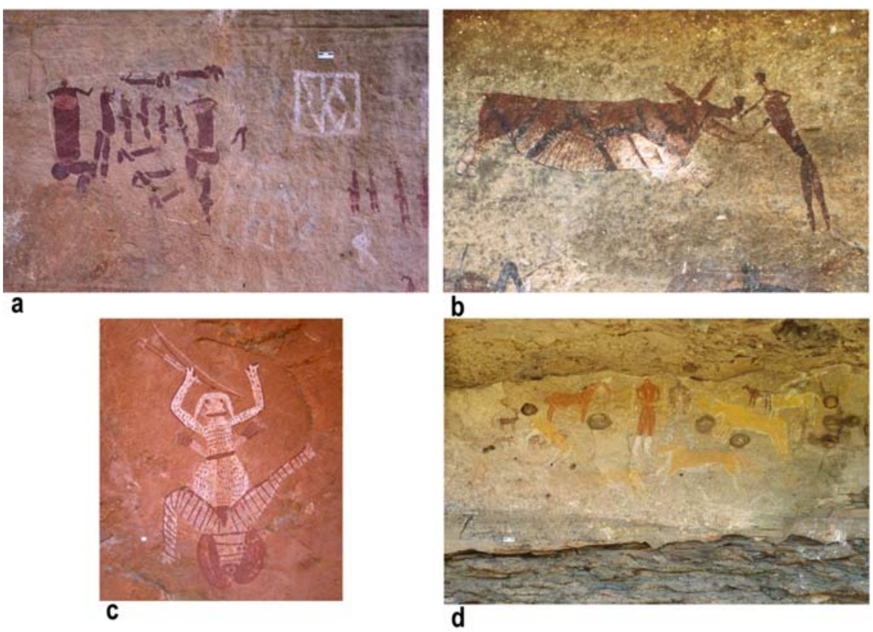
Other connexions to the Spirit World, which exists in multiple locations above and below the Ordinary World, are via water, striking landscape features, and events like death and dancing. These do not permit universal access because the Spirit World is dangerous and inversive. It requires great skill to negotiate its pathways, cul-de-sacs, and denizens like the Spirits of the Dead. Two great but capricious gods – whom the G/wi call *N!eri* (creator) and *//Gauwa* (trickster) – have a fearsome entourage of wives, carnivores and spirits (Guenther 1999: 61–64). Consequently, the task of traversing worlds is left to shamans – skilled negotiators of boundaries who make sense of the seemingly impossible such as being neither and both male and female (Atkinson 1992: 319). This skill is superhuman and requires what Ju/'hoansi call *n/om* – a supernatural potency vested by God in certain interconnected receptacles such as comets, honey, lightning, large animals, plants, rain, shamans or sun (Marshall 1999: 20, 49–62, 218).

> The spirit is in the air. When you dance it comes down to you. When it gets into you, you can see it as a string of light. The light carries you in the dance. It can take you to another person who needs healing or it can carry you to another village in the sky. The light is *num* [*n/om*]. It doesn't have another name than *num*. Xixae Dxao (Keeney 2003: 41).

But potency, like the gods, is complementary – a foundational feature of San cosmologies. Small amounts of potency aid apotropaism astral travel, healing, and rainmaking, but high concentrations can kill. Controlling potency and passage to the Spirit World requires everyone's labour (Katz 1982: 34–57). Nowhere is this complementarity better exemplified than in the Medicine Dance – perhaps humanity's



Cosmology of the African San People. Fig. 3 San material culture. (a) Bored stone, bone scraper, freshwater mussel shells, grindstone, lithics, pottery. (b) Medicine container. Hearst Museum, University of California Berkeley, California. (c) Decorated leather woman's apron. (d) Arrow.



Cosmology of the African San People. Fig. 4 San rock art. (a) Medicine Dance, (b) Rain-animal, (c) Therianthrope and (d) Colonists.

oldest surviving ritual (Hyperlink 2). The atmosphere of the Dance is social and electric. People clap, dance, sing and talk to create a spiritually charged and socially cohesive atmosphere that launches shamans to the Spirit World.

It is endlessly varied by disciplined improvisation, within the bounds of repeated musical phrases. When the awesome sound of the men's rattles is added to the singing and sharply clapped cadences, a music of truly unearthly beauty is

> produced. This music is one of the basic vehicles of transcendence, enabling curers to achieve the altered state of consciousness called trance (Biesele 1984: 165–166).

> In trance, with the support of the women in the community, who sing and clap, a master of trance works himself into a state where he transcends himself and enters the realm of the supernatural where the ghosts of dead ancestors live. Here he struggles with the ghosts. The struggle is intense both emotionally and physically. He is overcome with pain and fear, afraid that he will lose himself in the realm of the supernatural and not return (Wiessner and Larson 1979: 25).

The physical and spiritual labour of females, males, children, movement, sound, spirits and potency is thus not equal but harmonises. Shamans are pre-eminent but they serve a community. The Medicine Dance is an enduring *genius loci* still performed in Angola, Botswana and Namibia where it attracts non-San like Damara, Herero and Tswana for healing and community. The Dance incorporates elements of ecstatic Christianity and political resistance, whereby shiny European goods are eschewed and shamans act as agents of social change by voicing concerns about alcoholism, marginalisation and so forth (Guenther 1999: 195–6).

San Science: Past, Present and Future

San cosmology is thus not narrowly spiritual but entails "an all-encompassing world-view, the influences of which extend into every sphere of their existence" (Yates and Manhire 1991: 3). An especially complete synthesis of gender, science, religion and technology is !Kõ and //Gana arrow poison (Heinz 1978: 151; Neuwinger 2004; Hyperlink 3). The paralysing toxin comes from the haemolymph of *Diamphidia simplex* beetle larvae and cocoons, but not the adult beetle (Fig. 5; Hyperlink 4). These larvae live up to 1 m below the ground near a host tree, the sandy corkwood (*Commiphora angolensis*). Six to ten larvae are sufficient for one arrow's toxin, which is applied by man-the-hunter (Hyperlink 5). San arrows are tripartite constructions designed so that the impetus of the linkshaft breaks the reed collar, causing the shaft which the animal could otherwise dislodge from its body to fall away, leaving just the arrow point behind to deliver the toxin (Fig. 3d). But men are ignorant of the toxic larvae's location until women, more attuned to subterranean signs (Hyperlink 6), tell them where to look. This female–male, nature–science relationship is spiritually triangulated through the great God ≠Gao N!a who "taught them how to find it and how to put it on their arrows so that they would have meat" (Marshall 1999: 32).

Lest San be characterised as waning guardians of an ancient spirituality, it is useful to examine complementarities between San and Western worlds. Sometimes this juxtaposition is conflictual. Pfizer Pharmaceuticals were sued for bio-pirating ≠Khomani intellectual property of the appetite suppressing properties of the *Hoodia gordonia* plant, now marketed as a slimming product (Wynberg 2004). In more fulsome spirit, the Cybertracker project pairs renowned San tracking skills with Global Positioning System (GPS) technology to aid game management and counter poaching (Hawthorne 1999; ►www.cybertracker.co.za). San trackers, often text-illiterate but masters at reading sign, note spoor by selecting species-specific keypad icons. The GPS registers this input, capturing data like the location, movement, number and health of animals, which is transmitted to a central database. This hybrid approach is more effective than either San or Western science. Indeed, Western science may originate out of the art of tracking:

> To interpret tracks and signs trackers must project themselves into the position of the animal in order to create a hypothetical explanation of what the animal was doing. Tracking is not strictly speaking empirical, since it also involves the tracker's imagination. Generally speaking, one may argue that science is not only a product of objective observation of the world through sense perception. It is also a product of the human imagination (Liebenberg 1990: v).

More than science, San tracking is a deeply spiritual activity necessary for the renewal of life. "Tracking is like dancing. This is the Great Dance. You are talking to God when you are doing these things" (Hyperlink 7). However, while San cosmological complementarity works well in Habermasian ideal speech situations,[1] these examples of accord should not mask the devastation of acculturation, cultural property theft, forced removals and genocide experienced by many San. Celebrating only the positive can veer dangerously close to liberal social contracts and commons that are open to unpunishable abuse (Hardin 1968). Mindful of this, San have reformulated their egalitarian ethos to uplift

[1] Habermas (1929-) sets out five conditions for his ideal speech situation (a) Every subject with the competence to speak and act is allowed to take part in a discourse; (b) Everyone is allowed to question any assertion whatever; (c) Everyone is allowed to introduce any assertion whatever into the discourse; (d) Everyone is allowed to express his attitudes, desires and needs (e) No speaker may be prevented, by internal or external coercion, from exercising his rights as laid down in (a) and (b). (*Diskursethik*: 86). These conditions make possible free discourse and pure communicative action.

Cosmology of the African San People. Fig. 5 *Diamphidia* beetle cocoons and larvae used for arrow poison. From Neuwinger 2004.

themselves and to educate well-intentioned and wilful outsiders (WIMSA 2003; ►http://www.san.org.za). The long and ongoing tradition of San cosmology is not something conservative and ancient, it is a fund of beliefs, places, objects, skills and stories that allow people to innovate and to impact the modern world.

Endnote 1: The Name Game – San or Bushman?

Ethnonomy – the process by which people name themselves, are named by others, and the politics that determine which names stick – is critically important to people's sense of self. Both San – a Nama word meaning "vagabond" – and Bushman – an anglicisation of the Dutch *bosjemans* – are exonyms. Today's approximately 100,000 San who live in Angola, Botswana, South Africa and Zambia have group-specific autonyms like /Gwi, Ju/'hoansi, and !Kõ, which translate as people, real people or red people, but that do not apply beyond the group – even to other San (Traill 1995; ►http://en.wikipedia.org/wiki/Khoisan_languages). The corporate term Khoisan was coined by Leonhard Schultze in 1928 (Barnard 1992: 7) and conflates the overlapping but distinct histories of Khoekhoe herders like the Nama, with San. During Apartheid, Bushman and *Boesman* were deeply offensive, but today these words are being reclaimed as a form of resistance (Gordon 1992: 6–7). Where possible, group specific names should be used. Elsewise either San or Bushman are acceptable, if used respectfully.

Endnote 2: San and New Ageism

Thanks to films like Jamie Uys' *The Gods Must be Crazy*, books like Laurens van der Post's *The Lost World of the Kalahari*, and high profile academic research, San are viewed as a distillate of pure humanity – noble savages. Such stereotyping, while well intentioned and having some basis, leads to social and political marginalistion. Nowhere is this more apparent than in the New Age movement's appropriation of San shamanism and rock art (Sullivan 1995) and archaeology in general (Morris 2005). Modern primitives' urge to leave offerings at archaeological sites, to mimic ceremonies and dress, and continued idealistic portrayal of San cosmology causes communities great distress (Katz et al. 1997). New Ageism is a very partial practice that selectively ignores modern circumstances like the syncretic adoption of Christianity and very real social problems such as alcoholism, domestic violence and persecution and how San succeed and fail to deal with these.

Endnote 3: The Meaning of San Rock Art

In 1945 the French prehistorian Abbé Henri Breuil sent word to South African Prime Minister Jan Smuts of “a portrait of a charming girl who has been waiting for us on a rock in the Brandberg range for perhaps three thousand years.” Breuil was describing what he thought to be a Phoenician White Lady painted on the rocks of Namibia’s Brandberg (Breuil 1955; ►http://www.namibia-1on1.com/Namibia-Northern/White-Lady-Of-Brandberg.html). Breuil’s inability to acknowledge indigenous authorship of southern African rock art was influenced by the Eurocentric Great Chain of Being (Lovejoy 1936). Hierarchically ordering the world between God atop and rocks below; white humans were placed nearer God while San, Bantu speakers and Khoekhoen were placed near and even under rocks. Art produced by these lower races was believed either simply to record daily life or to spring from an innate native ability to make art. Appreciation of San rock art’s symbolic and spiritual meanings lay dormant until half-forgotten nineteenth and twentieth century ethnographies (►www.lloydbleekcollection.uct.ac.za) revolutionised southern African rock art research (Lewis-Williams and Pearce 2004; ►http://rockart.wits.ac.za). Today we know that most southern Africans made some form of rock art. Whether shamanistic San statements, group-specific Khoekhoen engravings and paintings, initiation and political resistance arts of Bantu speakers, or Depression-era marks of white work gangs, the landscape bears a multitude of marks – some of which have yet to be understood.

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List of Hyperlinks

Hyperlink 1. *Audio*: Track 1 of Traill, Anthony (Producer). *Extinct South African KhoiSan languages*. Booklet and Audio CD. Johannesburg: University of the Witwatersrand, 1997.
Hyperlink 2. *DVD Clip*: From DVD Accompanying Keeney, Bradford (Dir). *Ropes to God: Experiencing the Bushman Spiritual Universe*. Philadelphia, PA: Ringing Rocks Press, 2003.
Hyperlink 3. *Video Clip*: Heunemann, Dieter and Hans-Joachim Heinz (Directors). *!Ko Buschmänner (Südafrika, Kalahari) – herstellen eines Giftpeils*. Göttingen: IWF, 1975 . ►http://mkat.iwf.de/index.asp?Signatur=E±1824.
Hyperlink 4. *Online Article*: Neuwinger, Hans Dieter. Das larven-pfeilgift der Buschmänner. *Biologie in unserer Zeit* 6.3 (2004):75–82.
Hyperlink 5. *Video Clip*: Heunemann, Dieter and Hans-Joachim Heinz (Directors). *!Ko-Buschmänner (Südafrika, Kalahari) – Jagd auf Springhasen*. Göttingen: IWF, 1975. ►http://mkat.iwf.de/index.asp?Signatur=E+1825.
Hyperlink 6. *Video Clip*: Dieter and Hans-Joachim Heinz (Directors). *!Ko-Buschmänner (Südafrika, Kalahari) – sammeln, zubereiten und verzehren von 'veld-kos' durch frauen*. Göttingen: IWF, 1975. ►http://mkat.iwf.de/index.asp?Signatur=E+2119.
Hyperlink 7. *Video Clip*: Foster, Craig and Damon Foster. *The Great Dance: A Hunter's Story*. Cape Town: Aardvark/Earthrise/Liquid Pictures/Off the Fence Films, 2000. ►http://www.senseafrica.com/greatdance/movie/trailor.html.

Cosmology in Mesoamerica

Keith Jordan

The Native American peoples who occupied Central and Southern Mexico, the Yucatan Peninsula, Guatemala, Belize, El Salvador, and Western Honduras prior to the Spanish Conquest of the sixteenth century shared many aspects of both material culture and ideology. This cultural unity, underlying varying expressions of the basic pattern across linguistic, ethnic, and political divisions, is the basis for the modern anthropological construct of Mesoamerica as a distinct culture area. Among the achievements of the pre-Columbian Mesoamerican civilizations of the Aztecs, Maya, Mixtecs, Zapotecs, and others are complex myths and mental maps of the universe as they understood it. These elaborate conceptualizations encompass multiple realms of existence and sequences of creation and destruction across vast epochs of time. While each distinct culture generated its own cosmology, all such models of the nature of the cosmos are united by common features marking them as distinctively Mesoamerican. This entry will employ as representative examples the world views of two Mesoamerican cultures for which much information has come down to us across centuries, the Aztec and the Maya. The reader unfamiliar with the sources and chronology for Mesoamerica should view Notes 1 and 2 before reading further.

Shared Features of Traditional Mesoamerican Cosmologies

Although details vary across time and political/linguistic boundaries, pre-Columbian Mesoamerican cosmologies share a number of general characteristics. The universe is conceived as arranged in multiple levels, broadly divided into an upper world (the sky), a middle world (the earth), and an underworld beneath the earth. The upper world, home of the gods, may have 13 levels, while the underworld, land of the dead, usually has nine. The earth is pictured as a disc, square, or aquatic reptile floating on the sea. Its surface is divided into four quarters corresponding to the cardinal directions. At its center is a vertical axis symbolized by a tree or primordial mountain, bridging the multiple tiers of the cosmos above and below. This center may be identified with a capital city or sacred site, or with the body of a ruler. Deities, rulers, and ritual specialists use the central axis as a conduit to travel between levels of the universe. Other portals to the ancestral realm of the underworld are depicted as the mouths of mythical reptiles, and equated with caves. Mountains are envisioned as hollow sources of plenty, repositories of water and maize.

Similarities in maps of space are matched by shared, cyclical conceptions of time. The present universe is the last of a series of creations. Each prior cosmos fell victim to catastrophic destruction. A ritual calendar year of 260 days is paired with an approximate solar year of 360 days, a hallmark of Mesoamerican culture (see Calendars in Mesoamerica in this volume). Unlike contemporary Western thought, in the Mesoamerican vision, cosmology is distinguished neither from religion nor from politics. The social order and its activities – like warfare and human sacrifice – are part of the natural order and crucial to the viability of the entire cosmos. The forces that animate and manifest as the phenomena of nature are supernatural beings.

Mesoamerican thought is characterized by dynamic pairings of binary oppositions: male/female; upper world/underworld; rain/dryness; and death/life. Although sometimes labeled as dualism, these conceptions are not dualistic in the Platonic or Manichaean senses, i.e., separating mind and matter. Rather, the opposite qualities interact dynamically and are themselves manifestations of an underlying unity (Fig. 1).

Origins

The beginnings of Mesoamerican cosmology are lost in the distant past. Mesoamerican world views share features with Asian, Native North American, and South

Cosmology in Mesoamerica. Fig. 1 Ehecatl/Quetzalcoatl (*right*), a deity associated with life and fertility, and Mictlantecuhtli, god of death and ruler of the underworld, showing duality of opposing forces in the cosmos. Reconstruction of MS painting from *Codex Borgia*, p 56, Mixteca-Puebla style, Puebla/Tlaxcala (Mexico), Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia: A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Reproduced by permission of Alan Rodgers.

American shamanic traditions – e.g., a multilevel universe bridged by a vertical axis conceived as a world tree. Because of these similarities, some scholars trace the roots of Mesoamerican cosmologies back to the presumed shamanistic beliefs of the first settlers of the New World who crossed the Bering Strait or arrived by boat along the Pacific coast during the last Ice Age. Other parallels suggest connections with Asia: the occurrence in both areas of directional symbolism associated with colors, or the identification of the markings on the surface of the moon as a rabbit. However, the archaeological record does not yield clear evidence for cosmological beliefs in Mesoamerica from the arrival of the first hunter–gathers (pre-10,000 BCE) through the transition to a sedentary agricultural lifestyle (ca. 2000 BCE). The relevance of shamanism to understanding Mesoamerican civilizations has been questioned (Note 6).

The earliest clear signs of a developed mythic cosmology occur in the monumental art of the Olmec culture of the Mexican Gulf Coast. This civilization, which flourished between 1200 and 400 BCE, has been touted as the "mother culture" of Mesoamerica, although more recent views hold it to be the most developed regional manifestation of a pan-Mesoamerican art style and ceremonial complex. In the absence of readable glyphic inscriptions, reconstruction of Olmec cosmology is a speculative exercise, drawing on inferences from Maya beliefs (see shamanism in Mesoamerica in this volume).

Maya Cosmology

On the basis of artistic, inscriptional and ethnographic data, we know that the Maya of the Classic through Postclassic periods envisioned the earth as a disk or square surrounded by water, or as an aquatic animal, a turtle or a caiman. The earth's surface could be represented as a quadrilateral, based on the traditional Maya maize field or milpa. In the *Popol Vuh* (Note 5), this shape was mapped out by the gods using a cord during the last creation. This surface was divided into eight by the four cardinal and four intercardinal directions, and transfixed vertically in the center by the world tree, the central axis and path between upper, middle, and lower worlds. This cosmic tree was identified with the ceiba tree, whose sanctity may be related to the resemblance of its sap to blood. In Classic reliefs from Palenque, the world tree is depicted as a cross, with the Celestial Bird, Mut-Itzamna, perched at the top, and the entrance to the underworld, personified as the skeletal jaws of the White-Boned Serpent or Centipede, gaping at its base. In the sky, the world tree seems to have been equated with the Milky Way, called "the White Road" in Classic texts. Its uppermost terminus was located at the north celestial pole. Deceased souls, along with shamans, move up and down this conduit between cosmic tiers, hence the euphemism for royal death, "he entered the road," in Classic texts. As shamans, Classic kings were supposed to navigate between worlds along the world tree via trance states induced by bloodletting. The king's body itself is symbolically equated in art with this *axis mundi*.

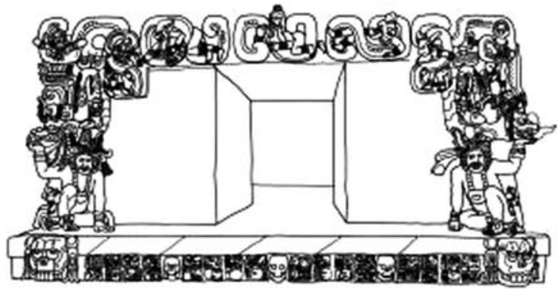
Each of the four cardinal directions was equated with a symbolic color. Red, color of the sunrise, represented the East, a positive direction because of its solar associations. By contrast, West was associated with black and had negative connotations because of its connection with sunset, and by analogy, death. North (white) was the direction of the sun's zenith, followed by dead kings in their apotheosis to the celestial world (Note 7). It was the domed house of the sky, raised by the Maize God during the last creation of the world. South (yellow) pointed to the depths of the underworld. The earth was supported by four beings referred to as Bakabs or Pauhatuns. According to the *Chilam Balam of Chumayel* (Note 5), they were survivors of the destruction of the third creation. In other sources, they are the winds. The Maya rain god, Chaak, is also depicted with four manifestations corresponding to the cardinal directions.

Below the earth lay the nine-tiered underworld, Xibalba, "place of fright." This underwater realm was pictured as dark, foul, cold, associated with disease, death and rot, home of monsters and malevolent gods like the Lords of Death named in the *Popol Vuh* by such epithets as "Pus Master" and "Stab Master." Xibalba rotates over the earth at night to become the night sky. Caves, the jaws of the earth, were entrances to Xibalba, paths taken by the setting sun as it entered the underworld. At the same time, caves carried connections with fertility, being the source of rain, clouds, and maize. Another type of cosmic portal, perhaps a manifestation of the *axis mundi*, is represented in Classic art by supernatural snakes, Vision Serpents. These entities, brought into transient existence by the bloodletting rites of Maya kings, serve as bridges between the rulers and the realm of their ancestors, who are seen emerging from the serpent's jaws to bestow their blessings (Fig. 3).

The upper world, with its 13 levels, was represented in art by the Skyband, a two-headed serpent or crocodile symbolizing the ecliptic. The serpent image may be a visual pun: in the Cholan Maya language, *kan* (snake) resembles *can* (sky). Skybands were used as borders demarcating the upper world in art. The ecliptic can also be represented as a cord which guides the celestial bodies across the sky. The daytime sun was represented by the male deity, Ah Kin or Kinich Ahau. At night, the sun passed through Xibalba, where it took the form of the Jaguar God of the underworld (although an alternate interpretation connects him with the moon). The moon could be represented by a goddess, often depicted as a youthful seductress, accompanied by the rabbit that was seen in its features. Lunar eclipses, recorded and predicted with accuracy, may have been the preserve of a separate divinity (Figs. 4–6).

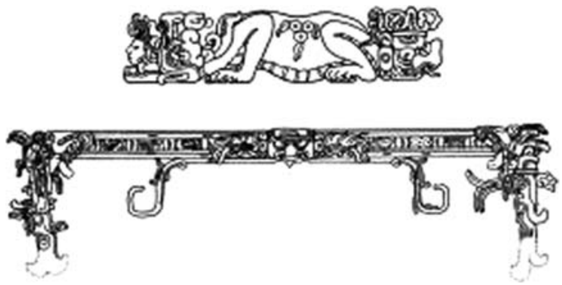
The Maya also charted the movements of Venus. As in other parts of Mesoamerica, this planet was associated with warfare. It is possible that military engagements were timed in the Classic period according to the planet's 584-day cycle, though recent epigraphic work suggests that more pragmatic factors no doubt also influenced such decisions. In the *Popol Vuh*, Venus is depicted as carrying the sun. The Maya kept track of the behavior of other planets visible to the naked eye, but our understanding of their planetary symbolism remains uncertain. For example, Mercury may have been identified with the deity Kawil, whose reclining posture may reflect the planet's observed position just above the horizon, but another interpretation links the same deity to Jupiter.

The stars were set in motion by the raising of the world tree at the last creation. Maya conceptions of the zodiac and constellations remain poorly understood. It appears that the Pleiades were envisioned as a rattlesnake (*Sab*), while the belt of Orion was equated with a turtle (*Ak*), through whose shell the Maize God

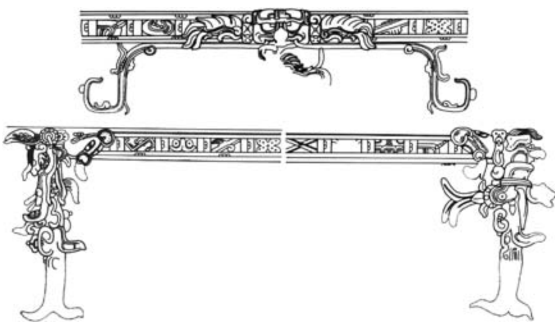


Cosmology in Mesoamerica. Fig. 2 Doorway of Temple 22, Copan, Honduras, Late Classic Period. The decoration of this temple structure symbolizes the Maya cosmos. At the top, the serpentine Cosmic Monster represents the sky. The crouching figures on either side of the entrance are bacabs or pauhtuns, the deities who support the world. The skulls at the base represent the underworld. The doorway itself represents a symbolic cave, entrance into the underworld. When the Copan ruler Waxaklahun Ubah Kawil (18 Rabbit), who commissioned the structure, entered the temple he was symbolically entering a portal to the supernatural world of his ancestors. Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan).

Cosmology in Mesoamerica. Fig. 3 Vision Serpents, Late Classic. Detail of two vision serpents with ancestors emerging from mouth and two double-headed serpent bars with deities emerging from opened mouths. Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI.



Cosmology in Mesoamerica. Fig. 4 Classic Maya Sky Serpents. Two variants of the double-headed serpent representing the ecliptic. *Top*: legged variant, Altar 41, Copan, Honduras. *Bottom*: stucco relief sculpture from House E of the Palace at Palenque, Mexico (Late Classic, ca. 600–800 CE). Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan).



Cosmology in Mesoamerica. Fig. 5 Skybands from Palenque, Late Classic Maya. Reconstruction of stucco relief sculptures from "bicephalic Room," House E, Palace. The top drawing shows the Celestial Bird and skyband, from the north wall. The bottom drawing represents a second two-headed deity, a composite of skyband segments from the west and east walls. The skyband on the Western wall has a saurian or reptilian head with Venus markings. Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI.

Cosmology in Mesoamerica. Fig. 6 Paddler Sun, Early Classic Maya. Drawing of lidded four-legged vessel. Each of four legs represents a downward facing peccary. Atop the lid, the Sun God, wearing a cap marked with k'in ("sun") paddles his canoe through a watery environment containing fish. This vessel has been interpreted as representing the Sun God paddling his canoe across the ecliptic and the constellation of Gemini. Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI.

resurrected at the last creation (Note 7). Alternatively, *Ak* may correspond to Gemini, and the Pleiades were also identified with 400 boys killed by the monster Zipacna, an event placed by the *Popol Vuh* shortly before the last structuring of the world. A scorpion constellation may be identical to Scorpio, or correspond to Gemini. Mut-Itzamna, avian shamanic alter ego of the sky deity Itzamna, seems to have been identified with the Big Dipper.

For the Maya, the present universe is the most recent of cyclic creations destroyed by past catastrophes. The last reordering of the cosmos occurred in 3114 BCE, the mythic starting point of the Long Count dating system (Note 6). According to an inscription in the Temple of the Cross at Palenque, the creator deities First Mother and First Father (the Maya Maize God) set three hearth stones at the center of the universe, identified with the stars Alnitak, Saiph, and Rigel. As the sky lay flat upon the earth, the Maize God lifted it up to its present position, supported by the world tree. This ordering of the cosmos set in motion time and the movements of the stars.

In the *Popol Vuh* creation myth, the gods of creation reside in watery chaos, silent and dark. They create the first version of the universe, populated by animals, but are unsatisfied because the beasts are incapable of worshipping their makers. To rectify this deficiency, the gods create the second world and make the first humans out of mud. However, these creatures were incapable of thought, and the gods destroyed them and their world by water. On the advice of an elderly couple skilled in divination, the gods created the humans of the third creation out of wood. These people were able to speak, but had no emotions, and did not recognize the gods as their creators. This failed experiment was brought to an end by a flood and rain of pitch. The few surviving wooden men were transformed into monkeys.

Order was brought out of the chaos left by the flood by the erection of the vault of the sky and separation of the earth from water. The gods created the current race of humans from maize, but they proved to be too smart for their creators' liking. As a countermeasure, the gods limited their understanding. From the interior of the terrestrial cornucopia, First True Mountain, came seeds, maize and water for the sustenance of humanity.

Aztec/Nahua Cosmology

The Mexica, or Aztecs, and related peoples of Postclassic Central Mexico, envisioned the universe as a fluxing reality permeated with spiritual forces in endless transformation. Like the Maya, they seem to have believed in an upper world of 13 levels and an underworld of nine, though this conclusion, based on colonial sources, has been questioned. The earth was pictured as a disk or a floating crocodilian or toad-like monster, Tlaltecuhtli, bounded by a square or circle of water joined to the vault of the sky. For the Aztecs, the central axis connecting the three realms of the universe transfixed the earth at their capital city, Tenochtitlan, on the site of the Templo Mayor (great temple). As in Maya cosmology, the world was divided by the four cardinal directions. East, associated with solar hues of red and yellow, was viewed as positive. North was referred to as the Land of the Dead, as it was believed that the journey of souls to Mictlan, the underworld, began here. It was cold and its color was black. West, the Region of Women, was associated with the positive colors, blue and green, while South, called the Region of Thorns, was symbolized by white. Each direction had its own version of the rain god, Tlaloc, in a similar fashion to the Maya Chaaks. A slightly different Nahua conception of directional symbolism, probably produced in Puebla or Tlaxcala, is illustrated in Note 8 (Figs. 7 and 8).

On the earth's surface, mountains were hollow repositories of water and clouds, entrances to Tlalocan, the paradise of the rain god. The mythical Mountain of Sustenance was the source of maize, from where it was stolen by the god Quetzalcoatl at the last creation for the benefit of humans. Rivers and caves were the hungry orifices of the Earth Monster, who bore crops for human survival but devoured humans when they returned to the earth at death (Fig. 9).

The upper realms included the paradise of the sun, to where the souls of warriors slain in battle or captured and sacrificed, and of women who died in childbirth, ascended after death. They were privileged to accompany the sun on its daily journey across the sky. Tlalocan was another celestial paradise where the spirits of humans who died by drowning, lightning, or diseases associated with water went to spend the afterlife in joy. The uppermost heaven belonged to the primordial couple, the creator deities Ometecuhtli and Omecihuatl. The sun

Cosmology in Mesoamerica. Fig. 7 Detail of ceremonial mosaic shield interpreted as representing the central axis of Aztec cosmology. A world tree sprouts on the upper level, the sun symbol with the four directions and the center laid out in a quincunx pattern decorates the middle level. A serpent spirals through the four layers of the cosmos. Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI.

was represented by the god Tonatiuh, and also equated with the Aztec tribal patron, the war god Huitzilipochtli. As among the Maya, Venus had a malevolent role among the heavenly bodies. The god of Venus as the Morning Star, Tlahuizcalpantecuhtli, is represented in the Borgia group of manuscripts with a skeletal mask, hurling darts at his victims. This deity was a manifestation of Quetzalcoatl. It is commonly repeated in the literature that another form of Quetzalcoatl, the dog god Xolotl, represented Venus as the Evening Star. Meteorites were equated with caterpillars and worms and were referred to as the excrement of the stars. Some stars were *tzitzimime* – demons who will devour humans at the end of the present creation. The Milky Way was represented as a divine couple, Citlaltonac and Citlalicue (Fig. 10).

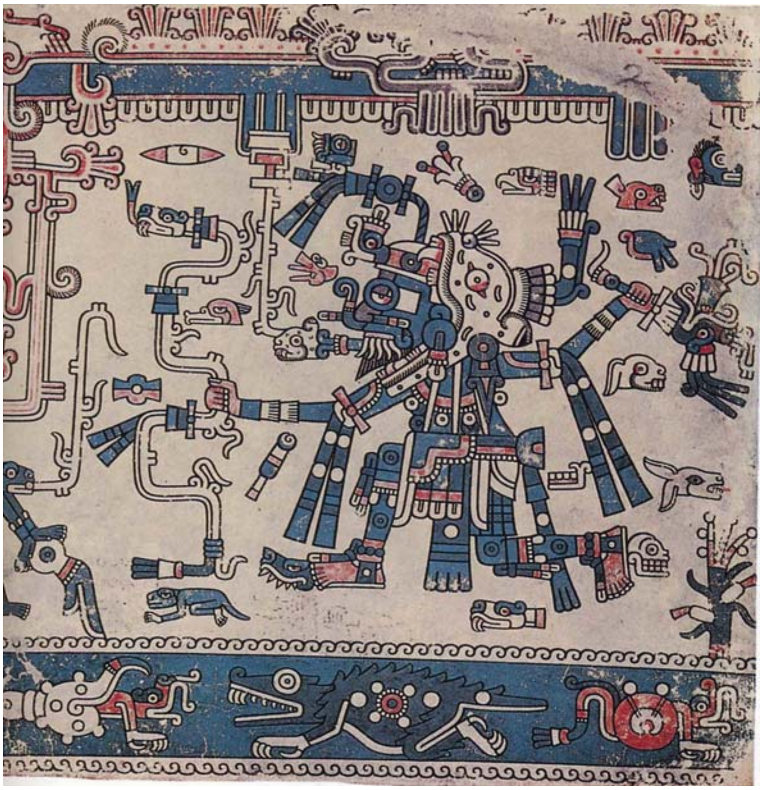
At the nadir of the underworld was Mictlan, land of the dead, destination of those souls who did not die in battle or by sacrifice. This was a shadowy half-world much like the Greek Hades, where the dead were not tormented but faded into nonexistence. It was reached by the soul after an arduous journey through bitter cold and obstacles like wind-blown knives. A dog was sacrificed and included in burials to help the departed navigate this difficult passage.

The Aztecs saw the present world as the fifth in a series of successive creations, or Suns, brought to an end by a series of destructions. According to one

Cosmology in Mesoamerica. Fig. 8 The five directions of the Nahua cosmos: the four cardinal directions and center, with deities. Clockwise from top right: sun god, patron of the East; Tlaloc, god of rain, patron of the South; Xipe Totec, Our Lord the Flayed One, god of agricultural fertility and patron of the West; Mixcoatl, god of hunting, patron of the North. Reconstruction of MS painting from the *Codex Borgia*, p 25, Mixteca-Puebla style, Puebla/Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia: A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola: NY: Dover, 1993. Used by permission of Alan Rodgers.

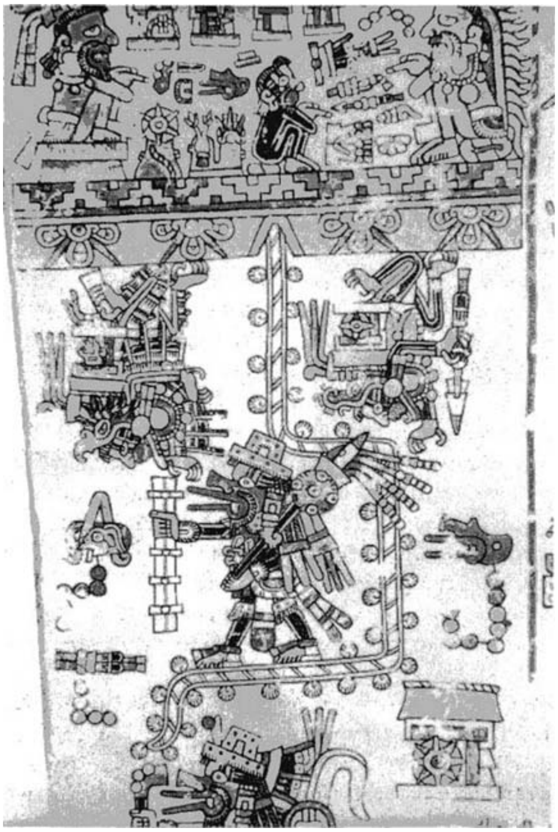
commonly repeated variant of the creation myth, the first world, Four Jaguar, was created out of primordial chaos, and ruled over by Tezcatlipoca, the protean god of kingship, fate, the night, and sorcery. The first created humans were giants – the Aztecs identified the bones of mastodons as their remains. At the end of this era, jaguars devoured these primal men. This catastrophe coincided with the defeat of Tezcatlipoca by his rival, Quetzalcoatl, god of the wind, fertility, and a culture bearer for later humans. The second creation, Four Wind, was effected and ruled by Quetzalcoatl in his manifestation as the wind, Ehecatl. In turn, he was defeated by Tezcatlipoca, and his world and its humans wiped out by hurricanes. The few survivors became monkeys. Tlaloc governed the third world, Four Rain. This creation was brought to a violent end by fire and water, and the survivors became dogs, turkeys, and butterflies. Four Water, the fourth world, appropriately had Chalchiutlicue, goddess of ground water, as its patron. Fittingly, Four Water was destroyed by a flood; its human survivors were changed into fish (Fig. 11).

After the destruction of four Water, Quetzalcoatl and Tezcatlipoca collaborated to raise the sky from the earth, supported on the trees of the four directions. The Milky Way marks their path where they walked across the new sky. A crocodilian monster, variously identified as Tlaltecuhtli or Cipactli, was vanquished by the two gods and split in half to become the earth. The gods altered her body to yield crops for humans, but in her pain, she required blood sacrifice in return for her bounty. Quetzalcoatl retrieved by trickery the bones of past humans from Mictlan to create new humans. He animated them by letting his own blood, another reason for offering blood sacrifices to the gods in gratitude. The gods assembled at the ancient city of Teotihuacan, to sacrifice themselves to create the Fifth Sun and start its motion across the sky. A disfigured god, Nanahuatzin, ("the purulent one"), sacrificed himself by immolation and became the sun. The future moon, who had hesitated to volunteer his life, followed Nanahuatzin's example and emerged from the flames as brilliant as the sun. The other gods, remembering his



Cosmology in Mesoamerica. Fig. 9 Tlaloc, god of rain, thunder, and lightning. MS painting from *Codex Laud*, p 45, Mixteca-Puebla style, Puebla/Tlaxcala region, Late Postclassic. Reproduced from Gordon Brotherston, *The Painted Books of Mexico*. London: British Museum Books, 1995, Fig. 148, p 135. Reproduced by permission of Gordon Brotherston.

Cosmology in Mesoamerica. Fig. 10 Tonatiuh, the Nahua sun god (*left*), and the moon with rabbit (*upper right*). Reconstruction of MS painting from *The Codex Borgia*, p 71, Mixteca-Puebla style, Puebla/Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia: A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Reproduced by permission of Alan Rodgers.



Cosmology in Mesoamerica. Fig. 11 Nine Wind, the Mixtec equivalent of Quetzalcoatl, descending from the heavens. MS painting from the *Tepexic Annals, Vienna Codex*, p 5, Late Postclassic. Reproduced from Gordon Brotherston, *The Painted Books of Mexico*. London: British Museum Books, 1995, Fig. 141, p 127, by permission of Gordon Brotherston.

cowardice, dimmed his brilliance by striking him in the face with a rabbit, leaving the pattern visible still on the moon's surface.

This present Sun, Four Movement, will be destroyed by earthquake. In the hopes of delaying this catastrophe, the Aztecs found further justification for human sacrifice on a grand scale to strengthen and nourish the cosmos.

Note 1: Historical Time and Space in Mesoamerica

The indigenous peoples of Mesoamerica, like all other Native Americans, are the descendants of migratory hunter–gatherers who arrived in the New World from northern Asia by 12000 BCE, and perhaps considerably earlier. By 2000 BCE, the first Mesoamericans had developed a system of agriculture based on the staples of beans, squash, and most important, maize. This shift in economy led to the rise of permanent village communities and increasing levels of social stratification and cultural complexity.

By 1500 BCE, hierarchical societies with sophisticated cosmologies, monumental architecture, urban settlements, and specialized artists had emerged along the Mexican Gulf Coast in the modern Mexican states of Veracruz and Tabasco, and in the highlands of Chiapas and southern Guatemala.

Mesoamerican scholars traditionally used the term "Preclassic" or "Formative" to refer to the period from these first manifestations of civilization down to the third century of the Christian era. This terminology is an artifact of the historical development and biases of Mesoamerican studies over the last 200 years. Because Maya art is relatively naturalistic and reminded nineteenth and twentieth century archaeologists of the Classical styles of the ancient Mediterranean, it was given a privileged status relative to the rest of Mesoamerican art. This, and Maya achievements in mathematics, astronomy and the calendar, led early scholars to equate the apogee of Mesoamerican civilization with the period when the Maya erected cities and monuments dated by hieroglyphic inscriptions using the Long Count system. This time interval, ca. 250–900 CE, thus became the Classic Period, and rather predictably, the periods before and after it became the Preclassic (1200 BCE–250 CE) and Postclassic (ca. 950 CE–1521). During the Classic, it was alleged, the Maya and other Mesoamerican civilizations were governed by theocracies of astronomer priests and lived in utopian peace, free from conflict. During the Postclassic, the political and social order found among the societies encountered by the sixteenth century Spanish, based on war, human sacrifice, and monarchy, supposedly eclipsed this priestly paradise.

Discoveries in archaeology and epigraphy during the second half of the twentieth century have shattered the illusion of a Classic period governed by pacifist stargazers. It is now clear that the Classic civilizations, especially the Maya and the city of Teotihuacan in the Basin of Mexico, were engaged in warfare and human sacrifice on a large-scale, and that the Classic Maya were ruled by kings who were as much politicians and warriors as they were priests. It is also apparent that Mesoamerican civilization did not "degenerate" after the Classic period. It merely changed in directions that did not suit the prejudices of early pundits. But the chronological system has remained in use, despite proposed alternatives. The Preclassic, however, is now generally referred to as the Formative, in an attempt to characterize it based on its own characteristics – the formation of the general Mesoamerican cultural pattern – rather than by comparison with the Classic.

The Formative Period is in turn divided into three stages. During the Early Formative (ca. 1500–900 BCE), Olmec civilization flourished on the Gulf Coast around the site of San Lorenzo, while chiefdoms in Oaxaca, Chiapas, and southern Guatemala participated with the Olmec in a system of trade and shared ideologies among elites. During the Middle Formative (ca. 900–300 BCE), San Lorenzo collapsed, and Olmec civilization became focused on other sites like La Venta. Elite centers as far away as the Mexican states of Guerrero and Morelos shared symbolism and perhaps even artists with the Gulf Coast. In Oaxaca, the Zapotec people founded the great city of Monte Alban, where the first evidence of the distinctive Mesoamerican calendar system appears. In the Maya region, urban centers with monumental architecture appear in both the highlands and lowlands of Guatemala.

By the Late Formative (300 BCE–250 CE), the Olmec culture declined and vanished from the archaeological record. In the central highlands of Mexico, the huge metropolis of Teotihuacan emerged as a major power with influence felt throughout Mesoamerica. In Veracruz and Chiapas, the oldest known inscribed dates in the Long Count come from this period. In the Maya region, huge cities rivaling their "Classic" descendants were raised at sites like El Mirador in Guatemala, and the ideology of Maya kingship began to take shape.

The Classic Period is usually divided into Early and Late phases. During the Early Classic (ca. 250–600 CE), Teotihuacan reached its peak of political, religious, and artistic influence on the rest of Mesoamerica, even apparently interfering in the political affairs of distant Maya city–states like Tikal, Guatemala. In the Maya area, fully developed hieroglyphic inscriptions appear. Centers like Tikal and Copan rose to political prominence and artistic glory. In Oaxaca, the Zapotec capital of Monte Alban reached its florescence. The Late Classic saw the full cultural and political development of Maya cities such as Tikal, Copan, Palenque, Yaxchilan, and Piedras Negras. In Central Mexico, Teotihuacan's sacred center was burned and abandoned, ending the city's dominant position, while other centers like Xochicalco and Cacaxtla flourished in its wake. Long-distance trade contacts are revealed by the eclectic art of these sites, showing influences from as far away as the Maya.

By 900 CE, most of the southern Maya cities were abandoned after overpopulation, soil exhaustion, drought and warfare led to the breakdown of the Classic Maya institution of kingship. No more Long Count dates were recorded. In Yucatan, however, Maya centers like Uxmal and Chichen Itza continued to thrive, the latter perhaps for several centuries. In Central Mexico, a multiethnic people, the Toltecs, established their capital at Tula in the modern state of Hidalgo, marking the transition to the Early Postclassic (950–1150 CE). In Oaxaca, the warring Mixtec dynasties described in their screenfold books began their rise to power. An art style or group of related styles, usually called "Mixteca-Puebla" after the two regions believed to be its place of origin, became an international visual language among Mesoamerican elites.

In 1168 CE, Tula was sacked and burned by invaders from the north, an event sometimes used to mark the inception of the Late Postclassic. In Yucatan and Guatemala, the Maya split into small warring polities. In Central Mexico, a certain degree of political unity was brought about by the Mexica or Aztecs. Originally from the north, the Aztecs migrated into the Basin of Mexico and founded their capital city of Tenochtitlan on the site of modern Mexico City, in the early fourteenth century. Within less than two centuries, they had established a system of tribute states, often erroneously labeled an empire, west into Guerrero, south into Oaxaca and Chiapas, and east to the Gulf Coast. The arrival of the conquistadors in 1519 brought Aztec hegemony – and native rule of any kind in central Mexico – to an abrupt end. By 1521, Tenochtitlan had been destroyed and Mexico became the Viceroyalty of New Spain. The Maya, less centralized, and with less gold to attract the attention of the invaders, held out longer. Yucatan was not firmly under Spanish control until the 1540s, and the last autonomous Maya kingdom, Tayasal in Guatemala, was able to maintain its independence until it finally fell to Spanish forces in 1697.

Note 2: Sources and Their Problems

Our knowledge of prehispanic Mesoamerican world views derives from several sources via which evidence of cosmological beliefs has survived both the ravages of time and the impact of the Spanish Conquest of the sixteenth century. Yet, each line of evidence is marked by ambiguities and gaps in information, simultaneously preserving and obscuring pre-Columbian conceptions of the universe. From the period of initial Spanish contact with Native Mesoamericans, we have written documents, chronicles, and letters by conquistadores and missionaries. In particular, the writings of Duran and Sahagun on the Aztecs, and Landa on the Yucatec Maya, have preserved much information about Mesoamerican cosmology in the sixteenth century. However, Colonial accounts of indigenous beliefs are frequently incomplete, propagandistic in their efforts to justify conversion of the "idolatrous" natives, and distorted by the conceptual frameworks of their authors. Western assumptions are forced onto very different views of the cosmos, leading to debate and uncertainty for centuries to come (Note 3: Did Mesoamericans Have Gods?). In addition, the validity of using these late traditions to interpret the beliefs of earlier Mesoamerican civilizations is limited, since systems of thought rarely remain static for centuries. Many attempts to "read backwards" from colonial sources to interpret earlier belief systems founder on the uncertainty created by such large gaps in time.

At the same time as they were preserving aspects of Mesoamerican cosmology in their writings, the friars of the sixteenth century were busy destroying another type of evidence – indigenous screenfold books. Many of these documents, painted on bark paper or deer skin, were burned by the colonists in their zeal to destroy Native Mesoamerican religions. Few have survived as a result (Note 4). These painted books contain scenes illustrating episodes from cosmogonic myths, symbolic maps of the universe, and astronomical observations. Unfortunately, they are frequently fragmentary or poorly preserved. Without surviving oral tradition, their imagery is often difficult to interpret, and owing to their fragility, only examples from the centuries immediately preceding European contact have endured.

Over the last half century, epigraphers have made tremendous progress in deciphering Maya hieroglyphs. These advances have led to increased understanding of Maya cosmology during the Classic Period (ca. 250–900 CE) on the basis of inscribed texts. However, work in this field is still in an early, rapidly developing stage, with the result that newly published translations are often provisional and sometimes quickly superseded – hallmarks of a discipline in flux.

Art historians have contributed to our comprehension of pre-Columbian conceptions of the cosmos through interpretations of iconography. While their work has led to the recognition of cosmograms, astronomical symbols, and creation myths in Mesoamerican art, it is frequently speculative and controversial. In particular, attempts to interpret the religious art of earlier cultures by using Conquest-era sources are fraught with uncertainty, as noted above. In a similar fashion, archaeology has played its role in the recovery of ancient Mesoamerican world views via careful excavation of monuments and art as well as traces of ritual behavior. But again, interpretation of the data in the absence of written texts or clear-cut continuities with historic observations remains limited by the incomplete nature of the archaeological record. The looting of archaeological sites, leading to the appearance on the art market of artifacts orphaned of their context, has further contributed to the loss of information.

A hybrid discipline, called archaeoastronomy in the US and astroarchaeology in Britain, arose in the 1970s out of collaboration between archaeologists and astronomers. It focuses on ancient knowledge and practice of astronomy as revealed by site orientations, building alignments, and visual images. In Mesoamerica, it has elucidated the understanding and observation of celestial phenomena in pre-Conquest times, frequently working in close conjunction with epigraphy and archaeology.

Traditional Mesoamerican cosmologies are by no means dead systems confined to the past. Indigenous conceptions of space, time, and creation persist among some of the present-day descendents of the pre-Columbian peoples, notably Maya groups in rural Guatemala and Chiapas, and the Mixtec of Oaxaca. Historic and contemporary ethnographic data have been used to clarify prehispanic beliefs, although again caution is needed when extrapolating meanings from the present to the past across centuries marked by the disruption of colonization and the influence of Christianity (Note 5).

Note 3: Did the Ancient Mesoamericans Believe in Gods?

The sixteenth century missionary friars who recorded accounts of Mesoamerican religions for the ultimate aim of destroying them, imposed preconceived frameworks derived from the classical Mediterranean and Judeo-Christian traditions onto the alien belief systems they sought to understand. Faced with images and stories of a myriad of supernatural forces, the colonial writers classified these mythic entities along the lines of the Greco-Roman pantheon of deities, each a discrete being with clearly distinguished personality, function, and symbols. The limits of this approach led to strange contradictions from the start. For example, the mercurial Aztec deity Tezcatlipoca, associated with both kingship and sorcery, was equated by the Spanish chroniclers with both Jupiter and Lucifer. However, the Eurocentric assumptions behind such taxonomies remained unquestioned until well into the twentieth century (Fig. 12).

In the 1970s, a number of scholars began to argue from closer reading of colonial sources as well as the results of archaeological, ethnographic and art historical research, that the Aztec, Maya, and Zapotec peoples had no conception of separate and distinct gods. Rather, what the Spaniards erroneously interpreted as a well-defined pantheon was in fact a series of overlapping symbolic complexes, representing natural phenomena conceived as protean and fluxing manifestations of a generalized notion of holiness or sacred force. The words employed for this dynamic concept – *teotl* in Nahuatl, *ku* in Maya, and *pee* in Zapotec – had been translated as "gods" by the Spanish.

Some modern writers – most notably the American anthropologist Joyce Marcus – have argued the extreme conclusion that ancient Mesoamericans had no gods at all, just symbols of natural phenomena and venerated ancestors. This interpretation in its strictest sense certainly applies to some alleged "deities." The Maya icon designated "God C" by the nineteenth century scholar Schellhas in his attempt to classify the supernatural images in Maya codices is now generally accepted by epigraphers and art historians to denote a general quality of holiness rather than a specific divine personality. On the other hand, it seems clear from recent hieroglyphic decipherments that the Classic Maya did believe in a series of relatively separate gods whose

Cosmology in Mesoamerica. Fig. 12 Tezcatlipoca, reconstruction of MS painting from the *Codex Borgia*, p 17, Mixteca-Puebla Style, Puebla/Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia: A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Used by permission of Alan Rodgers.

acts are recorded in texts and whose distinctive emblems appear in art. While more fluid and dynamic in their identities than the denizens of Olympus, these entities can be usefully conceptualized as gods, a view argued by the American anthropologist and iconographer Karl Taube, among others.

Note 4: Mesoamerican Screenfold Books

At the same time as they were creating one source of evidence for prehispanic Mesoamerican cosmologies via their writings, the Catholic missionaries of the Spanish Conquest were busy destroying another – the screenfold books of the indigenous peoples. These fragile testimonies to Native American thought were burnt as symbols of the "heathenism" or "diabolism" that the friars sought to replace with forced conversion to Christianity. As a result of this holocaust of texts, very few of these manuscripts have survived to receive the attention of modern anthropological, epigraphic, and art historical study.

Mesoamerican folded manuscripts, often referred to in the literature by the Eurocentric term "codices," consisted of long sheets of beaten bark paper or (in the Mixtec area) deer skin. Narrative scenes, deity images, and glyphs were painted, usually in polychrome, on a thin outer surface of plaster. The paper was folded like an accordion, dividing it into "pages" or "folios." The resultant manuscript was "opened" by unfolding it.

No prehispanic Aztec painted books survived the depredations of the colonial clergy. A manuscript illustrating Aztec deities and calendrical practices, the Codex Borbonicus, was once thought to represent such a miraculous survival, but art historical data now suggest a date early in the colonial period. From this transitional epoch, we have several manuscripts, in both screenfold and European bound formats, commissioned and annotated by Spanish officials and missionaries but painted by Aztec artists. Frequently, the style is a fusion of pre-Conquest traditions with varying admixtures of the visual language of European Renaissance art. Some of these books preserve Aztec myths and calendric information, albeit incompletely.

A group of screenfold manuscripts of late prehispanic (Late Postclassic) date have been labeled the Borgia Group because of their stylistic affinities with the best-known example, the Codex Borgia. These manuscripts appear to have been collected at the time of the Conquest and to have found their ways by often untraceable routes into famous European collections, hence their names. In the opinion of the majority of art historians and anthropologists, this group was painted in the present-day Mexican states of Puebla and Tlaxcala, though a small scholarly contingent still suggests a Mixtec origin. They are frequently labeled as "Aztec" in the popular literature. If the dominant theory is correct, the artists who created these works spoke the same language as the Aztecs (Nahuatl) but were politically and ethnically distinct. The Tlaxcalans, in particular, were the traditional enemies of the Aztecs and assisted Cortes in his destruction of Aztec power. The manuscripts of the Borgia Group seem to have been guides for a divination system based on the 260-day ritual calendar, also containing prescriptive representations of other rituals, astronomical information, and narrative scenes of mythic events in a distinct style characterized by bright, flat colors, bold outlines, and cartoon-like exaggerations of distinguishing features and costume elements. Their symbolic maps of the universe – like the frontispiece of the *Codex Fejervary-Meyer* reproduced here – constitute excellent graphic evidence for ancient Nahuatl cosmology.

Another group of screenfold manuscripts collected during the Spanish invasion and scattered through European collections was produced by the Mixtec in what is now the Mexican state of Oaxaca. Although the style has similarities to that of the Borgia group, the content consists mostly of historical and genealogical narratives documenting the deeds and land claims of elite families. The most famous of these manuscripts is the *Codex Zouche-Nuttall*, which chronicles in pictorial form the exploits of the eleventh century Mixtec king Eight Deer. All date from the last centuries before the arrival of Europeans. Although their emphasis is not on ritual or calendrics, images of origin myths and deities contribute to our knowledge of Mixtec cosmology.

All of these Central Mexican manuscripts include glyphs of names and dates in the 260-day calendar, rebus writing and symbols for geographic locales, but only the Maya painted books contain phonetic texts. Three examples escaped the friars' fires in the sixteenth century to appear in Europe: the *Dresden Codex*, the *Madrid Codex*, and the *Paris Codex*, named after their present-day locations. These books appear to have been painted shortly before the Conquest in Yucatan. A fourth book appeared in 1973, with claims that it had been discovered by looters in a dry cave in the Mexican state of Tabasco. Although it was rejected in some circles as a fraud at the time, subsequent radiocarbon tests indicate an age in the twelfth to thirteenth century CE, and the Venus tables it contains reflect Maya concepts that were not rediscovered until several years after the book's appearance. Contemporary consensus therefore holds it to be genuine. All of these Maya books contain tables of observations for predicting eclipses and the movements of celestial objects like Venus, almanacs for agriculture, and guides to ritual performance. Like the Borgia Group, they were once the property of indigenous priests.

Note 5: Maya Myths in Historic Manuscripts

In the centuries following the Spanish Conquest, some indigenous myths, including much information on cosmology, were preserved by being recorded in Latin script by Native writers. In Yucatan, several versions survive of the *Book of Chilam Balam*, or Jaguar Priest. These variations of the text are titled after the town that was each one's origin. The most famous example of these was composed in the town of Chumayel. These contain oral historical traditions, astrology, ritual practices, and prophecies tied to the cycles of time in the Maya calendar. Some of this material appears to be of prehispanic origin and is a valuable source for understanding the world view of pre-Columbian Yucatan. However, it is also clear that events from colonial history and the Judeo-Christian tradition also figure in the *Books of Chilam Balam*, suggesting the need for caution in using their contents uncritically as a basis for understanding pre-Christian beliefs.

In the southern highlands of Guatemala, an epic poem of the Quiche Maya, the *Popol Vuh* or "book of the mat" (mats were a symbol of rulership in ancient Mesoamerica), was apparently written down in Latin script by a Spanish-schooled Maya shortly after the Spanish Conquest. No original of this early version has been preserved, but copies were transcribed into the mid-nineteenth century when they came to the attention of European scholars. Like the *Books of Chilam Balam*, the *Popol Vuh* seems to contain a considerable amount of prehispanic material, drawn both from oral tradition and screenfold manuscripts, though here, too, Catholicism and colonialism have made their mark upon the contents. The *Popol Vuh* is a history of the Quiche people incorporating a version of the Maya myth of the previous creations and destructions of the universe. Perhaps the most well-known section is the saga of the Hero Twins, Hunahpu, and Xbalanque, whose adventures intertwine with and set the stage for the last creation of the cosmos and man.

Recent studies in Maya epigraphy and iconography have demonstrated that aspects of the *Popol Vuh* – especially the Hero Twins epic – represent survivals of Maya myths dating back to the Classic period and probably earlier. The Hero Twins' legendary battles with the gods of the underworld recur in Classic Maya vase painting, and contribute to the trappings and ideology of Classic Maya kingship. The art historical and hieroglyphic material has in turn begun to permit the reconstruction of sections of the Classic version of the myth that did not survive to be incorporated in the colonial text. The identification of the father of the Hero Twins with the Maya maize god, his role in the creation of the world, and further details of the twins' defeat of the lords of death have emerged from Classic scenes and texts. The case of the *Popol Vuh* is one instance where post-Conquest materials have been fruitfully used to increase our understanding of pre-Columbian beliefs and symbols.

Note 6: Olmec Cosmology

According to the theories of Joralemon (1996), based on his readings of Olmec iconography, the Olmec lived in a shamanic, multilevel mental universe akin to that of their Maya successors. In his view, the earth was pictured as a crocodilian Earth Dragon floating in a primordial sea. Mountains were its scutes, and vegetation sprouted from its back. Mountains may have been viewed as containing water as in later myths – certainly archaeology shows that the Olmec venerated mountains and springs. The sky was represented by a Bird Monster, and the ocean under the earth by the shark-like Fish Monster. As in Maya belief, this watery underworld was the home of ancestral spirits. According to Joralemon and other scholars like Reilly (1996), carvings of rulers seated in jaguar or serpent mouths are shaman-kings accessing portals to the underworld (Reilly) or the upper world (according to Karl Taube) through trance and ritual. The site of La Venta is now interpreted, along Maya lines, as a cosmogonic center, recreating the creation and structure of the cosmos through its architecture, buried offerings, and associated rituals. A stone mosaic intentionally buried there has been read as an image of a jaguar, associated with the underworld via later Aztec and Maya myths; or as the saurian earth monster on the surface of the sea. Serpentine (greenstone) pavements from the same center have been interpreted as representations of the blue–green watery underworld itself. A massive pyramid, forerunner of later temple platforms throughout Mesoamerica, is equated with the primeval "Snake Mountain" which emerged from watery chaos at the creation of the world in later cosmogonies. Schele (1996) has interpreted Olmec art as reflecting belief in a world tree, the bridge between levels of the cosmos, equated as among the Maya with the person of the ruler. These interpretations, which seek to demonstrate continuity between Olmec and later cosmologies, are widely accepted, but not without critics who call assumptions of such continuity in beliefs over several millennia into question (Fig. 13).

Cosmology in Mesoamerica. Fig. 13 This inscribed greenstone celt from Rio Pesquero, Mexico, depicts an Olmec ruler symbolically equated with the *axis mundi*. His legs form the head of a serpent, and he holds another in his arms. The four-stylized corn plants represent the four directions. The ruler occupies the center, representing the mediating vertical axis of the universe which, like the king himself in his role as shaman, provides humans access to the supernatural worlds above and below the earth. This interpretation is by Linda Schele and F. Kent Reilly and is based in part on later Maya iconography (Middle Formative, ca. 900–400 BCE). Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan).

Note 7: The Maya Hero Twins

The myth of the Hero Twins Hunahpu and Xbalanque from the *Popol Vuh* is intertwined with the Maya creation myth. Its action is set during the transition between the end of the third creation and the inception of the fourth. Recent discoveries from epigraphy and art history reveal that the Classic version of this myth was even more explicitly tied to the story of the making of the fourth world.

The saga begins with a first set of brothers, Hun Hunahpu and Seven Hunahpu. During the Classic period, Hun Hunahpu was identified as the Maize God, and his death and rebirth in the narrative were associated with the cyclical growth of corn. This first pair were avid players of the traditional Mesoamerican rubber ball game, known in the archaeological record from Olmec times, played by the Aztec and Maya at the time of European contact, and still practiced today in parts of rural Western Mexico. Unfortunately, the noise created by the brothers' favorite pastime irritated the ruling gods of Xibalba, who summoned them to the underworld and challenged them to a ball game where the stakes were life or death. Because of the supernatural powers and trickery of the lords of Xibalba, Hun Hunahpu and his brother were rapidly defeated and executed. Their bodies were buried but Hun Hunahpu's head was hung up on a tree for display. As befitting a maize god, its presence made the formerly barren tree sprout an abundance of fruit, identified with the calabash in the *Popol Vuh*, but apparently with cacao (chocolate) in some Classic Maya vase paintings.

One of the daughters of a lord of the underworld, Blood Moon, visited the tree out of curiosity at its sudden fertility. The skull of Hun Hunahpu hanging there spit into her palm, magically impregnating her. When her father learned of her pregnancy, he attempted to have her murdered, but she fled Xibalba to the middle world where she gave birth to Hunahpu and Xbalanque.

As youths, these twin boys distinguished themselves by a number of exploits. They defeated the bird monster Seven Macaw, who falsely proclaimed himself to be the sun. This usurper seems to have been equated in the Classic period with Mut-Itzamna, the Celestial Bird shown perched atop the world tree. The vanquishing of this false sun seems to coincide with the destruction of the last creation. The twins also conquered Seven Macaw's son, the crocodilian Zipacna.

Eventually Hunahpu and Xbalanque discovered the ball game equipment of their father and took up the sport with great energy. Their noise eventually also reached the Lords of Xibalba, who summoned them to a challenge like that which their father and uncle had failed to master. Unlike the first brothers, the Hero Twins rose to the occasion, outwitting the ordeals and tricks of the gods of the underworld with clever strategies and magical powers of their own. In the last and most spectacular of these supernatural feats, the Hero Twins followed the advice of a diviner and submitted to execution. Their bodies were burned and their ashes cast into the waters of Xibalba. The rulers of the underworld believed they had defeated these troublemakers as decidedly as they had beaten their father.

But Hunahpu and Xbalanque were reborn, appearing first as catfish and then disguised as itinerant magicians. They performed a magic trick in which they killed each other and then magically restored the other to life. Hearing of this spectacle, the lords of Xibalba were intrigued and summon the performers to demonstrate this wonder. Having seen this miraculous resurrection, the underworld gods are so enthusiastic that they demand to be used as volunteers for the trick. Predictably, the twins kill the lords of death as requested, but do not bring them back to life.

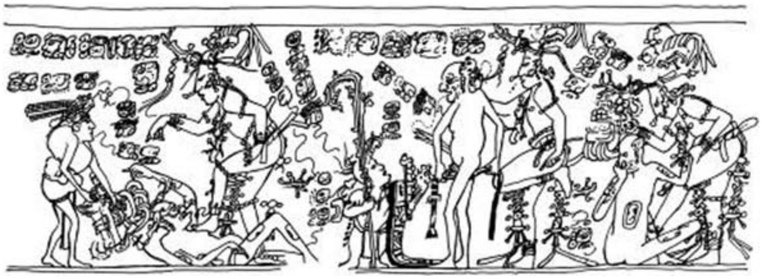
In the *Popol Vuh*, the twins attempt to raise their father and uncle from death, but are only partially successful, and cannot bring them back to the land of the living. The iconographic and inscriptional evidence from the Classic period provides an alternative ending. After defeating the lords of death, apparently with the connivance of the moon goddess and her rabbit, they succeed in resurrecting the Maize God, who is shown in several painted scenes as emerging from the body of a turtle representing the earth. The Maize God then acts as the demiurge of the most recent creation, separating earth from sky, raising the world tree, setting up three hearthstones (the traditional number in Maya houses) at the center of the universe, and erecting the vault of the heavens. In the Classic scenes and texts, the chief of the underworld gods is God L, an elderly deity associated with wealth and the profession of merchant. He appears not to have been sacrificed but humiliated and forced to pay tribute to the gods of the sky (Figs. 14 and 15).

Cosmology in Mesoamerica. Fig. 14 Resurrection of the Maize God. This scene from a Classic Maya (600–900 CE) painted ceramic vessel shows the resurrection of the Maize God, pictured emerging from a cleft in the carapace of a turtle representing the earth. He is attended by his sons, the Hero Twins. The skull at the base of the cleft represents the head of the Maize God, decapitated following his defeat by the rulers of Xibalba. As corn sprouts from seeds, so human bones were viewed by the Maya as the seeds of eventual rebirth in the afterlife, following the pattern set by the Maize God's story. Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan).

The Hero Twins have been equated with the sun and moon, and the first brothers with Venus in its twin guises as Morning Star and Evening Star. In both versions of the myth, the victory of the Hero Twins limits the power of death in the world and points the way toward the hope of rebirth. Like the first brothers, the Maya elite were believed to descend to the underworld after death, but they hoped to be reborn as were both the Hero Twins and the Maize God, and to ascend triumphantly to the celestial world like the latter following his resurrection. Like the Christian myth in Europe, the story of the Hero Twins was the template for tomb art and funeral practices among the kings of the Maya, a model for their anticipated conquest of death.

Note 8: A Nahua Cosmogram

The Codex Fejevary-Mayer is a painted manuscript belonging to the Borgia Group, manufactured probably



Cosmology in Mesoamerica. Fig. 15 This scene, painted in black line on a white background on a ceramic vessel of the Late Classic period, illustrates a section of the Classic version of the myth of the Hero Twins not found in the later *Popol Vuh*. Following his resurrection by the Twins, their father, the Maize God, is depicted triumphant over God L, chief of the Lords of the underworld. On the left, the Maize God is trampling his former persecutor, while in the scenes at center and right, the Lord of Death is stripped of his regalia by the victorious Maize God. The dwarf accompanying the Maize God represents the undeveloped or stunted ears of corn frequently found attached to complete examples. Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan).

in the Mexican states of Puebla and Tlaxcala in the century preceding the Spanish Conquest of 1521. The first image in this amazing pictorial document is a symbolic map of the cosmos organized around the four cardinal directions, complete with their associated divinities. This diagram, frequently reproduced in surveys of Mesoamerican art and religion, is a remarkable window onto the world view of the Nahuatl-speaking peoples of Central Mexico in the Late Postclassic period.

At the center of the diagram is the black world axis connecting the vertical layers of universe, represented by the fire god Xiuhtecuhtli. This deity spanned the three realms, and was thus equated with the *axis mundi*, as was his implement, the fire-drill. Streams of blood flow toward him from the four cardinal directions, representing the human sacrifices to sustain the gods. Each direction has its own associated tree, the pillars of the sky. As in most Mesoamerican maps and cosmograms, East is on top, with its patron deities Itzli (a personified sacrificial knife) and Tonatiuh, the sun god, its colors appropriately red and yellow. To the left is the North, ruled by Tepeyollotl, an aspect of the royal god Tezcatlipoca, and Tlaloc, the rain deity. North for the Nahuatl-speaking peoples was the direction where the difficult journey of souls to the afterlife began. Fittingly, its color is black. At the bottom is West, where the earth monster Tlaltecuhtli swallows the sun at sunset. The patron gods shown here are Chalchiutlicue, goddess of ground water, and Tlazelteotl, "eater of filth," a goddess of sin and confession. Its color is white. To the right is South, associated with blue and green. Here a cocoa tree accompanies the ruling deities of this direction, Mictlantecuhtli, the skeletal god of death and the underworld, and Centeotl, the goddess of mature corn. Between the arms of this cosmic cross are the four intercardinal directions: summer solstice sunrise, upper left; winter solstice sunrise, upper right; summer solstice sunset, lower left; and winter solstice sunset, lower right. The eight-lobed band around the world trees represents the 260-day ritual calendar. Like the other books of the Borgia Group, Fejevary-Meyer contains information for divining the future of individuals based on their birth date in the 260-day cycle. It probably belonged to a priest or oracle.

See also: ►Eclipses in Mesoamerica, ►Astronomy in Mesoamerica, ►Calendars in Mesoamerica

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Cotton Weaving in Ethiopia and Nubia

Michael Gervers

Archaeological material finds provide invaluable information about the nature and source of textiles and textile fibres in Nubia in the early Christian era. In the half century since Griffith and Crowfoot first identified cotton among the textile fragments excavated at Karanog and Meroe, much more cotton fabric has been retrieved from the rescue excavations of early habitation sites along the Nile subsequently inundated by Lake Nasser; i.e., between Aswan in Upper Egypt and Wadi Halfa in northern Sudan. The oldest fragments identified as cotton have been dated to the Roman period and may be as early as the first century AD. The great majority are attributable to the late Meroitic period, ca. 200–ca. 330 AD, at which time cotton appears to have been the most commonly available fabric. The following period, from ca. 330 to ca. 550 AD, sees a swift and remarkable change in the predominant textile fibre in the region. The use of cotton plummets and is replaced by animal fibre, largely camel's wool.

The quantity of cotton found in excavations of the Roman and late Meroitic periods has led many to conclude that the fibre reached Lower Nubia from the south, where it is thought to have been grown, since this area lies in the rain belt and could have provided the environment necessary for growth. However, no specific sites for cotton cultivation in Nubia and the Sudan at this period have been identified and in view of the chronology of the archaeological evidence, and of what is known of the political and economic situation and agricultural production of the period, there is good reason to suppose that vegetable fibres for textiles were not then grown in Nubia or even in the Sudan. Rather, the Nubians, lacking any such indigenous source of raw material, were obliged to import whatever they required either as cloth or raw fibre. These goods included linen, which, throughout much of the Middle Ages under the provisions of the *baqt* agreement, was one of the principal items received by the Nubians in exchange for slaves. The *baqt* was first formulated in the seventh century, by which time, in the absence of adequate supplies of cotton, the Nubians seem to have sought imported linen as an alternative. The cotton would have been *gossypium arboreum*, and its ultimate source would have been the west coast of India. How it reached Nubia is uncertain. It could have come via the eastern desert trade routes from such ports as Suakin on the Red Sea, or via the kingdom of Axum, which by 300 AD. enjoyed a thriving trade with India. The costs and difficulties of overland transport, however, make it more likely that cotton reached Nubia through the Roman world to the north via the Nile. Since the archaeological cotton remains from Nubia were not made from locally grown fibres, there can be little question of cotton reaching Ethiopia from the Sudan. One early reference which is universally accepted speaks of the direct importation to the Red Sea Axumite port of Adulis of cotton from India in the first century AD. The first indication we have of the production of fine cotton cloth in Abyssinia occurs at the end of the thirteenth century in the commentary of Polo: "Good cotton and buckram cloths are woven here". If his source for the supply is accurate, one can reasonably conclude that by that time cotton cultivation and weaving was well established in the highlands.

Textiles, especially imported, have always been an expensive commodity. Their distribution through the ranks of a society depends directly on the geographical diffusion of the raw material, the quantities produced and the availability of mechanisms to spin and weave it into cloth. An Egyptian source for cotton grown in India would explain why a blue and white cotton tapestry decorated with Egyptian symbols was among the Meroitic finds from Qasr Ibrim. It would also explain why the cotton, if imported raw from India and locally spun, would appear different in texture from contemporaneous cotton cloth of Indian origin discovered at Palmyra. Cotton cloth woven in the humid atmosphere of India could be much finer than that produced in the arid climate of Egypt or Upper Nubia. The latter, if woven on the warp-weighted loom, as is supposed, would have to be much thicker and coarser to prevent it from breaking under the stress of the weights. Consequently, it would have appeared softer than the material from Palmyra and more like wool. When cotton became less available from the fourth century and was replaced by wool, the warp-weighted loom would have been all the more appropriate for weaving it. Weaving in Ethiopia today is carried out almost entirely on a pit-treadle loom, whose treadles are suspended in a hole in the ground. The weaver sits at the edge of the pit with his legs inside so that his feet can operate the treadles. The origin of this loom in Ethiopia is uncertain, although numerous writers have noted how closely it parallels the Hindu loom, and some suggest that the technology is the result of direct importation from the Indian subcontinent. Endrei believes this loom originated in India for the purpose of cotton weaving. The specific characteristics of the Abyssinian loom, according to Boser, are its sturdy frame, the width of the comb and consequently of the cloth produced, and the depth of the pit. Boser goes on to say that regardless of how this loom got to Abyssinia, it did not spread thence to other parts of Africa. It did not spread, until recent times at least, even to southern and western Ethiopia. A close relative is the warp-weighted pit loom which is found frequently in Persia, Syria and Egypt where it was, and is, used particularly for weaving woollen, and in Egypt at any rate for weaving linen thread. It does not seem to be appropriate for weaving with a cotton warp as the strain placed by the weights on the thread would cause it to break. This restriction would explain the absence of the warp-weighted loom in Ethiopia, where cotton is by far the principal fibre used for weaving today. The technical association of the Ethiopian loom with cotton would also argue in favour of a common development, if not introduction, of cotton growing and weaving to the Abyssinian highlands.

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Crops in Pre-Columbian America

MURDO J. MACLEOD

Before the European invasion of the Americas, the native peoples harvested a large variety of crops under many types of agricultural and gathering regimes.

Dense concentrations of people had existed for centuries in Mesoamerica and Andean America, and had evolved complex societies of agricultural peasantry and stratified urban elites. These peoples, in fact most Native Americans, had selected and adopted a miracle grass, maize (*Zea mays*), which reached yields of over one hundred to one in regions of good soils, intensive irrigation, and monoculture such as the *chinampas* or "floating gardens" of the central valley of Mexico. These high yields led to maize dominance in many diets, and the societies which evolved around this cereal may have resembled those of paddy rice China, which had highly intensified, quasigardening systems, rather than those of Europe or Africa, which had lower yielding but more diversified systems associated with wheat, barley, millet, and sorghum.

Maize was often associated, especially in Mesoamerica, with various varieties of American beans, especially *frijoles* of the genus *Phaseolus*, which climbed the maize stalks; with squashes (*Cucurbitae*) and their relatives; and with chili peppers (*Capsicum*), often planted between the maize stalks. The insufficiencies of this basic diet led to heavy foraging and to the harvesting of unoccupied areas and forests. In fact, even in settled societies there appears to have been a harvesting continuum from irrigated maize gardens to collecting, often in forests which were themselves results of centuries of human selection and propagation. Thus, the modern student finds, paradoxically, intensive monoculture, plus slash and burn, plus areas of great biodiversity, all used by the same population.

Tubers of many kinds were widely cultivated but were somewhat more geographically restricted than the maize, beans, squash, and chili complex. Yams (genus *Dioscorea*), cassavas, or maniocs (*Euphorbiacae*), some of highland origin, were intensely planted, and eaten after conversion to flours and breads, in tropical zones such as the Caribbean and the Amazon Basin. In many such regions, cassava was the staple diet. Musae (bananas and plantains) also appear to have been or become a staple in parts of the tropical lowlands, but scholars dispute their origin, some claiming that they are not native to the Americas.

In the Andes, tubers were also of great importance. Varieties of potatoes (*Solanum*) have been cultivated there for about 8,000 years, selected by humans for the many microenvironments of the mountain tropics. Andean farmers sometimes plant as many as 200 varieties in a single field, although most are being phased out in favor of the modern selected potatoes. Several other tubers were cultivated in highland America, such as *achira* (*Canna edulis*); *arracacha* (*Arracacia xanthorrhiza*); *jicama* (*Pachyrhizus erosus*); *machua* (*Tropaeolum tuberosum*); *ova* (*Oxalis tuberosa*); and *ulloco* (*Ullucus tuberosus*), still a staple in parts of the Andes. This area also produced tubers and grains which could be grown at great altitudes in poor climatic and soil conditions. Maca (*Lepidium meyenii*), a tuber, can be grown just below the snowline, as can *kaniwa* (*Chenopodium pallidicanle*), and the better known quinoa (*Chenopodium quinoa*), both cereal grains rich in proteins and other nutrients.

Several other crops in America were traded widely before the European arrival. Cacao (*Theobroma cacao*), probably of Amazon origin, was known in the regions today called coastal Ecuador and Venezuela, but it was in Mesoamerica that cacao reached its greatest prominence. Planted along the Pacific coast from Colima to El Salvador, and in parts of Honduras, Tabasco, and Veracruz, cacao was important in trade, tribute, and ritual. In some parts of the region it was used as coinage, and there are also reports that in some states its consumption was limited to the aristocracy. Tobacco (*Nicotiana tabacum*) was somewhat different. Although traded in many regions of America, its use may have been limited to ceremonial occasions.

Mesoamerica also produced vegetable and insect dyes, especially blues from indigo (*Indigofera tinctoria*) and reds from cochineal (*Opuntia cochinellifera*). Both items were traded, paid over as tribute, and used for ceremonial purposes. American cotton and thread from cactus were parts of textile trades and tribute.

European invasion and its consequences had widespread effects on American crops and their diffusion. The catastrophic fall of the native population and the introduction of large- and medium-sized domesticated animals, such as horses, cattle, sheep, goats, and pigs, caused abandonment of fields, destruction of crops, and the disappearance of many forms of ground cover. European need for wood for construction, shipbuilding, and fuel led to the cutting down of forests and the crops harvested in them. Colonial demands for uniformity in taxation caused peasants to give up the growing of marginal cultigens, or ones unfamiliar, distasteful, or useless to the dominant culture. The introduction of animals, and of plants such as wheat, citrus trees, and sugarcane, all cultural preferences of Europe, took up agricultural lands, and drove out native species.

Many scholars have stressed the more positive side of these intrusions and exchanges. Introduced crops such as wheat and animals such as cattle transformed the American diet, and the vast quantities of wheat grown on the prairies of the United States and Canada, and on the Pampas of Argentina, have fed large numbers of people in many parts of the world.

The more positive view also emphasizes the diffusion of American plants throughout the world, while admitting that the impact of some of these exports has been noxious (tobacco) or ambivalent. The potato, for example, the introduction of which to northwestern Europe met some resistance at first, was blamed by some for the Irish famine. Its high yields and ease of cultivation led to a monoculture, rapid population growth, then famine and mass emigration – ironically to the Americas – when the potato crop failed. The advantages brought, nevertheless, by this productive, nutritious, human selection to the everyday diet of peoples living in the temperate zones are, of course, immense.

Some American crops, while having a generally beneficial impact when exported, had their "booms" modified or cut short by new technologies or crops. The two great American dyes, indigo and cochineal, after enjoying a century or two of flourishing trade, were destroyed by the invention of aniline dyes in the mid-nineteenth century. Sugarcane, not originally an American plant, nevertheless achieved great importance only when exported to the Americas. Plantation sugar, always prized by Europe but historically in short supply because of poor access to tropical areas and labor, boomed when northeast Brazil and the colonial islands of the Caribbean combined tropical climates, African slavery, intensified production, and reasonably close markets, and began to export huge shipments. Sugarcane transformed much of the world's diet, and was an important fuel for the industrial and commercial revolutions of the nineteenth century. Although it continued to be of importance its monopoly was destroyed by the rise of beet sugar.

There can be little doubt, however, about the continuing beneficial impact of the diffusion beyond the Americas of many of the native crops. Maize, with rice one of the world's two "miracle" cereals as far as yields are concerned, has spread, now largely as a hybrid, throughout the world, and its productivity has increased since the "Green Revolution." It has become a staple in parts of the Mediterranean, the Balkans, Africa, and South Asia, and continues to be the largest food item for the masses in many parts of Latin America.

Some American crops required modification or additions before their use expanded. Cacao did not suit European tastes when first encountered; indeed it was repugnant to many, until people learned to add sugar and vanilla. After Swiss and Dutch houses learned the process of making milk chocolate, cacao became an item of world diet, and West Africa is the main producer today.

Indeed, so pervasive today are some of the high-yielding American crops that their pre-Columbian American origins have been forgotten by the general public. Indian curry and Hungarian paprika, both based on American chili peppers, Italian tomato sauce, Irish potatoes, West Africa *ogi* and *kenkey* (maize doughs), and Swahili *posho* (maize meal), Turkish tobacco, and Swiss chocolate, are now thought of as age-old, integrated parts of regional and national cultures far from the Americas.

See also: ►Potato, ►Agriculture, ►Food Technology, ►Sugar

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Cuneiform

Carol F. Justus

Cuneiform was the script used throughout the Ancient Near East from the fourth to the first millennium BCE. Although a hieroglyphic script came to predominate very early in Egypt, the international second millennium correspondence of the Egyptian Sun King, Iknaton, used the cuneiform script. In the last millennium BCE Mesopotamian art depicts a set of scribes, one writing with a stylus on clay tablets, another on parchment. This later overlap between the use of parchment and clay as writing material foreshadowed the demise of cuneiform, the script by means of which literacy as a technological advance spread throughout the ancient world from early Mesopotamian sites such as Uruk in the lower Euphrates River Valley and Susa in what is now Iran.

The Script Form

Cuneiform (from Latin *cuneus* "wedge"; cf. German *Keilschrift* "wedge-script") is so named because of the wedge-shaped signs which make up the characters of the script. A reed stylus created these signs that resemble the head of a nail. Pressing one corner of the stylus into the damp clay of the tablet made a *Winkelhaken* or corner wedge (𒌋). This corner wedge could be elaborated by adding a vertical (𒁹) or horizontal tail (𒀸), or by tilting the tail at an angle. These basic shapes combine to produce the more than 700 signs of the cuneiform writing system. Cuneiform signs are read left to right, as are western European alphabetic symbols.

Alphabets used to write modern Western languages reduce those languages to writing on the principle of one sound to one written symbol. The principle underlying the cuneiform system was by no means so simple. A single sign might have phonetic or logographic values. A corner wedge alone could, as a syllabic unit, represent the syllable sound of "u" as in "U-gan-da" or, as a logogram, refer to the word for the numeral "ten". Two raised corner wedges combined with a vertical wedge (𒌓) form the phonetic syllable "ud" which also had the logographic meaning "day". While vowel sounds had a one-to-one correspondence with a sign as in "a, i, u": "a" (𒀀), "i" (𒄿), and "u" (𒌋), there were no signs for consonants such as "p", "t", "k", or "m". Cuneiform signs had phonetic values as syllables, so there were signs instead for "pa, ta, ka, ma, pi, ti, ki, mi" and so on. But a sign also had a logographic value as in the case of *ud* "day". This logographic–syllabic principle underlying the cuneiform script, unlike that underlying an alphabet, used signs to refer either to entire words (logograms) or to phonetic (syllabic) units.

The syllable sign "ud" is typical of signs that refer to vowel plus consonant sequences. Cuneiform also had syllabic signs for consonant–vowel sequences, e.g. (𒁲) "di", (𒄀) "gi", or (𒉌) "ni", and, less frequently, for consonant–vowel–consonant sequences: (𒋻) "tar" or (𒆳) "kur" (Table 1).

This system of writing thus easily recorded a language with consonant–vowel sound patterns and consonant clusters in the middle of a word, but not words which begin or end with consonant clusters like "st", or "sk" as in English "stop, skate, nest" or "desk".

Cuneiform. Table 1 Cuneiform signs and their sign list keys (cf. Borger or Labat)

Numerical key	Usual value	Sign shape
411	u	𒌋
480	dish	𒁹
1	ash	𒀸
381	ud	𒌓
579	a	𒀀
142	i	𒄿
457	di	𒁲
85	gi	𒄀
231	ni	𒉌
12	tar	𒋻
366	kur	𒆳
597	NINDA	𒃻
13	an	𒀭
533	mesh	𒈨𒌍, 𒈨

While cuneiform syllabic signs often represented speech sounds, the same sign might also have non-phonetic uses as well. In addition to syllabic (phonetic) uses, signs might function as determinatives as well as logograms. As a determinative, a cuneiform sign preceded (or followed) one or more sets of signs without any phonetic value. The non-phonetic determinative merely signaled to the reader that a word in question was of a particular semantic type. Typically, the determinative for "female" preceded a woman's name, the determinative for "male" a man's, or the determinative for "deity" the name of a god or goddess. Used as a logogram, as noted, a cuneiform sign stood for an entire word. Thus, either the single sign (𒃻) or the syllabic sequence *ni-in-da* might stand for Sumerian "bread". Likewise, "deity" might be written logographically in a Sumerian text using the "an" sign (nr. 13) or syllabically with the sequence *di-in-gi-ir*. Such dual mechanisms illustrate not only the relation between logographic and phonetic representation of words but also something of the syllabic structure of the Sumerian language which had word-medial (*-nd-* and *-ng-* in *ninda* and *dingir*) but not word-initial or word-final consonant clusters.

Scribes often used signs logographically for the lexical content of common words and syllabically for grammatical markings such as the possessive of a noun. Thus, "of god" in Sumerian might be written phonetically as *di-in-gi-ir-ra* (*dingir* plus the possessive suffix *a*) or logographically with the "god" sign plus the syllabic sign, *-ra*. Transliteration conventions using the Roman alphabet distinguish among determinative, logographic, or syllabic uses of cuneiform signs on a tablet by using lower case, upper case, and raised letters. Signs used phonetically are transliterated with lower case letters; signs used logographically but interpretable on the basis of a Sumerian word are transliterated using capital letters for the Sumerian word form. The Sumerian scribe's writing of the logogram for "god" plus syllabic *-ra* would thus be transliterated DINGIR-*ra* to distinguish it from a scribe's entirely syllabic rendition, *di-in-gi-ir-ra*.

Determinatives are transliterated as raised sequences, either before or after the "determined" word. Characteristically the plural determinative follows, while others often precede. Thus, "gods", written with the logogram for "god" (𒀭) plus a plural determinative whose Sumerian phonetic value was "mesh" (𒈨𒌍), might be transliterated in Roman letters DINGIR$^{\text{MESH}}$ and translated "gods". Similarly, the Sumerian sun god, Utu, would begin with the determinative for "deity" (𒀭) and continue with the name, Utu, written syllabically $^{\text{DINGIR}}$U-tu. However, the sun god's name was usually written logographically using the logogram for "day", $^{\text{DINGIR}}$UD (𒀭.𒌓), transliterated $^{\text{DINGIR}}$UTU (Sungod). To bring the use of cuneiform signs full circle, one might recall that the "god" sign (𒀭), besides its logographic reference to the Sumerian word, *dingir* "god", also had a syllabic reading, *an*. For a scribe, the same sign thus had multiple values. The sign (𒀭) had a phonetic (syllabic) value *an*, a logographic value "god" (Sumerian DINGIR), and a non-phonetic use as the determinative for "deity" to which modern scholars assign the phonetic value, *dingir*, for purposes of transcription.

Like determinatives, which had no phonetic counterpart in the speech represented by cuneiform signs, horizontal lines were often drawn across the tablet as a kind of punctuation aid. Because the structure of the languages written in the cuneiform script was very different from English, punctuation principles might also be expected to vary. In fact the scribes' horizontal lines across the tablet probably marked something corresponding in part to our sentences and partly to our paragraphs. These scribal lines occur from earliest Sumerian tablets down through adaptations of cuneiform to write Semitic and Indo-European languages.

Languages Written in Cuneiform

Questions about the range of sounds that written symbols might need to distinguish, and indeed which units of language should be represented by individual signs, have concerned linguists seeking to reduce languages to writing. Western European languages often solved these problems by borrowing the Roman alphabet. Cultures of the Ancient Near East borrowed the cuneiform script, as the alphabet did not yet exist in the third millennium BCE. Cuneiform scribes thus dealt with issues of defining the linguistic units to be represented by altering a system of cuneiform signs already in use to write Sumerian. Scribes in fact used the cuneiform script to write languages that differed from Sumerian. They then had to adapt the script to fit the needs of the languages they spoke. The words of some of the languages had long series of suffixes, for example, while others used word-internal vowel changes much as English does in "sing, sang, sung" or "stand, stood", and Indo-European languages had word-initial and word-final consonant clusters.

A major adaptation of cuneiform was for the East Semitic Akkadian that served as the basis for the spread of cuneiform throughout much of the Near East. Besides Old Akkadian, which had its own conventions for phonetic representations using the cuneiform script, major East Semitic languages include the Old Babylonian in which the southern Mesopotamian Code of Hammurapi was written and Old Assyrian, which records the northern merchant trade between Assur and Anatolian Kanesh (near modern Kayseri, Turkey) even before the time of Hammurapi. Babylonian and Assyrian continue in ever-changing regional forms for nearly 2000 years as Middle Babylonian, Middle Assyrian, Neo-Babylonian, and Neo-Assyrian. To the east of Mesopotamia the ancient language of Susa, Elamite, also used cuneiform, while Hurrians in Northern Mesopotamia, Syria, and Anatolia adapted cuneiform at different times to write their language. In second millennium Anatolia, the scribes of Hattusa used cuneiform to write Hittite, Luwian, and Palaic, Indo-European languages related to Greek, Latin, and the Germanic language family from which English is descended.

When scribes adapted cuneiform for use in writing other languages, some things changed more than others. While the signs often came to have peculiarly local values in different scribal schools, the most constant aspect of the cuneiform script was its core repertoire of determinatives and logograms. Where cuneiform was used, determinatives such as those for male, female, deity, land, and plural remained the same. Logograms for basic vocabulary, for god, ox, sheep, child, king, mountain, and river, also remained constant. The Akkadian scribe, for example, now had all the options available that the Sumerian scribe had, plus those that involved the phonetic representation of Akkadian. Akkadian nouns had three different forms depending on whether they were used as subject or object in the sentence, or as a possessive. The Akkadian word for "god" was thus *ilum* (nominative), *ilam* (accusative), or *ilim* (genitive), written as phonetic *i-lu-um, i-la-am, i-li-im* or logographic DINGIR-*lum*, DINGIR-*lam*, DINGIR-*lim* where syllabic signs differentiate case, or simply DINGIR, if the context was clear without the case ending.

When cuneiform spread via an Akkadian-based scribal school, scribal practices also spread. Thus, sign sequences were now often interpretable, not only on the basis of recognizing Sumerian, but also Akkadian, words. This created a further complication for scholars transliterating the tablets into a Roman alphabet. Instead of signs interpretable as Sumerian logograms (Sumerograms in capital letters), there are now signs interpretable as Akkadian logograms (Akkadograms) which scholars transliterate using italic capitals. Since the Hittites borrowed the script as a form of Akkadian cuneiform, Hittite scribes had still more options for writing "of god". While the Sumerian scribes wrote "of god" as phonetic *di-in-gi-ir-ra* or logographic DINGIR-*ra* and the Akkadian scribe used phonetic *i-li-im*, logographic DINGIR-*lim* or DINGIR-RA-*lim*, the Hittite scribe could write phonetic *si-u-ni-ya-as* (Hittite "god": nominative *sius*, genitive *siunias*), Sumerographic DINGIR-(RA), Akkadographic *I-LIM*, or some combination, DINGIR-(RA-)*LIM* or DINGIR-(RA-)*LIM-as*.

The Origin of the Cuneiform Script

The earliest attested use of cuneiform as a developed system of symbols to write a language was its use to write Sumerian ca. 3100. Modern Japanese, which has borrowed Chinese (logographic) kanji characters as a basis for reducing Japanese to writing, likewise uses syllabic symbols to augment logographic symbols. Because the Japanese syllabic symbols (*hiragana*) are an independent Japanese invention to adapt the Chinese script to a language structure for which the kanji characters were inadequate, scholars have hypothesized that Sumerian, with its logographic–syllabic script, represented an adaptation of an earlier "Proto-Tigridian" script of which we have no record, one used for a pre-Sumerian language of the Tigris river valley. Studies in the origin of writing, however, suggest that writing emerged as a new technology in what became the Sumerian city of Uruk.

The forerunners of the earliest cuneiform tablets were "impressed" tablets, tablets impressed first, not by the stylus which came to be used to write cuneiform, but by small clay artifacts known as tokens. The token-impressed tablets were economic documents recording amounts of various commodities that the society stored or transferred. Discrete symbols for commodities such as sheep, barley, or jugs of wine and oil were impressed on to the tablet. At first repetitions of the sheep symbol, for example, referred to the quantity of sheep in question and repetitions of the "oil jug" impression designated the quantity of oil. As the technology for writing and enumeration matured, forms became stylized to reflect changes in the thinking about the content. Concepts of quantity evolved separately from those for commodity, and both became increasingly abstract. What began as impressions of commodity signs and repetitions of the same sign to indicate quantities evolved as two sign types, "numerical signs" and pictographic signs, that developed independent logographic and syllabic values. "Numerical signs" were so-called before it was clear that their earliest forms did not stand for the abstract numeral values of today but only came to have numerical values as the "systems of numeration" evolved. Originally the 60 shapes of the "numerical signs" stood for values in a measure unit system that was specialized for a particular commodity or class of commodity. Sign values varied depending on the commodity quantified much as traditional measure units such as "foot", "inch", "bushel", "cup", and "quart" still do. While there are 12 in. in a foot and four cups to a quart, a "foot" does not have the abstract numerical value 12 nor quart the value four. Quantity values were also relational within the system for measuring commodities; they did not yet refer to abstract numerals.

Over time, the early accounting systems of the Sumerian city states that had used older systems of weights and measures with local values became standardized on the sexagesimal basis of factors six and ten. With further standardization on the base ten of the decimal system, the way was paved for the abstraction of number and the association of abstract numerical values with numeral words and signs. Calculation of amounts of commodities in terms of measure units and "numerical signs" replaced the older one-to-one calculation reflected in the early repetitions of impressed commodity symbols, and both are now mostly replaced by systems of abstract numerals. The specialization of script signs as "numerical signs" separate from commodity signs reflected an early stage in this evolution. In this respect, the evolution of cuneiform writing is inseparable from the evolution of early calculation and counting as the evolution of shapes took place as part of the evolution of the new meanings that motivated that evolution.

Commodity unit shapes developed independently of shapes for "numerical signs" when, instead of impressing the token into the clay, the scribe used a stylus to draw the shape of some tokens but continued to impress other shapes, some composite or with added lines. Drawn and impressed shapes that developed logographic and syllabic values became more and more abstract when the corner of a reed stylus came to create wedge-shaped cuneiform signs (http://www.utexas.edu/cola/centers/lc/numerals/numerals.html).

Over the millennia in which cuneiform was used, the shapes of the signs evolved from more pictographic forms to highly stylized symbols. Later Ugaritic use of wedge-shaped signs as an alphabet broke with the cuneiform tradition in assigning new values to sign forms.

Early Non-Cuneiform Scripts

The existence of other early scripts in the Ancient Near East attests to the rapid spread of literacy and numeracy. While Egyptian hieroglyphs are clearly independent script forms, the basis for reducing the early Egyptian language to writing is probably not independent of the new technology which arose in Mesopotamia as a response to economic and lifestyle changes involving the storage and transfer of surpluses of essential commodities. In the second millennium too a hieroglyphic script, Hieroglyphic Luwian (at first known as Hieroglyphic Hittite) developed independently in Anatolia and North Syria. This Luwian Hieroglyphic and the cuneiform script coexisted in different functions. The local hieroglyphic script recorded royal inscriptions in the Luwian language on stone monuments but cuneiform was the script of clay tablets. The fact that Hittite cuneiform tablets of Anatolia refer to "old wooden tablets" has led to speculation that hieroglyphic may have been inscribed into a wax coating on wooden tablets. Since none of these waxed wooden tablets has survived, such inferences, of course, remain speculative. The forms of the hieroglyphs are unrelated to the forms of cuneiform signs, but again the two scripts share a common conceptual basis for reducing language to writing. Hieroglyphic Luwian, like cuneiform and Egyptian hieroglyphics, is based on logographic–syllabic principles.

Decipherment

The cuneiform script was deciphered in the nineteenth century as a result of a trilingual inscription found at Behistun in Iran. The languages of the inscription were Elamite, Old Babylonian, and Old Persian, all written in a form of cuneiform. Both Elamite and Old Babylonian were unknown languages at the time, but Old Persian was known from Zoroastrian religious texts. The Old Persian inscription was first deciphered on the basis of hypotheses about the recurring symbols in Old Persian royal names. From there, hypotheses related the signs used to write the Old Persian with signs in the unknown scripts. Little by little, Old Babylonian and Elamite began to be deciphered. With the decipherment of the script came the decipherment and study of the different languages and cultures that used cuneiform to record their history and socio-economic structure. A not insignificant aid in the subsequent decipherment of Sumerian turned out to be the discovery of grammatical texts that Akkadian scribes had developed as pedagogical devices for teaching the learned language of the second millennium BCE, Sumerian, thereby training scribes to support the ever-growing bureaucracy of the ancient world.

Ongoing work on early cuneiform texts and their predecessors is now being catalogued as the Cuneiform Digital Library Initiative (CDLI: ►http://cdli.ucla.edu/).

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Dams and Irrigation in Ancient Arabia

Michael Harrower

Among the many scientific and technological accomplishments of ancient Arabia, dams and irrigation systems stand out as a remarkable testament to advanced skills in hydrological engineering. Arabia's ancient inhabitants developed sophisticated means of capturing and diverting water that not only involved detailed knowledge of water flows, but also required coordination of considerable labor for construction, operation, and maintenance. Although sometimes overshadowed by better-known Egyptian, Mesopotamian, and South Asian irrigation systems that supported some of the world's earliest and most influential civilizations, the remains of advanced water control systems have also been found throughout Arabia. Some of the ancient world's largest dams and most advanced flash-floodwater systems were constructed in Southwest Arabia (Yemen) during the late first millennium BCE. Southwest Arabian floodwater (spate) systems irrigated thousands of hectares and supported ancient states that gained wide recognition for trading aromatic tree resins including frankincense and myrrh to as far away as the Mediterranean. The tenth century AD geographer and historian al-Hamdānī was one of the earliest scholars to report on irrigation works of Southwest Arabia. In the eighth book of his treatise *al-Iklīl*, al-Hamdānī describes ancient monuments and briefly mentions a number of large dams, including the famous dam near Maʾrib, Yemen (Faris 1938 [945]: 34–35, 67–69). Ancient Southwest Arabian irrigation systems subsequently captured the attention of early western explorers, including Arnaud (1874) and Glaser (1913), and they remain a topic of considerable scholarly interest today (e.g., Brunner 1997a, b, 2000; Brunner and Haefner 1986; Darles 2000; Francaviglia 2000, 2002; Gentelle 1991; Ghaleb 1990; Hehmeyer 1989; Vogt 2004; Vogt et al. 2002).

The dam near Ma'rib (Yemen), capital of the ancient state of Saba, is one of the largest and most impressive examples of ancient floodwater irrigation (Fig. 1). Small-scale irrigation began in the region as early as the late fourth to early third millennium BCE (e.g., Ghaleb 1990) and by the first few centuries AD a dam 680 m long and 16 m high diverted water (via two massive sluices at it northern and southern extremities) to irrigate as much as 9,600 ha (Brunner 2000; Brunner and Haefner 1986). Interestingly, ancient Southwest Arabian state capitals such as Maʾrib developed not in relatively humid highlands where rainfall agriculture was possible, but along the margins of the Ramlat as-Sab'atayn Desert where irrigation farming required far more labor but could also dramatically boost agricultural production. Ancient Southwest Arabian kingdoms of Ma'īn, Awsān, Qatabān, and Hadramawt were part of an intricate network of trade and political relations and utilized analogous flash-floodwater irrigation technologies (Brunner 1997a, b; Francaviglia 2002; Gentelle 1991; Gentelle and Coque-Delhuille 1998). By the sixth century AD the power and influence of the Saba had dramatically waned. Damaged by powerful floodwaters the inhabitants of Maʾrib were unable to mobilize the labor necessary to repair the dam and agriculture continued at only a fraction of its former grandeur (Vogt 2004).

Many important questions surrounding the origins of irrigation in Arabia (including the degree to which local technologies developed independently or were inspired by developments elsewhere) remain largely unanswered. Unlike systems of Egypt, Mesopotamia, and South Asia that frequently diverted water from perennial flow rivers such as the Nile, Tigris, Euphrates, and Indus, irrigation systems of the Arabian Peninsula involved diversion of flash-floodwaters that typically occur only a few times a year, quickly appearing and disappearing in a matter of hours. Egypt and Mesopotamia are known to have some of the earliest and most extensive systems, and some scholars have thus speculated that diffusion from one or both of these regions was likely responsible for systems in Arabia (e.g., Bowen 1958). But if irrigation systems of Southwest Arabia did indeed diffuse from distant regions, dramatic modifications would have been required before they could operate amidst very different topographic, hydrological, and social circumstances. In Egypt and Mesopotamia, where a tremendous wealth of archaeological research has been conducted, a long history of alluvial deposition and land-use make

Dams and Irrigation in Ancient Arabia. Fig. 1 The massive south sluice of the ancient dam near Maʾrib, Yemen (photo by the author).

identifying the earliest irrigation and the precise techniques first involved a significant challenge (e.g., Wilkinson 2003). Although some of the world's first farmers experimented with water management in the Levant during the Neolithic, possibly as early as the seventh millennium BCE (Bar-Yosef 1986; Betts and Helms 1989; Miller 1980: 331–332) most relied on direct rainfall and/or naturally water-rich areas. By the sixth millennium BCE the prevalence of irrigation had begun to increase substantially. Farming settlements were established in areas of middle and lower Mesopotamia where rainfall was insufficient for cultivation (Maisels 1999: 125, 147–150), canal fragments are dated to before 5000 BCE at Choga Mami (Oates and Oates 1976), and linear arrangements of sites in Mesopotamia and Iran suggest they were located along canals (Adams 1965:119; Sumner 1994: 57). It was not until substantially later during the fourth millennium BCE that large-scale irrigation became a widely predominant means of plant food production. In both Egypt and Mesopotamia centrally coordinated irrigation was well underway by this time (Butzer 1976; Postgate and Powell 1988). While the first appearance of irrigation in Southwest Arabia may have been stimulated by aforementioned developments in the Levant, Mesopotamia, or Egypt, investigations in Yemen have traditionally focused on prominent large-scale systems, rather than their small-scale predecessors from which farmers first accumulated knowledge of water flow patterns and developed organizational means to control them. Recent investigations have made important strides toward identifying Southwest Arabia's earliest systems. Small-scale hillslope runoff systems have now been identified and dated to the late fourth millennium BCE in a number of widely dispersed locales throughout Yemen's rugged highlands (Ghaleb 1990; Harrower 2006; McCorriston and Oches 2001; Wilkinson 1999).

While peoples of ancient Southwest Arabia developed increasingly sophisticated flash-floodwater irrigation, other regions were simultaneously designing water control systems tailored to their own local circumstances. By the first millennium BCE underground infiltration galleries that captured water from upland aquifers (known in Iran as *qanats*) spread to Southeast Arabia (Oman) where they rapidly became a primary means of agricultural production (J. C. Wilkinson 1977, 1983; Lightfoot 2000). The inhabitants of Nabataean cities such as Petra (Jordan) and Meda'in Saleh (Saudi Arabia) constructed extensive hydraulic systems of dams, canals, conduits, pipes, and cisterns to provide water for domestic consumption, gardens, and fields (Akasheh 2002; Ortloff 2005). Increasingly complex perennial flow systems supported long and highly productive agricultural histories in Egypt and Mesopotamia. South Asian cities including Mohenjo-Daro and Harappa operated some of the world's first household water supply systems for drinking, bathing, and to remove domestic sewage (Scarborough 2003: 144–145).

In addition to irrigation's importance as an example of ancient technological expertise, water control has held an enduring place in explanations of ancient sociopolitical change. During the 1950s Wittfogel (1957) and Steward (1949, 1955) became key proponents of the hypothesis that the need for bureaucracies to coordinate large-scale irrigation was a primary factor responsible for the rise of centralized political leadership and the emergence of the world's earliest civilizations. Although scholars now recognize that irrigation was certainly not the only factor responsible for the rise of the world's first state societies, Wittfogel and Steward played an important role in emphasizing the near ubiquity of water control among early civilizations. Their assertions prompted a wealth of research on coordination and management of irrigation (e.g., Downing and Gibson 1974; Hunt and Hunt 1976; Kelly 1983; Millon 1962), and irrigation continues to be a focus of cross-cultural archaeological and anthropological research (Mabry 1996, 2000; Scarborough 2003). In some cases large-scale systems developed by accretion as individual farmers or groups of farmers constructed independently devised systems, while in others large-scale systems were designed, constructed, and operated by irrigation administrators with state sanctioned authority (Mabry 1996, 2000). While the so-called "hydraulic hypothesis" in its most simplistic formulation is clearly flawed and long outdated, water control undoubtedly did play a significant role in shaping the history of many ancient societies including those of Arabia and other arid environments.

See also: ►Alluvial Settlements on the Nile, ►Qanat, ►al-Hamdānī, ►Irrigation, ►Water control in Petra

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Decimal Notation

K. V. Sarma

Decimal notation is a system which imparts to nine figures (digits) an absolute numerical value and also a positional value which latter increases their value ten times by being shifted by one place to the left. Thus, the digits: 1, 2, 3, 4, 5, 6, 7, 8, and 9, coupled with the figure '0' which stands for zero or *śūnya* (nothing, empty), while expressing just their individual values when standing alone, can express also any quantity of any magnitude by their repeated use in the same number, and shifting of places, as needed. The importance of this contrivance is apparent from the words of the great French mathematician Laplace, when he says, "The idea of expressing all quantities by nine figures whereby both an absolute value and one by position is imparted to them is so simple that this very simplicity is the reason for our not being sufficiently aware how much admiration it deserves" (Srinivasaingar 1967). Halstead observes, "The importance of the creation of the zero mark can never be exaggerated. This giving to airy nothing, not merely a local habitation and a name, a picture, a symbol, but helpful power, is the characteristic of the Hindu race from whence it sprang. It is like coining the *Nirvāṇa* into dynamos. No single mathematical creation has been more potent for the general on-go of intelligence and power".

In Indian tradition, the need for enumeration and decimal notation stemmed from the adoration of gods and for ritualistic purposes. From Vedic times, the Hindus used the decimal notation for numeration. The *Ṛgveda* (ca. 2000 BCE) groups gods into three (1.105.5); there are three dawns (8.41.3); there were seven rays of the Sun-god (1.105.9); there were seven sages (4.42.8), and seven seas (8.40.5). There were 180 Marut-gods, or three times 60 (8.96.8); the God śyāvā gave as gifts cows numbering 210 or three times 70 (8.19.37). There were 21 followers of Indra, or three times seven (1.133.6), and the number of horses prayed for was thrice seven times 70 or 3 × 7 × 70 (8.46.26). In Vedic literature, besides the primary numbers, one to nine, expressed by the terms, *eka, dvi, tri, catur, pañca, ṣaṭ, sapta, aṣṭa*, and *nava*, the decuple terms from ten to 90, expressed by *daśa, viṃśati, triṃśat, catvāriṃśat, pañcāśat, ṣaṣṭi, saptati, aśīti* and *navati* are found. These are then sequentially multiplied by ten, taking terms from 100 to 10 to the power of 12, the terms being *śata, sahasra, ayuta, niyuta, prayuta, koṭi, arbuda, nyarbuda, samudra, madhya, anta*, and *parārdha*. In the matter of the arrangement of decuples in compound number–names, the practice generally followed in Vedic literature was to put the term of higher denomination first, except in the case of the two lowest denominations, where the reverse method was followed. See, for example, *sapta śātāni viṃśatiḥ* (seven hundreds and twenty, *Ṛgveda* 1.164.11), *sahasrāṇi śata daśa* (thousands hundred, and ten, *Ṛgveda* 2.1.8) and *ṣasṭ, sahasra navatim nava* (sixty thousands, ninety and nine, 60,099 *Ṛgveda* 1.53.9).

With respect to written symbols for numbers, since no palaeographic records of the Vedic age have been preserved, little can be said. However, a few Vedic passages occur where written numerical symbols are mentioned. In the *Ṛgveda* (10.62.7) certain cows with the mark of '8' (*aṣṭa-karṇī*) are referred to, and *Yajurveda-Kāṭhaka Saṃhitā* makes mention of pieces of gold with the mark '8' imprinted on them (*aṣṭa-pruddhiraṇyam, aṣṭāmṛdam hiraṇyam,* 13.10). Inscriptions and manuscripts, of later ages, all over India, use numerical symbols profusely. The tendency had been, from early ages, to spell out the numbers or make use of things permanently associated with a number to represent that number. For instance, eyes, hands, etc. were used for 2; moon, sky, etc. were used for 1, seasons for 6, and week for 7. Another method was to attribute specific numerical values for the letters of the alphabet and use those letters to indicate the specified numbers, a method which was mentioned by the Sanskrit grammarian Pāṇini of the fourth century BCE. These methods were very popular in the classical age in India, especially with mathematicians and astronomers.

See also: ►Mathematics in India, ►Sexagesimal System, ►Zero

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Decimal System and Measurement in East Asia

Shigeo Iwata

Decimal System

There exists at least one root word that seems to be common to all languages, namely, *tik*, which means a finger, an arm, or the numeral "one." The word *te* in Japanese language that belongs to Sino-Tibetan languages refers to a "hand" and *iti* means "one" (Table 1).

When modern humans branched out from Africa some 150,000 years ago, they may have been aware of the number "one." The Caucasoids branched off 100,000 years ago, and Australians 100–70 years ago. The Australians knew numbers as large as three before the eighteenth century. Mongoloids reached East Asia 70,000–50,000 years ago. The Japanese islands constituted an integral part of continental Asia about 12,000 years ago.

Sorai Ogyu (1666–1728) discovered that the cardinal numerals of one type in Japanese include a reduplication system of the vowel-exchanging type. In other words, the replacement of one vowel with another has the effect of doubling the value of the number as can be seen in *hito* (1): *huta* (2), *mi* (3): *mu* (6), *yo* (4): *ya* (8), and *itu* (5): *towo* (10). Apart from Japanese, examples of similar multiplication systems can also be found most typically in Korean (dialect: 1), Taiwanese (8), Micronesian (5), Melanesian (3), and Amerindian (15). The numbers that cannot be obtained in this method are 7 and 9, which can be readily given by combining the approach of one-to-one correspondence.

Peoples using these languages belong to the Mongoloid race. It has been estimated that the cardinal numerals between 1 and 10 emerged no earlier than 50,000 years ago, before these Mongoloids migrated outward from an area of East Asia and made their way to the North, East, and South.

Each of the several bone pieces of 28,000 years ago that were discovered in Shiyu site in China bears a number of lines. Each of these lines denoting a number suggests that the people used to record 20 or more numbers. The 22,430-year-old bone tubes excavated at the Zhoukoudian site in the southwest of Beijing bear symbols that have been deciphered as representing 3, 5, 10, and 13. The shape of the symbol for 10 leads us to believe that its creators employed the decimal system. Presumably, the Mongoloid completed the decimal system 50,000 years ago when they branched into East Asia, both North and South America, and the Pacific islands. The Chinese people recorded numbers as large as 30,000 in the period 3,300 years ago.

Decimal System and Measurement in East Asia. Table 1 Root word and meaning

Family or language	Form	Meaning
Nilo-Saharan	tok-tek-dik	One
Indo-European	dik-deik	To indicate/point
Caucasian (south)	titi, tito	Finger, single
Uralic	ik-odik-itik	One
Austroasiatic	ti	Hand, arm
Sino-Tibetan	tik	One
Indo-Pacific	tong-tang-ten	Finger, hand, arm
Eskimo	tik	Index finger
Amerind	tik	Finger
Na-Dene	tek-tiki-tak	One

Measurement

The greatest numbers of discoveries in East Asia consist of pit dwellings. In most of these cases, the wooden pillars no longer remain; the only evidence left is the postholes. The center of each posthole bottom presumably constitutes the center of gravity. Statistic calculations of the intervals between the centers derive a unit.

Table 2 indicates the age and unit length of typical dwellings. The plan views of some of the dwellings are given in Fig. 1. The mean value of the length of one unit is 17.3 cm. The magnifications of the unit of lengths most frequently used are multiples of 5. In the rare case where irregular numbers only are detected, it is presumed that no ruler was used for the construction.

These dwellings were designed according to a triangular standard, with the particular use of isosceles triangles and occasional employment of an equilateral triangle. Later in 8000 BCE or thereabouts, rectangular dwellings emerged.

The era when the practice of measurement began is considered to be the period in the middle of the range with the upper limit of 50,000 years ago when the decimal system was presumably completed and the lower limit of 25,000 years ago, which is the oldest

Decimal System and Measurement in East Asia. Table 2 Era and unit of length

No.	Site	Region	Year (BCE)	Unit of length (cm)	Standard deviation (cm)
1	Hasamiyama	Japan	26,000	17.3	0.67
2	Nishi-gagara	Japan	22,000	17.2	0.82
3	Shimonjo	Japan	18,000	17.3	1.01
4	Kogure-higashi-arayama	Japan	16,000	17.6	0.94
5	Tana-mukaihara	Japan	15,690	17.4	0.54
6	Taejon	Korea	13,000	18.1	0.60
7	Ushki	East Siberia	12,000	16.8	0.55
8	Kuzuharazawa	Japan	9,000	17.3	1.01
9	Momijiyama	Japan	7,120	17.2	0.68
10	Guhu	China	6,230	17.0	0.37
11	Egou	China	5,950	17.2	0.73
12	Gungsan	Korea	4,750	16.5	0.40
13	Uriba	Japan	4,620	17.4	0.31
14	Banpo	China	4,476	17.5	0.26
15	Giangzhai	China	4,182	17.3	0.18
16	Ichinosaka	Japan	3,875	17.4	0.34
17	Dadiwan	China	3,190	17.4	0.61
18	Ogakuchi	Japan	3,050	17.0	0.33
19	Wangwan	China	2,842	17.6	0.29
20	Ukonjiro	Japan	2,060	17.3	0.74

era indicated in Table 1. The region where measurement began in East Asia has yet to be determined.

The origin of the length 17.3 cm is not evident. At present, it is considered to match the hand length of an average female adult of a matriarchal society or the span of thumb and middle finger. Seven rulers that were used in the Chinese Shang dynasty in 1300 BCE or thereabout were found, of which four were made of bone, two of ivory, and one of jade. The shortest length of 1 *chi* is 15.773 cm and the longest 18.672 cm. The mean value and standard deviation of the length of 1 *chi* is 17.1 ± 1.47 cm. A ruler of 1 *chi* bear the graduations of 1/10, namely *cun* and 1/100, *fen*. Then, the length of 1 *chi* significantly increased because of the turbulence of social order. In the period from thirteenth century BCE to third century BCE, it took about 48 years for a measure to propagate from China to the Korean Peninsula, and 150 years or thereabouts to the Japanese Islands that were isolated from the Continent.

The construction ruler (a ruler used for building structures) is the first standard scale of each race and differs from others in the unit of length. The cubit in Egypt measured 52.5 cm, while the cubit in Mesopotamia was 50.0 cm long, the fathom in Indus was 168 cm, and the hand length in East Asia averaged 17.1 cm.

On the Dadiwan site in China, four measures used in the period of 3,190 ± 170 BCE were discovered. The mean value of unit volumes was 264 cm^3, which was close to the volume of *a gowpen* (*double handful*). Then, 2,800 years later in China, the standard of volume was set to 209 cm^3 with the unit name of *sheng*, which was four times as large as the volume of *a single hand-cupped gowpen*.

In Japan, it is highly probable that some of the potteries excavated from ancient sites of a period ranging from 2,800 to 2,300 BCE were made in accordance with standards of length and volume.

Assuming that such a positional notation as the decimal system was established before 50,000 years ago when modern humans arrived at East Asia and branched into various directions, the first measuring of length was used for building dwellings in a period between the above-mentioned era and 28,000 years ago. In the upper and lower ranges than the subject unit, one or more superior or inferior units were then created. With the gradual implementation of measuring systems of volume and other physical quantities, regional or racial cultures developed, and these different cultures integrated and evolved into the entire Chinese civilization. Thus, "Measurement was the mother of civilization," and "civilization began with measurement."

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Deśāntara

K. V. Sarma

In Indian astronomy, the *Deśāntara* of a place is its terrestrial longitude, i.e. the 'distance of the place' from a universally accepted zero meridian. In modern times, the meridian at Greenwich in England is accepted as the zero meridian, and the longitude is expressed in terms of the angle subtended, at the pole, by the Greenwich meridian and the meridian of the place in question. Indian astronomy had, from early times, taken as the zero meridian the meridian passing through the ancient city of Ujjain in Central India, cutting the equator at an imaginary city called Laṅkā and passing through the south and north poles. Again, in order to facilitate the conversion of the local time to that of the zero meridian and vice versa, the *Deśāntara* was expressed in terms of time-measures like *nāḍī* (or *ghatī*), equal to 24 min, as converted from the corresponding degrees. Since the earth completes one eastward rotation of 360° in 24 h, it is 15° an hour or 1° in 4 min. In terms of Indian measures, since 60 *nāḍīs* are equal to 24 h or two and half *nāḍīs* make 1 h, the rotation of 15° corresponds to a period of two and a half *nāḍīs*. Since 1 *nāḍī* = 60 *vināḍīs*, and 1 *vināḍi* = 6 *prāṇas*, the rotation will be 1° in 10 *vināḍīs,* or 1 min in 10 *prāṇas*. The *deśāntara* which is expressed in terms of time measure is done through either *nāḍīs*, *vināḍīs* or *prāṇas.*

Since the planetary positions derived by Indian astronomical computation are all related to the mean sunrise at the zero meridian, viz., the Ujjain meridian, to arrive at the positions at local places, a longitude correction or *deśāntarasaṃskāra* is called for. It is calculated in time-measures, as above, and is subtracted if the place in question is east of Ujjain and added if it is west of Ujjain.

The *deśāntara-saṃskāra* is expressed also in terms of the distance, i.e. in *yojanas*, of the desired place from the Ujjain meridian in the same latitude, at the rate of 55 *yojanas* for 10 *vināḍīs* or 1 min.

See also: ►Astronomy in India

Devācārya

K. V. Sarma

Devācārya, son of Gojanma and author of the astronomical manual *Karaṇaratna* (lit. Gem of a Manual), hailed from Kerala in South India. The epoch of *Karaṇaratna*, i.e. the date from which planetary computations were instructed to be commenced in that work, is the first day of the year 611 in the Śaka era, which corresponds to February 26 of AD 689. This places Devācārya in the latter half of the seventh century. We know he came from Kerala because he used the *Kaṭapayādi* system of letter numerals and the *Śakābdasaṃskāra*, which is a correction applied to the mean longitudes of the planets from the Śaka year 444 or AD 521, and a unique method of computing the solar eclipse, all of which are peculiar to Kerala, and because his work is popular in that part of the land.

Devācārya uses the elements of the Āryabhaṭan school of astronomy as the basis of his work, as he himself states towards the commencement of *Karaaratna*. His work is based both on the *Āryabhaṭīya* and on the second work of Āryabhaṭa, the *Āryabhaṭa-siddhānta*, as abridged in the *Khaṇḍakhādyaka* of Brahmagupta. The influence of the *Sūryasiddhānta* and of Varāhamihira are also apparent. It is also noteworthy that Devācārya himself innovated several thitherto unknown methodologies and techniques.

In eight chapters, the *Karaṇaratna* encompasses almost all the generally accepted aspects of Hindu astronomical manuals. Chapter I of the work is concerned with the computation of the longitudes of the sun and moon, and also the five basic elements of the Hindu calendar (*pañcāṅga*). Computation and graphical representation of the lunar and solar eclipses are the subjects of chapters II and III. Chapter IV deals with problems related to the gnomonic shadow, and chapter V with the calculation of the time of the moon-rise and allied matters. In chapter VI, heliacal rising of the moon and elevation of the moon's horns are dealt with. The last two chapters are concerned with the derivation of the longitudes of the planets, planetary motion, and planetary conjunctions.

Several peculiarities characterize Devācārya's work. Among these are the computation of the sun, moon, moon's apogee, and moon's ascending node using the 'omitted' lunar days, the *Śakābda* correction, and the application of a third visibility correction for the moon. However, what is most significant in the work is the recognition of the precession of the equinoxes and the rule that he gives for its determination on any date. Devācārya's measure of the rate of precession is 47 s per annum, its modern value being 50 s. Devācārya's importance lies in the fact that his work formed a record of the astronomical practices and methodologies for the quick derivation of astronomical data that prevailed in India during the seventh century AD.

See also: ►Āryabhaṭa, ►Varāhamihira, ►Precession of the Equinoxes

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Divination: Science, Technology, and the Mantic Arts in Traditional China

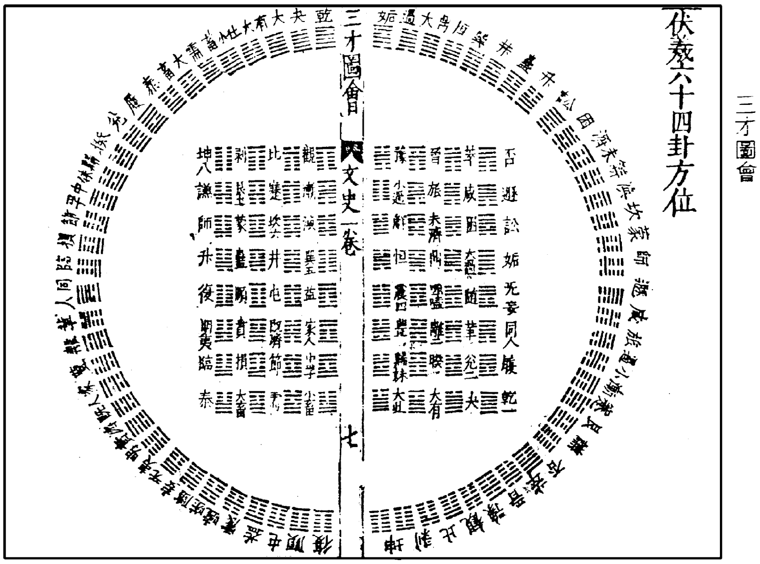
Richard J. Smith

From Neolithic times into the twentieth century, divination occupied an extremely prominent place in Chinese culture. By the third millennium, BCE at the latest – and some recent research suggests considerably earlier – specialists in reading stress cracks in the bones of various animals had already emerged as a distinct occupational group in north China. During the Shang dynasty (ca. 1500–ca. 1100 BCE), the interpretation of so-called oracle bones (the dried plastrons of turtles and the scapulae of cattle) reached a high degree of sophistication. Royal diviners sought spiritual advice on behalf of the Shang kings concerning a wide range of important topics, from the weather, agriculture, hunting and travel, to civil and military administration, the construction of buildings, the location of cities, religious sacrifices, and personal problems.

The inscriptions on Shang oracle bones do more than indicate the preoccupations of rulers, however; they also reveal patterns of thought and behavior that have lasted for several millennia in China. For instance, they document the early use of sexegenary cyclical characters ("stems" and "branches;" *ganzhi*) for marking time – a practice that continued in all subsequent dynasties and can still be seen today in traditional Chinese almanacs. They also suggest a deep interest in dream interpretation that has persisted throughout Chinese history. Furthermore, oracle bone inscriptions testify to an early preoccupation with astronomical observation, astrological prediction and numerology. Indeed, some Chinese scholars have argued that Shang dynasty numerological concerns led to the invention of the extraordinarily important divinatory symbols known as hexagrams in English (see below).

Paradigmatic Chinese sources such as the *Shijing* (Classic of Poetry), the *Shujing* (Classic of History), the *Yijing* (*I Ching*; Classic of Changes), the *Chunqiu* (Spring and Autumn Annals), the *Zuozhuan* (Commentary of Zuo), the *Liji* (Record of Ritual), and the *Zhouli* (Rituals of Zhou) – together with recently excavated inscribed bronzes and writings on both silk and bamboo, attest to the social and geographical spread of divination in the Zhou dynasty (ca. 1100–256 BCE). During the early Zhou, divination remained primarily a royal prerogative, but by the Spring and Autumn era (722–481 BCE) it had become far more diversified and widespread.

A particularly important development during this time was the "invention" of the legendary *Zhouyi* (Zhou Changes) – a divination manual based on sequences of 64 six-line symbols known as hexagrams (*gua*). Each hexagram had a name that referred to a physical object, an activity, a state, a situation, a quality, an emotion or a relationship – for example, *Ding* (The Cauldron), *Shi* (The Army, *Dun* (Withdrawal), *Meng* (Juvenile Ignorance), *Yu* (Contentment), *Song* (Contention), and *Tongren* (Fellowship). Each hexagram also possessed a short description of several characters called a *tuan* or *guaci* (usually rendered "judgment") and a brief, one-sentence "line statement" (*yaoci*) elucidating each line. Over time, the hexagrams and their two constituent

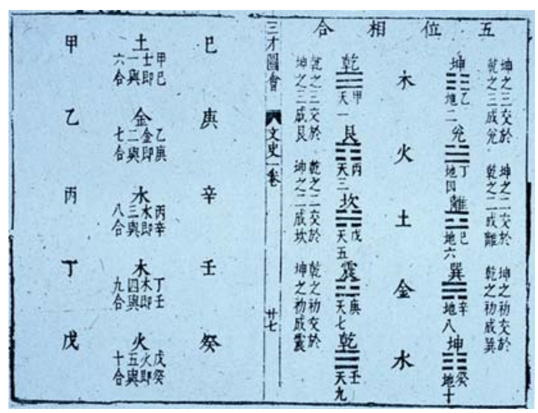


Divination: Science, Technology, and the Mantic Arts in Traditional China. Fig. 1 The Sixty-four hexagrams, organised in square and circular configurations based on the so-called Former Heaven (Xian Tian) sequence.

"trigrams" (also *gua*) came to be used in a wide variety of divinatory systems and also as scientific symbols (Fig. 1).

By the late Zhou period, a great number of mantic systems had developed in China, including various "schools" of astrology (*zhanxing*, *xingming*, etc.), geomancy (*dixing*, *xingfa*, *kanyu*, and later *fengshui*), physiognomy (*xiangren*, *kanxiang*, etc.), and various computational arts (known generically as *shushu*). This growing interest in divination was part of a general burst of remarkable philosophical creativity in the so-called Warring States period (453–221 BCE) – an era marked by social and geographical mobility, the exchange of new ideas, increased professional specialization, and the introduction of new technologies, including advanced methods of astronomical and calendrical calculation. Also, from the late Zhou dynasty into the twenty-first century, almanacs or "day books" (*rishu*, *tongshu*, *huangli*, etc.) – based on elaborate astrological calculations and correlations – specified propitious and unpropitious times for all kinds of activities, from mundane matters such as bathing, traveling, and beginning various kinds of work to extraordinarily important rituals.

During the Han dynasty (206 BCE–220 CE), the correlative cosmology of Dong Zhongshu (ca. 179–ca. 104 BCE) – based on concepts such as *yin* and *yang* and the five "agents" or "activities" (*wuxing*; identified with the "qualities" of wood, fire, earth, metal, and water), as well as the eight trigrams (*bagua*), the ten "stems," the 12 "branches," and the 64 hexagrams – influenced virtually all forms of Chinese divination, not to mention the related realms of medicine and natural science (Fig. 2). A significant feature of early Chinese divinatory, medical and scientific thought is that *yinyang*, *wuxing*, and other correlations often seem to have been more compelling than empirical observation – even when the correspondences and analogies were internally inconsistent or mutually incompatible.



Divination: Science, Technology, and the Mantic Arts in Traditional China. Fig. 2 Cosmic correlations involving the eight trigrams, the five phases and the ten heavenly branches.

During the early Han period, in 136 BCE, a series of pre-existing commentaries known as the "Ten Wings" (*Shiyi*), attributed erroneously but convincingly to Confucius, became permanently attached to the *Zhou Changes*, and the work became one of the court's officially recognized "Confucian" classics – hence the new name of the document, *Yijing*. These "wings," especially the so-called "Great Commentary" (*Dazhuan*; aka, the Appended Phrases or *Xici*), invested the *Changes* with a powerful, colorful, and inticing philosophical flavor. Moreover, they helped to explain the cryptic "judgments" and "line statements" of the basic text, attaching to both the hexagrams and trigrams a great many new meanings and associations. These ranged from family relationships, social roles, animals, and parts of the body to directions, seasons, times of the day, and colors.

Scholarly approaches to the *Yijing* varied substantially during the Han – in part, perhaps, because different versions of the work existed. We know, for example, that the Mawangdui silk manuscript of the *Changes*, produced in the early Han period, differs in several significant respects from later "standard" editions of the classic – not only in some of its judgments and line statements, but also in its ordering of the hexagrams (and even some of the names attached to them). But scholarly differences in the Han were also a function of the many ways in which the received text of the *Changes* could be interpreted. Indeed, for the next 2,000 years, literally hundreds of different approaches to the *Yijing* developed. Although only two main interpretive lineages are usually identified with the "Learning of the *Changes*" – the "Images and Numbers (*xiangshu*) School" and the "Meanings (or Morality) and Principles (*yili*) School" – in practice scholars drew freely from both traditions, developing complex schemes that related lines, trigrams and hexagrams to various calendrical, numerological, and philosophical interests and orientations.

At the same time, the *Yijing* inspired a host of derivative works, from simple prognostication texts (*chanwei* or *tuchan*) to more elaborate "apocryphal" treatises such as the *Qian zao du* (Opening Up the Regularities of the [Hexagram] Qian; also transliterated *Qian zuo du*). The *Changes* also provoked an extremely interesting divinatory book known as the *Taixuan jing* (Classic of Supreme Mystery) by a brilliant scholar named Yang Xiong (53 BCE–18 CE). This eclectic work reflects standard Han dynasty cosmological assumptions and intellectual fashions, but instead of using 64 hexagrams and 384 lines it employs 81 tetragrams (*shou*) and a total of 729 lines – each with an "appraisal" (*can*) loosely patterned on the line texts of the *Yijing*.

The wide circulation of Han divination texts suggests the ever-growing appeal of fortune-telling at all levels of Chinese society. Occult specialists known generically as *fangshi* dominated the mantic landscape in the Han and immediate post-Han periods, and as a result, every subsequent dynastic history, not to mention many local gazetteers and other such sources, contained special sections devoted to biographies of *fangshi*, usually called "technicians" (*fangji*).

Among the many divination techniques employed by *fangshi* were increasingly varied forms of astrology, "fate calculation" and numerology. Specialists also emerged in a myriad of related techniques: consultation of two diagrams closely associated with the *Yijing* and known as the *Hetu* (Yellow [River] Chart) and the *Luoshu* (Luo [River] Writing), the use of divining boards, oracle bones, milfoil stalks, and prognostication texts; the geomantic analysis of landforms; the selection of lucky days, the analysis of heavenly stems and earthly branches; communication with spirits; crack-making with bamboo; the interpretation of winds and vapors, birdcalls, and dreams; physiognomy, and eventually the divinatory evaluation of written characters. Most of these techniques had existed in the late Zhou period or earlier in some form, and virtually all of them continued to be used throughout the Imperial Era (up to 1912). The principal innovations of later years were the incorporation of certain zodiacal elements of Indian astrology into Chinese astrology, the use in front of temples and shrines of "spiritual sticks" (*lingqian*) and "divining blocks" (*jiao*), and a particularly dramatic form of oracular spirit possession known as "spirit-writing" (*fuji* or *fuluan*).

From the Six Dynasties period (222–589 CE) onward, Chinese Buddhists and Religious Daoists appropriated the symbolism of the *Yijing* and used a variety of other mantic texts in order to "know fate" – even though one's future was, in a certain sense, ordained by behavior in both systems of belief. In any case, we find a number of monks, priests and lay adherents from various periods of Chinese history who were experts in one or another divinatory technique. Some clerics even compiled mantic texts (*bujing*), such as the mid-fifth century work titled *Guanding jing* (The Sutra of Consecration). One of the most famous clerics in medieval China was Yixing (d. ca. 740), a Buddhist monk and official court astronomer during the reign of emperor Xuanzong, who excelled in fate calculation, physiognomy and geomancy as well as mathematics, calendrical science and classical studies. He is well known for his studies of Han scholarship on the *Yijing* and as the author or editor of several books on astrology and other forms of divination. He also served as a trusted adviser and interpreter of portents for his imperial patron.

From the Song dynasty (960–1278) onward, diviners increasingly relied upon a new device, the geomantic "compass" (*luopan*, *luojing*, etc.), to ascertain the relationship between "heavenly patterns" (*tianwen*) and "earthly forms" (*dixing*). This invention, derived in part from Han dynasty divining boards (*shi*), delineated celestial and terrestrial relationships by means of a series of concentric circles marked with standard Chinese symbols of time and space. Among the *Yijing*-related symbols regularly employed in these devices were the eight trigrams, the stems and branches of the sexegenary cycle, the 28 lunar "lodges" (*xiu*) and other such cosmic variables (Fig. 3).

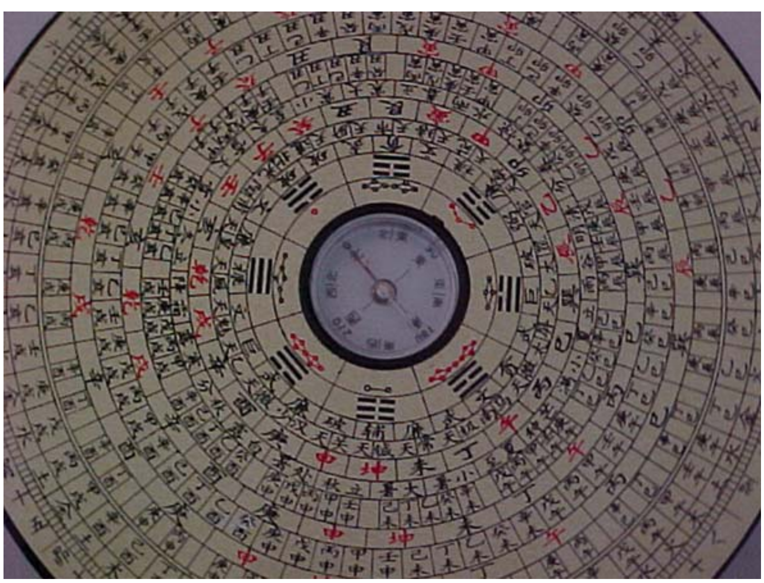
A Song dynasty poem reproduced in a famous Chinese encyclopedia testifies to the importance of the compass to the geomancer's craft. It contains the following lines:

> Between the lodges Xu and Wei points clearly the needle's path,
>
> But to the south the lodge Zhang "rides upon all three".
>
> The trigrams Kan and Li stand due north and south, though people cannot recognize [their subtleties],
>
> And if there is the slightest mistake there will be no correct predictions.

Over time, compasses became increasingly sophisticated, with up to 24 concentric rings and a host of symbolic variables that applied to several different divination systems. Similarly, fate calculation based on the time of one's birth grew more complex. Whereas pre-Song techniques involved at most a consideration of the year, month and day of birth, later diviners took into account the hour as well. These "four pillars" (*sizhu*) of destiny, each designated by two characters, came to be known as one's "eight characters" (*bazi*), an extremely common term in Chinese divination up to this very day.

The many hundreds of life stories contained in Yuan Shushan's massive and fascinating *Zhongguo lidai buren zhuan* (Biographies of Diviners in China by Dynastic Periods; 1948) abundantly testify to the central role divination has played in nearly all aspects of Chinese life for thousands of years. Many of the mantic specialists discussed by Yuan were employed by Chinese officials as formal or informal advisers, and many served in some sort of military capacity. A number made calendrical calculations and/or predicted weather, droughts and famines. Physiognomers in the employ of bureaucrats often evaluated personnel and sometimes also interrogated witnesses and prisoners. A few even served as negotiators with dissident groups. Diviners also assumed active roles in law enforcement, assisting with difficult legal cases, solving crimes, and helping to apprehend suspects or escaped prisoners. A great many fortune-tellers gave useful advice to officials concerning water management, public works, and the construction or repair of city walls, temples, schools and yamens (the office or residence of an official).

What made diviners effective enough in these roles to warrant biographies in local gazetteers and other such sources? Putting aside claims to supernatural power, the answer seems to be their technical expertise and social value – the product of both experience within their communities and psychological insight. Although experts in analyzing wind, rain, and clouds (*fengjiao*, *xiangyu*, *zhanqi*, etc.) – like all Chinese



Divination: Science, Technology, and the Mantic Arts in Traditional China. Fig. 3 A geomantic compass, with concentric rings reflecting various cosmic variables, including trigrams.

fortune-tellers (and most of the rest of the Chinese population as well) – they believed in the influence of supernatural forces, including “star-spirits.” They were also careful observers of natural phenomena. Geomancers used compasses to identify auspicious sites and times for building and making repairs, but they also knew a great deal about landforms and hydraulic systems – information of value in public works as well as military affairs.

Exponents of numerological techniques such as *liuren* (“the six *yang* waters”), *dunjia* (“evasive techniques”) and *Taiyi* (“method of the Great Unity [Spirit]”) – although concerned primarily with calculations to determine proper times and locations, often studied the arts of war as part of their training. And all diviners – fate calculators and physiognomers in particular – were quite naturally careful observers of human behavior. In short, well-cultivated talents of empirical observation and psychological insight gave fortune-tellers a substantial role to play in Qing administrative affairs.

In local communities, quite apart from their service to Chinese officials, diviners played important roles in helping to resist rebel invaders and bandits. Fortune-tellers provided technical assistance to their local communities in other ways as well. Some undertook famine relief, managed schools, or supervised public works projects. Others used their special talents in *liuren*, *dunjia*, and *Taiyi* predictions to help neighbors find lost or stolen property.

In a number of significant ways, fortune-tellers were like physicians in traditional China – an affinity too seldom acknowledged by historians of medicine. At least 170 of Yuan Shushan’s 1,115 biographical entries refer to individuals who knew both medicine and divination (*yibu*). One common denominator between the two diagnostic and prescriptive approaches was a shared cosmology, centered on theories of “responsive correspondence” (*ying* or *xiangying*). These correspondences involved considerations of time, place and spirituality (or demonology) as well as notions of physiology and psychology. Discourses in divination and medicine almost invariably revolved around the same basic cosmological concepts, including *yinyang* and *wuxing*, the eight trigrams and 64 hexagrams, the sexegenary stems and branches, positive and negative spirits (*shen* and *gui*, respectively) and so forth.

The four standard categories of Chinese medical examination – visual inspection, listening and smelling, questioning the patient, and touching the body – correspond closely to the approach of many diviners, physiognomers in particular. From the standpoint of treatment, practitioners of traditional Chinese medicine and divination often considered a patient’s moral behavior to be a significant factor in that person’s well being. Clients of both doctors and diviners were therefore advised to cultivate good thoughts and to banish selfish desires.

As “technicians,” physicians and fortune-tellers occupied the same status in Chinese society. Scholars conventionally described both professions as “minor employments” (*xiaodao*), to be investigated, perhaps, but not to be earnestly pursued. They also suffered many of the same criticisms. These had to do primarily with inconsistent theories, inaccurate predictions, and fraudulent therapies.

Scholars were particularly critical of fortune-tellers for their exploitation of the “ignorant” masses, and for their obviously mercenary motivations. They could not, of course, assail the idea of divination itself, for the practice had far too long and illustrious a pedigree in China’s classical tradition to ignore. But elites made a sharp (albeit rather artificial) distinction between their own “enlightened” beliefs and the “crude” customs of the populace at large. In short, the bias against certain “popular” forms of divination was fundamentally a class prejudice, masked by the rhetoric of Confucian morality. This elitist view of divination is reflected in a well-known adage attributed to the famous Song dynasty scholar Zhang Zai: “The (*Classic of*) *Changes* is for the planning of the superior person, not the planning of the petty person.”

Yet Chinese intellectuals made no significant headway in their effort to eradicate popular mantic practices during imperial times. Why? In the first place, most divination systems, like the cosmology on which they were based, had a high degree of complexity. This provided conceptual flexibility, and made “scientific” falsification all but impossible. In the minds of many, wrong predictions simply indicated that someone had misinterpreted the huge number of cosmic variables involved, or that either the diviner or his client was insufficiently “sincere” (*cheng*).

In the second place, as indicated above, fortune-tellers played important social roles in premodern China, serving as the equivalents of modern-day scientists, technicians, doctors, psychologists, and social workers. Moreover, divination drew strength from the fact that so many of its features resonated powerfully with other aspects of traditional Chinese culture, including philosophy, religion, art, literature and social customs. It reflected, for example, the eclectic, synthetic features of Chinese thought, the importance of writing (evident in mantic messages of all kinds, as well as charms, and the analysis of written characters), aesthetics (particularly evident in the case of geomancy), mythology, medicine, cosmology and popular symbolism (notably the popular *yinyang* illustration known as the “Diagram of the Supreme Ultimate” (*Taiji tu*) and the ubiquitous eight trigrams.

Finally, we should remember that the Chinese government reinforced the inherited cosmology and sanctified orthodox practices of divination in every way possible, at all levels. Officials and emperors sought mantic assistance in a wide variety of circumstances, determined to find the right time and the right place for all ritual events, large and small, the conduct of war, the construction of buildings, and so forth. Perhaps the single most significant manifestation of this administrative attitude was production of the state calendar, which dictated auspicious and inauspicious activities for each day of every year, based on the calculations of official diviners at the capital, who were located in the Imperial Bureau of Astronomy (Qintian jian) (Fig. 4).

During the late nineteenth century, Western imperialism brought new challenges to China, as well as new political, social and cultural options to Chinese intellectuals. Under these unprecedented circumstances, a new kind of cosmological critique arose – a political attack on the cosmological foundations of Chinese kingship itself. It was successful, and when the Qing dynasty finally fell in 1912, state-sponsored cosmology suffered a mortal blow. During the so-called New Culture Movement (ca. 1915–1925), which followed in its wake, modern-minded intellectuals such as Chen Duxiu (1879–1942) railed against Confucian values and ridiculed old-fashioned "superstitions" (*mixin*). He wrote in 1918, for example, that only by first casting away practices such as geomancy, fortune-telling, spirit writing and the use of charms, spells and alchemy, could the Chinese people begin to "put their minds right." He was not attacking a straw man, for old-style mantic techniques and cosmological assumptions remained in force, judging from the remarks of a well-informed foreign observer in the midst of the New Culture Movement: "At the present day," he wrote, "soothsayers, diviners and fortune-tellers abound throughout the land, and the people place implicit faith in their vain forecasts."

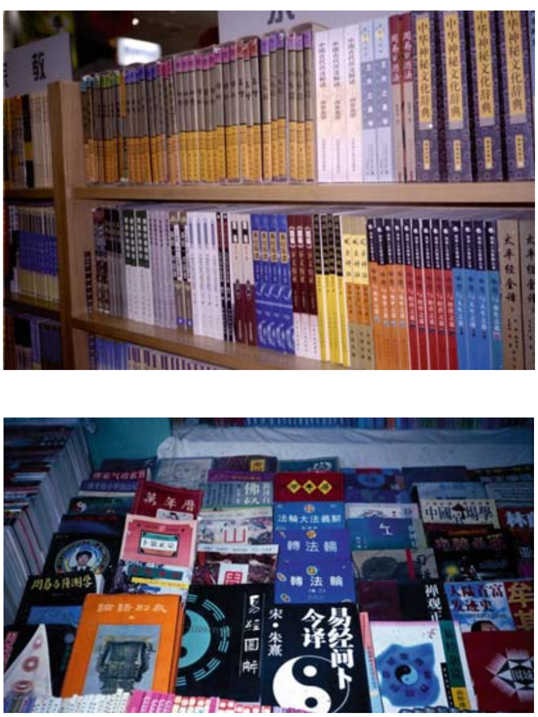
Periodic efforts were made by the Republic of China (from 1912 to 1949 on the Mainland and from 1949 – present on Taiwan) and the People's Republic of China (1949 – present) to discourage or eradicate "superstitious" mantic practices, but with only limited success.

Divination: Science, Technology, and the Mantic Arts in Traditional China. Fig. 4 A map of Heaven (round) and Earth (square), showing the influence of the eight trigrams and various heavenly bodies, including the sun, the moon, and the twenty-eight lunar lodges (xu).

Virtually all forms of traditional Chinese divination have flourished in both Hong Kong and Taiwan, and even in the People's Republic, despite sometimes fierce "antisuperstition" campaigns, particularly during the fanatical and destructive Cultural Revolution (1966–1976). Popular divination is alive and well, especially geomancy (*fengshui*).

Moreover, the so-called "Open Policy," inaugurated on the Mainland in 1978, has encouraged a dramatic revival of interest in, and publications on, divinatory works such as the *Classic of Changes*. During the 1980s this enthusiasm was known widely in the Chinese press as *Yijing re* ("*Yijing* Fever"). Part of the reason for this fever, which touched virtually every sector of Chinese society on the Mainland, is a profound spiritual crisis (*jingshen weiji*), which has induced many people to reexamine the contemporary relevance of their ancient past (Fig. 5).

The result has been a burst of new and creative *Yijing* scholarship, fueled by dramatic recent archaeological discoveries. On both sides of the Taiwan Straits, encyclopedias, dictionaries and other comprehensive compilations – as well as compendia produced by literally dozens of scholarly organizations devoted to *Changes* studies – have chronicled at great length the *Yijing*'s wide-ranging cultural contributions. So have



Divination: Science, Technology, and the Mantic Arts in Traditional China. Fig. 5 Examples of books on divination in Mainland Chinese bookstores and bookstalls.

the authors of general studies such Wang Shusen's *Zhouyi yu Zhonghua wenhua* (The *Zhou Changes* and Chinese Culture), Zhai Tingpu's *Zhouyi yu Huaxia wenming* (The *Zhou Changes* and Chinese Civilization), and Ying Dingcheng's *Zhongguo wenhua zhi benyuan* (The Origins of Chinese Culture).

Meanwhile, a number of more narrowly focused works have also appeared in a spate of recent scholarly series – notably the *Yixue wenhua congshu* (Collectanea on the Culture of *Changes* Studies) and the *Yixue zhihui congshu* (Collectanea on the Wisdom of *Changes* Studies). The individual volumes in these two series alone cover topics such as the relationship between the *Yijing* and Confucianism, Daoism, Buddhism, mathematics, medicine, astronomy, the humanities, historiography, aesthetics, geomancy, architecture, business management, the environment, *qigong*, and other forms of traditional physical and mental cultivation (*yangsheng*), and so forth.

In addition, there are a great many individual monographs with titles such as Xu Daoyi's *Zhouyi kexue guan* (The Scientific Outlook of the *Zhou Changes*) and his *Zhouyi yu dangdai ziran kexue* (The *Zhou Changes* and Contemporary Natural Science) – two of many similarly titled books and articles – He Shiqiang's *Yixue yu shuxue* (*Changes* Studies and Mathematics); Jiang Chengqing's *Yijing yu Zhongguo yishu jingsheng* (The *Classic of Changes* and the Spirit of Chinese Art); Chen Liangyun's *Zhouyi yu Zhongguo wenxue* (The *Classic of Changes* and Chinese Literature); Wang Zhenfu's *Zhouyi di meixue zhihui* (The Aesthetic Wisdom of the *Zhou Changes*); Shao Xuexi's *Yixue yu bingfa* (*Changes* Studies and the Art of War); and Tang Mingbang's *Dangdai Yixue yu shidai jingshen* (Contemporary *Changes* Studies and the Spirit of the Times).

One of the most powerful and persistent tendencies in recent *Yijing* scholarship has been the tendency to look at the *Changes* as a "scientific" document. During imperial times, a great many Chinese thinkers tried to approach the *Yijing* by way of mathematics, or at least a highly sophisticated numerology – notably Jing Fang in the Han, Shao Yong in the Song, and Jiao Xun in the Qing. And, as indicated briefly above, the symbolism of the *Changes* also came to be used as an explanation for various phenomena in the natural world. But efforts to link the *Yijing* to math and science in the twentieth century are now predicated on modern "Western" understandings of these two related realms of knowledge. Thus, impelled in part by national pride, Chinese scholars today – especially those educated in the West – have begun to use "data" from the *Yijing* to show connections to a number of different realms in modern mathematics and science, from linear algebra and quantum mechanics to molecular biology and computer coding. A readily available example in English is Johnson Yan's *DNA and the I Ching*.

See also: ►Fengshui; ►Geomancy in China

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Dwellings and Settlements

NEZAR ALSAYYAD, ROMOLA SANYAL

Traditional dwellings and settlements are the built expressions of a heritage that continues to be transmitted from one generation to another. Usually the product of common people without professional intervention they provide the habitat for much of the world's population. In fact, it is argued that professionally designed dwellings account for less than 1% of the total housing stock in the world. According to one estimate, traditional dwellings and settlements house between eight and nine million households in a variety of urban and rural settings (Oliver 1987).

In the twentieth century, interest in the social and cultural values, images and perceptions underlying traditional dwellings and settlements has become widespread among scholars in various disciplines. Specific labels, such as "vernacular," "indigenous," "primitive," "tribal," "folkloric," "popular," and "anonymous" have been introduced to describe the subjects of a variety of inquiries. Nevertheless, the inability to come up with a single appropriate label should not prevent a categorization of these dwellings and settlements as one analytical group. One thing common to all the above qualifiers regarding buildings and spaces is that they describe a process that becomes a norm when enough people in a given society adopt it. In this regard, traditional settlements exist in every part of the world and cannot be regarded as being simply primitive or exclusively a product of the developing world.

Since adoption of a practice into a norm is one of the fundamental qualities of tradition in built form, it is legitimate to use "tradition" as an all-encompassing umbrella term. Used this way, the term may also be useful in an age when scholars are beginning to recognize that the study of those dwellings and settlements, whose form originated as part of everyday processes rather than specialized professional aesthetic judgments, is an interdisciplinary arena. Unlike professional traditions like those of science or medicine, or professional architectural practice, the traditions of dwellings and settlements will remain an open field subject to great changes in position.

One may argue that a thing is traditional if it satisfies two criteria. First it should be the result of a process of transmission from one generation to the next; second it should have cultural origins mainly involving common people. As such, traditional dwellings and settlements are those buildings and spaces which provide for the ordinary activities of common folks and which are produced by both utilitarian logic as well as local aesthetics.

The vast numbers of traditional dwellings and settlements also allow for such built forms to be legitimately classified under the different names and qualifiers mentioned above. Many of these qualifiers originated from particular disciplinary bases and may not be interchangeable. For example, vernacular architecture in many parts of today's world often cannot be regarded as indigenous because it relies on imported materials to achieve local styles. "Indigenous" means of place, and has to do with origin. "Vernacular" means of the masses and hence does not have to be indigenous. It is also a category that has an underlying basis in class and social grouping. "Traditional" as a description is appropriate to use when discussing a system of core values that are transmitted from one generation to another. It is about process; as opposed to vernacular and indigenous, which are descriptions of how things are put to use (AlSayyad and Bourdier 1989).

The study of traditional dwellings and settlements as a field is not new – it was started in the early nineteenth century by Morgan and Morris. Bernard Rudofsky's famous exhibition at the New York Museum of Modern Art entitled *Architecture without Architects* and an accompanying book further popularized the study of vernacular architecture in the 1960s. The latter part of the decade saw further developments in the field with the publication of such ground breaking books as *House Form and Culture* by Amos Rapoport culminating in the *Encyclopedia of Vernacular Architecture of the World* by Paul Oliver. Some more recent publications include Paul Oliver's *Dwellings: The House Across the World* and Enrico Guidoni's *Primitive Architecture*.

The study of traditional dwellings and settlements can be defined less by subject than by method. Different means of analyzing traditional dwellings and settlements such as anthropological, architectural, archaeological, behavioral, structural, and so forth use different lenses to understand the ways and means by which people build dwellings and the symbolism and utilitarianism involved in building and conceptualizing these structures. Such varying approaches to studying traditional dwellings and settlements points to the fact that elaborate methods and meanings dictate the form and process by which dwellings are constructed. Factors such as culture, religion, gender relations, privacy matters, climate, security, economic conditions, and so forth intersect to produce dwellings that become part of the popular culture of a place.

Using such varying methods points to the various forms of settlements that are viewed as being "traditional." For example, in China, cave and pit dwellings found in the Hunan region are viewed as traditional forms of settlements (Fig. 1). Many of the people who live in these dwellings are peasant farmers who come from relatively low-income backgrounds. Cave and pit dwellings therefore allow them to not only save precious farmland, but also to save substantially on the cost of building a house as digging is the cheapest form of labor in the region. The Tunisian troglodyte dwellings, some 10,000 miles away, are primarily habitats of the ethnic Berbers. Largely found in the Matmata plateau area, in the south of the country which is part of the Sahara desert, these dwellings were claimed to have been built for purposes of defense against the invading Romans and later the Arabs (Fig. 2). As the threat increased or decreased, so

Dwellings and Settlements. Fig. 1 Cave and pit dwellings, China (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 875) (Courtesy of Paul Oliver).

Dwellings and Settlements. Fig. 2 Troglodyte dwellings in the Matmata plateau area, Tunisia (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 135) (Courtesy of Paul Oliver).

did the height at which these dwellings were carved or constructed. Thus these dwellings are a product of not only a traditional way of life but also climatic and topographic constraints under conditions of war and peace.

Such climatic and cultural conditions have also been used to explain the forms of Tharu homes in the Terai region of Nepal (Fig. 3). These homes are closely built together not only because the Tharu people live predominantly in forested regions where they are prone to animal attacks, but also because of their traditional beliefs in ghosts and the notion that anyone who sleeps alone is prone to attacks by evil spirits.

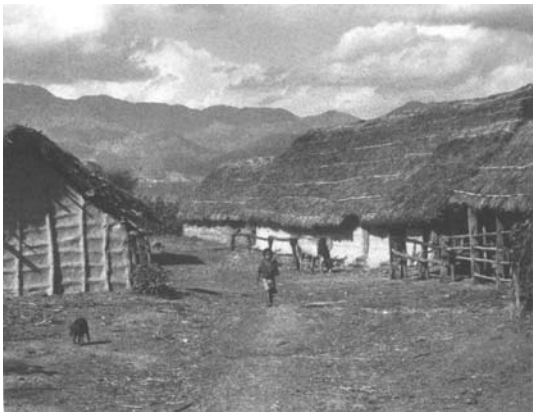
Additionally, climate has often been cited as the primary condition for the development of courtyard houses through much of the Middle East. While this type of building is associated primarily with Arab culture, its distribution extends from North Africa to South Asia where the *haveli* or atrium house is common to cities such as Jaipur and was developed under Mogul influence. The basic courtyard plan of the Ancient Egyptian peasants which partially survives today includes long single-storeyed rooms on three sides of a yard, the fourth being closed off by a wall as high as the buildings. Constructed of mud, the walls are the thickest where they are exposed to the sun. The courtyard plays a climatically important role regardless of the height of the building. At midday, the sun may reach the courtyard floor but the thickness of the walls and the adjacent buildings prevent excessive solar heating. Cool air in the rooms is drawn into the courtyard and warm air begins to rise, causing convection currents. The deep shadows created by the low angle of the sun offset the circulation of the air currents. When the sun sets, the temperature drops rapidly and the air circulates through the various rooms surrounding the courtyard keeping them cool till the next afternoon (Oliver 1987: 119–120).

Similar to climatic constraints are constraints presented by the environment as well. This includes the constraint of finding appropriate building materials. In the Altiplano and high Punda regions in Northern Chile, the only source of wooden building material is a cactus commonly known as *cardon* or *pasacana*. The plant once cut and dried produces a wood that is not only very strong, but resistant to rotting. It is cut into boards and bound together to construct doors, ceilings and floors. The bark, which is denser material, is used for window frames, rafters, and furniture-making (Sainsbury 1997: 223).

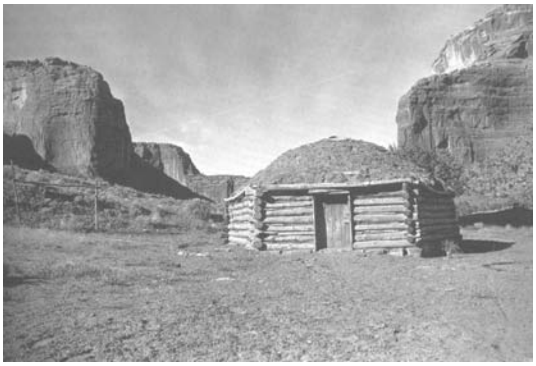
Questions of privacy are important factors in determining the form of space in traditional dwellings and settlements. How societies regard their relationship to external or public space is often a measure of the importance that they place on privacy. The delineations of public and private spaces vary from one culture to another. In some cultures such as that of the Ashanti, one finds most of the domestic tasks along with economic ones taking place outside the house itself, not inside as it is in most other cultures (Oliver 1987: 142).

As noted earlier, values and symbols play an important role in the development of traditional dwellings and settlements. One example of such practices is that of the Navajo Indians and the symbolic meanings of spaces in their hogans (Fig. 4). Here, the floor slightly dished represents the female (earth) and the roof slightly concave represents male (sky). Pollen smeared on the house posts supporting the roof symbolizes poles that support the sky. In the middle is the hearth which symbolizes the center of the world. Movement through this space is sun-wise (Oliver 1987: 142).

Aesthetics play an important symbolic role within vernacular architecture practices. In Sumatra, the Toba Batak *huta* (village) comprises of two rows of buildings



Dwellings and Settlements. Fig. 3 Tharu homes in the Terai region, Nepal (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 1041) (Courtesy of Paul Oliver).



Dwellings and Settlements. Fig. 4 Hogan of the Navajo Indians in Chinle, Arizona (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 1935) (Courtesy of Paul Oliver).

Dwellings and Settlements. Fig. 5 Toda Batak house, Sumatra, Indonesia (Source: Paul Oliver, *Dwellings: The House Across the World*, p. 199) (Courtesy of Paul Oliver).

Dwellings and Settlements. Fig. 6 Decoration on the façade of a Hausa merchant's house, Zaria, Nigeria (Source: Paul Oliver, *Encyclopedia of Vernacular Architecture of the World*, p. 581) (Courtesy of Paul Oliver).

facing the *halaman* or village plaza which in turn is always oriented east–west (Fig. 5). The massively constructed Toba Batak house has saddle-back pointed roofs and curving eaves which convey an impression of lightness and gable fronts that give shade. Planked panels are fixed over the external gable which comprise of three levels including a stair and balcony. These panels take on decorations which include finely carved spiral and foliated volute patterns and painted in black, red, and white. Female breasts and the *boraspati*, a local lizard, are also carved on to the façade, possibly as fertility signs. Batak houses are meant to be seen and admired from the *halaman*, the hierarchies of the village evident in the size of the dwelling and the quality of workmanship exhibited, which can be restricted by the village heads (Oliver 1987: 173–174).

Parallel to the Batak traditions of using aesthetics as a marker of social hierarchy is the Hausa practice of using external decorations to show wealth and prosperity (Fig. 6). The characteristic external house decorations of the Hausa appear to have developed in this century when attitudes to *azziki* or the gaining of prosperity and respect, which had thus far been restrained, were relaxed. Displays of success by homes of merchants and traders appear to have been condoned until 1930s by which time many houses had been elaborately decorated in *zanen gida* fashion and were seen in such cities such as Kano and Zaria. Over the mud walls, the finishing mud plaster was molded into the desired shapes by hand and coated with water-resistant layer of local cement made from mud, dung, and *laso*-mixed animal hair, and dye-pit residues. The pattern scribed with fingers with the unwanted parts scooped away left figures that stood in relief against the background. This was finished with local cement and whitewashed or painted in earth colors or in commercial paints (Oliver 1987: 180–181).

Methods of defining vernacular architecture have been categorized by others into four avenues of enquiry namely: object-oriented studies, socially oriented studies, culturally oriented studies and symbolically oriented studies (Upton 1993). While the first type tries to interpret the intention of a dwelling's creator and the second is concerned with overall social history, the third and fourth suggest a shift toward a typologized study of dwellings within certain socio-cultural and historic contexts, with the purpose of uncovering the enduring values of their builders and the symbols that signify deeper structures of society. A possibly fifth avenue of inquiry is that possibly qualified as "design-oriented studies" which include the work of those people who seek better ways of understanding the past without accepting a simplistic return to earlier traditions. While the above methods have been largely utilized to examine the American vernacular scene, one can easily apply such approaches to the larger field of traditional dwellings and settlements (Upton 1993).

The various methods of analyzing traditional dwellings and settlements also require a parallel study of the meaning of tradition itself. Some have argued that tradition is something that we value and pass on. The value attached is the element of "traditionality" sanctioned by history or nature itself. Intrinsic to tradition is the constraint of choice. The inability to choose the possibility of waiting is what provides value to an object or a practice. Unique to this concept is the introduction of time and of waiting to the concept of tradition. At some level, traditions emerge simply as a result of the absence of choice. It is the practice evolving out of constraint and that which we are able to reproduce that ultimately becomes tradition and is passed down from generation to generation. In modern societies, consumerism has eliminated many of the constraints folk societies faced and overcame by building on and creating traditions (Tuan 1989).

It can also be argued that there is no such thing as a "traditional building" but that there are only buildings that embody traditions. The idea that a building embodies tradition rather than it being the means by which the building came to be allows us to see the continuities between form, content, and process.

The application of the term traditional is vast and all encompassing. For this reason, defining a dwelling as being "traditional" requires an understanding of the attributes that lead to its being qualified in this manner. These attributes may include scale, temporality, continuity, economy, and technology. They may also be expanded to include the process and the product characteristics of built environments ranging from the identity of the designers and their interest on one hand to the degree of cultural specificity and morphological integration on the other hand (Rapoport 1989). The term traditional has almost always been seen as the opposite to the modern. Hence, in the view of some, it is not uncommon to view the traditional as being precontact and preliterate. This view, however, does not take into account how traditions emerge.

An important concern that lies at the heart of studying traditional dwellings and settlements is the common mistaken assumption that such built environments mainly exist in the Third World. It is interesting to note that those who study such places almost invariably do so by going elsewhere rather than looking at home. The Eurocentric view that modernity is fundamentally a Western project created an unjustified duality between the developed and the developing worlds when it came to viewing built environments. Begun earlier under British and French colonial rule, the "respect for the native" and the discussion around "traditional" forms was the outcome of the romanticism attached to the exercise of imperialism. Hence, modern was equated with Western, which has lead to an ongoing nostalgia particularly in the West for "authenticity" and "tradition" (Abu-Lughod 1995: 7–10). Similarly, this romantic view of traditional dwellings and settlements has led those who study and admire them to call for their preservation. But in many Third World societies, the rejection of the so-called traditional way of life should be seen as a natural evolutionary or reactionary process as opposed to a destructive one.

It has also been argued that the categorization of buildings and settlements into a "traditional" category has been a deliberate exercise on behalf of the community of architectural researchers. The idea of the architect as an aesthetic expert depended on distinguishing between professionally designed, aesthetically pleasing architecture, and the mundane structures produced by the masses for purely functional uses. Today, the search for the "traditional" must be seen through the need for differentiated products in a postfordist era. New movements in architectural practice such as New Urbanism attempt to use vernacular and traditional forms as a means of creating a sense of community by creating highly coded and zoned communities that reflect a continuity with the past. Designs borrowed from the traditional homes of the American South, for example, are used to invoke a sense of history. Here, the idea of invented tradition becomes intricately linked to the sense of identity and heritage that a community wants to project to outsiders. Poundbury, an experiment in town planning and architecture undertaken by the Prince of Wales, is a good example of this trend, produced under the belief that the best of architectural progress can be achieved by simply remaking new buildings in a traditional garb. Among the criticisms leveled at Poundbury has been the accusation of it being un-modern and nostalgically harking back to a past. Its praises have included the sentiments of its residents decrying contemporary architecture as being alienating and out of touch with the needs and aesthetics of the common people.

Today, and in many parts of the Third World following independence, many of the former colonies engaged in the exercises of modern nation-building. Their attempt to articulate a unique national identity became an important requirement for maintaining sovereignty. Traditions, whether new or invented, became part of a nation's identity and of the character of its physical spaces allowing these nations to create markers of uniqueness in an increasingly diversifying and competitive world.

One important cause of debates around using tradition as a means for designing and maintaining buildings and settlements has been the rise of global tourism. Some have argued that modernity depends in its very essence on instability and inauthenticity. For moderns, authenticity is thought to be elsewhere – in other historical periods and other cultures, in purer, simpler life-styles. The need for people to overcome the discontinuity of modernity materializes in their desire to see the authentic, the primitive, and the historical. In many instances, this desire materializes in the form of visiting the spaces of the "authentic" or "primitive" people and to view their ways of life (MacCannell 1976).

The search of tourists for authenticity and traditional lifestyles has become an important means by which countries and localities are able to generate substantial incomes. The preservation of traditional dwellings and settlements hence is not only a means of constructing local and national identity, but has emerged as an important mechanism to survive within the global economy. In this sense, "tradition" fulfills the multiple roles of identity creation, economic stimulus, and in some cases a tool for physical development.

Finally, the discussions about the consumption of tradition and the manufacture of heritage in a global era have led to calls for the end of tradition (AlSayyad 2001, 2004). Tradition, however, does not end. What may have ended, however, was our conception of it as a reservoir for revered authentic values. Today tradition may be found not only in real places but equally in the simulated and virtual world we inhabit. Tradition in built form will always be what we make and sustain everyday and everywhere through the occasionally contemptuous and ever-changing act of living.

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Dyeing: Indigo Dyeing in Sierra Leone

Cyrus Macfoy

Although many crops have played colorful roles throughout history, indigo appears to be the most colorful. Dyeing with indigo can be traced as far back as 7000 BCE, and is still widespread even today. This form of dyeing using various plant species is practiced in many countries and continents throughout the world, for example, in Mexico, Europe, Egypt, West Africa, Sumatra, Central Asia, Japan, the Americas and China (Adrosko 1968; Fox and Pierce 1990; Pettit 1974). Ancient Britons and other Europeans obtained the dye from *Isatis tinctoria* (woad) but later *Indigofera* from India and other Eastern countries. *Indigofera tinctoria* is native to India and Africa, while *Indigofera anil* of Central and South America, and *I. suffructicosa* is a native tropical American species adopted in Africa (Pettit 1974). Indigo is a vat dye (Vat Blue1), produced without mordants by a process consisting of a complex series of chemical reactions for the dye to be successful. A lot of care and patience is required. It shows fastness to light and water, it is insoluble and will dye all types of fibers (Adrosko 1968).

Now synthetic indigo used to dye blue jeans has almost totally replaced the natural one in most societies. This is because it is thought that synthetic indigo is cheaper to produce and more uniform in concentration than natural indigo. Natural indigo tends to be used today primarily by artists and craftsmen producing specialty products and by those dyers involved in textile conservation or historical recreation, or on ceremonial occasions notably weddings and funerals, and in traditional medicine (Abbiw 1990; Balfour-Paul 2001). These days some add a few crystals of synthetic indigo to the final dye in order to darken the hue.

Indigo dyeing using the plant species *Lonchocarpus cyanescens* or *Indigoferrra suffructicosa,* or other *Lonchocarpus* and *Indigoferra species,* such as *I. tinctoria* and *I. arrecta* all of which grow wild, were the most common and popular sources of color throughout West Africa (Polakoff 1982). Both Anglophone and Francophone countries were quite active in this indigenous technology, e.g. Mali, Nigeria, Senegal, Guinea, Gambia, Liberia, and Ivory Coast. Research on excavations from caves in Mali has shown that the indigo dyed cotton garments dated between the eleventh and the sixteenth centuries, indicating that by the eleventh century, weaving and indigo dyeing had already reached a high standard in West Africa. Many of the tie-dye designs found are similar to those still in use today (Balfour-Paul 2001).

Though the process is quite arduous, it provided a rich color usually missing in synthetically dyed fabric. The basic method of dye production is quite similar throughout the West Coast of Africa with some variation (Polakoff 1982).

In Sierra Leone, the word *gara* was once reserved only for indigo dyeing, but now it is used more widely for any form of dyeing, natural or synthetic. Since the 1960s, when commercial dyes started to be imported into the country from Germany, U.K. and Nigeria, various colors (violet, green, blue, red, brown, mauve, yellow etc.) became available in the market, apart from the blue "gara" color. The preparation of the commercial dyes and their application are far less complex and less time-consuming, but they are more expensive. Thus an improvement of the local natural dyes industry, taking due cognizance of the environment, will be invaluable in reducing the price. This latter unfortunately is now rarely used except by a few traditional dyers.

The gara industry, a local craft industry, has expanded over the years, giving an additional sense of economic satisfaction and self worth to these mainly female entrepreneurs who are self-employed. On occasion, men and children are also involved in the industry. Some gara dyers are full-time employees in other establishments but do the gara dyeing on a part-time basis. Some have even been trained at the Crystals Youth Club, a vocational center in Freetown. Other centers in different parts of the country include those sponsored by World Vision programs funded by the Canadian International Development Administration (CIDA) (CIDA Update 2001); CADS i.e. Center for Alternative Development Strategies for training and production of dyed goods; United Nations Mission in Sierra Leone (UNAMSIL) Trust Fund for training; Commonwealth Human Ecology Council who funded a gara project; and the Christian Reformed Church of North America. These regard the art of gara dyeing as more than a craft; it signifies hope. Displaced women as a result of the civil war, combatant girls and women have all benefited from such income generating tie-dye and batik training *inter alia.* Some non-governmental organizations (NGOs) have initiated microcredit schemes of which gara dyeing is one of the most commonly supported, but availability does not satisfy demand (Walker 1997). Since 80% of the dye producers are women and 95% of their raw materials imported, improvements of this dyeing technology will inevitably help improve the status of women and the environment.

Whatever the source of the dye, the beauty of the finished products obtained gives a great sense of pride and satisfaction to the dyers. This is more so with natural dyes since it gives some kind of connection to nature. Although attempts have been made to develop other colors such as green, brown and pink from local plants, these have not been followed up, mainly because of time and labor constraints.

Gara dyers also frequently investigate by trial and error. Innovative dyers sometimes investigate different types of fabrics, e.g. cotton, wool, polyester, viscose and rayon, rugs; different combinations of plants, and color fastness. Some even investigate adding the dye at various stages in the production of a garment (to fiber before it is spun, to yarn before it is woven or knitted into a fabric, or to the finished fabric or garment).

Even though there is tremendous usage and potential for development, especially for a country just coming out from a ten-year war, very few research investigations have been conducted in Sierra Leone on dyes, apart from reporting the methods used for indigo dyeing (Cole and Hamilton 1978; Crystal Youth Club 1985) and preliminary laboratory work on "gara" leaves (Wright and Cole 1988). In view of this paucity, further work on various plant species has however been conducted by MacFoy, Pratt, McEwen and Johnson at Fourah Bay College, University of Sierra Leone; and by MacFoy in the U.K. and USA.

Some of the results obtained from this work are reported in detail elsewhere (MacFoy 2003, 2005) on the ethnobotanical survey of the natural dyes used in Sierra Leone and on the history of indigo dyeing. In this West African country there is a wide gap between the rich and the poor and this latter group could benefit immensely from the development of natural dyes as a source of income generation. This research involved interviewing dyers, surveying the literature, cataloguing and collecting the plants used for preparing the dyes, obtaining knowledge of how the dyes are produced and the fabric dyed, and botanical identification of the plants.

Process for Indigo Dye Production and Dyeing of Fabric

This indigo dye is the most common natural dye in Sierra Leone, and several methods (seven identified in this study) are used with varying degrees of similarities for its production and subsequent use in fabric dyeing. In general, they involve production either from fresh leaves in the dyepot, leaf fermented into leaf balls but dye not extracted, indigo dye extracted into an insoluble lump, or use of the synthetic dye. In some cases up to four other plant species are added to the dye bath, for example, *Morinda germinata* (wanda) roots, and *Cola nitida* fruits (cola), *Mangifera indica*, *Rhizophora recemosa, Jatropha curcas* (fignut), *Capsicum frutescens* (pepper); and caustic soda (sodium hydroxide), which creates an alkaline pH environment for the fermentation to proceed from 3–7 days; local alum or ash from the 'Kobe' tree (*Sterculia tragacantha*); a black powder called colmet. Rusty nails or metal cups, or *Alchornia cordifolia* (Christmas bush) are also sometimes added to darken the shade. Another method involves mixing the indigo dye with sodium hydroxide (caustic soda) and sodium hydrosulphite in a ratio of 1:1:1 in water.

Dyeing is achieved by first washing the fabric with soap and water and then immersing the cloth (a special white fabric called bryleon of varying quality, or poplin (cotton/polyester) in the dye for different periods of time (sometimes varies from hours to 3–4 days) drying, dipping again, drying and so on, until the desired shade is obtained. After this, the dyed fabric is washed, dried in the sun and ironed by traditionally pounding with a stick on a wooden slab to produce a glossy shine on the cloth or by using other modern forms of ironing.

Pattern Production

Apart from dyeing the whole material uniformly, various patterns can be produced by dyeing only parts of the fabric, leaving the remainder undyed. These methods are known as sewing, tie-dyeing, knotting, folding, and resist dyeing or the use of candle wax/batik.

The full details of these are reported in MacFoy 2005.

It is clear from the above that natural dyes have a tremendous potential in Sierra Leone and other developing countries. There is a high demand for natural dyes in textile dyeing and in the food, beverage and cosmetics, paper and pulp industries in the US, Europe and Japan. Natural dyes can also serve as useful materials for teaching and experimenting in Adult Education Programs, and in schools and colleges.

Apart from dyeing fabrics, the colors obtained from the natural dyes could also be used as watercolors on paintings by making them thicker as well as experimenting on them for their use as food colorings, biological stains, inks, hair dyes, indicators in titration, in addition to their use in soaps, photography, paper, leather, medicine, eggs, plastics, rubber, automobile finishes, cosmetic industries, rugs, and table mats. Natural dyes can also be used to redye old clothing.

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Dyes

MURDO J. MACLEOD

The human urge to paint the body with symbolic, warlike, or identifying colors may have been among the earliest impulses which led to the discovery of color-yielding clays and plants. The dyeing of human clothing followed. Encounters, both warlike and peaceful, between groups then led to the identification of certain colors with specific regions or groups of producers, and exchanges began. This specialization and trade eliminated many of the poorer dyes of prehistoric times, which may have numbered many hundreds, and by the time recorded history took note of dyes only a relative few still saw widespread use.

Dye exchanges at first were very local. The major ones in ancient times were usually confined to the great areas of early culture and urbanization such as China, northern India, and the eastern Mediterranean. Later, trade in dyestuffs became more long distance, and, with European intrusions into Asia and invasion of the Americas, transoceanic and worldwide. This huge trade in natural dyes was destroyed and again reduced to a local level by the invention of coal tar or aniline dyes and other chemical dyes, in the mid-nineteenth century.

The production and exchange of colorants were always associated with certain other industries. Cloth manufacture and weaving were certainly the main ones. Others arose out of the limitations of some natural dyes. Many were not "fast"; i.e., they tended to fade or discolor when exposed to light, frequent washing, or wear and tear. Accordingly, much effort was historically expended in the search for mordants (dye fixers). Many of these were readily available, such as blood, dung, or urine. Various acids, alkalis, and wetting agents were widely used. Alum, an astringent, was probably the most common, and large cargoes were mined and shipped to dye factories and market towns. Minerals such as copper, tin, and iron also came to be used for mordanting, and thus added to the importance of mining for these minerals. Tree-borne dyes led to forest cultivation and above all, to extensive and destructive logging industries. The dye-yielding attributes of plants such as indigo stimulated the creation of plantation complexes.

The production of natural dyes and their use in dyeing textiles were often complicated skills requiring apprenticeships and years of training. Certain towns became known as dye centers or markets, such as ancient Tyre or medieval Venice in the Mediterranean, or Oaxaca in colonial Mexico. Guilds of dyers and castes devoted to weaving and dyeing were of considerable importance in European and Indian societies from medieval times.

Before European intrusion reached sub-Saharan Africa, Asia, Australia, and the Americas, there were several dyes which were produced and distributed over large areas. Perhaps the best known of the early root dyes was madder (from the Rubiaceae, of which there are over 30 species). *Rubia tinctorum* roots were used to obtain red dye in India, and were also known to the ancient Persians, Egyptians, Greeks, and Romans. For centuries Baghdad was the center of the madder trade, and it was cultivated extensively – rather than gathered as elsewhere – in Mesopotamia. After its use spread to Western Europe, the Dutch became the most systematic and scientific madder growers, combining it with their leading role in cloth making (wool) and cloth importing (silks and linens). The French began to compete in the eighteenth century, but the French revolution damaged the industry and it never revived.

Before the European expansion, the most widely used dye made from plant leaves was woad (*Isatis tinctoria* of the Cruciferae family). It yielded various blues and grays. Although easy to produce in the temperate areas of Europe and Asia, it was not a very brilliant or fast dye. Woad in medieval and early modern Europe was manufactured and marketed by powerful guilds which – by monopolies, boycotts, and powerful legislation – managed to prevent large-scale intrusions of other blues, especially indigos, from America and Southeast Asia, until the seventeenth century.

The leading dye made from woad has always come from brazilwood (*Caesalpinia echinata*), although many other trees such as lima, sapan, and peachwood, all soluble redwoods, are often lumped together as brazilwoods. These medium-sized trees have been widely used for dyestuffs in many parts of the world. They are cut into small logs, ground to powder, then soaked and fermented, often with an aluminum or other metal ore mordant. They yield reds and browns, except on silks. Before the sixteenth century, India, Sumatra, and Ceylon (Sri Lanka) were the main producers. Other woods, such as camwood from India, which imparted a rough feeling to cloth because of its resins, were also traded. Cutch or kutch, a brown dye, has been manufactured in India for over 2,000 years and comes from the leaves and twigs of various acacia and mimosa trees.

Humans have elaborated dyes from the bodies of insects and animals for millennia. The most expensive, prestigious dye of ancient times was Tyrian purple. It was manufactured in Crete by 1600 BCE, but is usually associated with the Phoenicians. Tyre became the great market center for this dye until captured by the Arabs in AD 638. Phoenician traders had spread its use all over the Mediterranean. It was so rare and costly that in many areas this fast, blue to purple dye was restricted to the clothing of high ecclesiastics, the aristocracy, or simply the ruling family. This colorant is extracted from a gland found in several shellfish, most notably *Murex trunculus*. A few similar dyes were used in the Americas before and after the European invasions, especially in Nicoya (Costa Rica) and on the Peruvian coast, but the American sources never produced enough dye to be of importance beyond local markets.

Insects have also been significant to the natural dye industry. Kermes is the oldest and most widespread of these dyestuffs. The insects harvested, *Coccus arborum* and *Coccus ilicis*, live on the holm oak (*Quercus ilex*), the shrub oak (*Quercus coccifera*), and a few other trees. Kermes is Armenian for “little worm” and is a scarlet dye. It is mentioned in the Old Testament and in the writings of ancient Greece, but its origins are probably Asiatic and it was much used in India.

The European invasions of South and Southeast Asia and of the Americas greatly changed dye usage by bringing new and better colorants into the international markets. Indigo, which produces a range of blues, became for about two centuries the most important of all dyestuffs. It is a vegetable dye of considerable fastness, and has been known in parts of Asia for over 4,000 years. *Indigofera tinctoria*, of which only the leaves bear dye, is of the order *leguminosae*, and belongs to the pea family. It was found in India, Southeast Asia, Africa, and America. It has been discovered in both Egyptian and Inca tombs, and its continent of origin is obscure.

Dutch ships carried indigo throughout the Indian Ocean, and then, in the seventeenth century, to Europe, where, despite a struggle, it eventually displaced woad. Bengal supplied large quantities in the late eighteenth century to the British textile industry. When American indigo, mostly produced in Central America, the Carolinas, and Georgia, began to flood the market in the eighteenth century, the woad industry collapsed in the face of this cheaper and better dyestuff.

Cochineal, a scarcer and more expensive dye, had a similar history. It is made from an American insect, *Coccus cacti*, which feeds on a cactus (*Nopalia* or *Opuntia cochinellifera*), and was used in Mesoamerica, especially in the Oaxaca region, long before the Europeans arrived. While its production is elaborate and costly, the result is a superior scarlet or crimson dye, and it soon replaced kermes in Asian and European markets and dyeworks. After bullion it was the most expensive item carried by the Spanish treasure fleets.

The brazilwood industry grew after the products of the American continents began to enter world commerce. Vast new stands were found in Brazil – hence the name – and to this was added logwood or campeachy wood, a large, tropical American tree (*Haematoxylon campeacheanum*) found especially in Campeche, Tabasco, and Belize. It yields black or blue dyes, plus edible seeds called *allspice*. By the seventeenth century it was in use in Africa and Europe.

One crop from America moved to Asia. Annato (*Bixa orellana*) was used by Mesoamerican peoples largely as a food additive and colorant, but when taken to Southeast Asia and India this dye, which is a poor, fugitive yellow to red, was used for cloth, especially monks' robes. It is so culturally accepted in these regions today that many writers describe it as indigenous.

The new dominance achieved by Asian and above all American dyes such as indigo and cochineal, both of which were spread by European expansion, lasted less than two centuries. They, in their turn, were overwhelmed by the new coal tar or aniline dyes invented in the mid-nineteenth century. Many of the natural dyes, however, remain in use in local and peasant economies.

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East and West

Edwin J. Van Kley

As traditionally used in the West, the terms East and West imply that the two are somehow of equal importance. While that might be arguable in the nineteenth and twentieth centuries it was certainly not true during the long reaches of human history prior to the nineteenth century. By 500 BCE the globe supported four major centers of civilization: the Chinese, the Indian, the Near Eastern, and the Western, considering Greek culture antecedent to what eventually became the West. Of the four the West was probably the least impressive in terms of territory, military power, wealth, and perhaps even traditional culture. Certainly this was the case after the fall of the Roman Empire in the fifth century AD. From that time until about AD 1500 the West probably should be regarded as a frontier region compared to the other centers of civilization.

From roughly 500 BCE to AD 1500 a cultural balance was obtained between the four major centers of civilization. During these millennia each center continued to develop its peculiar style of civilized life, and each continued to spread its culture and often its control to peoples and lands on the periphery. While the inhabitants of each center of civilization were aware of the other centers, sometimes traded with them, and occasionally borrowed from them, the contacts were sufficiently thin so that no one center threatened – commercially, militarily, politically, or culturally – the existence of the others. During this long period, that is through much of civilized human history, there was no question of Western superiority or hegemony. No visitor from Mars would likely have predicted that the West would eventually dominate the globe.

Obviously the Greeks and Romans knew quite a bit about the Near-Eastern world, especially about the Persian empire, that of Alexander the Great, and the successor states formed after its collapse. About India and China they knew much less, and what they knew was much less accurate. Although Herodotus (ca. 484–425 BCE) reported some things about India, most of the information available to the Greeks came from the writers who described Alexander's campaigns in the Indus Valley (326–234 BCE) and from Megasthenes. They described India as fabulously rich, the source of much gold and precious stones. It was hot; the sun stood directly over-head at midday and cast shadows toward the south in summer and toward the north in winter. They described huge rivers, monsoons, tame peacocks and pheasants, polygamy, and the practice of *suttee* (widow burning). However, they also reported fantastic things such as gold-digging ants, cannibals, dog-headed people, and people with feet so large that they served as sun shades when sitting. The Romans knew that India was the source of spices and that China, which they called Serica and well as Sinae, was the source of silk. There are even possible traces of Asian influence in some Roman silver and ivory work and perhaps even some influence of Buddhism on Neo-Platonism and Manichaeanism.

From about the fourth century, even before the fall of the Roman empire, until the return of Marco Polo from China in the late thirteenth century, Europe or the West added little factual information to its understanding of India and China. After the fall of the Roman empire there was no direct trade between Europe and Asia, and thus there were no opportunities to test the stories by observation. The rise of Islam in the seventh and eighth centuries completed Europe's isolation. During these centuries the old stories inherited from the Greeks were retold and embellished with little effort to distinguish fact from myth. To these were added three legends of more recent origin: the stories celebrating the heroic exploits of the mythical Alexander; those rehearsing Saint Thomas the Apostle's missionary journey to India and his subsequent martyrdom; and those describing the rich, powerful, Christian kingdom of Prester John somewhere to the east of the Islamic world with which European rulers dreamed of allying against the Muslims. Even the trickle of precious Asian products brought to Europe by intermediaries seemed only to confirm the image of Asia as an exotic and mysterious world, exceedingly rich and exceedingly distant.

The rise of the Mongol empire in Asia during the thirteenth century resulted in direct overland travel between Europe or the West, and China. The Mongols' success also revived hopes among European rulers of finding a powerful ally to the east of the Muslims. Even the devastating Mongol incursions into Poland and Hungary in 1240 and 1241 scarcely dampened their enthusiasm. Already in 1245 the pope sent an embassy led by John of Plano Carpini to the Mongol headquarters near Karakorum. He was followed during the ensuing century by a fairly large number of envoys, missionaries, and merchants, several of whom wrote reports of what they saw and did in Eastern Asia. Marco Polo's was the most comprehensive and reliable, and the most widely distributed of the medieval reports. By the time the Polos first arrived at Kublai Khan's court in 1264 it was newly established at Cambaluc (Beijing), from which the khan ruled the newly conquered Cathay (China). Like many other foreigners during the Mongol period (the Yuan Dynasty in China, 1260–1368) the Polos were taken into the khan's service. They were employed in the Mongol administration for 17 years during which time Marco traveled extensively throughout China. On his return to Europe he produced the first detailed description of China in the West based primarily on first-hand observation and experience. No better account of China appeared in Europe before the middle of the sixteenth century. Marco Polo described China as the wealthiest, largest, and most populous land in the thirteenth-century world. While his understanding of Chinese culture was minimal he accurately and admiringly described cities, canals, ships, crafts, industries, and products. He noted the routes, topography, and people encountered in his travels, including his voyage home through Southeast Asia to Sumatra, Ceylon and along the west coast of India.

The decline of the Mongol empire and the establishment of the Ming Dynasty in China in 1368 severed the direct connection between Europe and China. The fall of Constantinople in 1454 and establishment of the Turkish empire in the Near East disrupted the older connections between Europe and the near East and India. Europe's isolation from the outside world was complete, not to be restored until the opening of the sea route around the tip of Africa in the waning years of the fifteenth century. During this period no European appears to have traveled to China. Some few travel reports refer to India and Southeast Asia. Of them only that written by the humanist Poggio Bracciolini in 1441 and based on Nicolò de Conti's travels added to the West's store of knowledge about India and confirmed some of the more accurate of the ancient Greek reports. In fact amid the Renaissance humanists' enthusiasm for the rediscovery of ancient Greek literature, the Greek reports of India received new respect and attention.

During the long era of cultural balance before AD 1500 many important technological and scientific inventions and innovations appear to have migrated to the West from the other centers of civilization, more often from China than from the others. The migration of technology was usually gradual, involving one or more intermediaries, the inventions usually being established in the West without any clear ideas about their origins. Much of the basic technology that enabled the Europeans to sail directly to Asia in 1500 and later to begin their march towards global domination, was known earlier in the Asian centers and only later adopted or separately invented in Europe.

Among the more important technological borrowings were gunpowder, the magnetic compass, printing, and paper, all apparently originating in China. For none of them is the path of migration entirely clear, and thus for none of them can the possibility of independent invention be entirely ruled out. Gunpowder, for example, was known in China by 1040 and did not appear in Europe until the middle of the thirteenth century. The magnetic compass was fully described in an eleventh-century Chinese book, *Meng Qi Bi Tan* (Dream Pool Essays), written by Shen Gua in 1088. It began to be used in Europe during the late twelfth or early thirteenth century. Most likely Europeans learned about it from the Arabs. The case for moveable-type printing having been borrowed from the Chinese is more hotly debated than that for gunpowder or the compass. Wood-block printing was used in China by the seventh century, and paper was invented much earlier; the first printed books appeared there during the ninth century, six centuries before the invention of printing in the West by Johannes Gutenberg in 1445. Block printing probably became known in Europe through the introduction of printed playing cards and paper money during the Mongol period; medieval travelers frequently mentioned these. Because of the large number of Chinese characters the Chinese continued to prefer printing from page-sized blocks of wood carved as a single unit; European printing almost immediately employed moveable type, thus convincing some scholars that it was a separate invention. However, while they may have preferred block printing the Chinese also developed moveable type as early as the eleventh century. For none of these basic inventions taken separately – gunpowder, the compass, and printing – is the case for its diffusion from China to Europe indisputably demonstrated. Taken together, however, along with a rather large number of other technological and scientific innovations such as paper, the stern-post rudder, the segmented-arch bridge, canal lock-gates, and the wheelbarrow, which all appear to have migrated from China to the West, it becomes apparent that the general flow of technology and science in premodern times was from East to West. This would seem to increase the likelihood that these basic innovations also migrated to Europe from Asia. Those who used the technological innovations probably cared little about their ultimate origin and apparently did not seek it out. Nevertheless European mariners after 1500, confronted first hand with evidence that printing, gunpowder, the mariner's compass, and the like had been in use much longer in Asia than in Europe, frequently suggested that they had been borrowed from the Asians.

Even before gunpowder a group of military innovations found their way to Europe from China and India, again through intermediaries and apparently without Europeans' being aware of their origins. The Chinese form of the Indic stirrup was the most important of these and may have been as important to military development in the eighth century as gunpowder was later. The Javan fiddle bow and the Indian Buddhist pointed arch and vault were acclimated in Europe before 1100. The traction trebuchet along with the compass and paper appeared in the twelfth century. Still more important for subsequent Western scientific achievements was the adoption of Hindu–Arabic mathematics in the twelfth and thirteenth centuries: the Indian system of arithmetical notation, trigonometry, and the system of calculating with nine Arabic numbers and a zero were all practiced in India as early as AD 270. Some components of Indian mathematics may have come from Babylonia or China. They came to Europe, however, through the translation of Arabic writings, and the European borrowers usually credited India rather than China, Babylonia, or the Arabic intermediaries as the source of the new mathematics. Along with Indian mathematics, Europeans learned some elements of Indian astronomy and also became fascinated with the Indian idea of perpetual motion.

Also before 1500, Europeans sometimes attempted to imitate desirable Asian products, not always successfully. Already in the sixth century the Byzantine emperor Justinian monopolized the silk trade in his realm and expressed his determination to learn the secret of its manufacture. In 553 a monk supposedly smuggled some silkworm eggs into Constantinople carrying them in a hollow stick, perhaps of bamboo. Nothing is said in the story about the importation of silk technology, but less than a century later sericulture had obviously taken root in Syria. From there it spread to Greece, Sicily, Spain, Italy, and France. In Italy during the fourteenth century, water power was used in silk spinning, as it had been used in China much earlier. Attempts to imitate Chinese porcelain, however, were unsuccessful. The best attempts to do so were made in northern Italian cities during the fifteenth century. None, however, approached Chinese porcelain in composition, color, or texture. Nor did the Dutch Delftware of the seventeenth century, another attempt to imitate the Chinese product. Not until the eighteenth century were European craftsmen able to produce a hard-paste porcelain to rival that of China. Also appearing in Europe before 1500 were less important devices or techniques such as the Malay blowgun, playing cards, the Chinese helicopter top, the Chinese water-powered trip-hammer, the ball and chain governor, and maybe Chinese techniques of anatomical dissection.

While impressive, the West's importation of Asian science and technology before 1500 in no way deflected Western culture from its traditional paths. Seldom was the provenance of the new inventions or techniques known, and they could all rather easily be incorporated into the traditional Christian European world-view. They did not provoke any serious questions about the European way of life, its religious basis, its artistic and cultural traditions, or even its traditional scientific views. This is also true for the artistic and cultural borrowings from Asia prior to 1500. They too were often unconscious, and even when they were not they were regarded as embellishments or decoration, rather than in any way a challenge to traditional themes. For example. the incorporation into the Christian calendar of Saints Baarlam and Josephat, derived as they were from stories of the life of Buddha, resulted not in a Buddhist challenge to the Christian faith but simply in the addition of two new saints to the growing Christian pantheon.

Nevertheless, the borrowing and adaptation of Asian science and technology by the West before 1500 was indispensable in making the long overseas voyages to Asia and the protection of the ships and shore installations possible. Without gunpowder, cannons, the compass, the stern-post rudder, etc. there would have been no European expansion. While they had lagged well behind the other centers of civilization through most of civilized history, by 1500, European marine and military technology were beginning to equal that of the Near East. India, and China, and were obviously superior to that of the peripheral areas of Africa, Southeast Asia, and the Americas. The Portuguese voyages down the coast of Africa and Columbus' voyage across the Atlantic attest to Europe's rapidly improving technology.

A small Portuguese fleet under Vasco da Gama reached Calicut on the Malabar Coast of India in 1498, thus establishing direct contact between Europe and Asia by sea and also inaugurating a new era in the relationships between the four major centers of civilization on the globe. Soon after 1500 the Europeans began to dominate the seas of Asia, the Portuguese in the Indian Ocean being the first. The Portuguese, and later the Dutch and the English, moved along sealanes, visited seaports, and fitted into a trading world which had been developed earlier by Muslim traders and which stretched from eastern Africa to the Philippines. As the Europeans at first tried to compete in that world and later tried to dominate and even to monopolize it, they found Muslim merchants and merchant-princes to be their most formidable opposition. That they were able to move so rapidly and effectively into that international trading system was due not so much to their superior technology and fire-power as to the fact that the great Muslim empires of the sixteenth century – the Ottoman Turkish, the Safavid Persian, and the Mughul in northern India – seem to have been too busy consolidating their newly won empires to contest the European intrusion. These Muslim empires, as well as the Southeast and East Asian empires of Siam, Vietnam, China, and Japan had all as a matter of governmental policy turned away from the sea and looked inward to control of their land empires and to land taxes as the source of their wealth and power. Had any or all of these major Asian and Near-Eastern states seriously resisted the western incursion the story might have had a different conclusion. Apart from Muslim traders in the Indian Ocean those who formidably opposed European power in the sixteenth and seventeenth centuries were small Muslim commercial port-city states like Makassar on Celebes and Aceh on Sumatra. The Mughul emperors in northern India usually allowed the Europeans to trade freely in their ports, often exempting them from customs duties. Apart from the illegal but locally tolerated Portuguese settlement in Macao the Europeans were not permitted to trade in China at all. China briefly contested Dutch maritime power only in 1624 after the Dutch had spent 2 years raiding the coast of Fukien Province, burning villages, seizing junks, enslaving their crews, and constructing a fort on one of the Pescadores Islands; all in an effort to force the Chinese to allow them to trade freely at some port along the Chinese coast. Confronted with a full scale Chinese war fleet the Dutch commander hastily sued for peace and gratefully accepted the Chinese admiral's offer to let the Dutch trade on Formosa, which was not yet considered Chinese territory. From 1500 until about the middle of the eighteenth century the Europeans were able to carve out empires in the Americas, insular Southeast Asia, and the Pacific Islands, but they did not threaten the major centers of civilization in Asia.

During the first three centuries of direct maritime contact between Europe and Asia (1500–1800) the Westerners showed little sense of cultural superiority toward the high cultures of Asia. If anything they tended to exaggerate the wealth, power, and sophistication of the other centers of civilization. Most Europeans were confident that Christianity was indeed the true religion, and they quickly began to send missionaries to convert Asian peoples. By 1600, if not earlier, they were also justifiably confident that European mathematics, science, and technology were superior to that of the Asians. Those areas aside, however, Europeans were endlessly fascinated with what they discovered beyond the line and realized that they still had much to learn from the high cultures of Asia. Between 1500 and 1800 the currents of cultural influence continued to flow mainly from east to west, but during this era the impact of Asia on the West was usually more conscious and deliberate than previously, and it was primarily in areas other than science and technology.

The new seaborne commerce with Asia almost immediately brought greatly increased quantities and varieties of Asian products into Europe. Pepper and fine spices were the first to appear on the docks in European ports, but they were soon followed by such goods as Chinese porcelain and lacquerware, tea, silks, Indian cotton cloth, and cinnamon. Following these staples of the trade came also more exotic products: Japanese swords, Sumatran or Javanese krisses, jewelry, camphor, rhubarb, and the like, the list is very long. Some of these products, such as tea, provoked striking social changes in Europe. Attempts to imitate others resulted in new industries and in new manufacturing techniques, Delft pottery in imitation of Ming porcelain, for example. Attempts to compete with cheap Indian cotton cloth seem to have touched off a technical revolution in the British textile industry which we customarily regard as the beginning of the industrial revolution.

Along with the Asian products came descriptions of the places and peoples who had produced the products. The earliest sixteenth-century descriptions usually seem designed to inform other Asia-bound fleets about the conditions of trade. After Christian missions were established they were often intended to elicit support for the missionaries. However, before long the travel tales and descriptions became popular in their own right and profitable to publish. During the seventeenth century what had been a sizeable stream of literature about Asia became a veritable torrent. Hundreds of books about the various parts of Asia, written by missionaries, merchants, mariners, physicians, soldiers, and independent travelers were published during the period. For example, during the seventeenth century alone there appeared at least 25 major descriptions of South Asia, another fifteen devoted to mainland Southeast Asia, about twenty to the Southeast Asian archipelagoes, and 60 or more to East Asia. Alongside these major independent contributions stood scores of Jesuit letterbooks, derivative accounts, travel accounts with brief descriptions of many Asian places, pamphlets, newssheets, and the like. Many of the accounts were collected into the several large multivolume compilations of travel literature published during the period. In addition to the missionaries accounts, travel tales, and composite encyclopedic descriptions, several important scholarly studies pertaining to Asia were published during the seventeenth century: studies of Asian medicine, botany, religion, and history; and translations of important Chinese and Sanskrit literature.

The published accounts range in size from small pamphlets to lavishly illustrated folio volumes. They were published in Latin and in almost all of the vernaculars, and what was published in one language was soon translated into several others, so that a determined enthusiast could probably have read most of them in his own language. They were frequently reprinted in press runs which ranged from 250 to 1,000 copies. Five to ten editions were not at all uncommon, and some of the more popular accounts would rival modern "best sellers." In short the Early Modern image of Asia was channeled to Europe in a huge corpus of publications which was widely distributed in all European lands and languages. Few literate Europeans could have been completely untouched by it, and it would be surprising if its effects could not have been seen in contemporary European literature, art learning, and culture.

From this literature European readers could have learned a great deal about Asia and its various parts. Perhaps most obviously their geographic horizons would have been continually expanded. Gradually Europeans gained accurate knowledge about the size and shape of India, China, and Southeast Asia. During the seventeenth century, for example, several puzzles which had plagued earlier geographers were solved: for example, the identification of China with Marco Polo's Cathay, the discovery that Korea was a peninsula and Hokkaido an island. By the end of the century Europeans had charted most of the coasts of a real Australia to replace the imagined antipodes as well as those of New Guinea, the Papuas, numerous Pacific islands, and parts of New Zealand. Interior Ceylon and Java, as well as Tibet were visited and accurately described by Europeans before the end of the century. By 1700 only areas of continental Asia north of India and China, the interior of Australia, New Zealand, and New Guinea and parts of their coastlines remained unknown to the Europeans. Most of these lacunae were filled during the eighteenth century. Even more impressive than the greatly expanded geographic knowledge available to European readers in early modern times was the rapidly increasing and increasingly detailed information about the interiors, societies, cultures, and even histories of Asia's high cultures. Already during the seventeenth century European readers could have read detailed descriptions and even viewed printed cityscapes and street scenes of scores of Asian cities, interior provincial cities as well as capitals and seaports, and they could have learned countless details about Asia's various peoples, their occupations, appearance, social customs, class structures, education, ways of rearing children, religious beliefs, and the like. Details regarding Asia's abundant natural resources, crafts, and arts were described as well as its commercial practices and patterns of trade. Asian governments were described in exceedingly close detail, especially for major powerful states such as China, the Mughul Empire, Siam, and Japan. Jesuit missionaries in China, for example, described the awesome power of the emperor, his elaborate court, the complex imperial bureaucracy and its selection through competitive written examinations, and the Confucian moral philosophy on which it was all based. They also described the frequently less orderly and less savory practice of Chinese government, complete with detailed examples of officials' abuse of power and competing factions within the administration. Similar details were reported for the governments of all the major states as well as for countless smaller states. By the end of the seventeenth century European observers had published many sophisticated accounts of Asian religions and philosophies; not only the frequently deplored Hindu "idolatry" and widow burning, but also the Hindu world view which lay beneath the panoply of deities and temples, the various schools and sects of Hinduism, and the ancient texts of Hindu religion. Similarly sophisticated and detailed accounts of Confucianism and Buddhism were available, as well as descriptions of the beliefs of peoples like the Formosan aborigines, the Ainu of Hokkaido, and the inner Asian and Manchurian tribes. Seventeenth and eighteenth-century readers could also have learned much about Asian history; especially, but not exclusively, that of Asia's high cultures. By the mid-seventeenth century, for example, a very detailed sketch of China's long dynastic history culled from official Confucian histories by Jesuit missionaries had been published. Martino Martini wrote the *Sinicae historiae decas prima*, which was published in Munich in 1658. During the eighteenth century an important Chinese history, the *Tongjian Gangmu* (Outline and Details of the Comprehensive Mirror [for aid in government]) by Zhu Xi, was translated into French in its entirety by Joseph-Anne-Marie de Mailla and published in Paris (*Histoire générale de la Chine*, 1777). Not only history, however, but also news was reported to Early Modern readers. Their image of Asia was surely not that of a static world far away. Among the more important events reported in almost newspaper-like detail during the seventeenth century alone were the Mughul emperor's successful campaigns in the south of India, the Maratha challenge to Mughul supremacy, the fall of the Indian states of Golconda and Vijayanagar, the Manchu Conquest of China in 1644, the feudal wars and the establishment of the Tokugawa shogunate in Japan (1600), and the internal rivalries and wars in Siam and Vietnam. Natural disasters such as earthquakes, fires, volcanic eruptions, and the appearance of comets were also regularly reported. Readers of this richly detailed, voluminous, and widely distributed literature may well have known relatively more about Asia and its various parts than do most educated westerners today.

The post-1500 literature on Asia also contains a great many descriptions of Asian science, technology, and crafts: such things as weaving, printing, papermaking, binding, measuring devices, porcelain manufacture, pumps, water-mills, hammocks, palanquins, speaking tubes, sailing chariots, timekeepers, astronomical instruments, agriculture techniques and tools, bamboo and other reeds for carrying water, as well as products such as musical instruments, wax, resin, caulking, tung-oil varnish, elephant hooks and bells, folding screens, and parasols. Some, such as Chinese-style ship's caulking, leeboards, and strake layers on hulls, lug sails, mat and batten sails, chain pumps for emptying bilges, paddle-wheel boats, wheelchairs, and sulfur matches were quickly employed or imitated by Europeans. Some provoked documented experimentation and invention: Della Porta's kite in 1589, and Simon Stevin's sailing chariot in 1600. The effects of the new information on the sciences of cartography and geography are obvious and profound. Simon Stevin, whose sailing chariot was inspired by descriptions of similar Chinese devices, also introduced decimal fractions and a method of calculating an equally tempered musical scale: both of which might also have been inspired by Chinese examples. The sixteenth-century mariners' cross staff may have been inspired by the Arab navigators' *kamals*. The Western science of botany was profoundly influenced by the descriptions of Asian flora and by the specimens taken back to Europe and successfully grown in European experimental gardens; rice, oranges, lemons, limes, ginger, pepper, and rhubarb were among the most useful. More important for botany, however, the Asian plants provoked comparisons with familiar plants, the development of comprehensive classification schemes, and thus the beginnings of modern plant taxonomy. Some Asian cures (herbs and drugs) were borrowed, especially for tropical medicine. Chinese acupuncture, moxibustion, and methods of diagnosis by taking the pulse were minutely described and much admired by European scholars, but it is not yet clear to what extent they were actually used in Europe.

The flow of cultural influence was not exclusively from East to West between 1500 and 1800. Many Asians became Christian. Able Jesuit missionaries translated scriptures and wrote theological works in Chinese and other Asian languages; they also translated European mathematical and scientific treatises into Chinese. The Kangxi emperor himself studied Euclidian geometry, Western astronomy, geography, the harpsichord, and painting under Jesuit guidance. Like many Chinese he was fascinated by European clocks. Many Asians, including the Chinese, learned how to use western firearms and cast western-style cannon. However, the cultural consequences of these efforts were disappointingly small and of short duration. Before the end of the eighteenth century they seem largely to have disappeared along with the Christian mission. The Japanese, however, even during the closed-country period after 1640, were far more curious about Western science. Samurai scholars, for example, studied Dutch medicine and science and in the eighteenth century repeated Benjamin Franklin's kite-flying experiment. Nevertheless through most of the early modern period the Europeans were far more curious about and more open to influence from Asia than were any of the high cultures of Asia to influence from the West.

During the seventeenth and eighteenth centuries the new information about Asia influenced Western culture primarily in areas other than science and technology. The extent of this impact remains to be comprehensively studied, and even of that which is known only a few examples can be mentioned here. Asian events and themes entered European literature in scores of instances from Lope de Vega, Ariosto, Rabelais, and More in the sixteenth century to the several Dutch, German, and English plays and novels depicting the fall of the Ming Dynasty and the triumph of the Manchus in the seventeenth century, to Voltaire's literary and philosophical works in the eighteenth. Even popular literature, seventeenth-century Dutch plays and pious tracts, for examples, shows surprising familiarity with the new information about Asia. Asian influences in European art, architecture, garden architecture, and the decorative arts also began in the sixteenth century and culminated in the *chinoiserie* of the eighteenth century. Confrontation with China's ancient history challenged the traditional European Four-Monarchies framework of universal history and touched off a controversy among European scholars which by the mid-eighteenth century resulted in an entirely new conception of ancient world history. Some scholars, beginning with Pierre Bayle in the late seventeenth century, have detected a Neo-Confucian influence in the thought of Spinoza and in some aspects of Leibniz's philosophy. Chinese government and especially the examination system were frequently held up for emulation by European states during the seventeenth and eighteenth centuries. It might well be that the institution of written civil-service exams in Western states, beginning with eighteenth-century Prussia, was inspired by the Chinese example. Of more general importance that any single instance of influence, however, was the challenge presented by long-enduring, sophisticated, and successful Asian cultures to traditional European assumptions about the universality of their own. Perhaps here can be found the beginnings of cultural relativism in the West.

By 1600 European science and technology generally and especially marine and military technology outstripped that of any Asian society, whatever had been borrowed earlier from them. Also, while the fascination with and appreciation of the high cultures of Asia continued through most of the eighteenth century, the West between 1600 and 1800 experienced the radical transmutation of its traditional culture which resulted in the development of a rational, scientific approach to the use of nature, and society – to agriculture, business industry, politics, and above all warfare – which we have traditionally associated with the Scientific Revolution, Enlightenment, and Industrial Revolution. This transmutation has enabled Western nation-states during the past two centuries to establish the worldwide competitive empires which came to dominate all the other centers of civilization and has resulted in the global dominance of Western culture. The triumph of this transmuted Western culture has reversed the centuries-long East-to-West flow of cultural influence and threatens all of the world's traditional cultures. It should be remembered, however, that this rational, scientific, industrialized Western culture was not an obviously natural outgrowth of traditional Western culture, that in its early development it received important basic components from Asia, and that its triumph threatens traditional Christian Western culture almost as seriously as it threatens those of Asia.

See also: ►Compass, ►Gunpowder, ►Paper and Papermaking, ►Shen Gua, ►Military Technology, ►Mathematics, ►Technology, ►Zero, ►Colonialism and Science

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East and West: Africa in the Transmission of Knowledge from East to West

M. A. Tolmacheva

Africa's role in the transmission of knowledge from the East to the West has been strongly conditioned and circumscribed by its geographical location and relative isolation from European and Asian centers of civilization. Africa is to the south of Europe, home of the "West"; it is also positioned to the west and south of Asia, the historical and cultural "East" of Europe, from which it is separated by distance, the Sahara desert, and the Indian Ocean. The contiguity of the Eurasian landmass makes it easy for East–West communications to bypass Africa. Nevertheless, at various periods of premodern history Africa transmitted systems or elements of knowledge and culture to Europe, some generated in Africa, others developed in Asia in the Near, Middle, or Far East. The parts of Africa most actively involved in such exchanges are delimited by the waters of the Mediterranean and Red Seas, the latter guiding to Arabia and the Indian Ocean. The precise role played in these exchanges by Egypt, Ethiopia, and North Africa across time was subject to fluctuations in the environment, growth of early civilizations, long-distance trade, and the development of cities and elites. Nevertheless, Africa had a role to play in alleviating Europe's relative geographical isolation and, especially after the opening of the Cape route from the Atlantic to the Indian ocean, in supporting the global trading system connecting the Old World with the New.

Historically, the intellectual contribution of African societies to world civilization has been overshadowed by the magnitude of African economic and cultural inputs. In addition, numerous direct contacts between Africa and Asia (especially in the northern part of the continent and across the Indian Ocean) bypassed Europe for simple geographical reasons, or failed to have an impact on Western civilization because of circumstances of political, cultural, or religious nature (for example, the rise of Islam). This lack, inconsistency, and sporadic nature of intellectual interaction between Africa and the West are overlooked in some enthusiastic attempts to assert African primacy in world civilization based on incorrect interpretations of evidence. Reconstruction of the African cultures of the past faces serious problems because of the lack of writing systems among the majority of premodern African societies. In the absence of a written record, the historical existence of knowledge is often inferred from contemporary anthropological evidence or archeological data. To complicate things further, the secret of some African scripts that had existed in the past has been lost, as is the case with Libyan, Meroitic, and Tuareg. Thus the internal written evidence for the ancient period is currently limited to texts recorded in Egyptian hieroglyphics and the Ethiopic script. However, few of the surviving texts deal with scientific knowledge or formal disciplines of learning.

African elements in the culture of Ancient Egypt came primarily from the South (the Nile Valley above Aswan, where ancient Nubia and Kush were located) and the West (Libyan desert, Saharan oases and possibly Lake Chad region, and the rim of the Mediterranean). The prosperity and cultural splendor of Egypt during the Old and Middle Kingdoms (ca. 2600–1780 BCE) were second to none. Both depended on a flourishing agriculture which in turn reflected and supported the high development of astronomy, mathematics, hydrology, and technology. The texts and practices of ancient Egyptians provide evidence of elaborate knowledge of medicine, human anatomy, and chemistry. About the time of the transition from the Middle to New Kingdom (ca. 1500 BCE) Egyptian influence reached the Greek periphery. The early cultures of Crete and Archaic Greece show traces of Egyptian and North African influence. Later, Phoenician colonies in North Africa (most prominently Carthage) became a bridge between Africa and the northern Mediterranean. Although there is no record of formal transmission of knowledge from the Punic roots to Rome, some elements of Punic culture spread through the expanse of the Roman Empire as far north as the British Isles. Beginning with Herodotus (fifth century BCE), early Greek descriptions of Egypt and Africa make clear the Greek admiration for Egypt and vaguely acknowledge a certain cultural continuity with Egyptian learning and philosophy. Greek mythology hints at North African (Libyan) religious influence, and Greek folklore (e.g., Aesop's fables) reflects a cultural–philosophical connection with sub-Saharan Africa ("Ethiopia" of the Ancients). Egypt was recognized by the Greeks as both an integral part of Africa and a crossroads on the way east. After the conquest by Alexander the Great, Egypt (especially Alexandria) became a major center of cosmopolitan Hellenistic culture and long-distance trade connecting the Mediterranean with Arabia, Ethiopia, India, and East Africa. Late Greek and Greco-Roman astronomy, mathematics, geography, medicine, and philosophy drew upon the knowledge and thinking of Hellenized Egyptians. The geographical and astronomical works of the Librarian of Alexandria, Claudius Ptolemy (second century AD), continued to influence Western and Islamic scholarship until the sixteenth century.

With the rise of Christianity, Egypt, Ethiopia, and North Africa became a major stage for religious rather than scientific developments. Some of them involved religious controversies with Constantinople, Rome, and Near Eastern neighbors, and resulted in cultural and spiritual separation of the Asian and African Christian communities from mainstream Christian societies even where geographical isolation and remoteness (as in Ethiopia) were not a factor. A further transformation of cultural networks occurred after the Arab conquest of Egypt and North Africa in the seventh to early eighth century AD. Arabic became the language of learning and Islam the dominant ideology. A fragile cultural connection between Ethiopia, Egypt, and Byzantium survived for a few more centuries in the religious sphere; it channeled limited influences in theology, art, and hagiographic literature. One unrecognized consequence of this link is the use of Coptic (originally Egyptian hieroglyphic) elements in the Glagolitic (later Cyrillic) script invented in the ninth century for the Slavic vernaculars by the Byzantine monks, Cyril and Methodios.

The early Islamic science was a synthesis of Hellenistic, Middle Eastern, and Indian sciences, to which was added a considerable body of original knowledge, especially in mathematics, optics, geography, and medicine. Egypt and North Africa became a bridge by which these sciences were then transmitted from the Middle Eastern centers, especially Baghdad, to the rest of the Islamic world and to Europe. Islamicized societies of tropical Africa were most influenced by the legal, theological, and philosophical thought. This Islamic contact stimulated the adoption in the Middle Ages of the Arabic alphabet for writing in some African languages, such as Swahili in East Africa and Hausa in West Africa. Europe, on the other hand, primarily borrowed Islamic knowledge in the fields of natural and applied sciences and philosophy. The Iberian peninsula was involved in this process in a number of ways: first, through the spread of Asian food and technical crops and cultivation techniques as a result of Arabo-Berber occupation in the eighth century; second, in the eleventh to thirteenth centuries under the Almoravid and Almohad empires when Spain was united with northwest Africa as far south as the Senegal River; third, through the Christian translation activities of the late eleventh to sixteenth centuries; and finally as a transit point for transmission to the New World.

From the period of the later Crusades and under the Mamluk dynasties Egypt became the dominant Islamic partner of European traders on the Mediterranean and gained exclusive control of the Red Sea and thus access to the trade of the Indian Ocean. By the thirteenth century the transmission to the Mediterranean of the magnetic compass and the lateen sail (both of them products of the Indian Ocean societies) had been accomplished. After the Mongol conquest of Baghdad in 1258 Cairo became the foremost center of culture and learning for the Near East and Africa. In addition, it was a major transit point on the pilgrimage route to Mecca, visited by many Africans for purposes of both ritual and learning. Cairo kept this role despite the ravages of the Black Death in the mid-fourteenth century and the Ottoman Turkish conquest in 1516, and has retained it to a certain extent to this day. However, even before the fall of Byzantium in 1453 the balance of secular learning in the eastern Mediterranean had shifted, and Muslims became eager students of the early modern West. In the western Mediterranean, the European and Islamic powers interacted in the hostile atmosphere of the Christian Reconquista and piracy; by the sixteenth century the technological balance of power had tilted in Europe's favor, and the geographical arena of progress moved to the Atlantic.

In modern times, the European discovery of the New World and the expansion of the West to overseas colonial empires led to new patterns of communication which could connect Africa with Asia and the West Indies or the Americas without involving Europe. The new global networks served very different purposes and produced dramatically different results. One such early modern network was the Portuguese seaborne empire spread over three continents; its shipping lanes led from Goa in India east to Macao or west to Mozambique and Angola to Brazil, the vessels often completely bypassing Portugal itself. Another was the Dutch empire that connected the West Indies with the West African coast, South Africa's Cape settlement, the Persian Gulf, India, Malacca, and Indonesia. The new societies developing overseas were molded by the West but no longer European. A special, modern example of crosscultural interaction in the "Old World" is the South African colonial society where European farmers benefited from observing the herding practices and environmental adaptation of the indigenous groups (the Khoi-, San-, and Bantu-speakers). The Dutch-based Afrikaans language of white South Africans contains African loan words illustrative of such informal, unrecorded, and often unrecognized transmission of African knowledge to Western societies.

The Americas experienced heavy influxes of Africans capable of preserving in their midst some of the living African culture even under the conditions of slave plantation economy. These influences originated mostly in the tropical and equatorial areas of western Africa. Another channel of unstructured cultural transmission to early Latin America was the importation, within Iberian culture, of "Moorish" (i.e., Islamic or North African) elements, for example in architecture. Traditional knowledge of the African environment, technology, medicine, philosophy, and folklore, including occasional Islamic elements, colored the social, economic, cultural, and spiritual life of African immigrants in the New World and fed into the culture of the larger society despite cultural, religious, and social barriers. African food crops as well as methods of plant cultivation and food preparation spread first in the Caribbean and then on the American mainland. The introduction of rice as a North American plantation staple was accompanied by targeted purchases of slaves from African ethnic groups familiar with rice cultivation, including women whose role in African rice cultivation included seed selection, sowing, hoeing, weeding, and transplanting, as well as milling and cooking. Slaves imported from West Africa brought with them skill complexes that helped make the Carolinas and Georgia into rice exporters on a global scale. Africans contributed their experience of rice cultivation in rain-fed areas, river floodplains, and tidal lagoons; plant breeding skills, the use and adaptation of African agricultural tools, and rotational land use combining cattle grazing and agriculture in tropical and equatorial areas.

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East and West: China in the Transmission of Knowledge from East to West

Christoph Koerbs

Despite the distances between them and their totally different cultures, there has been more or less continuous communication between the West and China since classical Greek times. Although the connection was indirect and limited to trade in luxury goods, there were even in ancient times marvelous resemblances between Western and Chinese inventions in technology and engineering. Therefore it is natural to believe that a transmission of ideas and knowledge must have occurred, even if it is impossible to describe the exact exchange of any particular scientific achievement.

In the thirteenth century there was some considerable personal contact between the West and China, of which that of William of Ruisbroek (1210–1270), Marco Polo (1254–1324), and Odoric of Pordenone (1286–1331) are but the most famous examples. By the end of the sixteenth century in China an era of isolation ended and a new stage of intercultural exchange began. In this period the first Jesuit missionary fathers entered China, bringing with them knowledge of the sciences of Renaissance Europe. The Jesuits' scientific instruction was intended to aid their religious teaching by adding to the prestige of the culture they represented. Although in many respects Chinese technology was more advanced than European technology until the Renaissance, it lost ground in subsequent centuries. Francis Bacon (1561–1626) saw Chinese inventions, namely the magnetic compass, gunpowder, and the printing press, as crucial for the transformation of European society. However, after the generation of Leibniz (1646–1716), Wolff (1679–1754), and Voltaire (1694–1778) with the end of the Enlightenment movement, European philosophers and historians began to speak in a disparaging way of Chinese culture. From the late eighteenth century on, the myth of a closed China was born, and Europeans saw the scientific exchange between China and the outside world solely in terms of what the Chinese borrowed from the West. Though Chinese technological advances were old and undeniable, many authors of textbooks on the history of science, technology, and medicine still assured their readers that China never created science as a persisting institution and never consciously developed technology on the sound basis of a theory for applied science.

The British historian of science Joseph Needham (1900–1995) with his work *Science and Civilisation in China* began to restore the reputation of China as a cradle of scientific inventions (Needham 1954). He showed the patterns of transmission of these inventions and enriched the knowledge of Chinese science and technology. Sivin (1977, 1988), an American historian, introduced a different angle. He presented the argument that it is impossible to equate divisions of modern science and engineering with premodern Chinese divisions. Chinese science was not integrated under the authority of philosophy, as schools and universities merged them in European and Islamic cultures. The Chinese had sciences but not "science," not a single conception or word for the sum of all scientific divisions. Traditional Chinese terms for science might exclude empirical methods but include ethical or religious principles discovered through reflection on authoritative texts.

Since there is neither sound evidence for early adoption of Chinese science in the West, nor agreement as to whether Chinese science is distinct from sciences in the West, we have to answer each complex of questions separately. First of all, when immediate contact between China and the West was too limited to be noteworthy, we have to determine whether the Western world owed much to foreign influences which in turn made use of knowledge from China. Second, we must ask whether the conception of Chinese sciences inevitably leads to disparaging treatment by those scholars who are measuring two radically different things by the same standard. To draw a more balanced picture of Chinese scientific thought, we have to look for autochthonous features of ancient Chinese sciences and explain their characteristics.

To solve the first part of the puzzle, we have to consult Chinese historical records which contained much information on foreign relationships. Although there is clear evidence for Arabic, Babylonian, and Indian relations with China, recent archeological finds demonstrate the originality of Chinese culture in many ways. We still do not know enough about the routes and intermediaries by which neighboring states imported cultural artifacts from China. Many transmissions which finally reached the West transformed Chinese, Indian, Iranian, and Greek contributions simultaneously.

Under the Han rule (221 BCE–AD 220), as a result of military campaigns and diplomatic activities, China's immediate contacts with other cultures grew to a degree so far unrivaled in Chinese history. In this period China spread her concepts and skills around all of Asia. As early as 130 BCE, Chinese government officials set out to explore the routes into Central Asia and North China. The success of these missions is very difficult to reexamine, and yet it is probable, because in the official documents of these times we find many references to China's intercultural exchange. The first record of official visitors arriving at the Han court from Japan is for the year AD 57, and we can furnish proof of a mission from Rome which had reached China by ship in AD 166.

With the downfall of the Han Dynasty in AD 220 China entered a period of decline and disunity with respect to the transmission of ideas. After a period of domestication and growth under the later Han, Buddhism came from India into China. The spread of Indian thought was attended by a dispersion of Chinese thought westward. For the next 300 years the Silk Road which linked China with the West was the most important connection between the different culture groups. On this trade route goods and ideas were carried between the three great civilizations of Rome, India, and China.

Under the Sui reign (589–618), when China was consolidated again, grandiose plans aiming to unify the empire culminated in projects for new canal systems. As a result a great canal linking central and southern China was constructed, and long campaigns in Manchuria and on the Korean frontier were prepared. There was a direct relationship between waterway construction works and active foreign policy. Using the new canals for logistical support, the Sui realm was able to establish sovereignty over old Chinese settlements in the south, and extend its influence to other territories, especially in central Vietnam. In addition to these military operations expeditions were sent to Taiwan, and relations with Japan were opened. Sui colonies were established along the great western trade routes, and rulers of several minor local states of Central Asia became tributaries. This was the time when China was in contact with the eastern Turks, who occupied most of the Chinese northern frontier, and the even more powerful western Turks, whose dominions stretched westward to the north of the Tarim Basin as far as Sassanid Persia and Afghanistan. We can learn from the writings of the Arabian scientist and philosopher Al-Bīrūnī (973–1048) that the Turkish sphere of influence was a fertile soil for intercultural exchange. As a consequence of the history of Turkish engagement in Inner Asia remarkable transmissions of technological know-how took place and helped to spread, among other things, Chinese defense engineering and mechanical skills.

Various imports and influences into Arabic empires originated essentially from China, or were at least transmitted through the intermediary of the Turks. As we can prove by discoveries of imported pottery and textiles the links between Iran in the Sassanid period (AD 226–651) and China were extremely close. With the decay of Turkish power the new Tang dynasty (618–906) extended its power all over East Asia. Chinese western dominions extended even farther than in the great days of the Han, and trade developed with the West, with Central Asia, and with India. The Chinese capital was thronged with foreign merchants and monks. Every great city contained a variety of non-Chinese communities and had Zoroastrian, Mazdean, and Nestorian temples, along with Buddhist monasteries. This set the stage for even more transfers of knowledge and inventions.

Perhaps it is not exaggerated to call China under the Song rule (960–1279) the most advanced civilization at that time. During the Song dynasty an agricultural revolution produced plentiful supplies for a population of more than 100 million. Acreage under cultivation multiplied in all directions, and a variety of early ripening rice, imported during the eleventh century from regions in modern Vietnam and Cambodia, shortened farming time to below 100 days and made two crops a year the norm and three crops possible in the warm South. Among other new crops the most important was cotton, which provided clothing for rich and poor alike; silk and hemp were also important. Improved tools, new implements, and mechanical devices that raised manpower efficiency were widely used. Although advanced skills were guarded as trade secrets, many technical inventions of these times found their way into printed manuals used at home and abroad. Productivity of such minerals as lead, tin, silver, and gold increased tremendously. In manufacturing the Chinese improved processing in skill-intensive patterns; they began with mass production, and a division of labor as well, while skills and products entered into diversified specialization. High-quality earthenware progressed to genuine porcelain, which attained international fame.

Despite the fact that until the early eleventh century Chinese maritime trade had been dominated by foreigners, Chinese artisans developed a new type of ship at the end of the century, helping the Song empire to take control over the transport of merchandise and passengers across the waters of East Asia. The Chinese ocean-going junks with large proportions and tonnage were bigger, more solid, but also more comfortable than the Arabian and Indian ships. From the twelfth to the fourteenth centuries the Chinese fleet was at the peak of its power, at least on the routes linking China with the ports of South India. Chinese trade with Southeast Asia increased for the very last time at the end of the fourteenth century when China flooded Sumatra and Borneo with ceramics, and also coins, in exchange for spices, aromatics, medicinal drugs, and precious woods. Chinese ceramics of this period have been found in quite large quantities not only along the silk road, but also on the sites of ancient ports or depots along the navigation routes toward Indonesia, and in the great commercial cities of the Middle East.

In the thirteenth century after the Mongol conquest of China and the founding of the Yuan dynasty (1280–1367) Europeans developed a lively interest in Chinese affairs. The Roman Catholic Church also looked for potential converts among the non-Muslim people of Asia. After Franciscan envoys brought back information on what was known as China in the mid-thirteenth century, Pope Nicholas IV dispatched a mission to the court of the Grand Khan. The Mongol capital Khanbaliq (Beijing) became the seat of an archbishopric, and in 1323 a bishopric was established. From then on missionaries traveled to China and brought back first-hand information to medieval Europe. These reports inaugurated an era of discoveries and created a new vision of the world, with China as a part. Furthermore, shortly after direct contact with China was established, European philosophers and clerics speculated upon Chinese modes of thinking. Chinese medical treatises were translated into Persian, and Persian pottery techniques show some influences of Chinese handicraft. In addition, Chinese-type administration and chancellery practices were adopted by various Mongol dominions in Central Asia and the Near East. Some scholars suggested that the invention of gunpowder and printing in Europe was due to a sort of stimulus diffusion from China, although there is no sound evidence for a direct influence from China via the Near East.

During the Ming reign (1368–1644) Europe was unable to maintain its contacts with the Far East, partially because the Black Death broke off many overseas trade relations. Toward the end of the fourteenth century China was almost forgotten. Meanwhile Ming dynasty bureaucracy reoriented foreign policy, which made foreign contacts much more difficult. Ming China's influence in Southern Asia reached its climax during the early fifteenth century when official exploratory voyages brought most important South Asian states into the Ming political sphere. Besides protecting China's southern borders, these voyages were undertaken to monopolize the overseas trade by preventing private individuals from taking control of seafaring activities. Foreign states responded to these overtures not only because they feared military reprisals if they refused, but also because they saw great commercial benefits in relations with China. In these years Chinese missions established contacts with most of the important countries from the Philippines to the Indian Ocean, the Persian Gulf, and the east coast of Africa.

The Ming rulers also maintained China's traditional relationships with foreign peoples; they took for granted that the Chinese emperor was everyone's overlord and that other rulers of non-Chinese states were in a strict sense nothing but feudatories. Foreign rulers were expected to acknowledge the supremacy of the Ming emperor and to send periodic missions to the Ming capital to demonstrate their fealty and present tribute of local commodities. Tributary envoys from continental neighbors were received in selected frontier zones while those from overseas states were only accepted at three key ports on the southeast and south coasts. All envoys received valuable gifts in acknowledgment of the tribute they presented and also were permitted to buy and sell private trade goods at officially supervised markets. Luxury goods flowed out of China and some rarities flowed in. In order to preserve the government's monopolistic control of foreign contacts and trade, and to keep the Chinese people from being tainted by so-called *barbarian customs*, the Ming rulers prohibited private dealings between Chinese and foreigners and forbade any private voyaging abroad.

In the sixteenth century China came into contact with Jesuit missionaries who impressed the Chinese with the superiority of Western astronomy. The most famous of them, Adam Schall von Bell (1591–1666), was trained in Rome in the astronomical system of Galileo. After curing the Empress Dowager of a strange illness, Schall became an important adviser to the first emperor of the Qing dynasty (1644–1911/1912). He was soon given an official post and he also translated Western astronomical books and reformed the old Chinese calendar. Matteo Ricci (1552–1610), another Jesuit, produced the first edition of his remarkable map of the world, the Great Map of 10,000 Countries, which showed China's geographical relation to the rest of the world. Moreover Ricci taught the rudiments of mathematics and translated many mathematical treatises on Western science and engineering into Chinese, notably the first six books of Euclid. At the same time, many books and correspondences of Catholics like Ricci were published in Europe and caused an interest in Chinese culture. This period of intensive cultural exchange came to an end with the imperial decree of 1717 which prohibited the preaching of Christianity and ordered the deportation of all missionaries from the empire with the exception of those working at the court.

From this time on, for more than 100 years China reduced her contact with the West to a minimum. Trade was rigidly limited to a few ports where officials regulated it strictly and taxed all merchandise excessively. Chinese attitudes toward foreign relations clashed with those of the rising Western powers, especially after the newly expanding states of Britain, France, and Holland all began to develop major overseas empires. In these times, during the last decades of the eighteenth century, China's image changed, and

Chinese affairs were viewed in a rather negative way. After the turn of the century China no longer received favorable attention in the West, but metamorphosed into the very archetype of a backward country. By teaching the Chinese the science and technology of the West, Europeans believed they had to stimulate the scientific development of a culture without any noteworthy tradition of its own. For a very long time it was quite inconceivable to Europeans that China had anything to offer in return.

As mentioned above, to draw a more balanced picture of Chinese scientific thought, we have to look for special features of ancient Chinese sciences and explain their singularities. It is easy to understand why traditional Chinese sciences are hard to describe in the modern terms of Western science or engineering. For example, the Chinese science of geomancy (*fengshui*, or wind and water) cannot be assigned to any department of modern science. Since the concepts of geomancy differ significantly from premodern European natural philosophy, even recourse to ancient traditions of the West does not help. The geomancer aimed to adapt the dwelling places of the living and the dead in a suitable way to arrange them in harmony with the energy balances existing in a region. In Chinese thought every place has its peculiar topographical characteristics which can alter the local energies of nature. Directions of watercourses, shapes of wooded areas, or forms of hills are treated as important aspects for everything living in this region, and the forms and structure of objects built by humans are believed to be significant factors too. As the art of geomancy was dedicated to exploring the relations between the landscape and the living conditions of its inhabitants, it was an official state science, directed by the Board of Rites in the capital and patronized by the emperor himself.

Western scientists who have written about geomancy agree that this science recognizes certain types of energy which permeate the earth and atmosphere and animate the forms of nature. Further understanding has been obstructed by the impossibility of equating these energies with phenomena recognized by modern physics. In one aspect they evidently correspond to the emanations from the earth which are detected by water-diviners, or to the earth's magnetic currents. In another aspect they correlate to traditional Chinese medicine and acupuncture. Just as Chinese doctors commanded a great diversity of therapies and techniques, which they generally used in combination, geomancers did the same, and so traditionally both techniques are described as departments of the same science. Acupuncture is based on the same principles as geomancy, being concerned with the flow of subtle energies in the human body which correspond to those perceived by geomancy in the body of the earth. These remarkably abstract and comprehensive systems of acupuncture and geomancy are based on concepts describing the relations of the body, the mind, the immediate physical surroundings of the body, the earth, and the cosmos which are very different concepts from those in the West. What makes geomancy even more complicated are the differences between special schools of this science. One school believed that natural shapes in the landscape tended to affect the characters and destinies of those living within sight of them, while another school paid more attention to astronomical factors, horoscopes, and reading of the geomancer's compass. In Western terms geomancy seems like a mixture of obscure medicine, applied protophysics, esoteric speculations, superstition, or even swindling.

Another example of the interrelationship of different branches of traditional Chinese learning is the alchemical sciences (*fulian*). We can distinguish two major divisions of alchemy, internal (*neidan*) and external (*waidan*). Internal alchemy was concerned with longevity practices and interpreted immortality as the highest kind of health. A special branch also existed for the alchemical process of internal transformations. Adepts of this school considered the interior of the human body as a laboratory in which elixirs could grow by meditation, breath control, or sexual gymnastics.

In theories of external alchemy, the transmutation of metals into gold and the production of universal remedies for diseases were the focus of interest. Chinese adepts of external alchemy by and large were not interested in exploring chemical reactions, but in simulating cosmic series of transformation and creation. In the laboratories alchemists intended to produce new substances or to convert given materials into new substances by means of allegorical imitations of natural phenomena rather than by controlled chemical experiments.

It is important to outline some Chinese cosmological ideas briefly. This will help us to relate theories of creation and change to patterns of Chinese mathematical astronomy (*lifa*) and astrology (*tianwen*). In traditional Chinese thought, ideas about the origin of the world do not involve any concept of creation by an almighty creator but only by impersonal processes of spontaneous self-creation. The first fully developed cosmological idea is the *gaitian* (heaven as cover, or umbrella heaven) theory, whose origins are around the first century AD, although its first traces are to be found as early as 239 BCE. According to this theory, heaven and earth are flat and parallel planes. A variation of this theory depicts heaven and earth as bodies having a mild curvature very similar to the curvature of an umbrella. In both theories heaven is thought to rotate once daily about an imaginary axis, normally held to be vertical, and carry with it all the stars and heavenly bodies. Since the observer is some distance from the vertical

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axis, it is no contradiction that the polestar is not overhead. Rising and setting of the sun, moon, and stars are optical illusions caused by their entering and leaving the observer's pretended narrowed range of vision. Advanced variations of this theory initiated the idea of a spherical or complete heaven (*huntian*) which was thought to surround the earth and rotate daily about an axis inclined to the horizontal. In this theory heaven and earth are compared with the shell and yolk of an egg, e.g., the earth is said to be completely enclosed by heaven, rather than merely covered from above. Chinese astronomers continued to think in flat-earth terms until the seventeenth century, when Jesuit missionaries introduced Western theories.

Traditional Chinese astronomy does not use a zodiac of 12 signs laid out along the sun's annual path through the constellations. The celestial sphere is sliced into 28 unequal segments, which are said to radiate from the north celestial pole in the same way in which lines of longitude radiate from the poles of a terrestrial globe. These slices are called lunar mansions or lodges (*xiu*). Each mansion bears the name of the constellation found in it. By means of this system, astronomers were able to follow the progress of the stars in the sky, but the mansions also have an astrological function. Each mansion has a corresponding terrestrial territory to which the predictions based on phenomena observed in the sky are applied. The appearance of comets, haloes, or clouds guided the actions of the governors of the states associated with the mansions where those phenomena were observed. Along with the mansion system, 24 guiding stars were chosen by which the position of the other stars in the sky could be determined. In this, Chinese astronomy differs greatly from Greek helical astronomy, which is based on the observation of the rising and setting of stars just before dawn and just after dusk. In China, where the celestial Pole symbolized the Emperor, astronomers studied the circumpolar movements of the constellations around the Pole.

Another science very closely related to mathematical astronomy and in the same way entirely different from its Western correspondent is Chinese astrology. To distinguish mathematical astronomy from astrology we have to remember that from the very beginning astronomy was designed to make celestial phenomena predictable, whereas astrology served as an aid for interpretations of those phenomena which were unpredictable. In the West astrology is in a way the same as horoscopy, but in the Chinese context astrology and horoscopy differ widely. In traditional China the appearance of celestial phenomena guided the actions of the governors of the states. The Chinese astrologer observed and interpreted anomalous celestial or meteorological phenomena to reveal faults and shortcomings in the political order. There was a close correspondence between the cosmic and the political domains. For instance, from the second century BCE there has been the theory of *fenye* (field allocation). The sky was mapped upon political segments, so that strange phenomena discovered in a particular segment could be related directly to the corresponding political realm existing on earth. Throughout Chinese history the mediator between celestial circumstances and mundane affairs was the Emperor, who was responsible for the undisturbed course of all regularities on heaven and earth. Therefore, astrologers interpreted celestial omens as indications of imperial negligence or correctness. This attitude toward celestial phenomena also influenced calendrical and planetary astronomy. As a result of this attitude toward omens, almost every government aimed to control and sponsor mathematical astronomy and astrology.

Since changes in the heavens predicted important changes on the Earth, Chinese astronomy and astrology were incorporated into the system of government from the dawn of the Chinese state in the second millennium BCE. The result was a system of astronomical observations and records, thanks to which star catalogs and observations of eclipses and novae that go back for millennia survived. Chinese records, therefore, are still of value to every student of the history of astronomy. In our times Western astronomers have identified ancient Chinese observations of the sudden appearance of bright stars with the supernova explosions whose remainders have been detected by radio astronomy. Moreover, observations of sunspots made from the first century BCE onward helped to solve some problems of the variation of solar activity over the centuries.

Astronomy and astrology had no real effect on Chinese mathematics (*suanxue*). On the whole Chinese mathematics was algebraic and numerical in its approach rather than geometric. Since ancient Chinese mathematics was primarily oriented toward practical application, any search for the hypothetical meaning of numbers was rather a system of occultism built around numbers than an exploration into the realm of abstract mathematics. Some historians of mathematics have claimed that only the Greeks produced an abstract, logical mathematics that could function as the language of science. Chinese mathematics, however, consisted of reckoning rules, and, in spite of their great sophistication, these were only intended for practical use.

Perhaps mathematics serves best to demonstrate the whole problem of contingent affection of China by the West. In the first phase this Chinese science was disregarded, because it was inconceivable that a non-European culture was endowed with an efficient mathematical system. In the second phase, a few Western scholars made an attempt to understand such things as an abacus or counting-rods, but still theoretical primary sources were not used. In the next phase mathematical treatises were carefully studied and summarized in a reliable form. Today we can find several first-hand characterizations of the subject by experts in this field, but it is very difficult to obtain a balanced picture. It is clear that ignorance of Chinese sciences was mainly caused by misunderstanding.

See also: ►Gunpowder, ►Compass, ►Metallurgy, ►Agriculture, ►Chemistry, ►Navigation, ►Astronomy, ►Astrology, ►Calendar, ►Geomancy in China, ►Mathematics, ►Chinese Science, ►Alchemy, ►Metallurgy, ►*Gaitian*, ►*Huntian*, ►Stars, ►Eclipses, ►Fengshui

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East and West: India in the Transmission of Knowledge from East to West

Susantha Goonatilake

The exchange of ideas was more balanced in the time before the European Scientific Revolution, after which the lipid growth of knowledge in the West dwarfed the interregional traffic that had taken place earlier. The Western tradition of the last few centuries has become the only system studied in universities and practiced in centers of science and technology worldwide. Quite often there is no interaction between this new tradition and the earlier knowledge from regions such as South Asia, even though there are many areas of learning that could enrich the Western tradition.

A study of the growth of the European and the South Asian scientific traditions shows considerable areas of overlap and mutual influence from very early times. When Europeans in the Renaissance looked back to Greek sources for new inspiration, they were in fact looking to Greek sources partly influenced by the South Asians.

Generally speaking, India was outside the world of shared ideas and values of preclassical Greece. After the wars with the Persian empire the myth of a division into East and West was born, as was the concept of Europe. The conditions for a large scale traffic of culture and ideas between Greece and Asia were created when the Persian Empire became a bridge from the Mediterranean to the Indus. One sees South Asian concepts that arose between 700 BCE and 500 BCE in the later Vedic hymns, the *Upaniṣads*, and among the Buddhists and the Jains, being echoed in Greek thought.

There are striking parallels between the two traditions. The *Upaniṣads* seek one reality; this has its echoes in Xenophanes, Parmenides, and Zeno. Pythagoras is thought to have been influenced by the Egyptians, Assyrians, and Indians. He believed in the possibility of recalling previous lives, which is also typical of South Asian philosophy. Pythagoreans abstained from destroying life and eating meat, as do Jains and Buddhists. They expounded many theories in the religious, philosophical, and mathematical sphere that were known in sixth century BCE India.

In Plato's philosophy, the "cycle of necessity," a concept similar to Karma, was central. Humans were reborn as animals or other humans. The Indian elements *pṛthvī* (earth), *ap* (water), *tejas* (fire or heat), *vāyu* (air), and *ākāśa* (ether, or a nonmaterial substance) have their counterpart in Empedocles, who believed that matter had four elements: earth, water, air, and fire.

After Alexander's encounter there was explicit dialogue with India. Several who traveled with Alexander are said to have met with Indian sages. In late antiquity India was seen in some debates as the origin of philosophy and religion. In the second century AD Lucianus stated that before philosophy came to the Greeks, Indians had developed it. It has also been suggested that Gnostic thought was influenced by Buddhist literature. Gnostic Carpocratians strongly supported the idea of transmigration. At least one Gnostic philosopher, Bardesanes of Edessa (ca. AD 200) had traveled extensively in India. Mani, the Persian Gnostic of the third century AD, incorporated several Buddhist ideas into Manichaeism. By the second century AD India had almost replaced Egypt as the presumed origin of Greek thought and learning.

At a later period, Plotinus, the father of the Neoplatonic school, took part in the military campaign against the King of Persia. Neoplatonism recommended abstention from sacrifice and meat eating. Neoplatonism, *vedānta*, yoga systems, and Buddhism all have strong similarities. In the second century AD, Clement of Alexandria spoke often about the existence in Alexandria of Buddhists, being the first Greek to refer to the Buddha by name. He was aware of the belief in transmigration and the worshipping of *stupas*.

During the Roman Empire, contacts between the two places continued. There was heavy trade in luxuries with South India and Sri Lanka by the Romans, and ambassadors were sent to Rome. An Indian delegation visited Europe in Emperor Antoninus Pius' reign. In the reverse direction, Apollonius of Tyana traveled to India. These repeated interactions between the two regions probably resulted in the exchange of ideas from South Asia to Greece. The Buddhists had sophisticated discussions prior to Heraclitus around the concept of being in a state of flux. Buddhists and Ājīvakas added joy and sorrow to the five elements, which precedes Empedocles's views that love and hate acted mechanically on the elements. The Buddhists and others taught a doctrine of the mean several centuries earlier than Aristotle (340 BCE). In medicine, the Hippocratic treatise *On Breath* deals in much the same way with the pneumatic system as we find in the Indian concept of *vāyu* or *prāṇa*. In his *Timaeus*, Plato discussed pathology in a similar way to the doctrine of *tridoṣa*.

The above examples should not suggest that there were no transmissions in the opposite direction. The ancient world had much cross flow of intellectual traffic. A well known example from Greece to South Asia concerns ideas on geometry and astronomy.

When the Classical age collapsed, European and South Asian contacts continued in the Middle Ages through Arab intermediaries. The Arabs performed the functions earlier performed by the Persian, Alexandrian, and Greek empires which brought together the ideas of East and West. It is useful to trace the transmission of Indian sciences to Europe as well as trace those that were not transmitted but remained in the region only to be rediscovered much later. This is done to some extent in the article on Indian mathematics in this Encyclopaedia.

The European Renaissance and Scientific Revolution brought about many changes that have been considered unique. However, the evidence indicates that many of the results were known, some albeit in an incipient form, in South Asia.

Alchemy was an important precursor to the development of chemistry. Greek alchemical texts do not show an interest in pharmaceutical chemistry, a marked contrast with China and India. In the *Atharva Veda* (eighth century BCE) there are references to the use of gold for preserving life. The transmutation to gold of base metals is discussed in the Buddhist texts of the second to fifth centuries AD by concoctions using vegetables and minerals.

In the West, iatrochemists, especially Paracelsus, were of the view that the human body consisted of a chemical system of mercury, sulfur, and salt. Sulfur and mercury were already known to the alchemists; salt was introduced by Paracelsus. This theory differed from the four humors theory of the Greeks advocated by Galen (AD 129–200). An Indian alchemist by the name of Ramadevar taught a salt-based alchemy in Saudi Arabia in the twelfth century.

In medicine, the work of Suśruta laid the foundations for the art of surgery. Suśruta emphasized observation and dissection, and described many instruments like those used in modern surgery, listed several kinds of sutures and needles, and classified operations into types. The operations described included those for hydrocele, dropsy, fistula, abscess, tooth extraction, and the removal of stones and foreign matter. The ancient Indian surgeons practiced laparotomy and lithotomy, plastic surgery, and perineal extraction of stones from the bladder. The region had considerable knowledge in dentistry including artificial teeth making. In AD 1194 the king Jai Chandra when beaten in battle was recognized by his false teeth. Suśruta describes details of operations for the conditions of obstructions in the rectum and for removal of a dead fetus without killing the mother, considered a very difficult procedure. He describes plastic surgery of the nose and cataract operations on the eye.

At the end of the eighteenth century the British studied Indian surgical procedures for skin grafting to correct for deformities of the face, which became the starting point for the modern specialty of plastic surgery. Dharmapal collected several illuminating accounts by Britons on Indian medical practices in the eighteenth century. This included one by Holwell, who gave a detailed report on the practice of inoculation against the smallpox. The smallpox epidemics in the nineteenth and early twentieth centuries have been attributed to the cessation of this practice before the vaccination system could become widespread.

In the West after Democritus, atomic theories were further expanded by Lucretius in the first century BCE but then virtually vanished from intellectual view for 1600 years. In the seventeenth century Gassendi, Boyle, Newton, and Huygens revived the atomic perspective. Atomic views of several schools such as the Buddhists, the Jains, and the Vaiśeṣika persisted. The Vaiśeṣika's theory of atomism considered atoms as eternal and spherical in form. The disintegration of a body results in its breaking down to constituent atoms. A solid block like ice or butter melts, and this is explained as a loosening of the atoms, giving rise to fluidity.

Evolution is one other element in the modern phalanx of scientific ideas. Evolutionary ideas had existed among pre-Socratic Greek and Indian thinkers. However, evolutionary thinking in Greek tradition was brought to a sudden end by the ideas of Plato and Aristotle. Plato viewed the real world as consisting of unchanging forms or archetypes; Aristotle viewed the physical world as a hierarchy consisting of kinds of things. For Aristotle the universe was unchanging and eternal. The idea of evolution is found in the *Upaniṣads*, the writings of the Buddhists, and others.

The *Encyclopaedia Britannica* lists three major innovative transformations in British agriculture in the Era of Improvement in the eighteenth century. They were the invention by Jethro Tull in 1731 of the drill plough, "whereby the turnips could be sown in rows and kept free from weeds by hoeing thus much increasing their yields," the introduction of rotation of crops in 1730–1738 by Lord Townshend, and the selective breeding of cattle introduced by Robert Bakewell (1725–95). There is evidence that all three were in existence in India, as reported by British scientists working there.

Roxburgh, generally recognized to be the "father of Indian botany" in the contemporary tradition, put this as follows: "the Western World is to be indebted to India for this system of sowing," meaning the implicit rotation of crops in the Vedic period where rice was sown in summer and pulses in winter in the same field. Other British works have attested to the use of "careful breeding of cattle," various kinds of drill ploughs, and rotation of crops and mixed cropping.

The Scientific Revolution had a deep impact on the philosophical underpinnings of Europe. There was for example the dethroning of human exclusivity as the special creation of God, as exemplified by the trials of Copernicus or the criticisms of Darwin's evolutionary theory. The discovery of the unconscious by Freud and others is also in this class. None of these events would have had the same impact on South Asia, whose cosmology allowed for a large number of worlds, for evolution and change, for humans as part of a larger living world, and for a subconscious.

Aside from these historical examples, are there innovations occurring even now which are drawing sustenance from the earlier South Asian tradition?

Helmut von Glasenapp observed that ancient South Asian ideas on fundamental issues had several parallels with those in modern science. Some of these concepts were (1) an infinite number of worlds exists apart from our own; (2) worlds exist even in an atom; (3) the universe is enormously old; (4) there are infinitely small living beings parallel to bacteria; (5) the subconscious is important in psychology; (6) doctrines of matter in both Sāṃkhya and Buddhism are similar to modern systems; (7) the world that presents itself to the senses is not the most real; and (8) truth manifests itself differently in different minds giving the possibility of a multiplicity of valid truths.

Following are examples of innovations based on the past taken from a few disciplines. The first is medicine. A recent study has documented the use of honey and sugar as treatment for wounds and ulcers in both Āyurvedic and contemporary biomedicine. The tranquilizer Reserpine was based on an ancient āyurvedic medicine. Hoechst, the West German pharmaceutical company, used Āyurvedic literature to help identify useful medicinal plants. By the early 1980s, over 200 Indian medicinal plants were being tested every year in this program.

A recent study has evaluated the effect of *Rasayana* therapy which aims at promoting strength and vitality. The study covered six drugs from classical Āyurvedic literature. The clinical studies indicated that the drugs toned up the cardiovascular and respiratory systems and improved physical stamina. On the biochemical side, a significant drop in lipids was noticed.

References to curative plants in the Indian tradition go back to the Ṛgvedic period (3500–1800 BCE). The *Suśrutasaṃhitā* and *Carakasaṃhitā*, two compendia which are summaries of earlier works, dealt with about 700 drugs, some of them outside the subcontinental region. Clearly, a vast reservoir of explorable scientific knowledge exists.

One of the areas of study with a very long tradition in South Asia is psychology. There is also a very long tradition of sophisticated discussions on epistemology. There is potential for a fruitful interaction between these and the contemporary study of the mind, including the philosophy of language, methodology, ontology, and metaphysics.

Memory, motivation, and the unconscious are shown to have parallels in the theories of Freud and Jung, as well as in Patañjali. Similar parallels have been noted between the psychoanalytical theorists Heinz Hartmann and Erik Erikson, and the Hindu theory on the stages of life, as well as between Buddhism and early twentieth century analytical thought. Strong parallels between the concept of self-realization used in subcontinental traditions such as Vedantic Hinduism, Theravāda, and Mahāyāna Buddhism and the concept of self-actualization as developed in humanistic psychology by Arthur Maslow and Carl Rogers have been demonstrated.

Francisco Varela, a theoretical biologist and student of cognitive science and artificial intelligence, and coworkers have used Buddhist insights in extending the limitations of both the neo-Darwinian adaptation in biological evolution and of the current paradigm in cognitive sciences. Having noted that in Buddhist discourse, classical Western dichotomies like subject and object, mind and body, organism and environment vanish, Varela applies these discourses to several areas where these dichotomies had traditionally appeared. These include cognitive psychology, evolutionary theory, linguistics, neuroscience, artificial intelligence, and immunology.

Their position is that if cognitive science is to incorporate human experience, then it must have a means of exploring the dimension which is provided by Buddhist practice. Buddhist experiences of observing the mind are in the tradition of scientific observation. They can lead to discoveries about the behavior and nature of the mind, a bridge between human experience and cognitive science.

Another area of interest is that of adaptation in evolutionary biology. In the conventional view it is assumed that the environment exists prior to the organism, into which the latter fits. This is not so. Living beings and the environment are linked together in a process of codetermination or mutual specification. In this light, environmental features are not simply external features that have to be internalized by the organism; they are themselves results of a long history of codetermination. The organism is both the subject and object of evolution. The processes of coevolution result in the environment's being brought to life through a process of coupling. Taking the world as pregiven and the organism as adapting can be categorized as dualism. Buddhism transcends this duality in its codeterminative perspective.

The standard arithmetic that we use today, based on the decimal place system and the use of zero, was transmitted through the Arabs from South Asia. It entails certain standard procedures, algorithms, to perform various operations. But are these the only such operations that exist and are these the ones that are computationally the most efficient? Could there be algorithms that did not get transmitted from India through the Arabs, or those that were developed after the transmission?

Indeed there are many such, as Ashok Jhunjhunwala, a professor of electrical engineering in the Institute of Technology, Madras, has discovered recently. He has examined everyday practices in arithmetic in areas not yet influenced by European techniques such as those used by artisans and businessmen in the non-Europeanized sector. He came across simple but fast methods of calculation. He described eight of these methods which are faster than conventional methods. These included means of finding area, multiplication, squaring, division, evaluation of powers, square roots of numbers, divisibility of numbers, and factorization. They also included methods to catch errors. Jhunjhunwala has compared the speed of some of these old approaches with contemporary ones and found that some are faster. He is now applying these general methods to speed up calculations in computers.

Jhunjhunwala's collection of mathematics at the local level shows the proliferation of methods possible once the decimal system is understood. Local groups discovered new tricks, a process of grass roots creativity very much like the different responses to changing agroclimatic conditions across the world and the resultant variations in agricultural practices.

Time is yet another area to explore. There are many different philosophical discussions on *Saṁsāra* concerning what could be termed the nature of long duration processes. According to some Jain views, time was one of the causal factors in the evolution of nature; and Buddhism alone has a very large tapestry of conceptions of time.

One of these approaches developed an elaborate theory not only of atoms but also of moments, with some schools recognizing four types of moments and others three. Other theories were also proposed by different schools to relate the theory of moments to the fact of continuity of temporal events.

Virtual Reality brings into question the constructor and the constructed. These types of questions are regularly dealt with in Buddhist and other South Asian philosophies. In the virtual realities that use visual representations, parallels also exist with visualization techniques in certain branches of Buddhism. The author of a text on the topic, Howard Rheinhold, says that the Virtual Reality "experience is destined to transform us because it's an external mirror of something that Buddhists have always said, which is that the world we think we see 'out there' is an illusion."

The ethical and conceptual questions of the future brought about by modern science and technology could have many uses for South Asian perspectives.

There are many stores of valid information still to draw from. One authoritative estimate of manuscripts, roughly covering the areas of mathematics and astronomy, is about 100,000. Yet the recently published book *Source Book of Indian Astronomy* lists only 285. Of these only very few have been studied. They are mines of mathematical ideas and applications that have hardly been touched.

A passage from Suśruta stimulated the growth of modern plastic surgery in the nineteenth century in Europe. However, as Krishnamurty points out, that was only a stray reference in the many procedures described. It had the fortune of catching the imagination of a western expert. There could very well be many other descriptions that could be rediscovered for modern medicine. Under treatment for mental diseases Suśruta gives a very large list of plants. It is possible that screening of these plants could give rise to a much larger set of useful remedies.

Varela stated that the infusion of Eastern ideas into the sciences of the West would have as much an impact as did the Renaissance rediscovery of Greek thought. How far this may be true is for the future to decide. However, this would help make the present Western knowledge system more universal while still maintaining the rigor developed in the last few centuries. It would help both to enlarge the knowledge terrain covered by the present system as well as retrieve what is relevant from other traditions.

See also: ►Mathematics in India, ►Knowledge Systems: Local Knowledge, ►Time

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East and West: Islam in the Transmission of Knowledge East to West

Richard C. Taylor

Prior to its explosive expansion from the Arabian Peninsula, Islam itself had no substantive body of scientific learning. The Arabic term for knowledge or science, ^{c}*ilm*, had a developing history steeped in religious reflection and writing as a consequence of the extensive use of its Semitic root ^{c}-*l-m* in the Qur'ân. In contrast to the pre-Islamic "Time of Ignorance" (*jâhilîyah*), the advent of Muhammad as Prophet conveying the words of God in the Qur'ân marked the presence of a new, and frequently detailed and legalistic, understanding of how human beings are to submit (*islâm*) to the will of God in all aspects of their lives. Knowledge on the part of humans was viewed as having its source without exception in the Divine, though signs of the presence of Creator were understood to be evident in the created world. For Muslims, as a result, the place of primacy goes to religious sciences directly (the Qur'ân, the Hadîth, etc.) or indirectly (grammatical studies, law, etc.) which deal with what has been divinely revealed, without at the same time excluding natural knowledge. Later forms of knowledge were sometimes divided into the religious and the foreign sciences (al-Khwârizmî, ca. 976), the religious and nonreligious or rational (al-Ghazâlî 1058–1111) or the traditional religious and the philosophical (Ibn Khaldûn 1332–1406), although the philosopher al-Fârâbî (870–950) gave a different account classifying the sciences into those of language, logic, mathematics, natural philosophy, metaphysics, politics, law, and theology. While such distinctions in some cases reflected believers' deep distrust of foreign learning as superfluous to the guidance and injunctions of the Qur'ân and the natural perception of human beings, the readily apparent value of medicine, mathematics, astronomy, and even astrology led ultimately both to the full incorporation of Greek scientific and philosophical learning into Muslim intellectual and cultural life and to its enhancement and development at the hands of scientists and scholars in the Islamic milieu.

In the course of its expansion, Islam came to have dominance over populations of Christians, Jews, Zoroastrians, and others in Egypt and the greater Middle East who were already possessed of Greek medicine, technology, and scientific learning and who were active participants in the construction of long traditions of intellectual reflection on God, nature, and human

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learning. In addition to interest in medicine universal to all peoples, Arabian Muslims and converted native populations had practical religious interests in astronomy and geography because of Islamic precepts calling for prayer by the faithful in the direction of Mecca at five separate times daily and because of the need for exact calculations for holy days and for the proper arrangement and placement of mosques and their interiors. For those in positions of political leadership, there was also the practical need to discern matters related to quality and character of life present and to come as read in the stars by astrologists. Another sort of practical need which contributed to the demand for Greek scientific texts of a logical sort was that posed by theological debate both intramural and extramural to Islam. Christians as well as Jews and their Muslim students marshaled powerful arguments with enviable sophistication thanks to Syrian and Greek intellectual roots in a Hellenistic cultural tradition which had a long theological interest in Aristotelian logic due to controversies among Nestorians, Monophysites and others. In these contexts there arose demand for deeper understanding of the conceptual foundations of Greek knowledge incompletely conveyed in medicine and other vital areas. Thus, there was a need for translations of works which set out the theoretical and philosophical structures for medical, astronomical, astrological, and other studies. The comprehensive multigenerational translation movement arose in part in response to these needs in a way that would eventually have profound influence on Latin Europe.

Yet it was also driven by the ascendancy of the Abbasid dynasty (758–1258) and its ideology of inclusion of non-Arabian peoples in Islam and in its political, economic, and religious institutions to the benefit of its Persian supporters and to the detriment of traditional Arabian tribes. The unequivocal opening of Islam and its developing culture to all peoples seeking to become Muslim on the part of the Abbasids enhanced the dynasty's power and independence from past sources of political control. That independence was most evident in the founding of the new city of Baghdad with its deliberately designed planning for the location of institutions in the city which was quickly to become the center of a vast empire and the most important locus for the study of science and the development of knowledge in the world in the ninth to twelfth centuries. Recently Dimitri Gutas (1998) has offered the intriguing thesis that operating underneath all these obvious reasons for the translation movement was the continuation of a "Zorastrian imperial ideology" on the part of Sassanian leaders committed to the recovery of all knowledge conceived of as having been scattered throughout the world following the conquest of the Persians by Alexander. On this account, al-Mansur (r. 754–775), Abbasid founder of Baghdad under whom the translation movement was initiated in earnest, should be regarded as continuing the Sassanian project as part of a Zorastrian inspired agenda to amass all knowledge in the dominant language of the era, Arabic.

Transmission of Knowledge to Islam

The transmission of works of medicine, astrology, science, philosophy, and other materials was modest before the ninth century. An Arabic rendering from Sanskrit of the *Zij al-Arkand* derivative upon the *Khandakhadyaka* of Brahmagupta which was available around 738 provided important astronomical tables employed by Abû Ja`far M. b. Mûsâ al-Khwârizmî (d. 850) whose work was so important to the Latin West. He also made use of Ptolemy's *Geographia* and *Megale Syntaxis*, the latter available in Arabic as the *Majisti* by about 796 and known in the Latin West as the *Almagest*. As early as the late seventh century the Jewish physician Mâsarjawayh had rendered the medical *Panducts* of Ahrûn of Alexandria from Syriac into Arabic perhaps for use at Jundîshâpûr, the famous medical center. Organized and sponsored translations from Indian, Iranian, and Greek sources into Syriac and Arabic began to be produced in abundance under the `Abbasids, particularly during the reigns of al-Mansûr (754–775) and Hârûn al-Rashîd (786–809) at Baghdad, and under the influence of the Barmakid family of physicians and administrators. `Abdullâh b. al-Muqaffa` rendered from Old Persian or Pahlavi into an exemplary Arabic version an Indian work under the title *Kalîlah wa-Dimnah*, while he or his son Muhammad translated Aristotle's *Categories*, *On Interpretation* and *Posterior Analytics* and the *Isagoge* of Porphyry during the reign of al-Mansûr (754–775). The era of al-Ma'mûn (r. 813–833) who set himself as Islamic caliph over an Islamic empire was a time of religious turmoil (with the mihna or "inquisition") and also a time of a continuously increasing expansion of translations and scientific studies which continued under his successors to the Caliphate.

In the ninth century two major groups of translators can be discerned by style, vocabulary, and, to some degree, by interest. The name of the philosopher al-Kindî (801–866) is associated with a group with strong metaphysical interests. Ustâth/Eustathios was responsible for the translation of Aristotle's *Metaphysics* while ᶜAbd al-Masih al-Naᶜîma al-Himsî, a Syrian Christian from Emessa, provided a deeply influential paraphrase and commentary on *Enneads* IV–V of the Neoplatonist Plotinus, part of which was known as "The Theology of Aristotle" in an edition by the Baghdad philosopher al-Kindî. There were also translations from the *Elements of Theology* by Proclus

(412–485), head of the Academy at Athens, including modified versions in the treatise, *Kalâm fi mahd al-khair* (*Discourse on the Pure Good*), which was attributed to Aristotle or Proclus in the Arabic manuscripts and was later famously known in the Latin West as the *Liber de causis (Book of Causes).* These works indicate a powerful interest in late Greek Neoplatonic theology and its accounts of the One, the hierarchy of principles constituting the universe, the structure and functioning of the cosmos, and the ability of the human soul or intellect to apprehend principles and cosmological realities and to transcend the body for its own fulfillment and happiness. Also included in this group is Ibn al-Bitriq who translated Aristotle's *On the Soul, Meteorology*, *On the Heavens*, *Generation of Animals*, *Parts of Animals*, and perhaps a version of the *Parva Naturalia*, as well as Plato's *Timaeus*. As a group, their translations may contain transliterations, neologisms, and a tendency to simplify or eliminate complicated Neoplatonic hierarchies. Not himself a translator, al-Kindî championed the value of philosophical texts with the argument that foreign philosophical materials lead to the establishment of the sovereignty of God as the True One and as such should be welcomed by faithful Muslims. What is of special interest here is the implicit view that philosophical wisdom is a source at least coequal with Islamic revelation in the ascertaining of the nature of creation and the Creator. The importance of this moment becomes all the more evident in later philosophers for whom philosophy with its demonstrative argumentation is viewed as having primary access to truth, while religion and revelation are understood to be secondary manifestations of truth through image and representation. Of the same era of early translators was Theodore abû Qurrah, bishop of Harrân, who knew Greek, Syriac and Arabic and followed John Damascene in polemic against Islam and translated Damascene into Arabic.

The second group of the ninth century was that associated with the Nestorian Christian Hunayn b. Ishâq al-`Ibâdî (808/9–873) and his assistants whose achievement and influence in the transmission of knowledge was without equal in the entire Middle Ages. The account of Hunayn's role in the transmission of knowledge is a story of personal achievement and high scientific and scholarly standards. Removed from medical studies by his teacher at Baghdad, the physician, translator, and scholar Yuhannâ b. Mâsawayh, Hunayn disappeared into Byzantium (*bilâd al-Rûm*) to reappear 2 years later with a mastery of Greek and a penchant for quoting Homer in the original. The now trilingual (Syriac, Arabic, and Greek) Hunayn established his expertise with a translation of a Galenic work and attained a funded place among his colleagues. Sometimes translating into Arabic directly from Greek or Syriac, other times translating from Greek into Syriac and then from Syriac into Arabic, Hunayn and his assembled team of translators, `Îsâ b. Yahyâ, Mûsâ b. Khâlid, Yahyâ b. Hârûn, his son Ishâq, his nephew Hubaysh b. al-Hasan and others, set a high standard of quality for their work: they sought out Greek manuscripts to collate into a single version, worked to standardize Arabic technical vocabulary, and rendered phrases and sentences, not translating word-for-word, in a sophisticated effort to capture the sense of the texts. Hunayn was particularly interested in the work of the physician and epitomizer Galen (129–200?) and translated over 100 of his works and studied the corpus throughout his lifetime. Thanks in great measure to the *Fihrist* or *Catalogue* of the Baghdad bookseller Ibn al-Nadîm (ca. 935–990), our knowledge of works translated and of works available in his day is substantial. Details concerning the translation of Galen by his group are spelled out in a preserved the *Epistle* which Hunayn wrote giving an account of methodology and of which works by Galen had been translated to the extent of his knowledge. Other medical works translated included works of Hippocrates and the *Materia Medica* of Diosorides which constituted the Arabic pharmacopoeia. This latter was possible only because of extensive Greek pharmacological and botanical vocabulary on the part of the physician Hunayn. They went on during or shortly after his lifetime to translate into Arabic or Syriac, and to comment upon or abridge Plato's *Laws*, *Sophist*, *Timaeus*, and *Politics*, Aristotle's *Categories*, *On Interpretation*, *Prior* and *Posterior Analytics*, *Sophistics*, *Rhetoric*, *On the Soul*, *Magna Moralia*, *Metaphysics*, *Nicomachean Ethics*, *On Generation and Corruption* and *Physics*. This second phase of the translations also includes the work of the mathematician Thâbit b. Qurrah, a Sabian from Harrân and contemporary and collaborator with Ishâq b. Hunayn. Thâbit worked with a group of astrologers and mathematicians in the Harrânian tradition and translated Nicomachus of Gerasa's *Introduction to Arithmetic*, improved existing translations by Ishâq of Euclid's *Elements* and Ptolemy's *Almagest*, commented on Aristotle's *Physics*, and worked to carry on the Greek Neopythagorean metaphysics of numbers and astrology. Also active in the same era were the Muslim Abû [c]Uthmân al-Dimashqî who translated Aristotle's *Topics* and Porphyry's *Isagoge* as well as texts of Alexander and medical and mathematical works and the Christian Qustâ b. Lûqâ who rendered works of Galen and Hippocrates as well as the *Metaphysics* of Theophrastus, the *Mechanica* of Hero, the *Arithmetica* of Diaphantus and the *Placita Philosophorum* (*Opinions of the Philosophers*) wrongly attributed to Plutarch. Among other translations were commentaries and related philosophical materials by Alexander of Aphrodisias, Porphyry, Proclus, Themistius, and Nemesius as well as works by Ptolemy, Archimedes, Euclid and others. Many of the works mentioned here were translated more than once.

The final phase of translation began with the work of the Syrian Greek Christian Abû Bishr Mattâ b. Yûnus (d. 940) who had Muslim, Christian, and Jewish teachers, was an accomplished trilingual writer, and had as his student the renowned philosopher al-Fârâbî (870–950). He translated Aristotle's *Meteorology*, *De sensu*, *Poetics*, and *On the Heavens*. He also rendered into Arabic the *Posterior Analytics* from the Syriac of Hunayn and Ishâq as well as Aristotle's important philosophical account of the divine, book *Lambda* of the *Metaphysics* with the commentary of Alexander of Aphrodisias and other works by Alexander. Al-Fârâbî's student Yahyâ b. ^{c}Âdî (893/4–974) was a philosopher, theologian and logician as well as a translator and apparently rendered some Syriac translations by Hunayn, Ishâq and others into Arabic. He was involved with the preparation of translations of Plato's *Laws* and *Timaeus*, Aristotle's *Categories*, *Topics*, *Sophistic Elenchi*, *Physics*, *On the Soul*, *Metaphysics*, and *Poetics*, the *Metaphysics* of Theophrastus, and commentaries on Aristotle's' work by Alexander of Aphrodisias, Themistius and Olympiodorus. He also wrote commentaries on most of Aristotle's logical works while writing works of his own on logic, mathematics, natural philosophy, metaphysics, ethics, theology, scripture, and medicine. Of the same era were Ibn Zurcah (942–1008) and Ibn al-Khammâr (942–1017) who were also involved in translations of Aristotelian works, among them *On Generation of Animals*, *History of Animals*, *Meteorology* and works from the *Organon*. Their work brought to a close for the most part the great translation movement which had some beginnings during the reign of the Ummayads but was for the most part a phenomenon of the era of the Abbasids. A massive portion of Greek scientific, philosophical and other literature had been translated and was now in the process of being assimilated. As mentioned earlier, al-Kindî had argued for philosophy as a source coequal with revealed religion for the understanding of creation and the Creator. In the tenth century, the assimilation of philosophical learning in the work of al-Fârâbî takes a further more controversial step in asserting the primacy of scientific and philosophical argumentation over religion which is characterized as opinions set forth by the ruler for the end which that ruler determines. With profound implications for later Arabic philosophy up to the thirteenth century and for its impact on the Latin West, al-Fârâbî boldly asserts the primacy of independent natural reason characterizing religious revelation as at best a diminished, image-filled, and emotive form of the truth obtained properly by philosophers and scientists in the apprehension of primary principles and the attainment of philosophical and scientific demonstration. The universe was conceived by al-Fârâbî not as created ex nihilo but as emanated from the One as First Being in a hierarchy of intellects and cosmological spheres descending to the earth where human beings exist in a realm of natural generation. In his classical rationalism in Arabic philosophy al-Fârâbî is followed by Ibn Sînâ/Avicenna in the eleventh century and Averroes in the twelfth. What is more, in his construction of a framework of the sciences in his *Enumeration of the Sciences* al-Fârâbî set out clearly an Aristotelian inspired division of the sciences which would be central for the conception of knowledge both in Arabic thought and in the Latin West. Further, in his *Aims of the Metaphysics of Aristotle*, he set aside al-Kindî's view of philosophical metaphysics as a pursuit of God or theology as its object and argued instead that the object of metaphysics is being qua being in all its forms, with God studied as cause of being. This reinforced the view that religion and its revelation are regarded as secondary sources for truth and knowledge provided primarily for the guidance of those unable to take full advantage of the intellect's natural powers of reasoning and intellectual understanding. In this and in many other ways al-Fârâbî was influenced by the late Neoplatonic philosophers of Athens and Alexandria.

As indicated in the work of al-Fârâbî in particular, the story of the transmission of knowledge is not merely one of texts moving from one language to another. It is, in an equally important way, a story of the movement of ideas and their reception and development in a new language and cultural framework. This is all the more so in the case of knowledge and its movement from East to West via the Islamic route, for what was transmitted was oftentimes not only texts but methodological thought and intellectual advances and achievements made on the basis of wisdom garnered from foreign sources. Nearly all of the translators mentioned above were also physicians, scientists, or philosophers in their own right. It was primarily out of their desire for knowledge that they studied foreign works. Translation was in part a consequence of a natural thirst for knowledge on the part of the translators, their patrons and Muslim, Christian, and Jewish intellectuals. Thinkers such as al-Kindî and al-Fârâbî worked closely with those who were studying foreign texts and preparing translations. By the time of the Persian Ibn Sînâ/Avicenna (980–1037), the most influential of the philosophers, the cultivation of foreign knowledge within the context of Islam was yielding more new fruits on native Islamic soil. Ibn Sînâ himself developed a philosophical system with a new conceptual approach to metaphysics and other philosophical matters which had an overwhelming influence in Arabic and a powerful and longlasting impact on the Latin West. Conceiving God as the Necessary Being with arguments which would become standard fare in Arabic and Western Latin philosophical texts, Avicenna argued for a distinction of essence and existence in created entities inspired by issues in the Islamic theological tradition of Kalâm. Drawing on thinking from the Greek Neoplatonic Alexandrian school tradition, Avicenna set forth a view of the human soul as per se rational, immaterial and imperishable, a view much welcomed in translation in the Latin West.

Al-Bîrûnî (973–1043), an encyclopaedic contemporary and correspondent of Ibn Sînâ, wrote extensively on mathematics, astronomy, astrology, the astrolabe, pharmacology, gems, metals, and other matters in addition to his work on Indian thought. Working with translated Greek texts on mathematics and optics as well as more physical accounts of visual perception, Ibn Haytham (d. 1039), a physician as well as astronomer and mathematician, developed a theory of optics (*perspectiva* in Latin) and intromissive visual perception which became dominant in Islam and later in the Latin West where Roger Bacon championed his work. In the area of alchemy, the name of Jâbir b. Hayyân (d. ca. 815) and that of the great physician and scholar, Abû Bakr M. b. Zakariyyâ' al-Râzî (d. ca. 925), stand out in both Islam and the Latin West, although contemporary scholars raise questions about Jâbir's contributions to the corpus of works traditionally attributed to him. The great Islamic theologian, al-Ghazâlî, while severely critical of the philosophers on metaphysical matters, encouraged acceptance of and elaboration upon logic, mathematics, medicine, and the physical sciences. He vigorously combated many insufficiently well founded views of the classical rationalists al-Fârâbî and Avicenna in his *Incoherence of the Philosophers* and argued that the primacy of certainty regarding the human apprehension of the Divine can only be found in the Sûfî experience of gnostic *dhawq* ("taste"). Ironically, however, his *Intentions of the Philosophers*, apparently written in preparation for refuting the philosophers, was viewed as a work by a loyal follower of Avicenna in the Latin West where its explanatory opening section was lost in early transmission of the translation. In spite of the attack of al-Ghazâlî, classical rationalism continued its development in the East (where it moved closer to religious thought) and in Andalusia which was destined to become the primary locus of the transmission of science, philosophy, and the tradition of philosophical commentary to the Latin West. There the works of al-Fârâbî, including commentaries on Aristotle's writings, were studied by Ibn Bâjjah (d. 1139) who wrote his own commentaries and Averroes (Ibn Rushd d. 1198) whose commentaries of various sorts came to play a central role in the development of philosophy in Hebrew and Latin translations. Both these thinkers continued al-Fârâbî's rationalist approach giving primacy to philosophy and intellect, but Averroes distinguished himself by seeking to make a full return to the philosophical principles and texts of Aristotle and to set aside the accretions from Neoplatonism and from unsuitable religious sources. His *Long Commentaries* – containing complete texts of Aristotle with detailed commentary – had a profound impact on the Latin West and some important influence on Jewish thought. His arguments, *secundum Aristotelem*, for the unoriginated and eternal nature of the world, for the perishable nature of the individual human soul, and for the primacy of the philosophical over the religious, shocked the Latin West when properly understood and contributed in a central way to the Condemnations of 1277 which profoundly affected philosophical studies in Paris and other Latin centers of scientific, philosophical, and theological study. Nevertheless, his *Long Commentaries* on the *De Anima*, *Physics*, *On the Heavens*, and *Metaphysics* were constantly studied guides to the thought of Aristotle and also to the Greek Commentators Theophrastus, Alexander and Themistius whom Averroes cited and engaged in argument. In Hebrew translation the *Middle Commentaries* and *Short Commentaries* or *Epitomes* of Averroes came eventually to supplant the works of Aristotle and became the basis of new Commentaries in the Jewish philosophical tradition. In the Arabic tradition, however, the effort of Averroes to return to the pure arguments of Aristotle was not continued, in part due to the banning of philosophy in Andalusia as result of religious and political conflicts, in part due to a lack of interest to return to an Aristotelianism devoid of the mystical at a time when interest in Sufism and forms of illuminationism were on the rise, and in part due to the overwhelming influence of Avicenna throughout the lands of Islam. Another contributing factor was the strife in Andalusia itself as Christian and Muslim kingdoms contested for the Iberian peninsula.

Transmission of Knowledge to the Latin West

In the Latin West science and advanced learning had to be actively sought out from Greek and Arabic sources and then translated into Latin and carried North or West for an economically and politically expanding and intellectually developing Europe. In contrast to Islam, the West did possess some remnants of earlier Greek learning including translations of portions of Aristotle's *Organon* by Boethius (d. 524) and some other works such as Calcidius' incomplete *Timaeus* translation and commentary, as well as an understanding of the importance of philosophy and philosophical argumentation from Greek Fathers and in particular Augustine of Hippo whose influence in the West was pervasive and dominant in theology and philosophy for much of the Middle Ages. Moreover, Greek science and philosophy, while recognized as arising from a pagan culture, were not feared as foreign in the way that they were sometimes in Islam; rather, they were recognized as intellectual treasures to be recovered and put to use in the service of Latin Christianity. Individual scholars began to seek out Greek texts and learning and came to the frontiers of Islam in search of knowledge and more sophisticated intellectual understanding from a culture which had benefited from and added to the Hellenistic learning which it had received. Spain was by far the most productive geographic area for translations from Arabic, although some important work was done in Sicily with a few other works of significance being rendered into Latin in the Near East. Not unlike the Arabic translation movement, the Latin movement can be distinguished into periods during each of which translations were being made from Arabic as well as Greek sources.

While an important Barcelona manuscript containing Latin translations and other materials from the late tenth century provides valuable evidence of early interest in Arabic scientific knowledge about the astrolabe, the first translations of significance from Arabic began to appear in the eleventh century. Constantine the African (d. ca.1087), apparently a widely traveled and well-educated North African Muslim, converted to Christianity and became a Benedictine monk at Monte Cassino. According to one source, he brought with him many texts and undertook the task of translating and composing works on medicine when he had learned of the poverty of Latin Medieval medicine. His contribution to the Latin corpus was substantial and included works by Galen (*Ars medica* and a summary of the *Metategni*) and Hippocrates (*Aphorisms* and *Prognostics*, with commentaries by Galen) as well as work by `Alî b. al-`Abbâs al-Majûsî/Haly Abbas (*Pantegni*), Hunayn b. Ishâq/Johannitius (*Isagoge* or *Introduction to Galen's Tegni*) and others. These translations and other work by Constantine played a substantial role in forming the foundations of medicine and its study by Europeans. But it was the Twelfth and Thirteenth centuries which saw floodgates open and a wealth of learning pour forth into Latin Europe.

In the twelfth century, scholars engaged in translation and transmission of Arabic texts were, like their counterparts working in the Islamic milieu centuries earlier, eager and inquisitive scientists and scholars first and translators second. The great majority of them found Spain to provide the needed environment for their work. Some of them were natives to the area but a large number came from afar in search of scientific learning. An exception to this was Adelard of Bath (d. ca. 1142) who studied in France and then traveled widely in Italy and the Near East before returning to his native England. Among his translations were two of monumental importance to the Latin West: in astronomy al-Khwârizmî's astronomical tables in the usable version of Maslamah b. Ahmad al-Majrîjî of Cordoba and in mathematics Euclid's *Elements*. In 1126 he translated Abû Ma`shar's astrological *Introductorium in astronomiam*.

Toledo was a natural center for translation work after its conquest since its libraries contained books of science, philosophy, and religion and because it remained a place where Arabic was spoken and used by an educated class. It also became a place of refuge for trilingual Jews fleeing persecution in the South by the Almohad regime. There John of Seville (fl. c. 1130–1142) translated Qustâ b. Lûqâ's *De differentia spiritus et anime* for Raymond, the archbishop of Toledo (1125–1152) and famous patron of the translators, and a large number of astrological texts by Mâshâ'allâh, Abû Ma`shar and al-Farghânî in addition to the abbreviated version of the pseudo-Aristotelian *Secretum secretorum*. Robert of Chester apparently worked with Herman of Carinthia in that era to produce a translation of the Qur'ân. In mathematics Robert translated al-Khwârizmî's *Algebra*. Herman produced a second translation of Abû Ma`shar's *Introductorium* and perhaps also a second translation of Euclid's *Elements* in addition to Ptolemy's *Planisphere*. Plato of Tivoli was also interested in astrology and translated Ptolemy's *Quadripartitium* and a work by al-Bâttanî, an astronomer and disciple of Thâbit b. Qurrah the Harranian astrologer and mathematician.

At Toledo Dominicus Gundisalvi (d. 1190) devoted himself to the study of Arabic and Jewish thought, translating a number of important philosophical works, among them the *Fons vitae* of Ibn Gabirol/Avicebrol or Avicebron, the *Maqâsid al-falâsifah* (*The Intentions of the Philosophers*) of al-Ghazâlî/Algazel, and a large number of works from the comprehensive *Shifâ'* (*Healing*, rendered into Latin as *Sufficientia*) of the philosopher Ibn Sînâ/Avicenna, among them the *On the Soul* with Avendauth (Ibn Da'ud) and the *Metaphysics* with an anonymous assistant. Gundissalinus apparently worked frequently with an assistant. The nature of their collaboration is far from clear even though an account of it is given in the dedication of his translation of Avicenna's *On the Soul*. It apparently involved an intermediate step of translation into the local vernacular or a reading of the text out loud. He is also thought to have translated Isaac Israeli's *Book of Definitions* and al-Kindî's *On the intellect* as well as al-Fârâbî's *On the intellect*, *Enumeration of the Sciences*, and *Liber excitativus ad viam felicitatis (Indicating the way to happiness)*. Regardless of the precise nature of his collaborations, it is clear that his study and translations had substantial influence on the thought of Gundissalinus himself as evidenced in his own philosophical works, such as *On the Procession of the World* and *On the Division of Philosophy*, which in turn together with the translations played an important role in the formation of the thought of the great philosophers of the thirteen century and later such as William of Auvergne, Albertus Magnus, Thomas Aquinas, Duns Scotus, and others who made extensive use of these works as well as the translations of another scholar at Toledo, Gerard of Cremona.

At Toledo at the same time was the great scholar, lecturer and translator par excellence of the age, Gerard of Cremona (ca. 1114–1187), who had come from Italy to Spain in search of Ptolemy's *Almagest* which he then proceeded to translate from Arabic into Latin. He was a canon at the cathedral and, so, like Dominicus, under the patronage of Archbishop Raymond. The list of Gerard's translations is long and detailed and includes works on mathematics by Euclid (*Elements*) Thâbit b. Qurrah, al-Khwârizmî, al-Kindî and others; works on astronomy by Thâbit and al-Farghânî; a medical work by Avicenna, the great *Qânûn fî tibb* (*Canons of Medicine*), which was in use into and beyond the Renaissance; philosophical works of Aristotle: *Meteorology*, *On Generation and Corruption*, *Physics*, *On the Heavens* and the *Posterior Analytics*; works by the philosophers al-Kindî and al-Fârâbî; the influential pseudo-Aristotelian *Liber de causis*; and a vast array of other works of Islamic philosophical and scientific learning. Like Gundissalinus, Gerard seems to have sometimes worked with an assistant, although this does not seem to have always been the case. As for style, much scholarly work remains to be done in the definitive identification of genuine translations by Gerard before any comprehensive remarks can be made. Still, in his translations Gerard sometimes used a common method following the work of Boethius in translating from Greek into Latin in the early sixth century: *verbum ex verbo*. The attempt was made to give translations which reflected as precisely as possible the original text in the grammatical structure of the original language's sentences and in word-for-word translation. In the case of Indo-European Greek texts, this was a somewhat reasonable way of proceeding. But in the case of Latin translations of Semitic Arabic works, some of which had already gone through translation from Greek into Syriac and then into Arabic, the medieval Latin reader was left with an intellectually challenging exercise with the result that later translations from Greek were oftentimes preferred. Nevertheless, the translations from Arabic by Gerard (and Gundissalinus) frequently conveyed well and clearly the sense and letter of the Arabic.

Translators of the later twelfth and early thirteenth centuries include the Englishman Alfred of Sareshal who translated the pseudo-Aristotelian *De plantis*, on which he wrote a commentary, and Avicenna's *De mineralibus*. Marc, a canon at Toledo, translated medical works, the Qur'ân and some theological tracts of Ibn Tûmart. Most accomplished of Latin translators from Arabic of this era was Michael Scot who was in Toledo in 1215, Bologna in 1220, and Sicily in 1227 as court astrologer to Frederick II where he died in about 1236. Michael completed his translation of al-Bitrûjî's *De spheris* in 1217 at Toledo where he also translated Aristotle's *On Animals* in part. His greatest achievement, however, was responsibility for making works of Averroes available to the Latin West where they continued to be read through the time of the Renaissance. While it is certain that Michael was the translator of *the Long Commentary on Aristotle's On the Heavens*, on the basis of current scholarship it can only be said that it is likely that Michael was also the translator of Averroes's *Long Commentaries* on Aristotle's, *On the Soul*, *Physics* and *Metaphysics.* All of these Long Commentaries contained the complete text of Aristotle with detailed commentary by Averroes drawing on materials from the Greek and Arabic tradition. Michael also seems to have translated the *Middle Commentaries* on *On Generation and Corruption* and part of the *Meteorology,* as well as Averroes's *Short Commentaries* or *Epitomes* of *On the Heavens*, *Parva naturalia* and *On Animals*. Hermannus Alemannus, William of Luna, Petrus Gallegus, and Philp of Tripoli working in the mid-thirteenth century complete the list of well-known translators from Arabic. Herman is responsible for the Latin of Averroes' *Middle Commentaries* on the *Ethics* and *Poetics* as well as for the widely circulated ethical epitome, *Summa Alexandrinorum*. William also translated some of Averroes' texts: epitomes of logical works of Aristotle and middle commentaries on the *Posterior Analytics* and *Categories*. Petrus rendered Averroes' epitome on Aristotle's *On the Parts of Animals*. To Philip is ascribed the complete Latin of the *Secretum secretorum*.

While this enormous wealth of Greek and Islamic learning was being rendered into Latin from Arabic sources in Spain, Sicily, and the Near East, twelfth century Europe was also the recipient of a vast array of translations directly from the Greek by James of Venice, Henricus Aristippus, a certain Ioannes and others. In the thirteenth century there were substantial efforts of translation from Greek by Robert Grosseteste, William of Moerbeke and others. The transmission of knowledge into the Latin West came along two different roads, each of which had its origins in Greek learning. Via the Islamic route, however, the Latin West also received the sophisticated reflections and intellectual advancements of Islamic thinkers whose religiously oriented philosophical and theological reflections on the world and its Creator were oftentimes much closer to the mentality of Christian Europe than were the texts of Ancient pagan authors. The philosophical texts of the Islamic philosophers Avicenna and Averroes, sophisticated interpretations and complex new intellectual syntheses, early on "explained" Aristotelian works to Medieval Latins and thereby had a profound influence on the methodologies and analyses worked and developed by Christian theological and philosophical thinkers from the twelfth and thirteenth centuries and beyond.

For Jewish communities the thought of Moses Maimonides was dominant and, though he was much influenced by al-Fârâbî, it was Averroes who was most important in that tradition. In southern Europe few works of Aristotle were available in Hebrew, though Samuel ibn Tibbon translated the *Meteorology* in the early twelfth century. Instead the *Short Commentaries* (or *Epitomes*) and *Middle Commentaries* of Averroes on Aristotle's *On the Soul*, *Metaphysics*, *On the Heavens* and others proved most important. Some of the translators were Moses ibn Tibbon, son of Samuel, Shem Tov ben Isaac, Zerahyah ben Isaac Hen and Kalonymous ben Kalonymus who undertook translations of Averroes's *Long Commentaries* on the *Posterior Analytics*, *Physics* and *Metaphysics*. In the Jewish tradition the various commentaries of Averroes came themselves to be the subject of commentaries, most notably by Gersonides and his followers who wrote the so-called "super-commentaries" in the fourteenth century. One Kalonymos translated the *Incoherence of the Incoherence* – the commentary of Averroes on the *Incoherence of the Philosophers* by al-Ghazâlî – into Latin for the King of Naples, Robert of Anjou, in 1328, though sources are insufficient to determine whether this is the same or a different Kalonymos who translated from Arabic into Hebrew.

In the thirteenth and fourteenth Centuries translations in Andalusia and elsewhere continued to be made from Arabic into Latin and Hebrew and also into the local vernacular. Alfonso X (el Sabio), King of León and Castile (1252–1277), sponsored translations from Arabic into Castilian including codes of law, astrology, magic, and astronomy. In these centuries the translated texts of Arabic science and medicine became central to Western development and texts of philosophy came to play a central role in Christian theological and philosophical argumentation up to and beyond the Renaissance. In the fifteenth and sixteenth centuries more translations of works of Averroes appeared, this time mostly from Hebrew into Latin. What was most significant in this was their inclusion in Renaissance printings of the works of Aristotle. The Giunta edition printed in Venice in 1550–1552 (and reprinted many times thereafter) in eleven volumes also contained revised texts and new translations by Jacob Mantino (d. 1549) and allowed for the easy use of the translated works of Averroes and the earlier versions of the works of Aristotle to be consulted and studied together.

The centrality of the notion of ^{c}*ilm* or knowledge in Islam encouraged the pursuit of learning in all its various forms and the sharing of knowledge among all the people of society, Muslims, Christians, and Jews. Scientific study and philosophical discourse in the Islamic milieu was much influenced by the late ancient schools of Neoplatonism at Athens and Alexandria. That influence is evident in recognition of the independence of philosophy as an intellectual discipline distinct from religious tradition and its development of theological argumentation. Natural reason and intellectual insight as found in philosophy in the classical rationalist tradition constituted an independent way to the understanding of human beings, the cosmos and the First Cause. The philosophical and scientific works translated into Latin were from the most part from this classical rationalist tradition and conveyed methodologies of investigation bearing an understanding of the attainment of knowledge quite different from that found in the Latin West where the Augustinan notion of faith as the foundation for understanding and knowledge was widely dominant. In the Latin later Middle Ages rationalism of the sort found in the Arabic translations danced a careful and sometimes dangerous dialectic with thinkers committed to that Augustinian notion. Thomas Aquinas developed the notion of theology conceived along the lines of Aristotelian science. Siger of Brabant was attacked in argument and charged by Church authorities for his assertions about independent rationality. And the Condemnations of 1277 caused many thinkers to move away from the more explicit rationalism of Averroes and to find philosophical inspiration in the more compatible conception of God and creation and the rational found in Avicenna's works of metaphysics and psychology. The rationalist movement in the West continued to develop into the Renaissance and Early Modern periods where the Reformation and nationalism undermined Catholic dominance and philosophy and science generally developed into something which viewed itself and its methods as separate from traditional theology, revelation and its issues. The conceptions of knowledge by thinkers of the Islamic milieu founded on translated Greek texts and developed and reconceptualized by scientists and philosophers of the Islamic tradition came to play a central role in that development thanks to the Latin translators of Spain, Sicily, and other border lands. To that extent, the role of Islam, its culture and its people, played a central part in the modern conception of science as a discipline distinct from religion, a distinction at the foundation of today's world.

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Eclipse Observations

F. Richard Stephenson

The theme of this article is eclipse *observations*; for information on calculating and predicting eclipses, see the article on *Eclipse Theories*. Eclipses of the Moon and Sun are by no means rare events. In a typical century, as many as 95 lunar eclipses and 40 solar obscurations are visible at any given location (weather permitting). Observations of both types of event are frequently recorded in the history of several non-Western cultures. In ancient times, reports originate almost entirely from Babylon and China; these mainly commence after about 700 BCE. Although extant Babylonian eclipse records cease around 10 BCE, Chinese accounts continue (almost uninterrupted) down to the modern era. After the middle of the first millennium AD, further observations become available from Korea and Japan and also the Islamic world.

As yet, virtually no eclipse records have been uncovered from other major non-Western civilizations–such as ancient Egypt, India or Central America. Possible explanations for these deficiencies include loss or inaccessibility of original records, or less concern in these cultures with observation rather than prediction.

Surviving reports of eclipses are found in two quite distinct types of text: (1) chronicles and other literary works; and (2) astronomical treatises. Texts in the first category mainly note eclipses on account of their spectacular nature. Such reports, although often quite descriptive (especially in the case of total eclipses of the Sun) are usually devoid of technical details. However, astronomers often made careful timings of the various stages of an eclipse, as well as estimating the degree of obscuration of the Moon or Sun when the eclipse was at its height.

Most early non-Western cultures adopted a lunar (or luni-solar) calendar. For instance, in Babylon–and later in the Muslim world–each month commenced with the first sighting of the young crescent Moon. However, throughout East Asia months began at the conjunction of the Moon and Sun. On these systems, solar eclipses occurred either at the end or the beginning of a lunar month, while lunar eclipses took place close to the middle of a month.

Modern computations enable the date, time of day or night and other local circumstances of past eclipses to be determined with high precision. Early references to eclipses sometimes prove of value in dating historical events, while the more careful observations enable long-term variations in the rate of rotation of the Earth to be investigated with remarkable accuracy. Eclipses are thus among the most interesting of all celestial phenomena mentioned in history.

Before about 700 BCE, very few records of eclipses are extant and for most of these the dates are in doubt. It has been suggested that astrological tablets from the city of Ur contain allusions to eclipses occurring around 2000 BCE, but this is disputed. Clear references to eclipses, mainly of the Moon, are recorded on Chinese "oracle bones" from the latter part of the Shang Dynasty (ca. 1350 to 1050 BCE). These bone fragments, inscribed with a primitive script, are mainly concerned with divination. Unfortunately, few bone inscriptions are intact. In the case of the eclipse observations, the year is invariably missing, while the lunar month is only rarely preserved. As a result, determination of the exact dates with the aid of astronomical computations presents considerable difficulties.

An example for which the month is extant may be translated as follows:

> The divination on day *guiwei* was performed by Zheng: "Will there be no disaster in the next ten days?" On the third day *yiyu* an eclipse of the Moon was reported. (These events occurred) in the eighth month.

In common with numerous other Shang inscriptions, dates are expressed in terms of a 60-day cycle. This cycle has probably continued uninterrupted down to modern times. *Guiwei* and *yiyu* were the 20th and 22nd days of the cycle. The term *shi*, used to identify an eclipse, has remained in use in China down to the present day.

Probably the earliest surviving eclipse report for which a date can be confidently derived is from Assyria. This is recorded in the *Assyrian Chronicle* and may be translated as follows: "(Eponym of) Bur-Saggile of Guzana. Revolt in the citadel; in (the month) Siwan, the Sun had an eclipse (*šamaš attalu*)."

The *Assyrian Chronicle* is mainly a list of annual *limmu*–senior officials after whom the year was named. A complete list of *limmu* is preserved from 910 to 646 BCE, as well as the names of several Assyrian kings. Hence the year of the eclipse can be deduced as approximately 763 BCE. Computation shows that during the entire eighth century BCE only a single solar eclipse was large in Assyria: BCE 763 June 15. This date conveniently fits the lunar month Siwan, which was equivalent to May-June.

A few scattered reports of other eclipses (of both Sun and Moon) are preserved in Assyrian sources. However, much more extensive accounts of these phenomena are to be found in the records of ancient Babylon. Probably commencing about 750 BCE, Babylonian astronomers maintained a systematic watch for eclipses (as well as many other celestial phenomena) for around eight centuries. As well as noting the exact date of such events, estimates were given of the time of occurrence and magnitude (the maximum degree of obscuration of the Sun or Moon). The aim was to use these observations to enable better prediction of future eclipses to be made, although the ultimate goal was astrological. Both genuine observations and failed predictions are recorded on the Late Babylonian astronomical texts which were recovered from the site of Babylon in the late nineteenth century. Most of these clay tablets–many of which are badly damaged–are now in the British Museum. The operational rules of the Babylonian calendar are well understood. Although earlier years were counted from the accession of each king, they began to be continuously numbered from the Seleucid Era (311 BCE) onwards.

Among Babylonian records of eclipses, the best known is the total solar obscuration of 136 BCE. This is reported on two separate British Museum tablets, which give overlapping details. A composite translation–based on the work of Prof. H. Hunger of the University of Vienna–is as follows:

> Year 175 (Seleucid), intercalary twelfth month, day 29. At 24° after sunrise, solar eclipse (*šamáš* AN-KU). When it began on the south-west side, in 18° of daytime in the morning it became entirely total. Venus, Mercury and the Normal Stars were visible, Jupiter and Mars, which were in their period of invisibility, were visible in its eclipse [...]It threw off the shadow from south-west to north-east. [Time interval of] 35° for onset, maximal phase and clearing. In its eclipse, north wind...

When reduced to the Julian calendar, the Babylonian date is identical to that of a computed solar eclipse visible in Babylon: BCE 136 April 15. Computation shows that at that time, both Jupiter and Mars were too close to the Sun to be seen under normal circumstances, whereas Venus and Mercury were better placed for regular visibility. The unit of time here translated as "degree" (i.e. *uš*) was precisely equivalent to 4 min. Measurements were presumably made with the aid of a water clock, although reference to the device used is lacking. The "Normal Stars" were certain reference stars in the zodiac belt. Many similarly detailed descriptions of both solar and lunar eclipses are preserved on the Late Babylonian astronomical texts. Extant observations range in date from 713 to 10 BCE.

On many Late Babylonian astronomical texts, the date is damaged. However, unambiguous restoration is often possible. In the following account of a lunar eclipse, the name of the king is missing, but this omission presents few problems.

> [...] year 42, twelfth lunar month, day 15. At 1,30 (= 90) ° after sunset [lunar eclipse...] 25° duration of maximal phase. In 18° it became bright. West (wind) went. It was eclipsed 2 cubits below γ Vir.

The small tablet on which the above observation is preserved also mentions another lunar eclipse–in the 6th month of the same year. Among Late Babylonian kings, only Nebuchadrezzar II (42nd year = 563/2 BCE) and Artaxerxes II (42nd year = 363/2 BCE) are known to have reigned for such a long time. However, computation reveals that whereas during the appropriate year of Nebuchadrezzar there were indeed lunar eclipses in the sixth and twelfth lunar months, in the 42nd year of Artaxerxes II eclipses only took place in the third and ninth months. The date of the eclipse in the above text can thus be reduced to BCE 562 March 3. Furthermore, on this night the Moon would be about 3° to the south of γ Vir, in close accord with the record.

Occasional indirect allusions to eclipses are found in the Old Testament, notably in the books of the Prophets Amos (VIII, 9) and Joel (II, 31). However, the most direct reference to an eclipse in the history of ancient Israel is recorded by Flavius Josephus, a Jewish historian of the first century AD. In his *Bellum Judaicum*, Josephus described this event as occurring only a few days before the death of Herod the Great, and it is thus of importance in dating the birth of Jesus Christ. Josephus gives the following account:

As for the other Matthias who had stirred up the sedition, he (Herod) had him burnt alive along with some of his companions. And on the same night there was an eclipse of the Moon. But Herod's illness became more and more severe.

Josephus uses the standard Greek term *ekleipsis* for an eclipse. The events described occurred around the time of Passover, a spring full-Moon festival. Computation shows that between 17 BCE and AD 3, the only springtime lunar eclipses visible in Judea occurred on March 25 in 5 BCE (a total obscuration) and March 13 in the following year (a partial obscuration). The latter date fits better the chronology of the period, although the two dates are conveniently close together.

For several centuries after the birth of Christ, scarcely any eclipses (whether of Sun or Moon) are recorded in the non-Western world outside East Asia. However, during the ninth century AD, both Muslim astronomers and chroniclers began independently to note the occurrence of these events. Between about AD 830 and 1020, astronomers–largely based at Baghdad or Cairo–frequently made careful observations of eclipses, measuring the times of the various phases and estimating the magnitudes. The main motive for these activities was to test the reliability of contemporary eclipse tables, but lunar eclipses were sometimes effectively used to determine the difference in longitude between two selected cities. Astronomers would first make a prediction of when an eclipse would occur and then assemble one or more groups to observe it.

Our principal source of such observations is the *Zīj* (handbook) compiled by the Cairo observer Ibn Yūnus, who died in AD 1009. This work, dedicated to Caliph al-Ḥākim, is entitled *Ḥākimī Z'īj*.

Medieval Muslim astronomers were in the habit of determining eclipse times indirectly by measuring the altitude of the Sun, Moon or a bright star (probably with a sextant or astrolabe) and then converting the measurement to local time with the aid of an astrolabe or tables.

Among the many preserved lunar and solar eclipse reports, the following provide useful illustrations: a lunar eclipse observed at Baghdad on a date equivalent to AD 856 June 22 and a solar eclipse seen in Cairo on AD 993 August 20. The usual Arabic term for an eclipse was *kusūf*, meaning a 'cut' in the solar or lunar limb.

> (1) There was a an eclipse of the Moon on the night of the second day of the week (Monday), the middle of the month of Ṣafar in the year 242 of *al-Hijrah*… It was found by observation that the beginning of the eclipse occurred when the altitude of *al-dabarān* (Aldebaran: α Tau) was 9;30° in the east. The amount of revolution of the (celestial) sphere from midnight to this time, as we determined (from this measurement) with the astrolabe, was 50°. We did not determine its times except for the beginning. It was found (by observation) that the uneclipsed fraction of its body was more than one-quarter and less than one-third.

> (2) This solar eclipse occurred in the forenoon of the first day of the week (Sunday), the 29th day of (the month) of Jumāda al-Ukhra in the year 383 of *al-Hijrah*… The eclipse began when the altitude of the Sun was 27° in the east and was complete (i.e. reached its maximum) when the altitude was 45° in the east. The Sun cleared when its altitude was 60° in the east. About two-thirds of it was eclipsed.

In both of the above examples, the equivalent Julian date corresponds precisely to that of a computed eclipse.

It would appear that virtually no eclipse observations made by Muslim astronomers have survived for several centuries after AD 1020. However, many later reports of eclipses by chroniclers are preserved; these writers often emphasised the spectacular nature of these phenomena. A careful description of a total eclipse of the Sun occurring on a date equivalent to AD 1061 June 20 is recorded by the Baghdad chronicler Ibn al-Jawzī. Although he wrote a century after the event, his account is clearly based on an eyewitness description.

> (453 A.H.) On the fourth day of the week, when two nights remained to the completion of (the month of) Jumāda al-Aula, two hours after daybreak, the Sun was eclipsed totally. There was darkness and the birds fell whilst flying. The astrologers claimed that one-sixth of the Sun should have remained but nothing of it did so. The Sun reappeared after four hours and a fraction. The eclipse was not in the whole of the Sun in places other than Baghdad and its provinces.

Reference has already been made to eclipses recorded on ancient Chinese oracle bones. However, the earliest accurately datable reports of eclipses from China are found in a chronicle, the *Chunqiu* (Spring and Autumn Annals), covering the period from 722 to 481 BCE. Although no lunar eclipses are recorded in the *Chunqiu*, this work cites as many as 36 reports of solar eclipses. By this period solar obscurations were regarded as major portents, whereas lunar eclipses were considered to be of little astrological significance. Lunar eclipses only began to be recorded regularly in China from the fifth century AD.

For each of the solar eclipses which it records, the *Chunqiu* gives the full date–year of the ruler, lunar


至之日日在斗二十一度少檢十一年七月十
六日望月蝕加時在卯到十五日四更二唱丑
初始蝕到四唱蝕既在營室十五度末景初其
日日在軫三度以月蝕所衝考之其日日應在

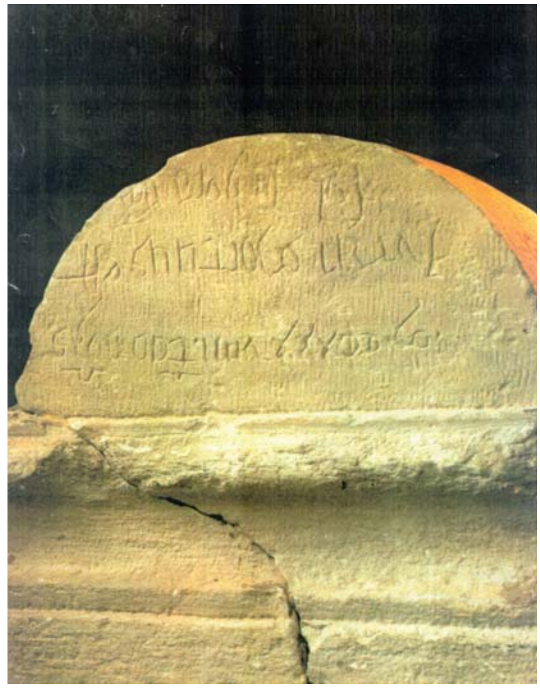
Eclipse Observations. Fig. 1 Chinese text in the calendar treatise of the *Songchu* containing timings of the lunar eclipse of AD 434.

month, day of the month and day of the 60-day cycle. Use of the sexagenary cycle (as in later Chinese history) greatly expedites the accurate conversion of dates to the Julian calendar. In almost every case the reduced date corresponds exactly to that of a computed eclipse visible in China.

Three total eclipses–occurring on dates equivalent to BCE 709 July 17, 601 September 20 and 549 June 19–are noted in the *Chunqiu*, but there are no allusions to such effects as darkness or the appearance of stars by day. Three further accounts (from 669, 664, and 612 BCE) describe eclipse ceremonies in which drums were beaten and oxen were sacrificed.

Records of the Han dynasty (202 BCE to AD 220) contain several reports of large partial eclipses of the Sun. For instance, the account of the eclipse of BCE 89 September 29 may be rendered as follows:

> Zhenghe reign period, fourth year, eighth month, day *xinyu*, the last day of the month. The Sun was eclipsed; it was not complete but like a hook… At the hour of *fu* (= 3–5 p.m.) the eclipse began from the north-west. Towards the time of sunset it recovered.

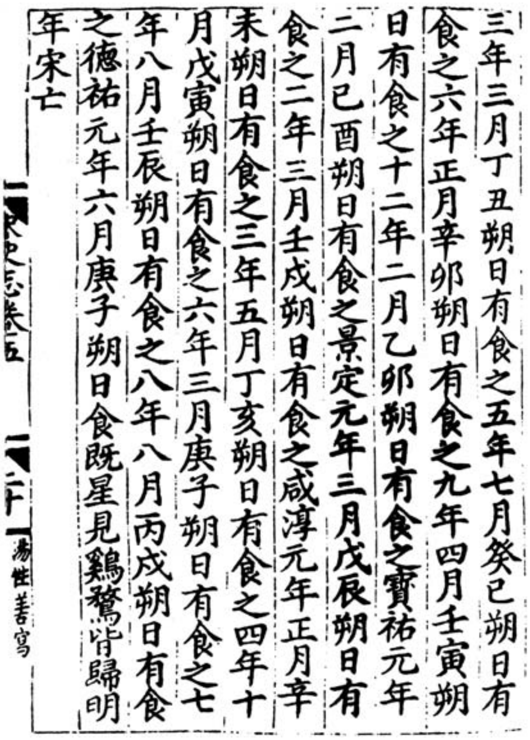


Eclipse Observations. Fig. 2 Latin inscription recording the "death of the Sun" as a result of the total solar eclipse of AD 1239. This is carved on a pillar at Marola, Italy. Photograph used with the kind permission of Dr G.R. Levi-Donati, Perugia, Italy.

The above record only notes the time to the nearest double hour. However, commencing in the fifth century AD eclipses of both Moon and Sun were often carefully timed using water clocks. The main purpose was to verify the accuracy of astronomical tables. Solar eclipses were usually timed to the nearest *ke* ('mark')–1/100 of a day and night–roughly equal to 15 min. For lunar eclipses, times were often expressed to the nearest fifth of a night watch instead–especially in earlier centuries. The period from dawn to dusk was divided into five equal *geng* (night watches), each of which was in turn divided into five equal intervals. Hence the watches and their subdivisions varied in length with the seasons.

The following account from the *Songshi* (History of the Song dynasty: AD 960–1279) uses both types of time units; the date is equivalent to AD 1186 March 25:

> Jiandao reign period, fourth year, second month, fourteenth day, *dingwei*, full Moon. The Moon was eclipsed… (various predictions)… On this evening when the Moon rose there was light cloud. Until the fall of darkness it could not be



三年三月丁丑朔日有食之五年七月癸巳朔日有
食之六年正月辛卯朔日有食之九年四月壬寅朔
日有食之十二年二月乙卯朔日有食之寶祐元年
二月己酉朔日有食之景定元年三月戊辰朔日有
食之二年三月壬戌朔日有食之咸淳元年正月辛
未朔日有食之三年五月丁亥朔日有食之四年十
月戊寅朔日有食之六年三月庚子朔日有食之七
年八月壬辰朔日有食之八年八月丙戌朔日有食
之德祐元年六月庚子朔日食既星見鷄鶩皆歸明
年宋亡

Eclipse Observations. Fig. 3 Chinese text in the astronomical treatise of the *Songchi* describing several 13th century solar eclipses, including the total solar eclipse of AD 1275.

> seen that the Moon was totally eclipsed. When the third mark of the initial half of the (double) hour *xu* was reached, as expected it was (partially) shining and so it could be known that the eclipse had been total on rising. It was restored to fullness at the third mark in the central half of the hour *xu*. This was the second division of the second watch.

The very earliest Korean records of eclipses appear to be copied from Chinese history and probably do not become independent until around AD 700. However, the many accounts of both lunar and solar eclipses which are preserved in later Korean history tend to be very brief, seldom giving more than the date of occurrence and noting if the eclipse was total. Eclipse records are mainly found in two major works. These are the *Koryo-sa* (the official history of Korea from AD 936 to 1392) and the *Choson Wangjo Sillok* (an extensive chronicle extending from AD 1392 to modern times). The Chinese luni-solar calendar was closely followed in Korea, although years were numbered from the accession of Korean monarchs. Around AD 1200, there are occasional references to lunar eclipse ceremonies in which the king, arrayed in white robes and accompanied by his closest ministers, attempted to rescue the Moon. However, these may have been no more than empty rites.

Commencing around AD 600, Japanese observations of eclipses are also numerous. Japanese historical sources are much more diverse that those of China and Korea, and it is fortunate that in the 1930s Kanda Shigeru made a detailed search of Japanese history down to AD 1600 for references to eclipses and other celestial phenomena. The earliest Japanese account of a total solar eclipse dates from AD 628 April 10, but this is extremely brief. Several detailed reports of later similar events are preserved, notably in AD 975 and 1460. The following account of the eclipse of AD 975 August 9 is taken from the *Nihon Kiryaku*, a privately compiled history:

> Ten-en reign period, third year, seventh month, first day. The Sun was eclipsed… Some people say that it was entirely total. During the (double) hours *bo* and *shin* (between 5 and 9 a.m.) it was all gone. It was the color of ink and without light. All the birds flew about in confusion and the various stars were all visible. There was a general amnesty (on account of the eclipse).

In this brief article it has only been possible to cite a minute proportion of the available eclipse records from the non-Western world. However, it should be clear from the selection offered here that many detailed and important descriptions are preserved. Early eclipse observations often reveal a remarkable level of sophistication, particularly in the measurement of times.

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Eclipses: Calculating and Predicting Eclipses

J. M. Steele

Many reports of attempts to predict the occurrence of eclipses of the sun and moon are preserved in the histories of non-Western cultures. The majority of these records come from ancient Mesopotamia, ancient and medieval China, and medieval Japan, with a few scattered examples from Demotic and Greco-Roman Egypt, India, and the Islamic world. In addition, descriptions of the methods by which the circumstances of eclipses can be calculated are known from China, India, the Islamic World, and Mesoamerica (for the latter, see the entry Eclipses in the Americas).

The earliest reports of attempts to predict eclipses are recorded in the correspondence between the Neo-Assyrian kings of Mesopotamia and their scholars during the seventh century BCE (Hunger 1992; Parpola 1993; Steele 2000b; Brown 2000: 200–206). For example, a letter sent by one Mar-Issar to the king reads (Parpola 1993: 347):

> To the king, my lord: your servant Mar-Issar. Good health to the king, my lord! May Nabû and Marduk bless the king, my lord! May the great gods bestow long days, well being and joy upon the king, my lord! Concerning the lunar eclipse about which the king, my lord, wrote to me, it was observed in the cities of Akkad, Borsippa, and Nippur. What we saw in Akkad corresponded to the other (observation)s. A bronze ket[tledrum] was set up; the darkness [… (break) …] I have extracted the [relevant] interpretation written on the tablet and s[ent] it, together with this letter, to the king, my lord. Moreover, I shall keep watch for the solar eclipse, as the king, my lord, wrote to me. Whether it occurs or not, I shall write to the king, my lord, whatever it may be. This lunar eclipse which took place, afflicted all countries, but all its evil is heaped upon the Westland. "Westland" means the Hittite country (Syria) or, according to another interpretation, Chaldea. With the king, my lord, all is well. However, the guard should not be neglected, and the relevant apotropaic ritual should be performed for the king, my lord.

This letter reveals much about the practice of astronomical observation during the Neo-Assyrian period. The author not only reports his sighting of a lunar eclipse in Akkad, but also notes that the eclipse was seen in two other cities, Borsippa and Nippur, and that all three observations were in agreement. The letter also illustrates the serious nature of eclipses in Mesopotamian divination: even though the evil associated with this particular eclipse is directed toward the "Westland," the king is nevertheless advised to have apotropaic rituals (involving the playing of a kettledrum) performed. Mar-Issar also says that he will keep watching for an upcoming solar eclipse. This reflects an awareness by the Neo-Assyrian scholars that eclipses of the sun and moon often take place half a month from one another: a lunar eclipse in the middle of a month may be preceded by a solar eclipse at the end of the previous month, or followed by one at the end of the current month (lunar months beginning with the first visibility of the lunar crescent were used in the Mesopotamian calendar).

Several other letters attest to this awareness of a half-month interval between eclipses of the sun and moon. For example, the report Hunger (1992: 502) states:

> An eclipse of the moon and sun in Sivan (Month III) will take place. These signs are bad fortune for the kings of Westland and Akkad; and now, in this month of Kislev (Month IX), an eclipse will take place.

The author of this report appears to be saying that during the current month, the ninth of a year, an eclipse will take place, and this will be followed 6 months later, in the third month of the following year, by both an eclipse of sun and moon. The scholar is referring to the observable fact that the shortest period between visible eclipses of the same kind is 6 months. This circumstance is due to the inclination of the moon's orbit to the ecliptic; for an eclipse to occur the moon must not only be in opposition (for a lunar eclipse) or conjunction (for a solar eclipse) with the sun, which recurs after one synodic month of about 29.5 days, but also be sufficiently close to the points where its orbit crosses the ecliptic (the ascending and descending nodes), which recurs after half a draconitic month (or a whole draconitic month to return to the same node). Because the draconitic month is a little over two days shorter than a synodic month eclipses do not take place every syzygy. After 6 synodic months, however, the accumulated discrepancy between the synodic and draconitic months will be roughly half a draconitic month, and so at this sixth opposition or conjunction the moon will now be close to the opposite node, and an eclipse may occur. In fact, however, the average interval for the moon's elongation at opposition or conjunction to increase by 180° is about 5.86 synodic months. This means that occasionally eclipse possibilities are separated by only 5 months. The existence of eclipse possibilities at 5-month intervals is alluded to in the letter Parpola (1993: 45):

> Concerning the watch of the sun about which the king, my lord, wrote to me, it is (indeed) the month for a watch of the sun. We will keep the watch twice, on the 28th of Marchesvan (Month VIII) and the 28th of Kislev (Month IX). Thus we will keep the watch of the sun for 2 months.

Understanding the nature of eclipse possibilities marks a crucial step in the development of eclipse theory.

Combined with an awareness of long-term eclipse cycles, it provides a means of identifying all eclipse possibilities (months in which a eclipse might occur as opposed to those where an eclipse will definitely not). The most well-known, and indeed most practical, eclipse cycle is the so-called "Saros" of 223 synodic months (which is very close to 242 draconitic months), after which eclipses recur with almost the same magnitude, and roughly 8 h later in the day. The Saros may very well have been identified and used by the Neo-Assyrian scholars (e.g., Parpola 1983: 51; Brown 2000: 205) although we lack the evidence to be certain (Steele 2000b). However, we have ample evidence that Late Babylonian astronomers knew and understood the Saros by at least 600 BCE (Steele 2002).

The knowledge that eclipse possibilities generally occur at 6-month intervals, with occasional 5-month intervals, allows the immediate determination of the number of eclipse possibilities within one Saros period of 223 months as follows: If there are a eclipses at 6-month intervals and b at 5-month intervals with Saros, then the relationship $6a + 5b = 223$ must hold, and so a must equal 33 and b equal 5. It is then a simple step to distribute these 5-month intervals as evenly as possible within the 223 months of the Saros to result in five groups of eclipses each beginning with a 5-month interval and subsequently containing eclipses at 6-month intervals, comprising eight, seven, eight, seven, and eight eclipses. This whole distribution repeats after one Saros, resulting in a large matrix of eclipse possibilities which can then be aligned with observed eclipses to produce a scheme for predicting all future eclipse possibilities (Britton 1989; Beaulieu and Britton 1994; Steele 2000b). Several Babylonian texts are set out in just such a matrix. These include a group of theoretical texts known as "Saros Canon" tablets which contain the months of eclipse possibilities (Aaboe et al. 1991) and a remarkable group of tablets that contain a compilation of more than 400 years worth of lunar eclipse observations and predictions put into a Saros matrix (Hunger 2001: 2–4; see also Walker 1997; Steele 2001; Huber and De Meis 2004). This collection is all the more impressive because over the 400-year period it covers, no eclipses were visible in Babylon that had not been predicted in advance by this matrix scheme.

The Late Babylonian Astronomical Diaries and related texts (Sachs and Hunger 1988, 1989, 1996) provide evidence that the Saros scheme described above was used until the end of the cuneiform record, with only occasionally minor realignments to account for the very rare unpredicted eclipses. However, beginning in at least the fifth century BCE, and therefore contemporary with many of the records in the Astronomical Diaries, the Babylonians developed theoretical mathematical methods to calculate eclipses. These developments culminated into two distinct lunar theories, known today as System A and System B (Neugebauer 1955). Both Systems A and B have as their goal the calculation of the moment of successive lunar syzygies, whether an eclipse will occur at that syzygy, and the date of first visibility of the lunar crescent which determines the beginning of the month by highly ingenious mathematical schemes which involve separating out the effects of lunar and solar anomaly. However, the two theories differ in how they calculate the various phenomena. For example, in System A, the increase in the moon's longitude from one syzygy to the next syzygy of the same kind is functionally dependent upon the moon's position in the zodiac at the previous syzygy (a so-called "step function"), whereas in System B it is dependent upon the previous increase (a "zigzag function"). In both systems, an eclipse is predicted whenever the moon at syzygy is closest to the node. The node itself is assumed to regress at a uniform rate through the ecliptic (Aaboe and Henderson 1975), and the moon's nodal elongation can then be used to gauge the magnitude of an eclipse (Britton 1989). It remains an open question why these mathematical methods, which admittedly result in predictions that are not significantly better than the Saros methods described above, were apparently not used to make the predictions found in the Astronomical Diaries.

Many aspects of Mesopotamian astronomy were transmitted to India, either through Persia or Greek intermediaries. However, most Indian eclipse theories are founded upon the basic principles of Greek geometrical astronomy. For example, in the *Pañcasiddhāntikā* of Varāhamihira (Neugebauer and Pingree 1970), a description of five astronomical theories written in the sixth century AD, we find several methods of calculating eclipses, all of which rely on determining the longitude of the moon and the lunar node at syzygy. If the distance of the moon from the node falls below a certain amount (known as the "eclipse limit") then an eclipse will take place. The circumstances of the eclipse are then calculated taking into account the effects of parallax.

Remarkably, eclipse theories of the kind reported in the *Pañcasiddhāntikā* were still being used during the eighteenth century in parts of Asia. A report written by Lt Col. John Warren in 1825 describes his meeting with a Tamil villager who computed a forthcoming lunar eclipse using shells on the ground as counters. He had memorized the tables resulting from Indian eclipse theories in oral fashion, and he was able to predict the eclipse with a remarkable level of accuracy (North 1994: 165–166).

Many hundreds of predictions of solar and lunar eclipses are reported in the dynastic histories of China

(Steele 2000a). These records, generally found in the *Dianwen* treatises, are often indistinguishable from reports of observed eclipses, simply giving the date of an eclipse. However, study of these dates has revealed that many do not correspond to eclipses that could have been observed in China and so they must have been calculated. Eclipse prediction was one of the most important tasks of the officially promulgated astronomical systems known as *Li* (customarily translated as "calendar"). The *Li* were reformed frequently throughout Chinese history, more often than not for political, rather than astronomical, purposes (Cullen 1993). Descriptions of these *Li* are found in the calendar treatises of many of the dynastic histories.

The oldest calendars to contain rules for calculating eclipses, the *Santong li*, the *Sifen li*, and the *Qianxiang li*, date to the Han period (ca. second century BCE to second century AD). All three make use of an eclipse cycle of 135 months. As in Mesopotamia, the eclipse cycle was used to identify all eclipse possibilities, not just eclipses which come 135 months after an observed eclipse. Assuming that the 23 eclipse possibilities within the 135-month cycle are evenly spaced, the mean interval between eclipse possibilities is 5 20/23 months. Adding on 5 20/23 months from the epoch date of the calendar (when it was assumed an eclipse had occurred), keeping the fractions in the running total, but rounding down to find the month of an eclipse, allowed the dates of all future eclipses to be calculated (Sivin 1969).

The first mathematical treatment of eclipses in China is found in the *Qingchu li* of the third century AD (Yabuuti 1963). Beginning with this calendar, eclipses were calculated by determining whether the moon at syzygy was sufficiently close to a node to produce an eclipse. However, unlike in India, the eclipse limits which were used to determine whether or not an eclipse would occur were not expressed in degrees of longitude, but used instead the number of days it would take the moon to reach the node, given by the ratio distance from node/daily lunar motion = x days. For example, in the *Dayan li* a lunar eclipse would occur if x was less than 3523.9/3040, and if x was less than 779/3050 the eclipse would be total (Yabuuti 1963). A simple arithmetical formula could then be used to determine the magnitude and duration of the eclipse from the quantity x.

A detailed theory of parallax was never developed in traditional Chinese astronomy; instead a number of semiempirical corrections were added into their calculations to try to account for its effect (Nakayama 1969: 144–145). However, these corrections were not generally sufficient. For example, in the *Dayan li* corrections were applied to take into account the moon's declination, but not its hour angle at the time of the eclipse. Similarly, the effect of geographical location was not fully taken into account in Chinese eclipse theory. In the *Dayan li* crude adjustments to the eclipse calculations were introduced to take into account the observer's latitude, but no corrections were applied for his geographical longitude.

Other countries in East Asia, most notably in Korea and Japan, adopted Chinese eclipse theory, along with many other parts of Chinese astronomy. Often, however, this adoption would lag significantly behind the reforms of the calendar which took place in China. For example, the *Xuanming li* was replaced in China in AD 892 but was still being used in Japan until AD 1685. Several hundred reports of predicted eclipses are preserved from Japan. Interestingly, these often include the calculated time and magnitude of the eclipse. Because the calendar did not take into account the difference in geographical longitude between China and Japan, the times are systematically off by about an hour and the magnitudes of solar eclipses are frequently very inaccurate (Steele 1998). A rare report which contains both the calculated and observed circumstances of an eclipse illustrates these discrepancies (Steele 2000a: 221):

> 2nd month, new moon, *dinghai* day [21 February 1319 AD]. The previous night heavy rain fell and a great wind blew. At dawn the wind and rain stopped and the sky cleared. That day the sun was fourteen fifteenths eclipsed. The loss [should have] begun at 4 marks and 17 *fen* in the hour of *mao*, as the calculated time [of the middle of the eclipse] was at 4 marks and 22 *fen* in the hour of *chen*, and [the sun should have] returned to fullness at 4 marks and 27 *fen* in the hour of *si*… Investigating at that time (it was seen that) the loss began during the hour of *chen* and it returned to fullness during the hour of *wu*. The calendar gave the eclipse as fourteen fifteenths, but it was only seven fifteenths eclipsed.

Despite these large discrepancies, we have no evidence of any attempts to correct or improve the *Xuanming li* eclipse theory in Japan.

See also: ▶Astronomy in India, ▶Astronomy in China

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Eclipses in the Americas

Hugh Thurston

We have no information about eclipses observed in America before the arrival of the Spaniards. There are two descriptions by Bernard Sahagún in his *General History of Things of New Spain* (Book 7: 8–10). Here is a précis.

> When the moon was eclipsed darkness spread. Pregnant women were afraid that their unborn children might be turned into mice. To protect themselves they put obsidian in their mouths and on their breasts.
> When the sun was eclipsed it turned red, became troubled, and turned yellow. There was tumult and everyone was frightened. People of light complexion were sacrificed and captives were killed. Suitable chants were sung in the temples. People said that if the eclipse is total it will be dark for ever.

This applies to the Aztecs. The Incas in South America, according to Garsilaso de la Vega (1609), thought that when the moon eclipsed it was ill. When an eclipse began they became afraid and sounded everything that would make a noise, even beating their dogs to make them yelp, so that the noise would awaken the moon from the sleep caused by the sickness.

Eclipses of the sun in 1496 and 1531 were pictured in the Aztec Codex *Tellerianus Remensis*.

Perhaps the most interesting eclipse observed in Mesoamerica is an eclipse of the moon on February 29th, 1506. Columbus was stranded in Jamaica, whose natives refused him provisions. He knew that there would be an eclipse of the moon that evening and threatened to destroy the moon if the natives did not agree to provide provisions. When the eclipse started, they agreed.

We have no records of eclipses observed by the Mayas. But we do have calculations concerned with eclipses. There are displayed on pages 51–58 of the Dresden Codex.

Each half-page of each page is a unit. The upper halves come first, so the lower half of page 51 follows the upper half of page 58. The first half-pages are an introduction; the table itself starts on page 53. It has 69 columns, which I have numbered, separated by broad

Eclipses in the Americas. Table 1 Transcription of the numbers from pages 51 to 58 of the Dresden codex

177	354	502	679	856	1033	1211	1388	1565	1742	1919	2096	2244	2422	2599	2776	2953	3130	3278	3455	3632	3809	3986
85	2	150	67	244	161	79	256	173	90	7	184	72	250	167	84	1	178	66	243	160	77	255
177	177	148	177	177	177	177	177	177	177	177	177	148	177	177	177	177	177	148	177	177	177	177
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
4163	4340	4488	4665	5020	5197	5397	5374	5551	5728	5905	6082	6230	6408	6585	6762	6939	7116	7264	7441	7618	7795	7972
172	89	237	154	71	249	166	83	260	177	94	11	159	77	254	171	88	5	153	70	247	164	81
177	177	148	177	177	177	177	177	177	177	177	177	148	177	177	177	177	177	148	177	177	177	177
24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
8149	8326	8474	8651	8828	9006	9183	9360	9537	9714	9891	10039	10216	10394	10571	10748	10925	11102	11250	11427	11604	11781	11958
258	175	63	240	157	75	252	169	86	3	180	68	245	163	80	257	174	91	239	156	73	250	167
177	177	148	177	177	177	177	177	177	177	177	148	177	177	177	177	177	177	148	177	177	177	177
47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69

columns ending in pictures which are not part of the table. In each column the top two glyphs are not astronomical; for example, in column 14 they are "death" and "owl" (Davoust 1997). Then comes a number, presumably a count of days, then three successive days in the sacred round, then another number.

In Table 1 I have translated the Mayan numerals into decimals and replaced the Mayan glyphs for each day in the sacred round by its position in the round (e.g. 1 Imix by 1, 13 Ahaw by 260 and so on). The diagram shows just the middle one of the three days. The top row is a cumulative total of the numbers in the bottom row.

There are a few mistakes in the Mayan table. For example, a dot is missing from the first number, which reads 157 instead of 177. But so many totals are right that it is easy to correct the few wrong ones. The interval between the days of the sacred round agrees with the intervals in the cumulative total. There are six places where 178, not 177, is added to the cumulative total (and to the sacred round).

To the nearest whole day, 177 is the number of days in six months and 148 is the number of days in five months. This suggests that the table is concerned with eclipses; an interval between eclipses of the moon is nearly always the sum of a number of six-month intervals with or without one five-month interval. (Because an eclipse of the moon occurs only at full moon, a whole number of months – lunar months, not calendar months – must elapse between eclipses.) The intervals between successive eclipses of the moon visible in northern Yucatán between AD 400 and AD 500 are 6, 11, 12, 17, 18, 23, 29, 35, 41, 53, 59, and 65 months. Each of these is made up as described: for example 17 is 6 + 6 + 5. This could easily give rise to the idea that a table for eclipses should use six-month intervals and a few five-month intervals.

Very few eclipses of the sun were visible in the Maya region and only a very nearly total eclipse would be seen. If the sun is even as much as 90% eclipsed the light will not be noticeably dimmed and looking at the sun would be painful.

How would the table be used? There are far too many columns for each to mark an eclipse, and far too few pictures for the entry before each to mark an eclipse, even though the gap between pictures consists of six-month intervals plus one five-month interval. Probably the Mayas had discovered how to pick out dates on which eclipses could not occur and the 69 columns represent 69 full moons that could not be ruled out (out of the 405 covered by the table), so the table eliminates 336 false alarms. (The Babylonians had a table which did this.)

Most early cultures had a relation of the form so many months equal so many days. The Mayas seem to have had 405 months equal to 11,958 days. (i.e. 135 months equal 3,986 days).

If we have a starting date for the table we can add the cumulative totals to it to find a date for each column. The introduction contains four dates in the Mayan long count (a) 9.16.4.10.8; (b) 9.16.4.11.3; (c) 9.16.4.11.18; (d) 9.19.8.7.8. Date (a) is 755 AD November 12th Gregorian, and is close to the date of a new moon. Date (b), 15 days later, is close to a full moon, and date (c) is close to the next new moon. Date (d), some 60 years later, is neither. With (b) as starting date we find from Liu and Fiala's *Canon of Lunar Eclipses from 1500 BCE to AD 3000*, that there were 49 eclipses of the moon in the period covered by the table, and every one is within 2 days of the date of a column. The ones near the beginning are mostly correct; several later ones are 2 days early. This may be because the table covers 11,958 days, whereas 405 months average 11,960 days.

Extra: Eclipses in the Americas

Authorities are not agreed on whether the Mayan table refers to eclipses of the sun or eclipses of the moon (or perhaps both). In favor of eclipses of the moon is the fact that there are enough of them for the Mayas to be able to deduce something about their distribution. In favor of eclipses of the sun is the fact that two of the dates in the introduction are dates of the new moon.

Although many writers of programs on television and authors of popular books believe that the Mayas could predict eclipses, few astronomers and Mayanists do. Exceptions are Victoria and Harvey Bricker, in Current Anthropology (1983) 24: 1–18.

See also: ►Calendars in Mesoamerica

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Elements: Reception of Euclid's *Elements* in the Islamic World

Sonja Brentjes

Euclid (ca. 3rd century BCE) was a Greek mathematician. His name and his major work, the *Elements*, are famous not only among mathematicians, but also to students of other disciplines.

The *Elements* were sent by the Byzantine emperor from Constantinople to the Abbasid caliph al-Manṣūr (r. 754–775) in Baghdad. We do not know if any of the scholars of his time prepared a translation or at least a summary for him or the scholarly community.

The earliest translation, according to medieval historical sources, was carried out by al-Ḥajjāj Ibn Yūsuf Ibn Maṭar (fl. between 786 and 833) for the famous Barmekide Yaḥyā Ibn Khālid (d. 805), wazir of caliph al-Hārūn al-Rashīd (r. 786–809) or, perhaps, the caliph himself. This translation seems to be lost in Arabic.

Some 20 years later, al-Ḥajjāj composed a second Arabic version of the *Elements*, which he dedicated to caliph al-Maʾmūn (r. 813–833). One of those sources reports he did this to gain the caliph's support, because al-Maʾmūn's love for knowledge and his generous attitude toward scholars were well known (Codex Leidensis 399, 1, 1897). To achieve this goal al-Ḥajjāj is said to have rewritten the *Elements* extensively with respect to their language, methods, and didactical features for people with knowledge in and love for this discipline, without changing the contents itself.

Some fragments of his version 2 seem to have been preserved in different forms:

1. As part of a collection of mathematical texts put together in about the sixteenth or seventeenth century in Persia
2. As additions to Arabic translation manuscripts in those parts which transmit by and large the edition of Isḥāq Ibn Ḥunayn's (d. 910/911) translation by Thābit Ibn Qurra
3. In parts of Book III and the complete Book IV of the preserved Arabic translation manuscripts
4. Perhaps as a variant of books XI–XIII in two of the translation manuscripts; and in a barely recognizable form
5. As parts of a commentary written by al-Nayrīzī probably at the beginning of the tenth century
6. As a paraphrase composed around a hundred years later by Ibn Sīnā (d. 1036)

Those fragments, although they differ in some essential aspects, are characterized by a technical language using expressions from algebra, arithmetic, early logical or theological writings, as well as some words borrowed from Syriac, characteristic of the early translations into Arabic.

Furthermore, two of the Latin translations of the twelfth century, one by Adelard of Bath (so-called version 1), the other ascribed by the editor to Hermann of Carinthia (Busard 1968, 1977), contain at least extracts, possibly also more, of one of the Ḥajjāj versions. It is still an unsettled question as to how close these translations are to an original Ḥajjāj text and to which Ḥajjāj version they are related. A third possible, but also still disputed, source for the Ḥajjāj tradition is the only surviving Syriac fragment of Book I. Finally, some of the Hebrew translations of the *Elements* contain notes which are related to some of the additions ascribed to al-Ḥajjāj in the above-mentioned Arabic manuscripts.

Al-Ḥajjāj's work, evidently, was crowned by success. In 828/829 he was ordered to translate the *Almagest*. The scholarly community eagerly accepted his translation and edition. They organized meetings discussing the *Elements*, the *Almagest*, and, probably other subjects. They composed editions and commentaries. Among the earliest works of this type are the editions made by al-Jawharī and al-Kindī (d. ca. 873). Except for short fragments, their texts are lost.

A fresh start was made in the second half of the ninth century. Perhaps because of the shortcomings ascribed to the earlier translation or for some other reasons unknown to us so far, Isḥāq Ibn Ḥunayn prepared a completely new translation of the *Elements*, probably before 872. Together with his translations of other important mathematical and astronomical texts, it was revised by Thābit Ibn Qurra at about the same time. Yet, we neither know the reasons for nor the extent of those revisions.

The version contained in nearly all preserved Arabic translation manuscripts seems to be this edition – at least in the Books I, II, V, and VII–IX. Other books, however, seem to be based on al-Ḥajjāj's work (see above). Most of the Hebrew translation manuscripts as well as the Latin translation by Gerard of Cremona are also derived to a great extent from Thābit's edition. This so-called Isḥāq/Thābit tradition exercised the greatest influence upon mathematical research and teaching in the medieval Muslim world until the late thirteenth century. It is characterized by a very literal translation of a text connected with the Greek edition made by Theon of Alexandria (fourth century). It differs in several aspects from the Greek critical edition made by Heiberg (1883). In some cases, Thābit is ascribed variant readings or even whole proofs taken from newly available Greek sources or other Arabic manuscripts, probably derived from the Ḥajjāj tradition. In other cases, the differences in text, diagrams, and proofs might well have been already present in the

Greek manuscript translated by Isḥāq Ibn Ḥunayn. This leads to two questions that we are unable to answer at the moment:

1. Did Isḥāq follow the methodological rules devised by his father Ḥunayn Ibn Isḥāq and collate manuscripts to establish a reliable Greek text or not?
2. Which criteria motivated him in his choice between different variants of the same theorem?

Until the end of the thirteenth century several new Arabic editions based on the two ninth-century traditions were produced. The most successful in terms of later influence were the two ascribed to Naṣīr al-Dīn al-Ṭūsī. Only one, however, consisting of 15 books, was composed by him. The other one, which contains only the genuine 13 books of Euclid, was finished in 1298, after al-Ṭūsī's death. Both versions replaced the earlier traditions, judging by the number of preserved copies, marginal notes in manuscripts, and references to the *Elements* in mathematical and nonmathematical works.

While the two ninth-century traditions follow the Greek text relatively closely, the two so-called al-Ṭūsī revisions are a free rewriting of the *Elements* with respect to language, didactics, proofs, and variations. Proofs are generally abbreviated and condensed, further definitions or lemmata have been added, and for some difficult points new proofs have been provided. Such a free attitude toward a received text by an accepted authority deviated from values characteristic of or defended by the scholarly communities in medieval Islamic societies. It can be observed, nevertheless, since the beginning of the ninth century in nearly all Arabic editions and commentaries on the *Elements*. This is one of the reasons that contemporary research about textual history is so difficult and the study of the mathematical results of the transmission so fruitful.

Although all 15 books of the *Elements* attracted the attention of Muslim scholars, the central points of interest were the parallel postulate (Book I), the definitions of ratio and proportion (Book V), and the geometrical theory of quadratic irrationalities (Book X).

Efforts to prove the parallel postulate started with Greek mathematicians and philosophers, since the form given by Euclid did not fit into their ideas about what an axiom or a postulate should be. Parts of this discussion were translated into Arabic as Simplikios' (sixth century) commentary on the definitions of Book I and, perhaps, Heron's (second century?) commentary on the *Elements*. Both commentaries are lost in Greek and Arabic. Extracts from both are preserved in a revised form in al-Nayrīzī's commentary on the *Elements*. Extracts from Heron's commentary can also be found in Ibn al-Haytham's great commentary. The Arabic analysis of the parallel postulate started at the beginning of the ninth century with al-Jawharī and other scholars.

The geometers working on this postulate followed two different approaches. One approach, represented by ᶜUmar al-Khayyām (d. 1131), sought to establish a theory of parallels independent of the Euclidean postulate which would allow them to prove theorem I,29, the first which Euclid proves on the basis of the parallel postulate, without using this postulate. In modern terms one could call this an effort to establish an absolute geometry. The second approach, represented by al-Jawharī, Ibn al-Haytham, Naṣīr al-Dīn al-Ṭūsī, and other scholars, was concentrated solely on proving the parallel postulate.

With respect to Book V the main result of the debate was, however, cautious and reluctantly formulated, the introduction of a new number concept, which enlarged – speaking in modern notions – the Greek concept of numbers as natural numbers (without one) to the positive real numbers (without zero) by ᶜUmar al-Khayyām and Naṣīr al-Dīn al-Ṭūsī. It was developed discussing compound ratios, i.e., the multiplication of ratios, already dealt with by Greek mathematicians. One of the reasons stimulating this research was its use in astronomy. Closely connected was the debate about the proportion theory for geometrical magnitudes. Although Arabic commentators did not reject this theory as wrong, they were dissatisfied with the fundamental definitions V,5 and V,7 about identity of ratios and inequality of ratios. They argued that the equimultiple concept used in those definitions, for instance definition, did not express the essence of a ratio clearly, which in their opinion was the measuring of one quantity by another one. They replaced it by a definition built upon the so-called Euclidean algorithm or, speaking in modern terms, on the comparison of the expansion of each ratio into a continued fraction. Among the medieval scholars who wrote treatises on it were al-Jawharī, al-Māhānī (ninth century), Thābit Ibn Qurra, and ᶜUmar al-Khayyām. The latter thought he had proven the equivalence between both theories of proportion, which allowed the use of all Euclidean theorems in Books V and VI in the second theory. Since proportions were of primordial importance for deriving and proving new results in geometry and astronomy, this was an essential project. His proof was based on a theorem that to three proportional magnitudes a fourth proportional always exists. The fundament of his proof for that theorem was a principle attributed to Aristotle about the infinite divisibility of (geometrical) magnitudes. Lacking the notion, not to mention a strict definition, of continuity, this principle, however, was insufficient for his purpose.

The main issue discussed with respect to Book X – which was perceived as the most difficult book of the *Elements* – was the question of how the geometrical magnitudes treated in it were related to the roots of non-quadratic numbers used by algebraists and arithmeticians. To answer this question in a meaningful way meant developing a new conceptual understanding of the objects involved and creating a technical language which made it possible to speak about geometrical and algebraic-arithmetical irrationals on the same mathematical level. After several incomplete trials during the ninth and tenth centuries, the equivalence of the different kinds of geometrical irrationals of Book X and simple as well as compound algebraic-arithmetical irrationals was established in the sense that one type could be translated into the other one. This debate not only brought the heirs of theoretical Greek mathematics together with practitioners trained in Eastern traditions, but it also attracted laymen from other fields, who ordered – at least until the fourteenth century – copies of such commentaries on Book X, asked for explanations of their contents, and were proud to possess them.

See also: ►Isḥāq Ibn Ḥunayn, ►Thābit Ibn Qurra, ►al-Nayrīzī, ►Ibn Sīnā, ►*Almagest*, ►al-Jawharī, ►al-Kindī, ►Ḥunayn Ibn Isḥāq, ►Naṣīr al-Dīn al-Ṭūsī, ►Ibn al-Haytham, ►ʿUmar al-Khayyām, ►al-Māhānī

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Embalming in Egypt

Aidan Dodson

Embalming is the artificial preservation of the body. In Egypt, the first examples date to Late Predynastic times (late fourth millennium BCE), when the tight wrapping of the corpse is first found at the site of Heirakonpolis. Prior to this, bodies were simply laid in graves in the desert, where in some cases the hot and dry conditions promoted the natural desiccation of the body, producing a wholly natural 'mummy' (Fig. 1).

It has been generally assumed that it was the observation of such corpses that led to the Egyptians developing artificial methods once the introduction of proper tombs divorced the body from the natural preservative environment. It has been further surmised that the motivation so to do was derived from a belief that physical preservation of the body was required for the successful existence of the spirit in the next world. However, there are no explicit statements of this in the ancient texts.

During the Early Dynastic Period and Old Kingdom (ca. 3000–2500 BCE), the emphasis was on the exterior appearance of the completed mummy. Each limb was separately wrapped, and a layer of plaster applied to the outer layer, enabling the modelling of the facial features, genitalia and other elements. On

Embalming in Egypt. Fig. 1 Naturally preserved mummy, now in the Egyptian Museum, Turin (photo by author).

Embalming in Egypt. Fig. 2 An early Fourth Dynasty crouched mummy, from Meidum and now in Bristol's City Museum and Art Gallery (photo by author).

occasion, the finished body was dressed in real clothing. The body was invariably placed on its left side, initially with the legs drawn up tightly against the body, later in a more relaxed, mildly flexed, pose (Figs. 2 and 3).

At the same time the first moves towards the preservation of the actual corpse itself were made. The internal organs, a key source of putrefaction, were sometimes removed and placed in four 'canopic' jars and/or a chest (Figs. 4 and 5). The viscera were ultimately under the protection of four particular deities: Imseti (liver), Hapy (lungs), Duamutef (stomach) and Qebehsenuef (intestines). The heart was always left in the body: according to Egyptian belief it was the seat of intelligence and thus needed to remain in place.

Embalming in Egypt. Fig. 3 Plaster layer from a Fifth Dynasty mummy from Giza, now in the Museum of Fine Arts, Boston, Massachusetts (photo by author).

Embalming in Egypt. Fig. 4 Twelfth Dynasty canopic chest from Dahshur, now in the Cairo Museum (photo by author).

Embalming in Egypt. Fig. 5 Canopic jars of King Taharqa (Twenty-fifth Dynasty) from Nuri, and now in the Museum of Fine Arts, Boston, Massachusetts (photo by author).

The organs were desiccated using natron – a mixture of sodium bicarbonate, sodium carbonate, sodium sulphate and sodium chloride. It is found naturally in

Embalming in Egypt. Fig. 6 Osiris, god of the dead, with the genii Imseti, Hapy, Duamutef and Qebehsenuef in front of him, and his sisters Isis and Nephthys behind him. This vignette comes from the Book of Dead papyrus of Hunefer in the British Museum (photo by author).

Embalming in Egypt. Fig. 7 Wrapped mummy of Ukhhotep (Twelfth Dynasty) from Meir, and now in the Metropolitan Museum of Art, New York (photo by author).

Egypt, most commonly in the Wadi Natrun some 64 km northwest of Cairo. This material came to be fundamental to the embalming process, and by the end of the Old Kingdom, the key activity in the mummification process was the placement of the body on a stone slab, upon which it was covered with powdered natron for approximately 40 days. By tradition, the entire mummification process was supposed to take 70 days, although there are known examples of its taking longer.

By the beginning of the Middle Kingdom (2100–1700 BCE), there had been major changes in the external presentation of mummies. Rather than having their limbs separately wrapped and left visible, the plaster was omitted and extra layers of padding and wrappings added to make the mummy essentially cylindrical, with a mask placed over its head and shoulders. These changes coincided with the rise to prominence of Osiris as god of the dead, and made the corpse into a simulacrum of the god (Fig. 6) which now lay fully stretched out, albeit still lying on its left side, facing east (Fig. 7).

As far as the physical body was concerned, a fair degree of experimentation is seen during the Middle Kingdom. Many were eviscerated in what was to become the traditional fashion, via an incision made in the left flank. There were, however, several mummies that seem to have been treated with an enema of tree-oil, most probably juniper or turpentine. This partially dissolved the viscera, the remains of which seem to have been extracted anally. The skin, desiccated with natron, was sometimes coated with resin. Brains were generally left in place, but in some cases were removed via the nose. To do so, the ethmoid bone at the back of the nose was broken through and a probe used to break up the decaying brain tissue, which was then allowed to drain out of the nostrils. The cavity would often be filled with linen and/or resin.

It was during the New Kingdom (ca. 1550–1070 BCE) that mummification reached its ‘standard’ form. Brain removal and organ extraction through the flank became usual in high-status interments, although some bodies retained their brains. Natron treatment often produced excellent results, particularly demonstrated by the considerable number of royal mummies that have survived. Resin was lavishly employed and, as well as being poured, via the nose, into the emptied cranium, was frequently applied to the face and body and moulded into little balls and used to plug ears, and, occasionally, the anus. It should be noted, however, that simple wrapping with linen was still practiced in the middle and lower ranks of society, as had always been the case, and always would do.

Various ritually protective items were increasingly placed on the body during the New Kingdom and later. For example, a stone beetle (the ‘heart scarab’) was placed above the heart, and an ornamented plate over the embalming cut in the flank. Various other amulets might also be placed within the wrappings, to surround the body with ritual protection (Fig. 8).

By the Twentieth Dynasty (ca. 1190–1070 BCE) a number of innovations began to appear. Lichen and sawdust began to be used to pack out the abdomen,

Embalming in Egypt. Fig. 8 Protective plate from the embalming wound of Queen Henttawi (Twenty-first Dynasty), now in the Cairo Museum (photo by author).

Embalming in Egypt. Fig. 9 Face of the Twentieth Dynasty mummy of King Ramesses IV (Cairo Museum), which has small onions acting as false eyes (photo by Martin Davies).

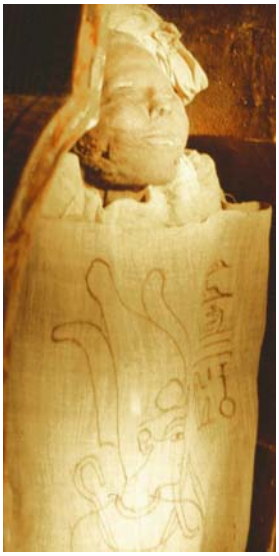
while small onions were sometimes placed in the eye sockets, all to impart a more lifelike appearance to the emaciated corpse (Fig. 9). This was taken further during the next dynasty, when elaborate packing began to be placed under the skin (Fig. 10). When successful, it produced a very lifelike effect; however, there were many examples of over-packing, and at least one body suffered the splitting open of its face as the skin continued to dry and contract.

Typically, the body cavity was filled via the evisceration cut, through which the back was also dealt with. Often, through this same cut the neck area was filled with semi-liquid mud or sawdust. The thighs were also accessible from this incision with the aid of sticks to push the filling down, although sometimes they were filled from a cut made in the back of the knees, an incision that was generally used to fill the calf. Some mummies show vertical incisions for stuffing in each buttock, with incisions at the ankles used to stuff the feet. Arms were packed through horizontal incisions made in the ventral and dorsal sides of the shoulders and sometimes in the elbows. To complete the effect, make-up was applied to the face, false eyes fitted and hair enhanced with hair extensions.

A further change, which started to appear during the Twentieth Dynasty, was the return of the viscera to the body after their separate desiccation, often accompanied by wax images of the four protective genii (Fig. 11). Interestingly, although now without a physical function, canopic jars were often retained as purely ritual objects, ultimately becoming solid.

The stuffing of the body was fairly short-lived, and had largely disappeared by the end of the Twenty-second Dynasty, although the body cavity was still generally filled with earth and sawdust. There was a revival in the placement of the viscera in canopic jars during the Twenty-fifth Dynasty (ca. 720–663 BCE), but during the Saite and Late Periods (663–332 BCE) the visceral packages were placed between the thighs or lower down, between the legs.

During the Graeco-Roman Period (from 332 BCE), there was a gradual decline in the quality of embalming. A typical feature of mummies of first century BCE and first century AD is the heavy use of liquid resin both inside the body cavity as well as on the surface of the body. The third and fourth centuries AD show that the bodies were neither eviscerated nor de-brained, but thickly covered with resin. One innovation of the Early Roman Period, however, was the gilding of the mummy. Fingers, toes, eyelids, lips, hands, feet, genitals, and on occasion the entire body were covered with a fine layer of gold. Another interesting feature of the Roman Period is the arm position found on many mummies. For the vast majority of Egyptian history, arms had been placed at the sides. However, the crossed pose is found on occasion during the Middle Kingdom



Embalming in Egypt. Fig. 10 The mummy of the High Priest of Amun, Masaharta, showing the packing typical of the Twenty-first Dynasty. It is now in the Museum of Mummification, Luxor (photo by author).

Embalming in Egypt. Fig. 11 Wax images of the four protective genii, as placed inside the body cavities of Twenty-first Dynasty mummies alongside the viscera, now in the British Museum (photo by author).

and, in particular, on the mummies of the kings of the New Kingdom. The pose – associated in particular with the god Osiris – was then revived in Roman times and is found in a large number of burials.

Mummification effectively came to an end with paganism, although there are a few examples of mummies that clearly belong to Christians. The creeds of Christianity and Islam took a very different view of the role of the corpse, bringing to an end three and a half millennia of development.

Embalming in Egypt. Fig. 12 Mummy of a ram, sacred to the god Khnum, and buried in his temple at Aswan, now in the Louvre Museum, Paris (photo by author).

Mummification was not restricted to human beings. At all periods of Egyptian history many gods had an animal form, and a representative of that creature would be kept in a temple as an incarnation of the god. These were often embalmed after death using similar methods to those employed for humans (Fig. 12); pets of high-status individuals were also mummified. In Late and Graeco-Roman times the production of animal mummies was greatly expanded to provide votive offerings for sale to pilgrims. In these cases the external appearance of the mummy was most important, and the actual embalming could be poor. Indeed, some such 'mummies' could contain minimal animal remains, or be wholly fake.

See also: ►Animal Mummies

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Engineering

Arnold Pacey

Engineering has become the paradigm or model for almost all technology in the West, hence terms such as “genetic engineering”, or “systems engineering”. Applied to the non-Western world, this use of language can be grossly distorting, preventing recognition of other paradigms. Thus the word “engineering” is best limited to construction works and related mechanical devices. Moreover, the smallest of such works, as carried out by individual house builders or farmers practicing irrigation, may often be better considered in other contexts, such as “building” or “agriculture”.

Three kinds of construction works need to be considered, namely those related to fortifications, monuments, and water management. Methods of construction were nearly always labor-intensive, so various ways of organizing a labor force are important for understanding what was involved. In Southeast Asia, for example, irrigation systems for rice culture were often built by groups of farmers working cooperatively. Thus on the island of Bali, there was a social unit known as a *subak* comprising all the farmers whose fields were watered from the same source, who had to come to a mutual arrangement about regulation of water flow, repairs and new construction.

By contrast, very large construction works were usually carried out by order of a king or emperor, supervised by state officials, and using conscript or corvée labor. An example is the New Bian Canal in China, completed in AD 635, on which five million people were said to have worked at different times.

The organization of labor, supervision of construction, and payment for materials might take other forms if the work was being done for a rich villager or other notable, or if it had been initiated by a religious community based at a temple. The latter were often very important, and in China, Buddhists helped pioneer the use of iron in bridge building as well as in the architecture of temples between AD 500 and 1200. Buildings for religious or funerary purposes were also built at the instigation of rulers, often on a very ambitious scale. One thinks of the pyramids of Egypt, Maya temples in Central America, and numerous temples in India and Southeast Asia.

Such buildings could be linked to apparently utilitarian engineering works. The temples of Angkor in Cambodia, founded about AD 880, were built on mounds created by the excavation of large reservoirs or tanks that were part of a system for supplying water for rice culture, and were also linked to a system of transport canals. Stone for building the temples was brought to the site along these canals. The irrigation works reached their fullest extent by about 1150, after which environmental damage – the formation of a ferrous hard pan – seems to have contributed to their decline.

Other remarkable works of hydraulic engineering include large reservoirs with elaborate systems of feeder canals in Sri Lanka, where some canals pass through tunnels from one catchment to another. These systems evolved slowly from about 200 BCE to AD 1300, and like the works at Angkor, may have had monumental as well as utilitarian significance. There were also early canal irrigation systems in India, and in Iran there was a specialized technique for tapping groundwater known as the *qanat*.

In the Americas, there were the impressive Chicoma canals in Peru and the dikes in the former Lake Texcoco built by the Aztecs to separate artificial cultivated islands (*chinampas*) from the salty water of the main body of the lake. The Aztec capital of Tenochtitlan adjoined this system of islands and dikes.

Reviewing early engineering along these lines leaves one with a strong impression of its connections with agriculture, especially where irrigation or other water control was necessary, and indicates the frequent role of state or government authorities with their interest in using engineering also for religious or monumental constructions. The latter were important in demonstrating and legitimizing the authority of the state and its ruler.

This view of engineering can be interpreted in terms of the theory of “hydraulic civilization” associated particularly with the work of Karl Wittfogel. According to him, the food requirements of growing populations made it essential to develop centralized states capable of organizing large-scale irrigation works. Thus hydraulic engineering is seen as primary, with many other forms of large-scale engineering developing from it. The importance of irrigation in much of Asia, in Egypt, and in parts of Central America seems obvious, and it is at least plausible to think that the necessity for such irrigation works was a driving force for innovation in engineering techniques and for growth of government organizations capable of managing them.

An alternative interpretation of world history arises from the argument that military power emerged for the first time as a distinct force in human affairs – as opposed to an occasional and ad hoc assembly of fighting men – toward the end of the Neolithic, not long before 3000 BCE. Proponents of this view point out that it was in states that expanded as a result of the growth of organized military power that engineering developed most rapidly. The earliest examples were in Mesopotamia and Egypt, but there were parallel developments in many other parts of Asia, notably with the rise of the first Chinese dynasties. Later on, the emergence of empires in Central America and Peru can be seen as having a roughly similar technological outcome. By contrast, kingdoms that remained small, tribal societies, and isolated communities of cultivators and pastoralists had different kinds of technology that hardly involved engineering at all. What may have made the difference was that the experience of creating and commanding armies provided a model for recruiting, organizing, and disciplining the labor force needed to construct fortifications and other large-scale works. In this view, then, military engineering was primary, and monument building and hydraulic engineering were extensions of the same basic techniques into other areas that interested rulers and their officials.

Military technology, of greater or lesser significance depending on which of these interpretations is adopted, is the subject of a separate article in this volume. Looking in more detail at the civil branches of engineering, we may note that state officials often played a part in surveying and supervising works, and typically had a good knowledge of the mathematics needed for laying out sites or estimating quantities. The first pyramids in Egypt were accurately square and were built on carefully leveled foundations. Centuries later, Chinese bureaucrats studied books on arithmetic that told them how to calculate quantities and estimate volumes of earth-moving needed on construction sites – but books on machines were rare.

Much early engineering involved the excavation of canals or the building of earthworks in the form of fortifications, dikes, irrigation terraces, or dams, with few striking innovations beyond increases in scale, surveying methods, or the use of gabions (wickerwork containers of stones) in China. Where irrigation canals needed gauging weirs or distribution boxes to divide the flow equally between several farmers, some intriguing designs were developed in Iran, many of them made of stone.

The earliest engineers used stone in construction long before iron tools were available, so that quarrying and dressing the material presented considerable problems. In Egypt, the pyramid builders used wedges and dolerite hammers to work limestone, and the architect and minister of state Imhotep, who was active around 2660–2650 BCE, was credited with the invention of building in stone. Transport was by barge where possible and then on sledges hauled along lubricated wooden tracks. In the absence of pulleys or any other lifting gear, stones were raised by hauling up ramps.

In the Americas, the most remarkable engineering in stone was the terracing and building accomplished by the Incas in Peru. As in Egypt, there were no iron tools, but stones of quite hard rock, including granite, were shaped by grinding until they fitted together very precisely. In the Americas, as in ancient Egypt and many other parts of the world, sun-dried mud brick provided a further option for the construction of buildings and fortifications. A notable example is the fortress of adobe brick at Paramonga, in the lowlands of Peru. In West Africa, mud or clay was sometimes used rather as modern architects use concrete, to form domes and shell-vaults (for example, at Zaria in northern Nigeria). City walls of mud brick (adobe) date back to the twelfth century AD at Kano (also Nigeria). They were extended twice in later centuries to encircle a 17-km perimeter, and in 1903 successfully withstood cannon fire from the British army.

While much hydraulic engineering depended on earthworks, spillways needed to be faced in stone to prevent erosion, and a dam designed so that overflow water could pass over its crest would usually need to be stone-faced throughout. A fine example was the long, low Cauvery River dam, built to serve an irrigation system in the Chola Kingdom of South India. It was built of masonry laid in clay around AD 200. At about the same date, Persian engineers were using iron dowels set in lead to fix together the massive stones they used in facing some of their dams, and also poured molten lead into the space between stones.

Looking back to an earlier age to consider mechanical aids for construction, one should note that the movement of large blocks of stone along the ground on rollers was not a simple procedure, and was rarely practiced in Egypt. However, the consensus remains that the invention of the wheel derived from experience with rollers, perhaps in Mesopotamia. There, at any rate, wheeled vehicles were in use by 2500 BCE. Moreover, in conformity with the view that military technology was the leading sector in engineering, the first known examples were on chariots and army supply vehicles.

The development of mechanical engineering from that time on is hard to document in detail. Some commentators stress the emergence of mechanisms involving wheels or rotary motion, such as the pulley (by 800 BCE) or the first toothed gears, probably made in the eastern Mediterranean regions soon after 500 BCE. Another approach is to notice the importance of three main kinds of mechanical development – firstly, a slow evolution of levers, pulleys, and hoists for lifting stone on construction sites; secondly, the development of siege engines, catapults, and other military hardware; and thirdly, the evolution of water-raising devices, sometimes for drawing water from wells, but sometimes also to supplement irrigation from canals or rivers.

One kind of mechanical water-raising device was the chain-of-pots. The simplest form of this may have originated before 100 BCE as a "necklace" of pots hanging over a roller or pulley which was hauled around manually. The bottom of the necklace dipped in water, and as it was pulled round, pots filled at the bottom, and then were tipped over the roller at the top to empty into a trough. An animal-power version, driven through wooden gears, and with a large wheel replacing the roller or pulley, developed five or six centuries later. Known as the *saqiya* or "Persian wheel", it came to be widely used in North Africa, the Islamic countries, India, and China. For example, as recently as 1904 some 4,000 were recorded in the Dongola province of Sudan, each irrigating about 15 acres (6 ha).

Other mechanical water-raising devices include the pedal-driven "dragon spine" pump used in Chinese rice culture, and the *noria*, a water wheel with containers attached to its rim, powered by the flow of a river. The latter was known in western Asia by 100 BCE and also has a long history in India and China extending into the twentieth century. Other water-raising mechanisms used in modern peasant cultures have included a form of Archimedean screw in Vietnamese rice paddies and lever-based devices in Indonesia.

The first water-powered mills for grinding corn were adapted to mountainous areas with streams rushing down steep gullies, and their design was perhaps suggested as much by experience of the potter's wheel as also undoubtedly by the *saqiya* and *noria*. Thus we might expect the first water mills to have been made in a mountainous district where there were people with experience of all these devices and also where there were quarries producing millstones for rotary hand-mills. These considerations support evidence indicating that Iran or Iraq is the place of origin of the water mill some time prior to 350 BCE. There were quarries known for their millstones both in Iran, and on the upper Tigris, in a region now in Turkey.

The mills invented at this date had horizontal, propeller-like water wheels that drove the millstones directly, and it appears that they were so effective that they were soon adopted in southern Europe and also China. Later, this type of corn mill was used in northern European countries (where it became known as the "Norse mill"), and most notably in the foothills of the Himalayas, especially in Nepal.

The alternative type of water mill which has a vertical water wheel driving the millstones through the wooden gears developed later, and had a more restricted distribution. However, it is noteworthy that it used the same kind of gears as the more widespread animal-powered *saqiya* or Persian wheel, namely "peg and lantern" gears, i.e., a wooden crown wheel with projecting peg teeth on the same horizontal axle as the water wheel meshed with a lantern pinion on the vertical axle.

Almost the only non-Western countries in which this type of gearing was developed beyond the basic corn mill or Persian wheel format were Iran, Iraq, and Syria in western Asia and China in the East. It is striking how little mechanical devices of this kind were used elsewhere. However, in western Asia and China, a considerable variety of water-powered (and animal-powered) machinery was developed, including machinery associated with papermaking and sugar refining, and windmills were also used, all before AD 950. In preparing pulp for papermaking, for example, water wheels turned cam shafts which operated trip hammers. On a smaller scale, experiments were also made with geared astrolabes and clock mechanisms, and in China, an astronomical clock powered by a slow-running water wheel was made by Su Song in the 1080s. At about the same time in Chinese industry, water-powered bellows provided the draught for a few of the many iron furnaces, and water-powered spinning mills were evolving in districts that produced the coarser kinds of textiles.

One distinctive feature of Chinese machinery (as compared with practice in the Islamic world) in the period up to AD 1300 was a preference for using an endless rope running over pulleys for transmission of power from water wheels, instead of gears and shafts. A comparable contrast in style and practice in the West occurred in the nineteenth century when American designers of New England textile mills favored rope drives from water wheels or turbines to different parts of a mill, whereas European millwrights still preferred gears and shafting.

In conclusion, it is worth observing that although a steady development of engineering can be discerned in several parts of Asia up to about AD 1200, it is hard to identify major innovations dating from after that time. Engineering was never the most important branch of technology over much of that continent, but even where it had developed strongly there was little further progress. One factor was undoubtedly the devastating Mongol conquests of Iran, Iraq, and China, completed by 1260, and then the European conquests that were beginning in 1500. The Mongols destroyed irrigation systems in parts of northern Iran, and allowed others to decay, thus undermining the basis of much engineering in that region. However, it is difficult to believe that conquest and political disruption are the whole story, and one must also look to institutional and economic factors that are beyond the scope of this article.

Another general point is that by concentrating on the civilian uses of technology and leaving the military aspects for separate treatment, this article inevitably demonstrates the great importance of hydraulic engineering. This may seem to justify the idea that many non-Western societies were "hydraulic civilizations." However, we probably need to be more aware of the many mechanical and structural ideas originating from the experience of building siege engines, chariots, city defenses, moats, and forts. Maybe, too, we ought to appreciate that military engineers traveled more than their purely civilian counterparts and probably contributed more to the spread of ideas. In the third century AD Persian rulers employed a captured Roman army on a dam-building project, presumably learning a little of Roman engineering in the process. In AD 751 a battle between Chinese and Islamic forces in Central Asia led to the employment of Chinese experts on papermaking in Samarqand, and resulted in the transfer of papermaking technology into the Islamic world.

However, the most important point we tend to neglect is that the organization and discipline of armies seem likely to have been a model, at many points in Western, as well as non-Western history, for the organization and management of civilian technology, especially large-scale construction projects.

See also: ►Military Technology, ►Technology in the Islamic World, ►*Qanat*, ►Clocks and Watches, ►Construction

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Environment and Nature in Africa

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Africa's location astride the equator subjects the continent's environment to tropical and subtropical conditions. Mean temperatures range above 15°C in the winter and above 25°C in the summer. During the northern summer the weather is hot and wet over Central Africa and the Guinea coast, arid conditions prevail over northern and most of southern Africa, and the east coast is affected by the southwest monsoon. During the northern winter the Sahara and the Mediterranean are affected by the westward flows of warm dry air, and the northeast monsoon regulates the weather over the east coast; warm rainy conditions prevail elsewhere except along the southwest coast. The surrounding waters have mean sea-surface temperatures above 20°C but regional peculiarities distinguish the coastal zones: the Guinea coast with its abnormal subhumid conditions; the hyperarid southwest coast with the cool and foggy Namib desert; the temperate Cape zone; the east coast affected by the monsoon winds and rains, the tropical easterlies, and the semidiurnal tides up to 6 m; and the Red Sea region with its extremely hot and arid climate and the highest seawater salinity in the world.

Only 9% of Africa's total land surface is well suited to agriculture. Most of the continent's ecological systems occupy latitudinal belts with the climate varying from subhumid to semiarid. The dense tropical forest extends several hundred miles on either side of the equator and along the Guinea coast where precipitation may reach 3,000 mm a year. To the north and south it thins out to woodland savanna and drier forest or bush. The southern edge of the Sahara, called "Sahel" (Arabic for "coast, edge"), forms a transitional zone between savanna and desert. The Horn of Africa is persistently dry, but the Kalahari desert is mostly grassland and scrub, with waterholes and even some marshes. The Ethiopian highlands form the largest single area on the continent where fertile soils, numerous rivers, and abundant rainfall allow for productive agriculture. The width of the coastal zone varies from less than 1 km to over 300 km (200 mile). Most African countries have mixed farming, and most land by area serves as pasture. The rainfall has had a profound influence on the distribution of population. Three rainfall thresholds mark the risk margin in traditional economies (1) where average annual precipitation is below 500 mm, agriculture cannot be sustained and total dependence on cattle is necessary; (2) where rainfall varies between 500 and 750 mm per year, it is impossible to subsist on agriculture alone, and supplementary stock-rearing is the customary solution; and (3) rainfall in excess of 750 mm per year is generally more predictable and more evenly distributed. Even then, the actual potential for agriculture and livestock raising depends on soil fertility, water evaporation, and ground water retention. African soils are generally poor, and agriculture requires large labor investment for subsistence maintenance. Only where soil fertility is combined with adequate water resources is surplus production possible.

Precarious existence in marginal environments makes for particularly strong connections between ecology and society. The harsh lands where water is scarce and grazing restricted historically produced fierce competition within a society and between neighboring societies. Cultivators and herdsmen displaced hunters and gatherers; possession of iron for weapons and implements played a key role in this process. For insurance against famine, in addition to stock-keeping, farmers cultivate different plots, if possible in more than one ecological zone to take advantage of variations in the seasonal rainfall patterns and temperatures either using the same crop (e.g., maize or bananas) or different crops. Usually, two harvests are possible. Cultivation became linked with the idea of civilization, and the conceptual opposition between culture and nature found expression in the dichotomies of farm/bush, coast/hinterland, and civilization/barbarism noted in various settled societies. This polarity was also reflected by the classification of animals into wild or carnivorous, therefore “evil” and unfit for human consumption, and domesticated or herbivorous, suitable for food.

Subsistence patterns affect residential mobility, division of labor, dominant forms of property and ownership patterns, land tenure, social networks, typical marriage age, and marriage transactions. The transhuman cycle depends on the particular botanical and hydrological environment and may vary from regular moves between wet-season villages and dry-season camps to a continual migration of over 1,000 km throughout the year. In mixed-economy societies, women often provide the bulk of the wet-season horticultural labor and men the bulk of the pastoral activities. Traditional forms of wealth associated with production and sustenance, such as iron hoes or cattle, are still included in bridewealth payments. In sub-Saharan Africa, land was traditionally held in tenure by the producers rather than owned. Towns grew in ecological oases or on trade routes. Markets developed between two ecological zones whose growing and harvest seasons differed, to trade for seed, food (in case of famine), and local specialties. There were seasonal markets, like those on the east coast regulated by the monsoon calendar, and “weekly” markets (e.g., held every fifth day as in the Shambaa country).

There is no formalized or universal world view in African systems of thought. Man is the center of the universe but he is not master of it. If harmony between man and nature is lost, the ensuing chaos harms man the most. In most cosmologies, the earth exists for man’s sake but he must show it respect. Nature is seen as animated by spirits, and people depend on it for survival. Nature rituals, especially agricultural rites, punctuate the annual religious cycle: planting, first-fruits, and harvest ceremonies, etc. Special rituals relate to stock-keeping. Rain-making rituals are the most important. They are performed by specialists–priests, witch-doctors, or royalty (such as the Lovedu rain-queen in southern Africa fictionalized by Ryder Haggard as “She Who Must be Obeyed”). Shaka, the founder of the Zulu warrior state, declared himself the greatest of all rain-makers. Such specialists are not “mere” witch-doctors but well trained in weather lore: people are aware that there is order in the laws of nature which normally do not change. They do not ask for rain in the middle of the dry season; the rituals are performed before the rains to ensure their proper and timely coming, if the rains fail to arrive, or to stop the rain when too much water may damage the crops and fields. In Zambia, when the rains start, people wait for a few days before working in the fields. An Ashanti farmer addresses his ancestors and the earth at the beginning of cultivation, saying:

> The yearly cycle has come round and I am going to cultivate. When I work, let a fruitful year come upon me, do not let a knife cut me, do not let a tree break and fall upon me, do not let a snake bite me.

At planting, the Venda of South Africa distribute grain symbolically cooked in the field over a grass fire. At first-fruits ceremonies, grains of the new crop may be sprinkled in the field for the spirits or the remains of last-year’s crop cooked and eaten. Among the Basuto the first gourds are taboo until the chief tastes them and offers a cooked dish of the new food to the ancestors.

Traditional African views of nature are thoroughly socialized and transmitted through folklore and rituals. West African cultivators hold that while gold is rare and expensive, iron was given to man by God for universal use as tools. The Zulu believe that the sun, moon, and stars were given by God so men could see, and that cattle were created by God to be man’s food. The Masai think that cattle were given by God exclusively to them, and so consider raiding the herds of their neighbors legitimate. A chief's fields must be cultivated first because their fertility, as his virility, guarantees the whole community's well-being. At the Yoruba harvest festivals, gifts of yam tubers due the chief from each household serve as a tool of unwritten population census. When women pound meal, their long-stemmed pestles are thought to knock against the sky. The stars of the Pleiades are thought to follow one another "like cattle returning home from pasture." Water is sacred, and boiling it "kills" the water spirit. Many plants and seeds are used for medicinal purposes. Sacrifices at religious festivals, rain-making ceremonies, and seances of divination and spirit-possession involve agricultural produce (e.g., yam, various cereals) and cooked foods, and domestic animals and fowl (especially chickens; sheep among Muslims, and on very special occasions cattle).

The universe is unending in space and time. The past and present matter greatly, the future matters only within the next growing cycle. The major rhythms of time are the seasons of rain and dry weather, migrations of birds and animals, flowering of certain plants, lunar months, and day-and-night sequences. The minor rhythms are in the lives of humans, animals, and plants as they move from birth to growth, then procreation and death. The calendars of African peoples are punctuated by references to natural phenomena and production activities. Since there is little temperature variation, the difference is not between the hot and cold seasons, but wet and dry. Usually, the two major seasons are the Greater Rains and the Lesser Rains. The Bantu word for "year," *mwaka*, literally means the rains at the beginning of the Greater Rains. On the East African coast they come in March; the Lesser Rains beginning in July or August are not a good planting season, but about October come the Latter Rains, the second cultivating season. Despite long-term Islamic influence and many Arabic loan-words, the Swahili language has preserved Bantu names for the cardinal points, dominant winds, days of the week, and times of day which reflect the sailing, agricultural, and stock-rearing aspects of Swahili culture. Some coastal cities created an office of "Master of the Sea" or "Master of the Beach." The word "Swahili" itself is derived from the Arabic for "coasts, coastal settlements." The name "Benadir" for the coast of southern Somalia means "harbors."

The pre-Islamic Bantu calendar calculated the annual cycle in 12 months of three 10-day "weeks" (decades, as in ancient Egypt) but within the year it distinguished lunar months in two phases. Different African peoples have "weeks" of 4, 5, 7, 8, 9, and 10 days. Traditional African time-reckoning is not mathematical but event-based. For example, the historical chronology of the Shambaa people of Tanzania is based on the memory of famines. The daytime computation of the Ankole of Uganda begins with the morning milking (about 6 a.m.) and follows the sun with references to times of rest, drawing water for people, driving cattle to drink, returning them to grazing, etc. The lunar months may be called "hot month," "month of rains," "weeding month," "bean harvest month," "hunting month," and so on.

The dwelling and settlement patterns too are affected by reference to the universe and nature, as well as gender. The Dogon of West Africa orientate their village north to south and visualize its plan as a human body prostrated on the ground. The smithy is the head, the family houses are in the center, and separate women's and men's houses, like hands, are on the east and west. Millstones and a foundation altar are lower down like sexual organs, and other altars are at the feet. The shape and orientation of the house mimics the Dogon vision of the earth and the sky as a couple in union. The rooms, the roofs, and the supporting posts indicate the male and female parts; the placement of the hearth, door, and stones supporting cooking pots, even the sleeping arrangements are regulated by traditional spatial orientation. Gender relations in Africa may control the division of both labor and space, and even the use of space for burial. Women play an important role in cultivation, especially of garden crops, and food processing, including disposition of vegetable refuse. Often in charge of food crop seed selection, they also specialize in the knowledge and use of medicinal plants. Men dominate tasks and space involved in herding and animal care, from breeding to the disposition of animal dung, important as organic fertilizer. Among the Bemba of Zambia, who practiced slashing and burning trees for ashbed millet cultivation, the axe became the symbol of masculinity.

Environmental factors have conditioned some major processes in African history, such as population movements and settlement, agricultural production, state formation, and long-distance trade. For example, the arid expanses of the Sahara desert both protected and isolated West Africa from more extensive contacts with North Africa, the Mediterranean, and the Nile Valley, and the remoteness and paucity of resources of the equatorial forest led to historically low population density and lack of contacts with the outside world; the highlands of Ethiopia kept the country independent and self-sufficient but also isolated for much of its history. By contrast, the Swahili culture of the East African coast was totally predicated on coastal location with easy and regular contacts with the Indian Ocean world, its prosperity fed by fishing, agriculture, and trade. In the West Sudan, the rise of medieval empires of Ghana, Mali, and Songhay was supported by efficient agriculture, access to gold and control of the rivers. However, most African rivers, including the Nile, are not navigable throughout their complete course or through the year; they are thus unable to serve as major communication arterials. Material culture of different localities still demonstrates its dependence on availability and qualities of timber, fiber, clay, and pigments. Traditional architectural forms developed in West Africa reflect the needs of mud construction in the rainy climate, while in East Africa stone architecture was limited to the coast because of reliance on coral rock.

The numerous migration legends of African peoples are misleading in that they highlight the movement of small segments of population while masking a general cultural stability reflective of ecological zones rather than specific ethnic groups. In areas suited to agriculture, shifting cultivation was a usual response to soil exhaustion or population growth until the twentieth century. Although access to water and pasture normally was a key to stability of settlement, some societies developed a tradition of moving large cities to prevent exhaustion of natural resources. Archeologists have suggested that the decline of Great Zimbabwe in the fifteenth century followed overexploitation of subsistence agriculture, in addition to droughts and other factors. Inland East African irrigation and terracing systems were able to support dense populations of people and cattle, but were abandoned before the nineteenth century. On the Atlantic coast, intricate knowledge of food crops and local conditions allowed for wetland rice cultivation in the alluvial and tidal lands; salt-water-tolerant varieties of rice were later exported to the Americas along with enslaved skilled practitioners of cultivation and food processing. In drier areas with sparse vegetation and meager topsoil, ecological changes could lead to long-distance migration, especially by herding populations. The West African *jihads* of the eighteenth and nineteenth centuries were spearheaded by mobile, pastoralist communities such as the Fulani, and affected mostly the Sahel and savanna zones of the Sudanic belt where both cattle and horses (for cavalry) could live. In the sixteenth century, agricultural Ethiopia suffered major invasions first by the nomadic Somalis and then by the cattle-herding Galla (Oromo). In a later expansion of the Amhara Ethiopian empire, the Amhara armies invading Oromo territories could not feed themselves because the Oromo pastoralists did not grow crops and could evacuate their herds from the path of an advancing army. Once some Oromo settled and became cultivators, they avoided stock-rearing for fear of cattle-raiding Somalis or Masai. In the nineteenth century, southern Africa became the theater of two major late migrations based on cattle-herding and a search for pasture: the southbound Mfecane led by the Zulu and the northbound Great Trek of the Dutch Boer farmer immigrants.

The wagons used by the Boers were the first wheeled transport in sub-Saharan Africa, where trade was moved by head porterage in consequence of the tsetse fly infestation and lack of salt in animal diet, which caused the absence of draft and pack animals. Growing contacts with the Western world led to the development of new trade patterns and regional economies: new trade routes connected the forest societies with the Atlantic coast, and some mobile groups (e.g., with access to rivers in the west or sea in the east) became the major agents of change. In the interior, populations seeking safety from slave-raiding moved their villages into inaccessible hills while those seeking trade moved their towns from mountain slopes into plains. By mid-nineteenth century a transcontinental system of routes was in place.

To this day, Africa's food production and raw material bases are still traditional, small-scale and rural; food productivity is the lowest in the world. Sixty-five percent of the continent's population derives its livelihood from agriculture. However, the picture of a static self-subsistence economy is false. African societies have shown both adaptability to change and readiness to experiment. The early spread of three Asian crops – yam, taro, and banana – revolutionized the economy of the humid regions. American food crops (especially cassava, sweet potato, maize, and groundnuts), introduced early by the Portuguese, spread quickly across the continent and still continue to displace indigenous crops; they were followed by tomatoes, various beans, chili, potato, tobacco, cocoa, agave, and avocado. Innovation improved food supply stability and contributed to agricultural intensification and population growth. Former hunters and fishermen, like the Bakuba of the Congo (Zaire) basin, once they were able to produce agricultural surplus, underwent an economic revolution which allowed them to develop the handicrafts and create a kingdom in the seventeenth century. The risk and responsibility for trying the new crops dwelled with the chiefs or kings, who were deemed responsible for environmental management. In the first half of the nineteenth century the sultan of Zanzibar became a major innovator and plantation owner when he transformed the island into a clove-producing garden; coconut plantations were developed, some numbering hundreds of thousands of trees. While for almost 2,000 years the main articles of African trade with the outside world had been gold, slaves, and ivory, agricultural diversification in the nineteenth and twentieth centuries has led to increasingly varied international trade.

European settlement succeeded only in temperate zones free of tropical fevers. The emphasis on cash crops and the spread of perennial crops (oil palm, cocoa, coconuts, coffee, cotton, etc.) have reduced shifting cultivation and sometimes undermined indigenous strategies for coping with the threat of famine. Application of Western methods of agriculture has been successful in cultivating sisal, tea, and pyrethrum but has shown no advantage in the production rubber, groundnuts (peanuts), oil palms, cocoa, coffee, or sugarcane. Indigenous cattle, although considered poor by Western standards, have shown greater resistance to epidemics of rinderpest, lung sickness, etc., several of which devastated regions of eastern Africa in the nineteenth century, facilitating European colonization. Although, in general, adoption of new crops gave people additional means to shape their environment, many rural anticolonial movements were linked to environmental issues. Sometimes European settlers tried to limit indigenous hunting to protect game for colonial elite or misinterpreted African agricultural methods as destructive, thus justifying land expropriation. Numerous attempts to introduce western agricultural machinery, both pre- and postindependence, have failed because of their unsuitability to weak soils, traditional multicrop multistory cultivation, and the socially determined patterns of labor and land tenure. Today, the hoe remains the major farm implement and women still grow 80% of the food consumed by their families and 50% of the cash crops. The lack of protein, especially in the children's diet, persists as a major obstacle to the development of a productive and healthy African society.

Africa is a continent rich in resources which faces enormous environmental challenges, including deforestation, desertification, loss of biodiversity, and degradation of water resources. In 1960 Africa was a net food exporter but since the 1970s it has developed a dependence on food imports and aid. The droughts and famines of the 1970s, 1980s, and 1990s have been exacerbated by civil wars and government policies, in addition to poor communications and transportation. Deforestation, inefficient cultivation, and destruction of the wildlife are tolerated to feed people quickly. Draining marshes helps reduce the incidence of malaria, typhoid, river blindness, and cholera, but creation of new reservoirs increases bilharzia (schistosomiasis). Hydroelectric power dams built in recent decades have eased Africa's energy dependence, but during droughts the water supply is sometimes insufficient for electricity. Despite government steps for natural preservation and sustained development, some colonial practices such as big game hunting have been replaced by poaching; in Angola and Mozambique, warring factions engaged in predatory elephant hunting for ivory – during the conflicts of the 1970s to 1990s. Nevertheless, Africa suffered from colonial intrusion relatively less than other, formerly more isolated, continents, and Africa's potential for preserving and successfully exploiting the environment is higher than in any other developing areas of the world. Under the prevailing low-technology conditions, indigenous ecological knowledge is an important developmental resource. Planning, changes in mentalities of both rural and urban populations, and wide dissemination of appropriate information are keys to the solution of the many current problems.

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Environment and Nature in the Amazon

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The Amazon is bordered by the Andes Mountains, Guyana Highlands, Brazilian Highlands, and the Atlantic Ocean. The Amazon is about the size of the continental United States of America. Portions of the Amazon are included within the territories of nine South American countries: French Guiana, Surinam, Guyana, Venezuela, Colombia, Ecuador, Peru, Bolivia, and Brazil. However, about 80% of the Amazon is in Brazil.

The Amazon remains a mystery to most outsiders, but their impressions are often more fiction than fact. Demystifying the Amazon requires an understanding of its diversity and human residents. Here biological, indigenous, and colonial ecologies are briefly considered.

Biological Ecology

About half of the world's tropical rain forest is in the Amazon region, the largest reservoir of biological diversity in the world. Typically within just a few square miles of forest live more than a thousand species of plants and hundreds of species each of birds, mammals, amphibians, and reptiles. Most of the Amazon is a variant of tropical rain forest. Among the variants are moriche palm, cloud, mangrove, and anthropogenic forests. However, there are also pockets of various kinds of savanna or grasslands within many forest areas.

The climate in tropical rain forest is characterized by high temperature, rainfall, and humidity rendering it the norm for plant growth on this planet. Every other kind of plant community is some deviation in response to stresses such as lower rainfall and/or temperatures. The Amazon is frost free. There is usually no synchronous dormant period in plant growth, unlike in drier and colder regions. The average yearly temperature is around 75°F (24°C) and the average yearly rainfall is 2,000 mm or more. The greatest temperature fluctuations are diurnal instead of seasonal.

The dynamics of the ecosystems of the Amazon are mostly related to variations in the amount and distribution of water through time and space. Variations in rainfall more than temperature usually mark the seasons. In the wet season it rains almost daily while in the dry season it rains at least a few days each week although not necessarily for the entire day. Changes in the distribution of water trigger changes in the local distribution and abundance of fish and other wildlife.

Throughout the Amazon water is common in one form or another such as rivers, streams, lakes, ponds, pools, and swamps. The Amazon River is the longest in the world (6,700 km), has more than 1,000 tributaries, drains about 40% of the continent of South America, and carries 20% of all of the river water in the world. The flood plain (fluvial zone) and the interior (interfluvial zone or terra firme) are two general types of environments in the Amazon. During the wet season the level of the water in various aquatic ecosystems may rise as much as 20 m. However, actual flood plains compose less than 10% of the region. Thus, most of the Amazon is interior forest that is not regularly flooded.

There are at least three major types of water in the Amazon (clear, white, and black) with very different physical and biological characteristics. For example, black waters are associated with white sands; they are tea colored, high in acidity, and low in nutrients, productivity, and diversity.

It has been estimated that there are at least 30,000 species of vascular plants in the Amazon, although the number may be much higher. The plant community of the tropical rain forest is characterized by its height, luxuriance, and diversity. Giant trees with few, if any branches in their lower levels stand like tall columns. Often there are several layers in the structure of the forest which reflect a vertical zonation in the microclimate and associated plants and animals.

Animals are relatively scarce in most ecosystems of the Amazon. While species diversity is high, their population density is low and individuals within a population are patchy in spatial distribution. Moreover, most species are arboreal, small in body size, solitary, camouflaged, and nocturnal. Also animals only comprise a fraction of the mass of the forest, and most of those are invertebrates. Accordingly, animals are not readily available for the hunter, zoologist, or tourist. The major exception to these generalizations about animals is the peccary (wild pig) which is terrestrial, large in body size, large in group size, diurnal, noisy, and leaves obvious trails. Wild pigs are usually the most important prey by weight for most indigenous hunters. However, in riverine areas fish are the primary protein source for millions of people. The Amazon as a whole has the richest freshwater fish fauna in the world with some 3,000 species.

Until a couple of decades ago it was thought that these forests were primeval, pristine, and static. But more recent research reveals that forest distribution has alternately contracted and expanded with oscillations in rainfall abundance and distribution over the last million years correlated with Pleistocene glaciations. The Amazon is also influenced by the climatic oscillations called El Niño and La Niña.

Indigenous Ecology

The extent of human antiquity, farming, population settlement, and density in the Amazon implies significant human influence on the environment over time. Estimates of human antiquity in the Amazon range to more than 11,000 years ago. Pottery dated from as early as 7,500 years ago has been recovered at various sites. Pottery is associated with relatively permanent settlements and farming. By about 1,000 years ago chiefdoms were flourishing along the larger flood plains with some population centers estimated up to 100,000 people.

It might appear that the environmental impact of traditional indigenous societies is negligible because of their usually low population and lack of Western technology such as chainsaws. However, collectively through space and cumulatively over time their environmental impact can be substantial. Yet most of this impact is within the levels and processes of natural disturbances. This is the case for traditional swidden or shifting horticulture. Annually during the dry season members of a household or community cut small plots of forest. After they have dried out the debris, it is burned, and then crops are planted just before the rains of the wet season begin. The garden is harvested for a few years after which it is gradually phased out over a decade or more as the forest encroaches. Through time the swiddens in various phases in an area collectively create a mosaic of plant and associated animal communities at different stages of ecological succession (development), thereby enhancing local biodiversity. Estimates are that 10–40% of the terra firme forest is anthropogenic.

The descendants of the original colonizers of the Amazon created societies that were usually to some degree ecologically and socially sustainable. In the interior forests away from major rivers these societies were most often characterized by a population with low density and high mobility combined with a rotational system of land and resource use and management for foraging (hunting, fishing, and gathering) as well as for farming. Most traditional indigenous populations enjoyed relatively good nutrition, health, and quality of life prior to major disruptions from Western contact, such as the Yanomami in the mountainous border area between Brazil and Venezuela. The viability of precontact cultures was usually facilitated by a worldview integrating attitudes, values, customs, and rituals emphasizing harmony between humans and nature, such as in the case of the Desana of Colombia.

Through intimate daily experience and observation in interacting with their habitat, local people have acquired extensive, detailed, and reliable knowledge about the animals, plants, soils, waters, and other aspects of the ecosystems in their territory. This is reflected in native languages with extensive vocabularies of words for plants, animals, environments, and other natural phenomena of the ecosystems in their local and regional habitats. As an example, the Ka'apor of Brazil recognize at least 768 species of plants, 112 of which have medicinal uses. In Peru, the Matsigenka distinguish 69 different environments based on vegetation, 7 based on fauna, and an additional 29 based on various abiotic factors. They recognize ten different types of soils as well. Also in Peru, the Matses identify as many as 178 different environments.

All of this ecology is further complicated by the reality that many cultures do not segregate the natural and supernatural. For instance, many Amazonians believe that shape-shifters exist as animals that might assume human form and vice versa. Usually shape-shifters are species that are mysterious and powerful from a human perspective, such as jaguars, anacondas, otters, and dolphins.

The indigenous cultures of the Amazon have contributed much to the rest of the world. For example, the root crop manioc or cassava was probably domesticated in the Amazon some time between 7,000 and 9,000 years ago. It grows well even in the poorest of tropical soils and it is resistant to pests and drought. The starchy roots are naturally stored in the ground until needed for food. The distinct advantages of manioc account for its spread throughout the tropics of the world since European contact. Today it ranks as the fourth most important source of food energy in the world. The cashew nut, guava, papaya, peanut, and pineapple are among the foods now consumed in many parts of the world that were originally domesticated by ancient Amazonians.

Among the numerous technological innovations discovered and developed from nature by Amazonians are the drug curare which is used to tip arrows and blowpipe darts for hunting monkeys; the poison rotenone from vines and other plants used to stun fish in quieter sections of waterways; and the rubber latex used for waterproofing containers and footwear. Now the world uses curare for anesthesia, rotenone as an insecticide, and rubber for tires and a multitude of other purposes.

Colonial Ecology

Today some 800,000 people live in 379 distinct indigenous cultures in the Amazon. In addition, millions of other people have migrated into the region in the last few centuries since its "discovery" by Europeans. Now the total human population of the Amazon is more than 25 million. Most of these people are peasants living in rural areas with a mixture of subsistence and market economies. Also they are in various ways and degrees a biological, cultural, religious, linguistic, and ecological mixture of Europeans, Africans, and Amerindians.

Many peasants, like indigenes, believe that areas of the forests and waters are enchanted. These places may be associated with drowning, ghosts, mysterious lights, and other extraordinary phenomena. They are thought to be frequented by potentially dangerous spirits. These beliefs influence the way resources and places are used, and this probably helps to preserve the biotic productivity of species of game, fish, and plants.

In the last few decades Western experiments in economic development have repeatedly failed with grave economic, social, and ecological consequences. The accumulated historical record of the many blatant failures clearly demonstrates that to this day Westerners do not yet know how to develop the Amazon without degrading and even destroying it. A different combination of causal factors is responsible for environmental destruction in different places and times in the Amazon, but among the principal ones are cattle ranching, logging, monocrop plantations, mineral and oil extraction, hydroelectric dams, and transmigration (government colonization programs).

There has been considerable investigation and documentation on Amazonian systems of natural resource use, management, and conservation. Yet most Westerners have yet to recognize that, prior to European "discovery," the Amazon had already been discovered, colonized, and even developed by indigenes for millennia. If outsiders would recognize and appreciate the intelligence, creativity, philosophy, science, technology, medicine, cultures, and religions of indigenous and peasant societies in the Amazon, then they might learn sustainable uses of the forest and aquatic ecosystems. Fortunately, in recent decades Amazonians themselves are becoming increasingly organized, vocal, and assertive in defense of their land, resource, and other rights.

The keys for outsiders to unlock the mysteries of the Amazon include attention to diversity in all its manifestations; to the worlds, perspectives, and concerns of the residents; and to scrutiny of history and colonization.

Considering the accelerating gravity and urgency of the environmental and social degradation and destruction in Amazonia, it is questionable whether this basic science approach is sufficient and ethical. A new approach is required that seeks to integrate basic and applied research with advocacy and action. It would be concerned primarily with promoting the self-determination and other basic human rights of the residents of the Amazon through collaborative research that empowers them with strategic information.

The Amazon environment is no longer an undiscovered frontier awaiting Western colonization under the pretense of progress through civilization and economic development. Coming decades will reveal whether or not outsiders have the knowledge, understanding, and wisdom to treat the Amazon and its people in a more reasonable and just manner than previously. If there is any hope for the future of the Amazon, it lies primarily with the people who actually live there.

See also: ►Swidden

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Environment and Nature in the Andes

David L. Browman

The Central Andes were the home of the Incas, an ancient civilization who created an enormous empire, larger in area than the Roman empire. Only indigenous peoples of the Himalayas have adapted as well as the native Andeans to high mountain environments. The ancestors of the Incas arrived in the Central Andes as nomadic hunters and gatherers perhaps 15,000 years ago. They began agropastoral lifeways (camelid herding and plant cultivation) around 8,000 years ago. Many of the contemporary human–nature relationships can first be identified as developing during that period.

An essentially treeless grassland – the Ecuadorian *paramo*, the Peruvian *puna*, the Bolivian *altiplano*, and the Argentine salt *puna* – which is the home of the native herders and sierra farmers – occurs along the upper slopes, plateaus, and tablelands of the Andean mountain chain. Because similar elevations support trees elsewhere in the world, the question is raised: why is the zone essentially treeless today? Is it because of the elevation and low temperature regimes currently extant? Is it because of a past climate shift? Is it because of human agency?

A popular theory is that somehow the native people destroyed the trees through mismanagement. However, pollen samples prove that these areas were significant grasslands long before any substantial human settlements existed. They supported large herds of wild camelids – guanaco and vicuña – whose subsequent domestic relatives – llama and alpaca – were the basis of support the first Andean civilizations and continue to be economically important today.

On the other hand, one cannot deny significant and extensive impact on the landscape by the humans and their domestic animals. Overgrazing has resulted in decrease in palatable species; an increase in thorny and woody bushes, cacti, and less palatable grass species like *ichu* (*Stipa Ichu*); and an increase in plants toxic to grazing animals. Annual or semiannual burning of pastures to provide new growth for herds has also resulted in changes in plant assemblages, as it removes trees and other woody plants. Cutting trees and woody plants for fuel has further increased deforestation of the small refuge zones where trees persisted. In the presence of grazing pressure from domestic camelids, the tree species usually cannot regenerate. Grazing pressure and human agropastoral activities have significantly depressed the tree line on the eastern slopes of the Andes.

Human activities thus have markedly impacted the local environment since the first major presence of human groups in the high Andes, but the presence of extensive treeless areas predates the colonization of this area by humans. Thus, while human activities are clearly very important in the present configuration, the contributions from the wild herds of deer guanaco and vicuña which preceded the humans must also be an important factor in the occurrence of these grasslands, as well as that of elevation and meteorological conditions.

The domestic llama and alpaca herds were critical for survival of several highland groups. They provided meat, fat, blood for food; wool for clothing, bags, and rope; leather for footgear and equipment; bones for tools and religious items; dung for fertilizer and fuel; and labor power as caravan animals carrying trade goods. They also served as "banks on the hoof," resources which could be mobilized for emergencies during the irregularly occurring but not infrequent environmental catastrophes such as sustained droughts, unseasonal frosts, and the like.

Risk and uncertainty also contributed to reliance on extrasomatic sources of help as well. The gods responsible for protecting the flocks and for insuring their increase were believed to dwell among the surrounding peaks. Annual ceremonies, called *pagos*, from the Spanish verb "to pay," were held to "pay" the gods for current success and to petition for the future increase of flocks. A male and female animal were selected from the herds, fed *chicha*, the local corn beer (*making chicha*), and "married" to begin the next season's offspring. These llamas and alpacas were treated and thought of as kinfolk of the herders. Today these ancient fertility ceremonies have been conflated with Catholic rituals, and are held during Carnival. Often small *illa* or animal figures of the desired type of animal are blessed and buried with offerings. In Inca times these were sometimes gold and silver, while today they are ceramic, stone, or tin (*Hammered gold objects*).

Plant agriculture was an exceedingly risky undertaking at this elevation; folklore suggests that crop failure occurred as often as 25–35% of the years. Andean people thus sought to reduce agricultural risk through a variety of strategies. Because rains could fall on one field but not on another a kilometer away, or because early frosts or late freezes could hit a valley bottom one time, but a high slope another time, the farmer might own two dozen or more small plots, scattered over several elevations, in several microenvironmental areas. Every farmer maintained a dozen or so varieties each of potatoes and other seed plants, because in one year a tuber which thrived in dry soils would be the only one to produce, in another year a variant which thrived in moist soils excelled, and in a third year a variety which did well in saltier soils yielded best.

In addition to the procedures to manage risk in maintaining biodiversity among their crops, the local residents developed other strategies as well to cope with risk. Elaborate freeze-drying techniques were employed to produce dehydrated potatoes, *chuño* (*potato's poisonous roots*) and other tubers. These technological procedures served two purposes: enhancing palatability and providing storable surplus. Most of the high elevation plants grown for consumption had significant quantities of phytotoxins, making them poor choices for foodstuffs until various dehydration processes removed the phytochemicals. As a serendipitous by-product, the resulting detoxified tubers could be stored up to 20 years, providing a critical component of sustainability.

Herders often provided a necessary component of this detoxification process, as in following their herds, they located "salt" or mineral licks with various comestible earths. They collected these geophageous clays and traded them with agriculturalists. These clays were fabricated into sauces to consume with meals. Residual phytotoxins in the tubers which had not been removed by dehydration processes, freeze-drying, or by cooking became bound with the clays. In addition, bioavailable minerals were exchanged, thus doubly enhancing the quality of the food.

Propitiation of the resident gods for plants was as important as it was for the herd animals. The deity known as *Pachamama* (earth mother) was responsible for providing plant foods for the humans. Proper behavior involved offering a few coca leaves or other items before planting the field, much more substantial rituals at the harvest, and practices in daily life such as always decanting a few drops "for Pachamama" each time one took a drink, thus attempting ritually to insure adequate moisture for the crops.

Andean farmers developed a series of strategies to modify the landscape to control nature, particularly moisture and temperature parameters. Andean peoples did not simply adapt to the ambient conditions – they were active agents who shaped and created Andean environments, and who transformed and built the landscape in which they lived.

The Lake Titicaca basin is an excellent example of the variety and range of practices employed. The local farmers, who practice small-scale intensive agriculture, make capital improvements to their lands, which are inherited by their descendants. The current elaborate landscape patterns are thus the result of multiple small increments accumulated for millennia. The flat plains usually were poorly drained; they suffered from too much water in the rainy season and too little in the dry season.

The local agropastoralists constructed raised fields systems or *waru–waru* (*Waru waru*) and sunken smaller garden patches or *qochas* (*Qochas*) to address these problems. Construction of raised, ridged fields, with swales or canals between the ridges, resulted in ridge top areas above the waterlogged soils in the rainy season, eliminating rot among the tubers. Both the *qocha* system and the intervening canals among the raised fields trapped rainwater, which was curated through the dry season to provide a continuing water supply.

In addition to managing moisture, these systems also ameliorated temperature extremes. Thus the raised field patterns, and furrows in the *qochas*, were constructed either parallel to, or perpendicular to, the path of the sun, an orientation which permitted maximum solar energy capture by the water. This water kept the fields slightly warmer at night, and often radiated enough heat to prevent frost damage while the surrounding unmodified grasslands suffered heavy freezes.

While this technology was employed through the Inca period, European invaders brought the oxen and plow (and in this century, the tractor). Raised fields could not be plowed efficiently by European technology, and hence they were leveled. Although Western technology permits much less labor per unit area, and thus is more efficient in that sense, the productivity per unit area has fallen off.

Anthropologists have recently reconstructed experimental raised fields in the Titicaca basin. These fields provide both increased yields and decreased environmental risk: local seed growing without any high-tech inputs have produced two to four times more per unit than crops growing on the European-style fields. On more than one occasion, unusually severe, out-of-season frosts have destroyed all the crops in the plowed flat fields, but have at worse only inflicted a little freeze damage on plant tops in the raised fields. While more labor intensive, the original indigenous technology has proved superior to Western technology in these environmental circumstances.

In addition to the raised fields and *qochas*, other landscape modifications were constructed to provide the same kinds of soil improvement and nutrient capture, erosion control, microclimate control, and moisture control or water management. Most noted among these are the stone-faced terraces or *andenes* (*Andenes*) and irrigated pastures or *bofedales* (*Bofedales*). For example, among the local hills, as well as the mountain valleys elsewhere in the Central Andes, often only the valley bottoms or hill bases had adequate moisture for crops, but because cold air is heavier and settles to the lowest areas, these same locations had the greatest risk from frosts. Elaborate terrace systems were constructed, with water provided by extensive canal networks. Thus hillslopes initially too steep to be plowed were remade into a myriad of small, level, irrigated plots. Because they were along the lower and middle valley/hillslope flanks, they were too low for high elevation freezes but above the pools of supercooled air that collected on the valley bottoms. Thus agricultural terraces were often frost-free during most of the growing season.

Irrigated pastures (*bofedales*) were another means of managing water and temperature for the alpaca and llama herds. While llamas are more like camels in their ability to secure nutrition from high cellulose and other less palatable forage, alpacas thrive on moister, softer vegetation varieties. The neonates of both species are vulnerable to low temperatures in the first few days after birth. Herders thus developed elaborate canals and check dam systems, to bring water into suitable low-lying areas, where artificial rather swampy irrigated pastures (*bofedales*) were created. The lush environment created optimal fodder for the alpacas, and the ponds provided heat-sinks to ameliorate nearby temperatures on cold nights.

The modification of the environment is exhibited in multiple other ways as well. Rivers and streams have been channelized, artificial canals have been constructed, springs have been enlarged and improved, and various holding ponds and reservoirs have been constructed. Various causeways, roads, and paths lead to constructed villages, defensive retreats (*pucaras*), cemeteries, shrines, and monuments. Fields are marked off by stone walls; large rock piles are scattered among the landscape, some for agricultural reasons and others for religious purposes. Stone corrals are found at various elevations. The Andean peoples of the Titicaca basin thus extensively transformed the local environment; such transformation is typical throughout the Central Andes.

Various strategies were employed in agropastoral production zones to provide the structure and rules for the allotment of irrigation water, distribution of communal and individual land, regulation of land use, scheduling of agricultural activities, definition of crop types, and cycle of rotational fallow. Included in these was the development and maintenance of high biodiversity among crops suited for a wide range of environments.

The Andean peoples often anthropomorphized their environment. The indigenous concept known (in Aymara) as *taypi* structures part of the human relationship with nature. *Taypi* physically is the center between two opposing concepts, the point of necessary convergence where the cosmological centrifugal forces that permit differentiation exists simultaneously with the centripetal force that ensures their mediation. It is thus both an integrating and separating center. The human body is divided into three components, with the *taypi* integrating center the heart and stomach. The cosmos is divided into an upper world, this world, and a lower world, with the earth as the mediating point between the upper and lower world. Hence humans, as residents of this earth, arbitrate not only between forces of good and evil, but also serve to mediate between the natural environment and the gods. Just as the human body is animated and integrated as a whole by an exchange of fluid elements (blood circulating, water drunk and expelled, air inhaled and exhaled), so too is nature. Analogies are made between the circulation of fluids to animate humans and the circulation of fluids to animate nature.

The human imagery overlay upon nature is even extended to the organization of some of the Andean groups. One of the mechanisms employed to deal with the environmental risks is to spread humans over the landscape, in a pattern similar to the spreading of fields discussed above. Thus a village might send family members up to a new hamlet in the herding zones, or down to lower elevation corn growing areas, spreading production risk so that in case there was complete failure in one zone, the community would have direct access to resources in other environmental zones because they had residents living there. In the case of one group from the Qollawaya, the settlements in the lower, middle, and upper ecological zones were conceptualized and referred to by terms of the human body, with the middle elevation home village thus seen as the heart and vitalizing component of the group, and the landscape itself as replicating the human body. Andeans hence perceive their lifeways as essentially harmonious and replicating nature.

The environment thus is a dynamic, historically contingent component of the Central Andes. The Andean peoples did not simply adapt themselves passively to ambient ecological conditions. Rather they were active agents in the creation, shaping, and transformation of a highly patterned, artificial landscape.

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Environment and Nature: Australian Aboriginal People

Dorothy Tunbridge

Australian Aboriginal people's traditional relationship to their land from a philosophical, economic, and spiritual viewpoint was quite different from that of the Europeans who arrived toward the end of the eighteenth century. Aboriginal environmental philosophy was related to their being observers, knowers, and users, rather than managers and interferers. This approach was the essence of their genius, enabling them to survive successfully for 40,000 years – perhaps much longer. Their philosophy could be described as nonmaterialistic ecocentrism, expressed through totemism, Dreaming, and the law, contrasting markedly with European materialistic anthropocentrism.

During the millennia before European occupation the continent had undergone big climatic changes followed by enormous environmental ones. Aboriginal people experienced the gradual extinction of the megafauna, commencing from the earlier part of their occupation, and, between 15,000 and 6,000 years ago, the decrease in the size of the continent as the sea level rose, mostly imperceptibly.

One of the significant technological innovations affecting Aboriginal use of the environment was the grinding stone or "grindstone". Dating from around 18,000 years ago, it gave impetus to settlement in the arid center where there was heavy dependence on seed foods. A lack of suitable stones in some areas, e.g., southwest Queensland's Channel Country, brought about trade in the course of which grindstones were carried very long distances. Aboriginal mythology underlines the importance of the grindstone right up to the time of European occupation.

As the sea level rose, mainland Australia became separated from Tasmania as well as from New Guinea. As the new conditions became stabilized, an extremely rich and diverse flora and fauna developed. Then, in the period from 1500 BCE to the beginning of the Christian era, colder and drier conditions emerged – perhaps the reason that around this time Aboriginal people made major changes in their methods of exploiting resources. Technological innovation included the emergence of the small tool tradition, and in Victoria, the introduction of water control systems. The building of brush and stone fence traps and pitfalls may also have been developed during this period to allow bigger catches of wallabies and kangaroos. There is some evidence of the reorganization of society at this time, perhaps to enable better exchange and sharing of resources in the face of new conditions.

Economic Use of the Environment

Although the archaeological record gives a general picture of Aboriginal life, the most detailed knowledge comes from the ethnographic record made since European occupation. Aboriginal cultures and life-styles varied considerably throughout the continent, according to specific needs, beliefs, knowledge, and availability of resources.

Aboriginal people were hunter–gatherers who mostly operated freely within a limited range – their own "country" – in small groups or bands who moved according to the season and the availability of resources. They were not acquisitive, often leaving behind all but the most needed tools as they moved around. With few (arid zone) exceptions, they did not store food. Included in the diet was a wide variety of flora and fauna – fish, land and sea mammals, some insects, birds, lizards, and snakes, depending on where people lived – providing a healthy, mostly nutritious diet, low in fat and sugar. Generally people did not take out more plants or animals than were needed for day to day survival.

Housing, implements, weapons, clothing, and other utilitarian, ritual, and decorative items were fashioned from materials taken from the environment, e.g., stone, plant material (wood, fibers, thorns, leaves, twigs, branches, gum), animal products (bone, hair, skin, feathers), and soil (mud, ochre).

Examples of cnafted wooden instruments and weapons include the spear, waddy or club, and boomerang (each used in fighting and hunting), the scoop-shaped dish (a carrying bowl, ash cooking bowl, or shovel), digging stick, shield, playstick, message stick, and spear-thrower. Wood was also the basic construction material for boats. Shelter in most areas was constructed of wood and branches, and of bark; they were quickly made and easily abandoned. Wood could be selected for its shape, requiring little or no working for some implements such as building poles, witchetty grub hooks, skewers, brooms, walking sticks, axehandles, spindles, firesticks, fire-making sticks, laddersticks, and implements of secret rituals such as droughtsticks for causing drought. Other plant materials were used in making the tools of daily life, e.g., plant fibers for making string to be woven into bags, nets, headbands, etc., and for making baskets, thorns for tattooing, leaves for bedding, branches for brush fences, and gum for glueing.

Animal skins were used against cold winters for clothing, and animal hair was woven for string from which such items as headbands, phallocrypts, belts, net traps, and bags were made. Bone items included awls and the bones used in "boning" rituals.

Stone items included hafted hatchets and adzes, unhafted cutting tools chipped from hard stone or quartz, clubs (handheld and thrown), and grindstones. These items were often traded by those communities who had the best supply of raw material. In places where stone abounded, e.g., the Flinders Ranges, stones were also utilized as meat-chopping blocks, throwing weapons for killing, gravestones and other sorts of site markers and stone arrangements.

Modification of the Environment?

Debate continues regarding the extent to which Aboriginal people modified the environment in times past. Many scholars believe that although they utilized materials from the environment, they did not *substantially* alter the environment itself. Others differ. Two issues often debated are the extinction of the megafauna and the use of fire.

It has only recently been confirmed that in antiquity Aboriginal people killed megafauna species at all. As to fire, the fact that they used it extensively is not disputed; what is debated is whether or not they used it deliberately to manipulate and alter the environment substantially. There is still no conclusive evidence that they did this to a degree that made the Australian environment vastly different from the way it would have been had they never inhabited the continent. From everything known about Aboriginal environmental philosophy and practice, large-scale intervention in the environment to change the way things were would seem unlikely. Aboriginal people's skill lay in their observation and utilization of nature as it was, including the natural potential fire regime.

The concept of Aboriginal "firestick farming" arose in the 1950s as a reaction to the somewhat idealistic view of Aboriginal people's "[having lived in] harmony with the environment". This notion is part of a general view that in recent millennia Aboriginal people modified their environment to the point of being the most significant agents of change within it. More likely, however, is the view presented here, that as change occurred – mostly imperceptible at any given time – Aboriginal people gradually adapted to the new conditions.

The "firestick farming" model has become popular because of its idealistic portrayal of "traditional" Aboriginal people in European terms, firstly as more like (superior) European farmers, and more recently as "resource managers". This is also often the case with new views of Native Americans and other indigenous people.

Traditional Ways of Looking After the Land

Aboriginal people, like all hunter–gatherers, were above all observers of their environment. Their traditional concept of "looking after the land" was diametrically opposed to a European view. First and foremost it was a question of knowing, and to some extent, of not doing rather than of doing. Every individual had both the need and the right to know his own country to which they were attached through totemic affiliation and the ties of kinship, and to be informed on its terrestrial and celestial natural phenomena.

Dreaming history (mythology) was largely the encyclopedia of knowledge. Here were "stored" maps, vital environmental information, and laws concerning people's relationship to the land. Knowing the land meant above all maintaining the Dreaming. The Dreaming had an ecological rationale, the actions and habitat of the totemic ancestral species mostly coinciding with those species' typical behavior and habitats. Place names reflected the Dreaming; they remain today as windows on Australia's environmental past, many incorporating names of species of flora and fauna once prevalent but now extinct.

Knowing the rituals and accompanying songs was also considered crucial in looking after the country. Recently Aboriginal people have even blamed their own failure to maintain the songs and rituals for the dramatic loss of species following European occupation: "We can't look after the country now; no one knows the songs any more."

Totemism, whereby an individual or a clan was in a special relationship with a species or phenomenon in the natural world, was a powerful link between the people and the environment. Maintaining a proper ritual attitude toward one's totemic species was an essential part of looking after the country. In some places this meant maintaining a taboo on killing one of one's own or a near neighbor's totem species – an act akin to fratricide. In some regions, individuals had only one personal totem; elsewhere, through clan membership individuals had a number of totems.

In parts of Australia the lands belonging to a totem clan were located in that totem species' quintessential habitat. This meant that in those places species were protected from human predation in their best refuges. Taboos on hunting and food gathering also applied around certain sacred sites, sometimes ensuring that the best waterholes were completely protected. There are examples also of taboos on killing female kangaroos, which would help to ensure the continuity of the species, and on interfering with certain plants because these were a specific animal's food. These examples, however, do not represent large-scale strategic planning in conservation, even though their evolution would, to some extent, have had that effect.

Over all, then, Aboriginal people's "looking after the land" (rather than "land management" – a very European concept) was based on using knowledge skillfully and performing the associated rituals. Indeed, it was the very fact of *not* having management schemes that interfered unduly with the ecosystem, which was the secret of Aboriginal survival. The "strategy" for success was knowing.

Environmental Dispossession

According to the philosophy which European colonizers took with them to Australia from 1788 onward, it was the duty of individuals to give value to the land – otherwise seen as valueless – by going beyond the laws of nature through work. As the Australian environment was not "worked" in their understanding, they regarded it as completely empty – *terra nullius* – when they arrived. They would give it value by working it and extracting profit from it. Aboriginal nonmaterialistic ecocentrism, valuing both the human and nonhuman world in a holistic way, had nothing in common with European anthropocentrism and materialism. The philosophy of the dominant group soon prevailed, and Aboriginal people were dispossessed of their land and their traditional lifestyle, if not of their lives. The change to the environment as Aboriginal people knew it was irrevocable. Indeed, the speed and scale of faunal loss may have been unprecedented in the history of the world. For many communities today, the only records of the species which sustained their forefathers are subfossil material, old songs, and Dreamings.

Aboriginal People and the Environment Today

Dispossession has not occurred to the same degree for all. In the process of adapting to their changed environment as Aboriginal people have always done, some desert communities have in recent times introduced new ways of looking after the land, while not abandoning old ways of maintaining the Dreaming and the rituals which reinforce knowledge. Also, there is increasing interest in traditional Aboriginal environmental knowledge, and here and there attempts are being made to apply it with Aboriginal help, to "bring back" the country.

Traditional ways of caring for the country, however, operated within a supporting philosophical, religious, and economic framework – on a very different landscape, generally for different goals, and above all, on a continent wide basis. It is therefore unlikely that the traditional package of environmental nurture will be reintroduced on a large scale.

Perhaps more significantly, Aboriginal people are seeking – and getting – more involvement in environmental management. Some see it as one way of getting back the country. While dispossession may have left many with limited traditional knowledge to apply, it has not removed their sense of belonging to the land. Moreover, 1993 native title legislation (*Mabo*) is motivating a new appreciation of Aboriginal people's long relationship to the unique Australian environment.

See also: ►String

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Environment and Nature in Buddhism

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Buddhism is an enormous, diverse, and complex subject. There are many variations on Buddhism's basic themes manifested in the three major traditions (Theravada, Mahayana, and Vajrayana or Tantric) and also in variants of these in the form of at least 18 schools and their numerous sects. Much of the diversity in the expression of Buddhism results from the diversity of its numerous geographical, ecological, demographic, historical, cultural, linguistic, religious, national, and political contexts. Although estimates vary, there are at least 354 million Buddhists living in 86 countries of the world. Another complication is that many Buddhists adhere to more than one religion, or follow a mixture of elements from different religions, such as Animism and Hinduism in Thailand, Confucianism and Daoism in China, or Shintoism in Japan. An additional variable is that, as in any religion, in Buddhism too there are differences between ideals and practice, text and context, clergy and laity, scholar and laity, urban and rural, young and old, and so on. This tremendous diversity within Buddhism renders most generalizations difficult and tenuous, and they should always be recognized as potentially problematic, especially without adequate explanation and qualification that is usually not feasible in a limited space.

Underlying the enormity, diversity, and complexity of Buddhism, nevertheless, are some common denominators. The three refuges chant usually begins Buddhist ceremonies:

Buddham saranam gacchami.
Dhammam saranam gacchami.
Sangham saranam gacchami.
In the Buddha I take refuge.
In his teaching I take refuge.
In the monastic community I take refuge.

This chant reflects the three ultimate components of Buddhism: the Buddha, his teachings (*Dhamma*), and the community of followers, especially the monks and nuns (*Sangha*). One formally becomes a Buddhist simply by publicly vowing to pursue these three refuges. The individual's pursuit of enlightenment commences with accepting the Dhamma, starting with the Four Noble Truths, and then following the Noble Eightfold Path as discussed below.

This essay surveys nature and environment in Buddhism within the framework of the Buddha, Dhamma, Sangha, and laity, and in relation to the Four Noble Truths and the Noble Eightfold Path. Furthermore, Buddhist ecology and environmentalism will be considered from the past to the present and into the future, from East to West, and in terms of contemporary criticisms, problems, issues, and controversies. This brief survey of the main points under each of these themes is distilled from one of our previous publications (Sponsel and Natadecha-Sponsel 2003). This brief version ends with a list of the references for the quotations and then a short list of selected books for further reading on various aspects of Buddhism in general. Also see the bibliography of books on Buddhist ecology and environmentalism at the end of this article. In this essay all Buddhist terms are in Pali, unless another language is used in quotes or in personal or place names. Pali is the ancient literary language for Theravada Buddhism and remains its ecclesiastical language.

Buddha

The relevance of the Buddha's life and teachings to nature and the environment is clear in at least three respects. First, major events in his life were associated with trees, groves, forests, and other natural phenomena. Second, he often drew on parables about animals and other aspects of nature to illustrate moral and other principles. Third, during his lifetime it appears that population and economic pressures were leading to deforestation and resource depletion in some areas where he lived and traveled. Thus, if nature was so relevant to the Buddha, then surely nature is relevant to Buddhism and vice versa.

In the early accounts of the Buddha's life it is not easy to distinguish between fact, legend, and myth. Nevertheless, these basic facts are clear: his birth as a human being, his renunciation, studies with Hindu spiritual teachers (*gurus*), long period of asceticism and intense meditation, enlightenment, 45 years of teaching followers, establishing the Sangha, and his discourses or sermons (*suttas*). In addition, the core principles of the Buddha's teachings, such as the Four Noble Truths and the Noble Eightfold Path, can be taken as factual.

Buddha is an honorific title meaning an enlightened or awakened being. The historic Buddha's original name was Siddhattha Gotama. His conventional dates are 566–486 BCE. He was born under a Sal tree (*Shorea robusta*) in a grove called *Lumbini Park* near Kapilavastu (now Madeira), about 130 mile north of Benares in the border zone between present-day India and Nepal.

During his youth Siddhattha's father, King Suddhodana, sheltered his son from sights of the suffering beyond the royal palace. However, eventually Siddhattha witnessed sickness, old age, and a corpse. These impressed him with the suffering and impermanence of human existence. Then when he observed a holy man, he was inspired to search himself for a spiritual solution to the problems of the human condition. Thus, at 29 years of age, Siddhattha made the Great Renunciation. This was a radical decision to leave his family, wealth, and future as a king to become a wanderer in a religious vision quest.

Nature was the context and source of Siddhattha's search for and eventual achievement of enlightenment. For 6 years he pursued spiritual awakening with various *gurus* and through rigorous asceticism in the forest. In the process, among many other things, Siddhattha realized that moderation (The Middle Way) was the best path, instead of the extremes of either asceticism or hedonism. Eventually he pursued contemplation and meditation on his own during 7 days at the base of a bodhi fig tree (*Ficus religiosa*) near the town of Bodhgaya. There, at the age of 35 years, he finally attained enlightenment (Buddhahood).

After his enlightenment under the bodhi, the Buddha subsequently spent a week meditating under each of several other trees: Nigrodha or Indian fig (*Ficus indica*), Mucalinda (*Barringtonia acutangula*), and Rajayatana or kingstead (*Buchanania latifolia*). Then he went to the royal Deer Park of Isipatana in Sarnath (now Dhamek), just north of Benares along the Ganges River. He knew that the five monks (*bhikkhu*) he had previously associated with would be there. In his first discourse the Buddha introduced to these monks the Four Noble Truths and the Noble Eightfold Path.

For the next 45 years of his life the Buddha wandered over much of northern and eastern India as a religious teacher. He died at the age of 80 while reclining between two Sal trees in a grove outside the small town of Kusinara and in the company of many of his followers. When death was near the Buddha declined to appoint a successor, instead he said the Dhamma and monastic rules (*vinaya*) should guide followers. In addition, in his sermons he repeatedly advised that every individual should think on his own and test his teachings against their own reason and experience. Accordingly, Buddhism lacks any single centralized authority, although different schools and sects may have recognized leaders, the most well known being the Dalai Lama for Tibetan Buddhists.

Teachings

Bodhi (1987: vii) aptly summarizes the relevance of the teachings of the Buddha's (Dhamma) to nature:

> With its philosophical insight into the interconnectedness and thoroughgoing interdependence of all conditioned things, with its thesis that happiness is to be found through the restraint of desire in a life of contentment rather than through the proliferation of desire, with its goal of enlightenment through renunciation and contemplation and its ethic of non-injury and boundless loving-kindness for all beings, Buddhism provides all the essential elements for a relationship to the natural world characterized by respect, care, and compassion.

For Buddhists, the pursuit of knowledge, understanding, and wisdom begins with the Four Noble Truths: all existence is suffering (*dukkha*); ignorance and desire are the primary causes of suffering; yet suffering can end; and the way to end it is to understand and pursue the Noble Eightfold Path. Suffering covers a wide diversity of conditions, including dissatisfaction, discontent, disharmony, discomfort, irritation, friction, pain, illness, dying, and death. The ultimate aim of the Buddhist is to reach enlightenment in order to end suffering; first, in one's present life; and second, in one's successive lives in the endless cycle of rebirths. As Ryan (1998: 2) asserts: "The fundamental postulate of Buddhism is that all beings are united in distress, in dukkha." From this perspective, then, the moral universe of Buddhism transcends humanity to encompass all beings, and accordingly, Buddhism becomes relevant to nature and environment (to explore some Buddhist texts see: ►http://www.accesstoinsight.org). The Mahayana tradition goes even further. In Mahayana, Buddha-nature refers to the potential of all beings and things to become enlightened. In Chinese and Japanese Buddhism, for example, trees and even rocks are considered to have Buddha-nature; thus it is assumed that they strive for and are eventually destined to achieve enlightenment. Consequently, a *Bodhisattva* is a person who forgoes seeking the end of his or her own suffering (reaching enlightenment or *nibbana*) in order to strive to reduce the suffering of all other beings and things.

Most lay Buddhists do not study the formal texts (sermons, monastic code, and scholastic treatises), but learn about the more important principles in them through the Sangha and popular media. The most outstanding example of the latter is the *Jatakas*, a collection of 547 parables about the Buddha's previous lives. In these he is often represented as an animal that sacrifices its own life to save others. These stories illustrate how the Buddha cultivated the core virtues of wisdom, nonviolence, compassion, loving-kindness, generosity, and so on. They also exemplify the interconnectedness and interdependencies among beings. Furthermore, they imply that animals have a moral sense; i.e., they are capable of making ethical choices and behaving accordingly. The great popularity of these stories probably influenced many Buddhists to have positive attitudes toward animals through affording them intrinsic value. The *Jatakas*, as readily accessible moral allegories, provide, in effect, many of the essentials of an ecocentric environmental ethic for Buddhists.

The Noble Eightfold Path through thought and action progressively encompasses wisdom (right understanding and resolve), virtue (right speech, action, and livelihood), and concentration (right effort, mindfulness, and meditation). Arguably each of these eight components is relevant to nature to the degree that it is correlated with the pivotal principle of extending nonviolence (*ahimsa*), compassion (*karuna*), and loving-kindness (*metta*) to all beings and things. Right livelihood, for example, would include occupations or life ways that do not harm any beings and things. Of course, it is impossible to live without causing some harm; even vegetarians sacrifice plants for food. However, a Buddhist can strive to minimize harm as much as possible. Buddhism makes the elemental and pivotal distinction between need and greed. In pursuing the Middle Way, an individual would attempt to satisfy as modestly as feasible the four basic needs that the Buddha recognized (food, medicine, clothing, and shelter). As a consequence, in effect the individual minimizes his or her harm to other beings and reduces pressure on the environment, including the inevitable waste and pollution that accompany resource consumption. Ideally, Buddhists should be concerned with the contemplation of nature instead of its consumption. This is what is now termed *voluntary simplicity*, one indispensable ingredient for developing a sustainable, green, just, and peaceful society. As Timmerman (1992: 74) asks: "How can we survive on a planet of ten billion points of infinite greed?"

The key to Buddhist ethics and practice is the primacy of the individual's mind. Ultimately this has profound importance with numerous ramifications in terms of recognizing the causes and solutions of environmental problems. From a Buddhist perspective, although certainly important, the usual sources – science, technology, education, government, law, politics, business, and industry – are neither the cause nor the solution of the ongoing and worsening global environment crisis. Instead, the cause and the solution are found in *the collective, cumulative, and synergetic consequences of the behavior of the individuals who* *compose humanity*, albeit some individuals and groups may be more responsible (or irresponsible) than others. Environmental health is then not so much a matter of the scientific, technological, and bureaucratic management of resources, waste, and pollution, as it is the spiritual management of ourselves. People must be motivated as well as informed to limit their own reproduction, consumption, waste, and pollution in order to minimize harm to other beings and things.

If it is understood that the first negative precept (nonviolence) and the first positive precept (compassion and loving-kindness) apply to all beings and things, not just to humanity or some sector thereof, then the environmental implications are immediately obvious and undeniable. Indeed, there is an ecologic here; it is possible to detect elements reminiscent of ecology in Buddhism, and conversely, elements reminiscent of Buddhism in ecology, even if these are only a coincidence. Both Buddhism and ecology (1) pursue a monistic rather than dualistic world view, instead of dichotomizing either organism and environment or human and nature; (2) consider all life, including that of humans, to be subject to natural laws; (3) adopt holistic and systems approaches regarding the unity, interrelatedness, and interdependence of the components of nature; and (4) teach respect and even reverence for nature, including the intrinsic as well as extrinsic values of other beings. Although most of these similar elements may be merely parallels rather than identities, surely they are complementary and can even be mutually reinforcing in both theory and practice for contemporary Buddhists.

Clergy

Ideally, the Sangha, the monastic community of monks or nuns, exhibits attributes that are similar, and in some instances even identical, to many of the characteristics of a sustainable, green, just, and peaceful society. Among these are a small-scale and egalitarian community based on nonviolence, moderation, cooperation, and reciprocity in satisfying basic needs. Monks and nuns have extraordinary sociocultural status and power to transform nations like Thailand that are overwhelmingly Buddhist into a more ecologically sound society because of their unique social and moral roles. By contrast monks and nuns hold a mirror to society, as, for example, in their vow of poverty. Spiritual development is their goal, rather than Western style economic development through materialism and consumerism. By drawing on the ecological wisdom embedded in the Buddha's life and teachings, monks and nuns have significant potential to contribute to far sounder environmental world views, attitudes, values, and practices of lay Buddhists.

Many of the more than 200 rules for monks (*vinaya*) are relevant to nature. Several aim to prevent monks from knowingly harming any living being. They can only eat fruit without seeds or if someone else has already damaged them. *Bhutagama*, the Pali term for a living plant, means the home of a being. For a monk to intentionally cut, burn, or kill a living plant is an offense. It might endanger some animal's habitat, among other things. Harming even small animals like ants should also be avoided, although harming large animals is much more serious. Injuring or killing an organism like a worm by digging in the ground is forbidden and could lead even to expulsion from the Sangha. Also a monk cannot deliberately have someone else kill an animal for him. The rains' retreat (*pansa*) is the period during the wet season each year when monks refrain from traveling in order to avoid trampling on young crops and small animals that are more abundant then. Monks should check water, or strain it, before using it for drinking or other purposes to avoid knowingly harming any visible organisms in it, even mosquito larvae. They are prohibited from polluting water in any way as well. A monk is prohibited even from acting in self-defense if that would injure another being. In these ways and in many others monks are supposed to protect and respect all life.

In several places in the sacred texts of Buddhism when the issue of vegetarianism arose the Buddha explicitly refused to prohibit monks from eating meat, mainly because they subsist on alms food volunteered by local laity. Vegetarianism was only an option. Today, although widely admired, it is not common in Theravada countries and Japan. However, most monasteries in China and Korea as well as Zen monks in Japan are strictly vegetarian. Vegetarianism is one way that an individual can reduce harm and offer compassion and loving-kindness to other beings as well as provide a model or raise awareness for other people (on vegetarianism see: ►http://online.sfsu.edu/~rone/Buddhism). Collectively and cumulatively over time Buddhist temples and monasteries may help promote the conservation of biodiversity. Many temple complexes can be viewed as sacred ecosystems with groves of bodhi, banyan, and other trees and associated animals. People are prohibited from disturbing plants, animals, fish, and other natural phenomena in and near a temple complex.

Instead of living in a temple or monastery, since the time of the Buddha many monks and nuns have spent much of their time wandering in forests or on mountains, or living and meditating in caves. Such secluded and peaceful places are more conducive to meditation and enlightenment. However, in recent times, many forest monks have become environmental activists as well. They view deforestation as sacrilegious, a threat to the forest monk tradition since the forest is their sacred habitat. Also they understand the suffering that deforestation causes to local humans and other beings. Out of compassion for the suffering which diverse beings experience as a result of deforestation, numerous monks have initiated environmental education programs, sustainable economic development projects, and rituals to protect remaining forests in Buddhist countries such as Cambodia, Laos, and Thailand (for examples of the above see: ►http://www.earthsangha.org, ►http://www.keap-net.org/project_environment.htm, ►http://www.mro.org, and ►http://www.suanmokkh.org). [Editor's note: see also Susan Darlington's article on Thailand's activist monks.]

Laity

For Buddhists the ultimate pilgrimage is the spiritual journey through meditation to discover the Buddha-nature within oneself. This is a vision quest that reveals the oneness of the individual and nature, and thereby the emptiness of self through interconnectedness and interdependence. However, since ancient times, Buddhists have also undertaken pilgrimages to sacred sites associated with the Buddha and other Buddhist personages, as well as to temples, shrines, and other sacred places, many on mountains and/or in forests. In Tibet, Mount Kailas is sacred to Buddhists as well as to the Hindu and the Tibetan Bon religions. At its foot Lake Manasarovar is also considered sacred and a component of pilgrimages. Because many of the sacred places associated with Buddhism require certain prescriptions and proscriptions, such as not killing any beings, the result, even if inadvertent, is that these sites often function in effect as sanctuaries of nature as well as religion.

To the extent that the laity follows the Buddha's example and teachings as well as those of the clergy, they are also relevant to nature. The laity and the clergy are interdependent. The laity provides for the material needs of the clergy, while the clergy provides for the spiritual needs of the laity. However, whereas the clergy cannot harm other beings, the laity must do so in order to obtain food and income from farming, fishing, and so on. Still, the laity is supposed to minimize harm to other beings as much as is practical.

To this day lay individuals may gain merit by planting trees, especially in and around temple yards. In Thailand sometimes tree seedlings are given to people attending a funeral so that they may plant them to gain merit for the deceased and themselves. Planting trees reminds people of the Buddha's life and teachings, including the interdependent relationships between humans and nature.

Engaged Buddhism belies the stereotype or myth that Buddhism is necessarily a detached, escapist, or egocentric religion. A phrase coined by the Vietnamese monk, Thich Nhat Hanh, engaged Buddhism is simply the active application of Buddhism for the benefit of others; i.e., putting compassion, loving-kindness, and other principles into practice. It is a matter of emulating the Buddha's life and following his teachings. Among the various concerns of engaged Buddhists are nonviolence, peace, human rights, participatory democracy, social work and community development to alleviate poverty and other problems, appropriate technology such as organic farming and recycling, sustainable and just economic development, and environmentalism (for examples of socially engaged Buddhism, see: ►http://www.bpf.org and ►http://www.sulak-svaraksa.org).

The West

Buddhism originated in northern India more than 2,500 years ago and in subsequent centuries spread far beyond into other parts of Asia. By at least the mid-nineteenth century, if not much earlier, Buddhism started to have some influence in the West. Today there are about four million Buddhists in the USA, over a million each in Europe and Russia, 140,000 in Australia, and 5,000 in South Africa.

East and West, however, are not completely separate. For centuries they have influenced each other in numerous and sometimes profound ways. For instance, Henry David Thoreau (1817–1862), a student of Asian philosophy as well an icon for environmentalists, first translated into English from French a portion of the *Lotus Sutta* for the Transcendentalist journal *The Dial*. Also his period of relative seclusion and voluntary simplicity in nature at Walden Pond near Concord, Massachusetts, was somewhat reminiscent of a forest monk. In turn, Thoreau's political tactic of nonviolent civil disobedience deeply influenced Mahatma Gandhi and others in Asia and elsewhere.

Beyond Thoreau, Buddhism was among the influences on many other seminal Western pioneers and leaders in ecology and/or environmentalism: Ernst Haeckel (coined word ecology), John Muir (pioneer conservationist), Aldo Leopold (land ethic), Albert Schweitzer (reverence for life), E. F. Schumacher (Buddhist economics), Arne Naess (deep ecology), Gary Snyder (Zen poet and deep ecologist), Bill Devall (deep ecologist), John Diado Loori (Zen environmentalist), Joanna Macy (Nuclear Guardianship Project), John Seed (Council of All Beings), Philip Kapleau (vegetarianism), Peter Matthiessen (novelist), Fritjof Capra (physics), Petra Kelly (German Green Party), Michael Soule (conservation biologist), and Rick Klugston (Director of the Center for Respect for Life and the Environment).

Today there are more than a thousand Buddhist centers in the USA alone, often with a mailing list of thousands. Many practice conserving resources, recycling, and reducing waste and pollution. Voluntary simplicity may be considered to be an environmental as well as Buddhist virtue. Vegetarianism is often followed using organically grown foods. Such practices can be observed, for example, at Green Gulch Farm in Sausalito, California; Zen Mountain Center near Mountain Center, California; and Zen Mountain Monastery at Mt. Tremper, New York.

Contemporary Buddhism and environmentalism resonate with one another in numerous and diverse ways. In particular, for Westerners, Buddhists and some others, Buddhism provides new perspectives, rationales, insights, values, and methods for dealing with environmental questions, problems, issues, and controversies. For instance, Buddhist monks have symbolically ordained trees to protect them in Thailand, and this has inspired similar ceremonies by activists in California (see Buddhist contributions on the UN Earth Charter: ►http://www.brc21.org).

Problems

Ultimately the problems and limitations regarding the relevance of Buddhism to nature and the environment appear to revolve around two types of related but separate discrepancies – ideal vs. actual behavior and academic vs. practical interpretations. The ideals of Buddhism seem to be environmentally friendly, whereas the actual behavior of many Buddhists is far too often not so. This paradox is evidenced in the widespread natural resource depletion and environmental degradation in most countries that are predominantly Buddhist, although it appears that Bhutan and Ladakh are lingering exceptions to this pattern for the most part. Nevertheless, this discrepancy does not invalidate the idea that in principle Buddhism can be environmentally friendly. One must be careful to avoid confusing Buddhism and Buddhists. There are internal contradictions and discrepancies in every religion as well as in other social institutions like government, science, and education. The deficiency is not in Buddhism, but in Buddhists, who, after all, are merely human. An important part of the solution is to educate people about the negative consequences of their actions so that they are more willing to alter their behavior to eliminate or at least minimize such consequences. Also Buddhists need to adhere more closely to the Noble Path as it applies to ecology and environmentalism.

The second discrepancy is the difference between the purely academic understanding of Buddhism, especially the interpretation of the texts, and the actual understanding and daily practice of Buddhism by Buddhists, i.e., context. Ideally context should faithfully reflect text, but critics deny that this is the case in reality. Much of the criticism boils down to the accusation that Westerners are imposing their modern concerns for ecology and environmentalism on Buddhism, whereas a supposedly authentic scholarly interpretation of the texts by the critic indicates that Buddhism is irrelevant to such matters. However, there is considerable room for differences of opinion in the interpretations of the same texts among Buddhologists (scholars of Buddhism) (for an example of a critic, see articles by Ian Harris in the online *Journal of Buddhist Ethics*: ►http://www.jbe.gold.ac.uk).

Such puritanical, literalist, or fundamentalist criticisms of the application of Buddhism to contemporary concerns like the environmental crisis do not afford sufficient attention to the actual practice of Buddhism by Buddhists who do not always think that rigid adherence to text is so important. Indeed, the Buddha himself repeatedly emphasized that individuals should test his teaching against their own reason and experience, instead of blindly accepting authority, tradition, or dogma. Furthermore, the scholarly study of Buddhist texts alone may not have much relevance for the actual realities of the daily practice of Buddhism by its adherents. At the same time, there are individuals who have been both Buddhist scholars and monks for decades. The most notable personages in this regard, Buddhadasa Bhikkhu from Thailand, Thich Nhat Hanh from Vietnam, and the Dalai Lama from Tibet, think that Buddhism has significant ecological and environmental relevance. Note that each of these scholar monks represents one of the three main traditions of Buddhism (for example, see: ►http://www.suanmokkh.org, ►http://www.plumvillage.org, and ►http://www.tibet.com).

Another criticism is that Buddhism is basically escapist; it is concerned only with individual enlightenment through meditation and therefore oblivious to any practical problems of ordinary human existence. This last point ignores the example of the Buddha himself, who, among other things, opposed the caste system in India. It also ignores socially engaged Buddhism that is no modern invention, even if the particular term is so. Beyond skeptics, critics, and antagonists who question that Buddhism has any relevance to nature, environment, ecology, and environmentalism, there are other problems. For instance, Kraft (1997) identifies these dilemmas facing Buddhist environmental activists:

1. Gaps between the Buddha's teaching and contemporary sociopolitical realities.
2. Buddhism emphasizes individual morality and action yet many environmental problems demand collective responsibility and action.
3. Competition between meditation and engagement.
4. Whether to be identified as Buddhist or just blend in with other activists.

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5. The environmental soundness of spiritual practice and rituals. However, in the opinion of the present authors, as long as Buddhists are faithful to the core principles of the Dhamma, then compassionate actions of loving-kindness on behalf of all beings and things are still Buddhist, this no matter how new the particular situation or how innovative the specific actions (for examples of Buddhism in contemporary society, see: ▶http://www.globalbuddhism.org and ▶http://www.urbandharma.org).

Future

It is unlikely that people millennia or even centuries ago ever conceived of possibilities like anthropogenic mass species extinction or global warming which have increasingly preoccupied many in recent decades. However, inevitably new problems and issues arise that require creative interpretations and approaches by Buddhists, and this must have happened throughout the 2,500 years of the history of Buddhism, considering the diversity of contexts and situations in which it has flourished. That Buddhism has endured for so long is a clear demonstration of its continuing relevance and adaptability for its adherents. Now the most important challenge for Buddhists is to cultivate social, political, and environmental actions that more closely approximate the ideals of Buddhism, especially the Noble Eightfold Path.

If more Buddhists and other people were aware of the negative environmental consequences that are the collective and cumulative results of their individual behavior, then many might change for the better and thereby significantly relieve environmental problems. When reason and morality follow adequate knowledge and understanding of the continuing and even worsening environmental crisis, then this may lead to wisdom and action in improving how humans interact with nature. The difference Buddhism makes is that, instead of grounding environmental conservation in self-interest of the individual (egocentrism), society (sociocentrism), or human species (anthropocentrism) as most Western schemes advocate, it is based on respect for other beings and things as having intrinsic value (ecocentrism).

It is noteworthy that in Bhutan, Ladakh, Thailand, and elsewhere, clear symptoms are surfacing of a growing disillusionment with the uncritical and wholesale pursuit of "modernization" and associated phenomena like materialism and consumerism. Revitalization movements arise in many societies in response to the problems, stresses, and dissatisfactions with rapid and profound sociocultural change. Buddhist-motivated community development and environmental conservation initiatives are becoming significant forces in this revitalization within Buddhist societies.

Undoubtedly, the primary concern of the Buddha was suffering, its causes and alleviation. The Buddha repeatedly stated that ultimately he taught only two things, about the cause and the end of suffering. Certainly the world is bound to suffer even more than ever before during the twenty-first century as a result of accelerating human population and economic growth. With the inevitability of the increased suffering of humans and other beings in coming decades, Buddhism may well prove even more relevant than ever before. Buddhists must apply critical and radical thought in examining contemporary problems and issues, something needed in our time as much as in that of the Buddha and probably far more so. Now this must include genuine interfaith dialog so that everyone may learn from each other's religions by comparison and contrast in order to cultivate a more sustainable, green, just, and peaceful world.

For the future, the main task for Buddhists, as well as for those non-Buddhists who simply have an intellectual interest in Buddhism, is to explore deeper and wider into the relevance of this religion for nature and environment, especially for each of the different schools and sects, and in both text and context (see Prebish 1999). Those who are practicing Buddhists also need to strive to apply the Dhamma as faithfully as possible in their interactions with their local environment and nature in general. Buddhists owe no less to the Buddha, the Sangha, and other beings as well as to themselves. It is a matter of survival for Buddhism as well as for nature and humanity.

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Environment and Nature in Buddhist Thailand: Spirit(s) of Conservation

SUSAN M. DARLINGTON

Two contradictory images strike the traveler in northern Thailand: first is the lush, forested mountains rising beyond expanses of rice paddy land and small farming villages. Second is the spotty appearance of the mountains, denuded of primary growth in large areas and filled instead with economic crops such as cabbages or corn. Both images are set against the backdrop of congested cities, particularly Bangkok and Chiang Mai, through which all travelers pass before seeing rural areas. The contrasts inherent in these scenes point to a major tension in Thailand between the push to develop economically and efforts to conserve and protect the nation's natural resources.

The struggle to find a balance between development and conservation occurs in many arenas, including culture and religion. Various actors for both pro-development schemes and conservation projects use cultural and religious beliefs, practices and attitudes toward nature to promote their positions. Religious beliefs themselves are not intrinsically either ecologically or developmentally oriented, but they can be interpreted in ways to support either conservation or development. The Thai government, for example, has used Buddhism to promote rapid national economic development; on the other hand, a handful of Buddhist monks and nongovernment activists incorporate both indigenous spirit beliefs and Buddhist practices to foster an environmental ethic on a local level. Both approaches claim to be based on intrinsically "Thai" understandings of the world as well as basic Buddhist teachings. Yet, as will be shown below, both are reinterpretations of religious beliefs and practices and, particularly in the case of activist monks, examples of cultural creativity designed to promote specific political agendas.

In the search for "Thai" approaches to environmental conservation, a key cultural source is Buddhism. The Thai population is approximately 95% Buddhist. It is important to note, however, that for Thais, Buddhism incorporates spirit and Brahmanic beliefs and practices (Kirsch 1977; Tambiah 1970). Yet scholars and activists often downplay spirit and Brahmanic beliefs in their environmentalist efforts, opting primarily to look at the ecological knowledge of rural peoples and at how Buddhism can be used to promote an environmental ethic (see Chatsumarn 1990, 1998; Darlington 1997a, b, 1998; Davies 1987; Kaza and Kraft 2000; Pipop 1993; Sponsel and Natadecha 1988; Sponsel and Sponsel-Natadecha 1995, 1997; Swearer 1997, 2001, 2003; Tucke and Williams 1997).

Buddhism alone, however, does not encompass the full range of concepts and attitudes of rural Thais toward nature and the forest. A complementary set of cultural beliefs that influence attitudes of and behavior toward the natural environment in Thailand is spirit beliefs. In particular, the interplay between Buddhism and spirit beliefs affects rural people's concepts of the forest and the ways in which they approach or value it. Similar beliefs are found throughout the Tai cultural region (which includes northern Thailand, Laos, southern Yunnan Province, China, and parts of Burma and northern Vietnam; see Pei 1985).

This syncretic religious system can be clearly seen in northern Thailand where, as across the nation, it contributes to an elaborate cosmology that includes the natural, human and spiritual environments (see Kirsch 1977). This sacred geography provides the framework for efforts to use cultural and religious concepts for both developmental and environmental – both inherently political – ends.

Spiritual Geography

There is no traditional word in the various Thai language dialects for "nature" (Davis 1984: 85). The word used today, *thammachaat*, is a combination word borrowed from Sanskrit. Its root words are *thamma*, or "dhamma," meaning truth (or the teachings of the Buddha, in a more specific context), and *chaat*, meaning life or rebirth (from the concept of reincarnation). Davis (1984: 85) argues that Thais adopted the concept of "nature" underlying this term because of European influence. This concept did not correspond with any indigenous ideas. It is, according to Stott (1991: 144), "too refined and wide in its meaning, embracing as it does all natural phenomena, such as rain, wind and sun, and even natural human behaviour." Applying the concept of *thammachaat* to the forest sanitizes the barbaric qualities of the wild, bringing it closer within the control of people (Stott 1991: 150). The effects of this process, as we will see, can be either pro-conservation or pro-development. It can enable people to take advantage of the forest resources without fear or concern over maintaining a balance between the civilized and wild worlds, by emphasizing domination and control of the former over the latter. It also has the potential to influence people's attitudes in the direction of responsibility toward rather than domination over the natural environment.

Before the introduction of the concept of *thammachaat*, there was a distinction between the human-built civilized world (*muang*) and the wild, uncivilized forest (*paa thu'an*) (Stott 1991). The civilized world centered on human settlements, particularly the walled cities of northern Thailand in which the kings and princes lived. In a careful linking of religion and geography, civilization radiated outward through the ruler's religious merit from the *muang* (here meaning the city) to nearby towns and outlying farming villages (Stott 1991: 145). The forest, on the edge of the social and religious domain of the *muang* and the ruler's influence, was the world of wild, dangerous and unpredictable beings, including tigers, bears, gods, spirits and non-Tai hill peoples.

Even today, lowland Thais (in the north called *khon muang* or "people of the *muang*") often consider the hill peoples backward or uncivilized because their ways of life are different from those of Tai peoples. The hill peoples follow their own cultures, speak their own languages, eat different foods, and, especially, are not Buddhist. They are predominantly animist, each group having its own elaborate set of beliefs and practices that the lowland, Buddhist Thais tend to see as primitive. Buddhism for Thais is an element of their cultural identity, and a key component of the sacred geography that has defined their civilization for centuries.

At the same time, most Thai Buddhists also believe the universe is inhabited by spirits and gods. Buddhism as a religion has never denied their existence. The classic treatise on Thai cosmology, *The Three Worlds According to King Ruang* (from the 13th century, translated by Reynolds and Reynolds 1982), describes the interplay between the heavens (the realms of *theewadaa* or celestial beings), earth (where the humans live), and the hells (the place of *phii* [spirits] or lower level beings living out the consequences of negative behavior). All sentient beings, according to this Buddhist cosmology, can be reborn at any level of these three worlds depending on the merit of their actions in each life. Even the gods, who lead lives of pleasure and comfort, will eventually pass away and be reborn. Only humans can achieve enlightenment, release from the cycle of rebirth and suffering.

While Thais view the three worlds as distinct, they are not isolated from each other. Usually the *theewadaa* and *phii* of the upper and lower realms are benign and do not harm humans. If provoked, however, the *phii* in particular may harass or even possess some humans. Thais believe some *phii* are malevolent and go out of their way to avoid or appease all spirits. Other *phii* may simply appear to people as their paths cross. Guardian

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spirits (considered both *theewadaa* and *phii*, illustrating the vague nature of these concepts) monitor and protect particular places. Some are considered "lords of the land," associated with the *muang* or principalities of the past (see Shalardchai 1984). People fear the spirits, *theewadaa* and *phii* alike, because of their supernatural qualities and powers.

Many different kinds of spirits inhabit the northern Thai cosmos. There are ghosts, or *preta*. This ambiguous term covers the spirits that all people become at death before they are reborn into another form of existence. It also denotes the hungry ghosts, *phii* that are constantly hungry and thirsty because their tiny mouths cannot open fully. People believe these *phii* were greedy in a former life and are now paying the consequences of their actions through insatiable hunger.

Other kinds of *phii* include tutelary spirits that help people who ritually respect them and follow the ethics that they enforce. Some of these are guardian spirits of particular places, such as a village or a household. Spirits live in forested areas, occupying trees, fields and streams. People make offerings to these spirits before they cut down a tree or clear a field for their crops. Every year villagers hold a series of agricultural rites, including offerings to the spirits of the fields, continually thanking them for allowing the forest to be cleared and the crops to grow. Spirits also look after the cremation grounds and sacred groves that surround some villages as well. In some areas these are the only patches of forest that have not been cut down. They have been left standing due to people's fear of and respect for the spirits believed to live there.

A number of deities or celestial beings share the northern Thai world as well. These *theewadaa* also receive ritual offerings and propitiations for their powers to influence the human world. There are four lords who rule over the four cardinal directions, overseen by Indra. (Indra is a god borrowed from Indian cosmology and was probably introduced into the region before Buddhism's arrival.) Two female spirits affect people's interactions with the natural world. These are Mae Phosop, the rice goddess, and Mae Thoranee, or Mother Earth. These *theewadaa* can either help farmers with their rice and other crops or punish those who offend them.

The annual rituals performed in honor of the various *theewadaa* are examples of how northern Thais interact with supernatural beings. Humans do not have control over these beings, but exist in a balanced and dynamic relationship with them. People can influence the *phii* and *theewadaa* for temporary periods but must continually renew their relationship through rituals.

An example of these rituals is an annual rite performed in April during the Thai New Year in honor of Lord Indra, the Four Lords and Mae Thoranee. A layman trained in Brahmanic practices, often a former monk, usually conducts the rite. Even though technically there are no Buddhist elements to the ritual, I have seen the rite done by a monk. Northern Thais do not make such distinctions within their religious system, and none of the villagers, including the monk himself, saw any contradictions in his performing the rite.

The ritual involves propitiating the six deities with offerings of food, rice, betel nut, cigarettes, and clay models of buffalo, elephants, and other useful and powerful animals. After the formal ritual, conducted in the center of the village, trays made of banana tree trunk and bamboo, loaded with the offerings, are carried to the four cardinal points of the village boundary for the Four Lords. Two trays are left in the center of the village, one on a pole for Lord Indra, the other sitting on the ground at the pole's base for Mae Thoranee. In addition to honoring the deities, the ritual exorcizes the village of evil or harmful forces. These negative forces are carried to the edge of the village with the trays for the Four Lords and are exiled to the wild space beyond the settlement. The Four Lords help guard the village boundaries, as well as looking after the region of each direction. Besides the annual performance for the entire village, ritual specialists will perform this rite when serious illnesses or calamities occur within the village or individual households.

Probably the most feared of the spirit world are the *phii* that inhabit the forests. As the *paa thu'an* represents the antithesis of the civilized world, people see the spirits that live there as especially dangerous. The divide between *muang* and *paa thu'an*, and between Buddhism and animism, however, is not absolute. Even the forest can be used by people if they take the proper precautions, including conducting rituals to propitiate and appease the gods and spirits that dwell there. The rites need to be done on a regular basis or every time someone wants to use forest resources such as trees for building houses or animals for food.

Buddhism and Spirit Beliefs

Buddhism does not teach that spirits do not exist. Instead, its teachings emphasize developing one's ability to control fear, such as the fear of spirits, through recognizing the impermanence of all things, including one's self. This is a learned skill, however, often developed through years of practice and confronting fear (see Kamala 1997).

When I first began to study Thai Buddhism, I did not expect to find many monks who believed in spirits. Living in northern Thailand and studying with monks, however, I soon realized the extent of the interplay between Buddhism and animism. One monk's story in particular highlights the dynamic relationship between the two.

As a novice in his teens, living in a small, rice-farming village in northern Thailand, this monk walked several kilometers daily to attend classes on Buddhism. His journey took him along a long stretch of road that ran through the rice fields and forest between his village and the next. Often he traveled this road at night when his lessons ran late. He walked with trepidation as the villagers told tales of a hungry ghost that haunted the fields and forest at night.

One dark, moonless night, he related to me years later, as he walked the road, he saw a light across the field. No houses sat in that area, and it was not the season for villagers to be hunting frogs at night. The novice froze in his steps as the light glided across the field toward him. "The hungry ghost," he thought, hardly able to breathe.

As the light came closer, the novice tried to still his panic. All the warnings people had given him about walking this stretch of road at night flooded his mind and he regretted not heeding them. Then he remembered why he walked this way – to study Buddhist scripture in the temple in the district town. "I'm a monk," he thought, "I'm not supposed to fear ghosts. This ghost can't harm me."

With that thought, the light stood still a few meters into the field. The novice smiled at his own silliness and continued on his way home. He never told anyone of his experience until years later, after the forest had been mostly cut down and the road was more traveled, even at night. No point in fostering these fears, he told me, as his story would have only confirmed people's belief in the hungry ghost.

The tale of the hungry ghost involves only one kind of the many *phii* and *theewadaa* in northern Thai cosmology. Nevertheless, it shows how belief in a spirit causes fear and can potentially keep people out of certain places. It also illustrates the belief in the superiority of Buddhism over spirits in the cosmological hierarchy, a belief that has been used to change the spiritual geography, civilize untamed areas and develop the forest.

Buddhism and Forest Development

Buddhism has contributed to civilizing the forest in the modern era through subduing the wild forest and its spirits, enabling human settlements to expand beyond city boundaries. In the late nineteenth and early twentieth centuries, forest-dwelling monks bridged the space between *muang* and *paa thu'an* (Stott 1991: 149; see also Kamala 1997; Tambiah 1984; Taylor 1993a). These Buddhist monks chose to follow thirteen ancient ascetic practices, including forest dwelling, called *thudong*, that aided meditation and purification. Their spirituality enabled them to face the fears of the wild that most lay people held and enter and even live within the forest for extended periods (Kamala 1997). Forest monks brought elements of the civilized world to the forest, blurring the distinctions between the two. Their presence helped quell villagers' fears of the forest spirits, leading them to move into the forest, settling previously wild, dangerous and unlivable areas. If the monks could live there, people believed, then, under the protection of their spiritual powers, so could devout lay people.

Kamala (1997) points to the presence of forest monks as one of the factors that enabled the Thai government to "invade" and then "close" the forest in the twentieth century. She refers to two relevant eras. First was the Forest-Invasion Period (1957–1988), in which the military-backed government manipulated the Buddhist Sangha (or monkhood) in order to promote economic development that led to significant deforestation across Thailand (Kamala 1997: 229–243). The second was the Forest-Closure Period (1980-present), in which the government, in an effort to retain control of dwindling forest resources, banned monks – and most lay people – from living in the forests (Kamala 1997: 243–249).

The governmental efforts to develop and control forest resources, and the use of the Sangha in this process, was epitomized by Field Marshall Sarit Thanarat, the autocratic ruler who, after coming to power through a coup in 1958, pushed Thailand into an intensive development policy. Aiming to bring Thailand into the global economy, Sarit promoted agricultural intensification and expansion based on export and industry. He emphasized a shift toward cash cropping and bringing more forest land under cultivation, continuing the concept of "civilizing" the wild forest and making it useful for humans. He also drew on traditional cultural values to promote his development agenda. Ishii comments:

> Sarit thought that national integration must be strengthened to realize national development. To attain this goal he planned to start with fostering the people's sentiment for national integration through the enhancement of traditional values as represented by the monarchy and Buddhism (Ishii 1968: 869).

Sarit incorporated Buddhism into his development campaign through community development and missionary programs involving monks (Keyes 1971; Tambiah 1976: 434–471). These programs included *thammathud*, which sent monks as missionaries to politically sensitive and economically poor border provinces; *thammacarik*, through which monks worked among minority hill peoples to convert them from animism and bring them into the national economy; and community development programs sponsored by the two national Buddhist universities.The involvement of monks in development programs provided legitimacy and encouraged Buddhist lay people to participate. At the same time as they contributed to national economic growth, however, these monks inadvertently were a factor in the accompanying environmental degradation. The balance of the spiritual geography shifted. The elements of fear of and respect for spirits that limited encroachment into forested land in the past were negated by monks' engagement in and support of national economic development (see Somboon 1977, 1982).The contribution of individual Buddhist monks to the destruction of the forest can be seen on the local level as well, through the act of subduing forest spirits. The following quote from an ethnography done in a northeastern Thai village in the 1960s illustrates villagers' beliefs in forest spirits and the potential role Buddhism plays in overcoming them so that people can use forest resources. It concerns a particular kind of tree, the *takien* tree, in which spirits live.

> *Takien* trees are most well-known for female malevolent spirits. Nevertheless, the villagers have to overlook their harm whenever they wish to cut them down. A certain person with an especially strong *mantra* will have to conduct a ritual to subjugate the spirits. After a rite is performed, the tree may be cut down.
>
> If a person is uncertain as to whether or not it would be right to cut down the tree, he would cut the trunk with an axe and leave the axe stuck in the tree overnight. If the axe is found fallen from the tree in the morning, the man would be able to cut the tree unharmed. Sometimes if the government wants a particular tree, the cutter would put an official emblem on it. This would supposedly bring no danger to the cutter.
>
> When the *takien* tree is cut, one would usually hear the cry or groan of a woman. Sanguan Srisuwarn [a villager] recounts that once he went to carry a *takien* tree which had already been cut. He could not even get close to the tree. Big flies were swarming the tree so thickly that it was impossible to do anything with the tree. This is supposed to have been the doing of the *phi*. So they had to ask a monk from Wat Nong Yang to chase the *phi* away. The monk made holy water and sprinkled it all around with a *takien* branch. After a while the flies were gone (Kingkeo Attagara 1967: 44–5; quoted in Stott 1978: 16).

A professor at Chiang Mai University told me of stories of villagers asking monks to exorcize spirits from forested areas so that they could cut down the trees and establish farms in the northeast. I never directly met anyone who had witnessed such actions, but the logic of such actions makes sense. The accounts of the government using forest monks – directly and indirectly – to facilitate economic development of forested areas (Kamala 1997: 229–249) and involving other monks in community development and Buddhist missionizing activities since the 1950s (Keyes 1971; Tambiah 1976: 434–471), together with descriptions such as the quote above, suggest that the use of Buddhism to civilize the *paa thu'an* was a common event.

Spirituality and Conservation

In more recent times, however, a small number of monks are working to use Buddhism to protect the forest and the natural environment. These self-proclaimed "environmentalist monks" (Thai: *phra nak anuraksa*) promote environmental conservation based on Buddhist principles such as compassion and the interdependence of all beings. They are concerned about the suffering resulting from unmonitored economic development and environmental damage. They cite the Buddha's close connection with the forest, including stories that his birth, enlightenment and *parinibbana* (physical passing) all occurred in the forest, to support their calls for people to protect forested areas. Monks have undertaken projects to create protected community forests, clean up polluted rivers, and challenge illegal logging in national parks.

While environmentalist monks emphasize Buddhist principles in their work, they are aware of the importance of the cultural contexts in which they work. Some incorporate local beliefs in their environmental work. For example, Phrakhru Pitak Nanthakhun of Nan Province in northern Thailand recognizes the potential of spirit beliefs to support conservation projects and gain villagers' commitment to them. In 1990, he sponsored a ritual that symbolically ordained a tree in his home village in order to establish and sanctify a protected community forest (Darlington 1998). Before the tree ordination, the villagers held a ceremony asking the village guardian spirit, one of the region's "lords of the land," for permission to create the community forest and his help in protecting it. They established a shrine at the base of the tree to be ordained and made offerings to the guardian spirit. Phrakhru Pitak did not attend the ceremony, but neither did he oppose it. He commented later on the combined effect of the two rituals:

> Holding a tree ordination, establishing a shrine for the guardian spirit and placing a Buddha image as the "president" of the forest to forbid cutting trees are all really clever schemes. It's not true Buddhism to conduct such rituals. But in the villagers' beliefs, they respect the Buddha and fear some of his power. Thus we can see that there is

> nothing so sacred or that the villagers respect as much as a Buddha image. Therefore we brought a Buddha image and installed it under the tree which we believe is the king of the forest and ordained the tree. In general, villagers also still believe in spirits. Therefore we set up a shrine for the guardian spirit together with the Buddha image. This led to the saying that "the good Buddha and the fierce spirits help each other take care of the forest." This means that the Buddha earns the villagers' respect. But they fear the spirits. If you have both, respect and fear, the villagers won't dare cut the trees. (Quoted in Arawan 1993: 11; my translation)

Most villagers would agree with the assessment that since the tree ordination there has been greater co-operation in protecting the community forest and less encroachment within it.

While many of the villagers developed an understanding of the principles of ecological conservation through the education sessions held by Phrakhru Pitak prior to the ceremony, the impact of both the Buddhist principles applied to forest conservation and the power of the spirit's charge to guard the forest cannot be denied. The local people's indigenous knowledge of forest ecology, which is fostered and encoded in their spirit beliefs, their awe for the sacred aspects of the project, their respect for Phrakhru Pitak and the newly introduced concepts of conservation all work together to heighten the villagers' cooperation and responsibility to preserve the remaining forest.

Nevertheless, the element of fear may have had more of an impact than Phrakhru Pitak intended. Over the two years following the ordination ceremony, four deaths and several illnesses occurred in the forest that villagers attributed to retribution from the spirits for violation of the terms protecting the community forest. The people who died or became ill were all believed to be cutting wood or hunting within the protected areas. Their misfortunes were determined by spirit ritual specialists to have been caused by forest spirits who were offended by these people's actions.

Although some other monks have criticized Phrakhru Pitak for using the fear of spirit beliefs to achieve the ends of environmental conservation (due to both the use of fear and because many monks deny spirit beliefs as being counter to the teachings of Buddhism), he sees it differently. The villagers believe in and respect the spirits of the forest. Their relationship with these spirits defines and reaffirms their understanding of how the world works – in its natural, supernatural and human aspects. The monk also recognizes that northern Thai belief systems are not static. They have evolved over time, adapting to incorporate various elements of Indian culture, including Buddhism, that have entered the region over several centuries. He recognizes and uses the traditional sacred geography rather than trying to alter it to achieve his aims.

Just as Buddhism was used throughout the twentieth century by the government to encourage a shift in villagers' attitudes toward the forest in the service of development, Phrakhru Pitak sees the potential for using religious and cultural beliefs to change people's attitudes again – only this time in the service of conservation. Recognizing the continual evolution of people's beliefs and practices, Phrakhru Pitak integrates traditional beliefs with Buddhist practices to promote an ecological ethic. While the government and pro-development forces emphasize what they see as "pure" Buddhism (thereby invalidating non-Buddhist beliefs), the monk seeks to incorporate all attitudes toward the natural world. Rather than civilizing the forest through imposing Buddhist concepts in order to conquer and use it, he hopes to instill values that recognize the importance of the forest as an integral component of the environment, which includes humans (Buddhist and non-Buddhist alike), animals and spirits. Through the Buddhist concept of interdependence (Pali, *paticca-samuppada*, or dependent origination), he teaches that humans need the forest for a well-balanced life.

Accompanying such rituals as tree ordinations, Phrakhru Pitak offers villagers concrete methods for achieving this balance. He acknowledges that he cannot merely forbid people from using forest resources as these provide their livelihood. He works with farmers to develop appropriate, sustainable and organic agricultural techniques, including integrated agriculture. This method is based on using complementary plants and animals that sustain and support each other, rather than growing a single cash crop that requires chemical fertilizers or pesticides. Phrakhru Pitak encourages villagers to farm for their own subsistence first, only selling any surpluses that may remain. In this way, he hopes they can avoid getting into debt through the high costs and risks of growing a single cash crop.

Phrakhru Pitak does not only work with Buddhists. He involves the non-Buddhist hill peoples in Nan Province in his environmental education programs, recognizing their relationship with the forest and the potential demise of their traditional lifestyles through rapid economic development and deforestation. As with the lowland Buddhist villagers, Phrakhru Pitak emphasizes the importance of integrated agriculture and sustainability among hill peoples and respects and uses their spirit beliefs in engendering their understanding of their relationship with the natural environment and their cooperation in conservation efforts.

Phrakhru Pitak's tree ordination program is only one example of the kind of work he and other environmentalist monks undertake. In conjunction with the tree ordinations, for example, he also incorporates modified *thaut phaa paa* ceremonies, which are traditionally performed by villagers to offer "forest robes" (*phaa paa*) to monks in merit-making rituals. Phrakhru Pitak expanded the rite to include people's giving tree seedlings along with the robes. The seedlings, after being accepted and sanctified by the monks, are then given back again to the villagers to plant in deforested areas. The trees selected are kinds such as fruit trees that are productive without having to be cut down (Darlington 1998).

In 1993, Phrakhru Pitak expanded his work to increase awareness of the importance of water for all life through a project designed to show the polluted state of the Nan River and garner support for cleaning up and maintaining the quality of its water and wildlife. Again incorporating local beliefs, Phrakhru Pitak performed a traditional "long-life" ceremony for the river in a two-day event in Nan City attended by villagers, government officials, military personnel, nongovernment organizations, and over 200 monks from across northern Thailand. At the same time, he established a fish sanctuary, marking the boundaries of a section of the river within which fishing was not permitted and where the fish would be fed. Here he followed the model of a village upriver from the city; in this village, within a year of creating a fish sanctuary, villagers claimed the numbers of fish increased rapidly, and they were better able to balance between protecting the fish and providing food for their families.

The "long-life" ceremony itself, called *syyp chaa taa* in the Northern Thai dialect, is an exorcism ritual usually performed to rid a person of negative forces and promote a long and healthy life. While Phrakhru Pitak performs several such rites a month for his followers, he says he does not actually believe in the physical effectiveness of the ritual. Rather, he views it as an opportunity to teach people about ways to live their lives following the teachings of the Buddha, thereby decreasing the problems and suffering they face in their lives and ultimately living in greater harmony with the natural world. Adapting the ceremony to the river afforded a similar opportunity to teach the importance of caring for the river and its resources, both water and fish.

Phrakhru Pitak skillfully included elements of Thai society that often oppose the work of the environmentalist monks – government officials, military leaders and businessmen. All of these groups often have stakes in promoting economic development along the lines laid out through government policy, as discussed in the previous section. Phrakhru Pitak believes, however, that these people are not inherently bad nor do they aim purposely to degrade the natural environment and the quality of life of the people who depend upon it. They have merely been led astray through the traditional Buddhist evils of greed, ignorance and anger, on which most environmentalist monks blame the problems of rapid economic development. Through involving the government, military and businessmen in their projects, activist monks such as Phrakhru Pitak hope to teach them as well as the villagers the value of living an ecologically balanced life.

Activists in southern Thailand used a similar approach in organizing several Dhamma Walks (*Dhammayatra*) around Songkhla Lake (Santikaro 2000). The purpose of these walks was to bring attention to the environmental degradation of Thailand's largest lake, a unique and complex ecosystem, to local people and local and regional government officials. Participants aimed to strengthen the voice of local, usually poor and marginalized, people. The issues identified by local people included a lack of fish to eat, bad water and reduced water levels, theft of water taken before it drains into the lake, loss of land through nearby urban population increases, and the breakdown of community and loss of traditional livelihoods (Santikaro 2000: 208–209). Buddhist monks, members of a national, small but growing network of activist monks called Phra Sekhiyadhamma, led the walks, and included local people, village leaders, nongovernmental organization workers, foreign environmental activists, and some local government officials. The participants drew on local culture, both Buddhist and Muslim, in order to foster sympathy and commitment to protecting the lake's ecosystem (including the people whose lives are integrally entwined with it). Unfortunately, few Muslims actually participated in the walks, pointing to perhaps too great an emphasis on Buddhism rather than truly integrating local cultures in the project. Nevertheless, the group succeeded in building confidence among the lake's people, involving local monks who previously did not engage in environmental conservation and gaining awareness nationwide for the problems unique ecosystems such as Songkhla Lake face due to unmonitored development. Anthropologist Ted Meyer, who chronicled the walks, observed the potentials of the activities for creating change:

> I believe the lake walks have created a unique kind of public space in which a very broad range of issues can be explored by participants and observers. These issues include not only the current state of human relationships with nature at the local and global level, but also the meaning and significance of Buddhist practice, the possibilities and problems of cultivating relations of trust between people of very diverse backgrounds, and the challenges of designing effective strategies for social change. The breadth and openness of this space makes it possible, I believe, for a unique kind of spiritual and social creativity to take place. That same breadth and openness, however, also increases the range of difficulties that may be encountered (quoted in Santikaro 2000: 213–214).

Demonstrating further cultural creativity and the willingness to face the potential difficulties, environmentalist monks undertake numerous other activities across the country. These programs include a monk who teaches environmentalism to young people through a bird watching club in northeastern Thailand. Another leads children on Dhamma Walks in the forest surrounding their village in northern Thailand while taking the opportunity to talk with them about both the Buddha's teachings and the ecology of the forest. This same monk (the hero of the hungry ghost story) also runs a model integrated agriculture farm designed to teach villagers sustainable methods and encourage a shift away from cash cropping.

Even monks identified as "forest monks" (a category that indicates ascetic monks' retreat from the social world to meditate in the wilderness rather than any inherent activist stance toward the forest) protect and maintain the forest within their temple compounds even while everything surrounding them is being cut down (see Taylor 1993a: 246–252). As Taylor noted in 1993,

> Presently the only remaining primeval forests in the northeast with a semblance to that described by elderly informants and pre- and post-war bibliographical texts are small pockets dotted here and there throughout the relatively less accessible parts of the countryside. The forest monastery, the ancestor/spirit forest (*paadorn puutaa*) and cremation grounds (*paa chaa*) are normally the only forested areas in close proximity to villages (Taylor 1993a: 250).

The presence of monks, ancestors, and spirits, whether those believed to inhabit the forest naturally or ghosts of the recently deceased, all contribute to protecting forested land. Thai villagers respect and even fear both monks and spirits; thus they avoid destroying forested areas connected with both. This level of protection is not enough, however. These areas tend to be small, often surrounded by denuded land. The quality of the environment within these patches of forest often deteriorates as well due to the loss of the larger ecosystem that used to enclose them. And ironically, as noted earlier, even the presence of forest monks can often empower people to overcome their fears and cut the forest.

The two approaches described here reflect a (self-) conscious shift in the application of religious beliefs and practices toward influencing people's attitudes toward the natural world. The case of Thailand illustrates the various ways religion, tradition and culture have been used to influence people's relationship with nature, in favor of both economic development and nature conservation. While neither is intrinsically superior to the other – arguments are made on each side of the need for either development or conservation for the good of the country – the potential for affecting the future is clear. Given the severity of environmental degradation and deforestation in Thailand, largely attributed to rapid economic development (see Hirsch 1993, 1996a, b; Hirsch and Warren 1998; Lohmann 1991, 1993, 1995; Pinkaew and Rajesh 1991; Rigg 1995a, b; Rigg and Stott 1998), I find it encouraging that some monks and activists, such as Phrakhru Pitak, are engaging in the creative use of all Thai traditions and beliefs – Buddhism and spirit beliefs – for the long-term benefit of both people and nature. The spiritual geography of Thailand has been altered for political ends, but hopefully not to the point of irreversible damage to either the natural environment or the people who live within it.

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Environment and Nature: China

Kenneth J. E. Berger

China represents one of the four ancient civilizations of the world, the others being Egypt, Mesopotamia, and India. The one unifying feature of these civilizations is that they all developed along the floodplains of major rivers. The Chinese civilization started along the valleys of the Yellow and Wei Rivers and gradually expanded to the middle and lower parts of the Yellow River and eventually across the North China Plain. It was not by accident that this occurred. Flood plains are well suited to agriculture and China's greatest natural resource is her agricultural land. The river waters also served other purposes such as domestic (drinking, cooking, washing), aesthetic, recreational, irrigation, and fishing.

The early Chinese knew that their livelihood was dependent on nature and in turn believed that their fate and nature were intertwined. This belief caused them to hold the soil in reverential regard and, in some areas, even to consider the rain to be the life-giving seed of the Supreme Ruler in heaven. Humans were considered equals to all forms of life. Prosperity and happiness depended on an ability to adjust successfully to the various forces of nature. To go against nature or to tamper with it might disrupt its equilibrium and ultimately prove to be harmful.

This cooperation with nature, however, did not mean that the early Chinese submitted passively to life. Instead they felt that humanity was the means through which nature's full potential could be realized. In fact, according to some historians, the Chinese have had more of an effect on their environment that any other people (Keswick 1986). Nature, in turn, has endowed the Chinese with some of the world's most productive agricultural areas. The Chinese regarded the alteration of their environment as a type of adornment and not as a form of mastery and control. Through their diligence and devotion, they were able to develop a natural system to explain nature and the environment. Their understanding was further modified according to ancient traditions and customs, which preserved in the Chinese a spirit of sacred reverence for the divine powers of nature and a sense of community with it. They looked upon nature and the environment not as a dead or inanimate thing but rather as a living breathing organism, in a fashion somewhat similar to the present-day Gaia Hypothesis. The Chinese saw a chain of spiritual life running through every form of existence which bound together, as in one living body, all things existing in heaven above and earth below. They had an aesthetic, poetic, emotional, and reverential way of looking at natural objects.

The fourth and third centuries BCE marked a transition period during which ancient Chinese natural philosophy developed into a more sophisticated and systematized theory. Out of their observation, identification, and dependency on nature came Daoism, a philosophy based on nature. The Daoists championed the independence of each individual, and maintained that the only concern should be to fit into the great order of nature, i.e. the *Dao*. They believed that if left to itself, the universe proceeds smoothly according to its own harmonies. They emphasized the unity and spontaneity of nature. Mankind's efforts to change or improve nature only destroy these harmonies and produce chaos. Humanity's place in nature was to be in harmony with it since both humans and nature obey the same laws. Thus, they are in a constant dynamic relationship with one another, each able to affect the other's flow. As Laozi (ca. 561–467 BCE) stated in the *Dao De Jing*, "Man follows the way of earth, earth follows the way of heaven, heaven follows the rules. The rules are the *Dao*".

At the same time that Daoism was flourishing, another school of philosophic thought was also flourishing, known as the Naturalist School. This attempted to explain nature's workings on the basis of certain cosmic principles, one of which was the basic dualism of nature, the *Yin yang* Principle. *Yang* represents masculinity, light, hotness, dryness, hardness, roundness, activity, heaven, the sun, etc. *Yin* represents femininity, dark, coldness, wetness, softness, squareness, passivity, earth, the moon, etc. Rather than being in perpetual conflict, *yin* and *yang* are mutually complementary and balancing. The greater *yang* grows, the sooner it will yield to *yin*; likewise the greater *yin* grows, the sooner it will yield to *yang*. In addition, *yang* always contains some *yin* and *yin* always contains some *yang*. *Yin* and *yang* continually interact, creating cyclical change. For example, *Yin* and *yang* helped explain the seasons and the proper actions which should occur, in spring: plow, in summer: weed, in autumn: harvest, in winter: store. The interdependence of the two principles was well symbolized by an interlocking figure, which today is used as the central design element in the flag of South Korea. This *yinyang* concept was eventually incorporated into Daoism, with *Dao* being the natural process that unites the two.

When perfect balance and harmony exist between the *yin* and *yang* elements and qualities, growth of all living things flourishes and *qi*, the cosmic breath, enhances the environment. *Qi* is believed to exist in all living and nonliving things. This concept of *qi* is pervasive throughout Chinese customs and traditions, from acupuncture to kung fu. It is through *qi* that all things in the universe are related and attached to each other and integrated in the united whole.

The early understanding of the forces of nature which was accumulated over the years, together with the concepts of *yin yang, qi*, and later concepts, eventually developed into a complex science known as *feng shui*. Simply put, *feng shui* is an early form of ecology, conservation, and environmental science. It unites heaven, earth, and humans in such a way that a respect for nature is developed along with the ideas of renewability and sustainability of resources.

The most famous of the Chinese philosophers was Confucius (551–479 BCE). He was primarily concerned with society and interpersonal relationships. As such, the Confucian view of nature is only relevant with respect to how it affects human relationships and interactions. However, he did recognize the importance of the human–nature relationship. This can be seen in the Classics, a set of books associated with Confucianism.

In the *Yijing* (Book of Changes), it is stated that, "The great man is the one who unites his morals with heaven and earth." *Li Ji* (Book of Rites) in turn states, "Man is the heart of the heaven and the earth…, so a holy man must treat heaven and earth as the root of behavior." It also says that "to chop down a tree or kill an animal at the improper time is unfilial." The *Doctrine of the Mean* states, "Let the states of equilibrium and harmony exist in perfection, and a happy order will prevail throughout heaven and earth and all things will be nourished and flourish." Therefore, in order to unify with nature, we should obey the regularity of nature and take care of it. According to the *Yijing*, also known as the *I Ching*, the Chinese concepts are revere nature, unify with nature, adapt to nature, spare nature, learn from nature, and play in nature. The Confucian thus asks people to act in a proper manner and to take care of nature; so by leading a moral life, people can assist heaven and earth to maintain a harmonious balance.

Mencius (371–289 BCE), a disciple of Confucius, said, "If you do not interfere with the seasons of husbandry, the grain will be more than can be eaten. If you do not use a net in a fish pond, the fish and turtles will be more than can be consumed. When cutting wood only go into the forest and hills when it is the proper time, and the wood will be more than can be used. Not allowing the exhaustive consumption of fish and turtles, nor the exhaustive use of the woods, enables the people to live and die generation after generation without interruption." In other words, resources are for the perpetual use of mankind.

The last major influence on the Chinese concept of nature and the environment is that of Buddhism, which came to China from India in the first century AD. Buddhism gave to the Chinese a respect for the lives of all living things, because it is believed that all things have the potential to achieve Buddhahood and that animals are but a form in which something has returned in its new incarnation. Everything in the world has a relationship with everything else, be it animate or inanimate. The only difference is in the closeness of the relationship.

The concepts of nature and the environment in ancient China are basically a group of general principles, such as the cyclic nature of the natural world, the equality of the natural laws, the creativity of nature as expressed in its biodiversity and abundance, and the belief that everything contains both a positive and negative part. Through Confucianism, these concepts became part of morality; through Daoism, they became part of philosophy; through Naturalism, they became part of cosmology; through *feng shui*, they became a part of science; through Buddhism, they became part of religion. The concepts were easily understood and incorporated into an understanding as to how humans should live their lives, i.e., in harmony with nature.

See also: ►*Yinyang*, ►Geomancy in China, ►Divination, ►*Qi*, ►*Feng Shui*

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Environment and Nature in Hebrew Thought

Jeanne Kay Guelke

It is perhaps inappropriate to include a section on Hebrew thought in an encyclopedia on non-Western cultures. When the Hebrew Bible was adopted in translation as the Christian Old Testament, it became one of the intellectual cornerstones of western civilization. The two principal divisions of Jewish culture and ethnicity, central and eastern European (*Ashkenazi*) and Mediterranean and Near Eastern (*Sephardi*), have extensive European roots. Nevertheless Christianity and Judaism diverged in critical ways over the interpretation of their shared scriptures.

The Hebrew Bible and Jewish Law

The essential core of Jewish belief is the first five books of the Bible, notably the set of 613 commandments (*mitzvoth*) handed down to Moses on Mount Sinai. The rabbinical interpretations of Mosaic law (*halakhah*) and explanations of biblical narratives codified principally in Babylon and Palestine during the first centuries of the Common Era as the Talmud (together with some subsequent commentaries on the Talmud) form the essence of traditional Jews' understanding of the cosmos and permissible activities within it. "Hebrew thought" as a body of literature in the Hebrew (or Aramaic) language is not identical with "Jewish thought" (which includes Yiddish prose and other writings from the Diaspora) but there is a strong correspondence based upon Jewish origins in the ancient Near East.

In the Hebrew Bible, one God created the heavens, the earth, and their creatures, and pronounced them "good." God placed the first humans in the beautiful Garden of Eden "to dress it and keep it." Humans were given control over soil and biota: "the fish of the sea, the fowl of the air," but the Bible explicitly reserves control over physical forces of the environment, notably climate, to God. The Bible links humans' ability to shape nature to their liking to their obedience to God's will. In the biblical narratives, few humans are righteous enough to accomplish dominion over nature.

God commanded the patriarch Abraham and his descendants, the Israelites, to worship God exclusively and to obey His commandments. The books of Numbers and Deuteronomy explain environmental change in the form of divine blessings and curses for human good deeds and misdeeds. The Israelites are to receive a homeland, abundant rainfall, and crop yields if they obey the *mitzvoth*, but drought, insect plagues, and the "scorched earth" resulting from warfare if they disobey. The environment is a principal means through which God expresses Himself and registers His authority.

The Hebrew Bible and Talmud have little explicitly to say about environmental conservation in the modern sense. There are proscriptions in Jewish law against cruelty to animals, destruction of fruit trees during warfare, tilling the soil during the sabbatical year, and working (and hence altering nature) on the Sabbath day. There is little evidence in the Bible that Middle Eastern, Iron Age farmers and pastoralists even understood that humans were capable of causing extensive environmental degradation (with the possible exception of overgrazing), and considerable evidence that they attributed environmental deterioration to God's wrath. These cast considerable doubt on some scholars' assertions that the Judeo–Christian tradition is the root of the West's callous treatment of nature, simply on the basis of a few verses in Genesis mandating human use and domestication of plants and animals. Needless to say, both Christian and Israeli settlers in recent centuries have subsequently cited the Genesis injunction for human dominion over nature and Isaiah's prophecy that the desert shall "bloom like the rose" as a license for resource exploitation.

The ancient Jewish dietary laws (*kasruth*) identify certain animals and slaughtering practices as "clean" or "unclean" as food for the Jewish people. Although the scriptural statement that some species are "abominations" on the Jewish table does not imply reverence for all of nature, the forbidden animals, by the same token, would not have been hunted or raised inhumanely. A modern environmentalist interpretation of kashruth is that God expressly limits Jews' exploitation of the Creation.

Today when many environmentalists seek to undo the dualism between humanity and nature, it is worth nothing that the Hebrew Bible indeed has no words for “environment” or “nature” that distinguish these concepts from culture: only the universal and integrative concepts of “everything” (*olam*) or Creation. In the Bible’s original Hebrew (though not in most English translations) animals have souls (*nefesh*, *ruach*) just as people do. Trees and stars praise God and shout for joy.

The Bible is full of evocative nature poetry, notably in the prophets, Job and the Psalms. Eagles, lions, the cedar forests of the mountains of Lebanon, the desert after a rain shower, and lush pastures seemed especially inspirational to the ancient Hebrew mind. The Israelites’ formative early experiences with the desert (as in the book of Exodus) and Mediterranean crop zone appear throughout their religious texts.

The Jewish scriptures also describe an annual cycle of holy days that were based on a lunar calendar and changing seasons as they would have affected ancient farmers and herders. The festival of *Shavuot* (Weeks), for example, celebrates the gathering of first fruits of the land. *Sukkot* (Tabernacles) in autumn culminates a series of days set aside for repentance and atonement with prayers for the winter rains so essential for agriculture in the Near East. While such environmental connotations were weakened among urban Jews of the Diaspora (who nevertheless continued to observe the holy days), they are quite obvious to visitors of rural Israel today.

Middle Ages and Early Modern Times

With the postbiblical Diaspora or exile from Palestine following Roman destruction of Judaism’s institutions and sacred sites, Jews literally scattered to the four corners of the earth. Often forbidden by host governments from attaining the most basic of human rights, owning land, living outside of urban ghettoes, or working at most occupations, many Jews were prevented by anti-Semitism from forming a close relationship with environments where they settled. Preserving their faith and studying Torah and Talmud were largely indoor activities.

Although development of Jewish environmental thought was thus limited, medieval Jewish philosophers and mystics who developed the Kabbalah teachings believed that all of nature was imbued with divine emanations, or even with divine substance. Some leaders of the eighteenth-century pietist Chassidic movement of Eastern Europe were noted for retreating alone to the fields and forests for prayer and mystical insight. The agrarian Zionist movement of the late nineteenth and early twentieth centuries advocated a return of Jews to Israel, in the belief that working the soil of their ancient homeland would redeem and ennoble oppressed European Jewry.

Recent Past and Present

The recent history of Hebrew thought on the environment and nature is best exemplified by the modern state of Israel. Since its inception in 1947, it has experienced many of the same environmental problems as other industrialized countries, with particular concerns about water scarcity and reforestation. Israel’s push for development of new settlements and industries despite a hostile international political scene, and its land use needs for military security often overrule environmental preservation priorities. Hostilities between Arabs and Jews clearly have had an environmental impact, notably in the recent expansion of Israel’s “security” landscape and in tensions between Arab range lands and Jewish reforestation projects.

Nevertheless Israel is one of the few nations in the Near East with a variety of environmental organizations, such as the Society for the Protection of Nature in Israel (founded in 1953), a Ministry of the Environment, and a system of nature preserves and national parks. Two noteworthy parks, Chai-Bar and Neot Kedumim, are maintained to preserve specimens of vanishing desert fauna and flora, respectively, mentioned in the Bible.

The Israeli response to nature has not lost its ancient religious roots. Some Orthodox Jews in Israel use traditional prayers for rain as a response to drought, and accept halakhic rulings about agricultural fields together with scientific agronomy practice.

Many Jewish environmentalists throughout North America today seek to integrate their faith and environmental concern. Some are reexamining the rabbinical concept of *Tikkun Olam* (healing everything) as the performance of *mitzvoth* necessary to restore planetary health. Vegetarianism for some fits in well both with Jewish dietary laws and environmentalist beliefs about the sanctity of life. Clearly the synthesis of ancient traditional texts, religious practice, and recent environmental awareness will lead to a rapid evolution of environment and nature in Jewish thought in the near future.

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Environment and Nature: India

D. P. Chattopadhyaya

The philosophical and scientific ideas developed in India over the centuries are, on analysis, found to be deeply related to ecological issues, both generally and specifically. Like the ancient ideas of China and of the Hellenic world, the ancient Indian ideas of the comparable period are cosmological and comprehensive in character. The *Vedas* and *Upaniṣads*, Laozi's *Dao* or in Parmenides' *Nature of Being* were all engaged in search of the first principle, One. They were all obliged to relate it to Many–Many individual objects of knowledge. The One–Many relationship is pregnant with both cosmological and ecological implications.

Broadly speaking, the objects we know around us are biotic (living) or abiotic. However, to many thinkers, especially to the pluralists and evolutionists, this twofold classification is simplistic and inadequate. They try to draw our attention to different grades of being or reality – physical, chemical, paleontological, botanical, biological, psychological, and spiritual. The scientific philosophers of the Vedic insights, of the *Samkhya* persuasion, and also of later times could discern different subgrades within each of these grades. These graded characteristics of different living and nonliving beings have to be recognized if we are to understand the complex and the interactive character of our environment. This insightful approach to ecology as an integral part of cosmology is evident in the tradition of Indian thought. It is very clearly available, for example in *Caraka-Saṁhitā*.

In ancient India the good of human life was thought of in the context of life's environment. The right relation between the individual and his environment received serious attention even at the levels of primary and secondary education. The aim was to impart basic knowledge of personal hygiene and medicine. This education was meant for all. In a way medical education was universal. It is interesting to note the five compulsory subjects for all high school students: Grammar (*Śabdavidyā*), Art (*Śilpasthānavidyā*), Medicine (*Cikitsāvidyā*), Logic (*Hetuvidyā*), and Science of Spiritual philosophy (*Adhyātmavidyā*).

Both abstract and concrete areas of knowledge, understood in their interconnection, are all relevant to the exercise of adjusting to our environment. Linguistic communication, artistic articulation, logical ratiocination, and medication are in different ways intended to awaken the best in us and to strike a balance with the large world around us. From the strength of body to the span of life, from good health to peace of mind, all are a unified function of food, personal hygiene, right actions, and character.

Life has a rhythm of its own, which is not necessarily manifest. The *Dharmaśāstra* are full of injunctions on how to attain that rhythm in terms of purity, diet, regulation, ablutions, behavior, and physical and mental disciplines. These have to be followed as part of daily (*dinacaryā*) as well as seasonal routines (*ṛtucaryā*). Food and drink habits and fulfillment of natural urges, avoidance and indulgence in sexual acts, and eating some ordinary things like curds, buttermilk, and honey are all necessary to define our correct relation with the environment. However, this normative rhythm can hardly be generalized, for it is integrally related to the individual constitution (*prakṛti and svāsthya-vṛtti*).

The traditional Indian medical system (*Āyurveda*) takes a comprehensive view of a person. It neither encourages asceticism and mortification of the flesh nor promotes unregulated sensualism. It highlights the importance of a "sound mind in a sound body". It points out that *svāsthya-vṛtta* or philosophy of hygiene is to be supplemented by *sadvṛtta* or the right life. Rightly understood, the philosophy of hygiene is a way of life containing in it the principles of eugenics, ethics, and healing.

In ancient Indian thought the basic principles of ecology are ontologically oriented and cosmological in implication. The three main concepts of the Vedas which are evident in *Āyurveda* are *satya* (truth, right, reality, or being), *svadhā* (self-position, self-power, or spontaneity) and *ṛta* (proper, suitable, and settled order). The basic point which is being emphasized here is that the true nature of reality cannot be changed by human will which is not informed of that reality. No technological skill, no arbitrary will of this or that person, can go indefinitely against the true nature of reality without causing harm to those who try to follow this wrong path. Even the most sophistical biotechnology cannot tamper with the essential nature of reality, the true Nature or *Prakṛti*. This role of the concept of truth has both ontological and axiological implications. Humans are required both to know reality in its true nature and to live and shape their lives accordingly.

Humans are also aided by the principle of becoming or the dynamic nature of reality in shaping their best possible life. This possibility is contained in the concept of *svadhā*. Reality has within itself the impetus or power for self-unfolding or gradual disclosure. It is not static, fixed, or self-enclosed. The world as reality and as a whole is perpetually expanding. This macrocosmic truth of *svadhā* is at work also in human nature. Consequently, human freedom knows no bounds. Nature and its laws are not antagonistic to the human will to be free. When we can discover the laws governing the true nature of the relation between individuals and the world, our knowledge of the world helps us to live in harmony with it. That harmony creates a favorable environment which not only nourishes our bodies but also enables us to be free from social conflict and tension. When we are free from ill health, we are better placed in our relation to nature. When we fail to strike the balance with nature, we are not only likely to be poorer in health but also less capable of getting the best out of our environment.

Finally, besides the true nature of reality (*satya*) and the power of self-disclosure (*svadhā*) what helps us to have a right environment is suggested by the concept of *ṛta*. It is orderliness or the law-governed character of reality or nature. From the change of seasons to the changing periods of life, *ṛta* is clearly perceptible. Even human cultures are found to exhibit certain rhythms. Cultures are characterized simultaneously by fragile and stable features. The rhythm of nature is not antagonistic to the spirit of human freedom. Our lives, both individual and collective, are marked by a sort of dynamic equilibrium.

The above three concepts embodying certain abstract principles may appear irrelevant to our actual lives. However, to the thinkers of *Āyurveda* the principles of philosophy and ethics, or those of good living, are inseparable from the basic characteristics of reality.

The same principle is illustrated in defining the ideal principles of town planning and village planning. Aśoka, the Buddhist emperor of ancient India, said that trees, plants, and shrubs of medicinal value had to be planted around every village and along the roadsides. The people were allowed to use the leaves, fruits, and bark of the trees. This practice survives today. Like geography, history, science, and arithmetic, the general principles of hygiene and physiology and simple methods of curing cuts, wounds, and everyday ailments were prescribed for everyone's general education. The underlying belief was that individuals had to be able to take care of their elementary medical needs.

The Indians believed that every village should be so constructed that its population must have the professional service of a medical practitioner (*vaidya*). People were advised to reside in a place with plenty of water, herbs, sacrificial sticks, flowers, grass, and firewood, and which yielded abundant food. They were also advised to live where there was safety of property and person, where the outskirts were beautiful and pleasing, and where there was a strong presence of learned people.

Ancient Indian thinkers paid attention to the development and preservation of the right type of environment for human life. The state was assigned a very important role for the purpose. It was expected to lay down rules and regulations for rubbish disposal and drainage systems. The state also determined where and how the quality of food and drink should be preserved. Those who violated these rules and thereby polluted the environment were punished. Equally conscious were the decision-makers in charge of public health. The state had a very important role to perform for preservation and promotion of a healthy environment. Various types of punishment were prescribed for cutting for the tender sprouts of trees.

Kautilya mentioned elaborate laws for the promotion of agricultural activities. For example, he prohibited high agricultural taxes and bonded agricultural labor and attached much importance to animal husbandry and soil preservation.

See also: ▶Medicine in India: Āyurveda

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Environment and Nature: Islam

Parvez Manzoor, Ziauddin Sardar

The sacred text of Islam, the *Qurʾān*, contains a theology of ecology, for nature and ethics are at the very core of its moral worldview. Indeed, so central is the theme of the affinity of nature and ethics that even outside observers, such as Marshall G. Hodgson, have epitomized the dictates of the Islamic commitment as "the demand for personal responsibility for the moral ordering of the natural world."

The creation of humanity is one of the grandest themes of the *Qurʾān*. It is alluded to either philosophically in a symbolic language or biologically, employing the medium of natural science. Philosophically, the first assertion is that of the purposefulness and meaningfulness of human life. The Quranic teleology is preeminently moral: humans are to execute the will of God, but it is an undertaking which they have imposed upon themselves. It is a pledge made by man and woman to God. Hence, God, for His part, has endowed them with all the faculties essential to undertaking this august moral mission. Nature is the testing ground of this moral responsibility. Men and women are thus enjoined to read its "signs." For this purpose, nature has been created both orderly and predictable. The creation of human beings and the creation of nature are thus two chapters of the single theme of moral responsibility and trust that is the *sine qua non* of Islamic commitment.

Nature, therefore, is a trust or *amāna* and a theatre for a Muslim's moral struggle. According to the *Qurʾān*, heavens, earth, and mountains refused to assume this responsibility which humans took upon themselves voluntarily. By doing this, no doubt, humans showed ignorance and hubris – but also their willingness to serve God's purpose. As trust is a mutual commitment, it may also be surmised that God, by entrusting people with this responsibility, expressed confidence in their ability. No wonder that in the Quranic worldview and Islamic tradition the individual is known as the trustee, or *khalīfa*, of God.

The Islamic rationale for an ecological ethics rests on the Quranic notions of *khalīfa* and *amāna*. Nature, being the gift of God to man, is accepted in Islam as an estate over which we have temporary control but no sovereign authority. Our relationship with nature thus can never be ethically neutral. Islam views nature essentially in a teleological perspective and therefore the claims of man's dominion over her have no resonance in Islam.

While Islam is a monotheistic faith belonging to the Arabrahamic tradition, its teachings on environment and nature contrast sharply with its sister religion of Christianity. To give an example, the Hebrew story of creation is transformed in Christianity into the doctrine of the fall. Creation thus appears to the Christian mind as "fallen," and nature is viewed as opposed to grace. St. Augustine, to take one example, believed that nature was "unredeemed," just as many Christian theologians maintain that nature cannot teach man anything about God and is therefore of no theological and spiritual interest. Salvation is the humbling of nature by the miraculous, the intrusion of the supernatural into history. The nearest thing in the physical universe that reflects the miraculous is man. Holiness exists only in a man-made environment. Thus, nature, so devoid of God's presence and grace, may be "tortured"; it may be justifiably subjected to scientific experimentation. The Islamic view is very different. Creation (nature) in the Quranic view always bears the "signs of God" and is necessary for man's salvation. It is in accordance with this that Islam holds that there is no such thing as a profane world. All the immensity of matter constitutes a scope for the self-realization of the spirit. All is holy ground, or as the Prophet Muḥammad said, "the whole of this earth is a mosque." Earth, creation and nature thus have a sacramental efficacy in Islam which can be ill-accommodated with the perverse applications of the "dominion ethics". The claim for nature's "salvational worth", however, may never be construed as a token of its autonomy. In fact, Muslim theologians have always claimed that nature has no meaning without reference to God; without Divine purpose it simply does not exist. (Hence, nature is simply known as the created order.)

The ethical link between faith in God and love for His creation is fully demonstrated in the life of the Prophet Muḥammad himself who declared that whoever is kind to the creatures of God is kind to himself. One authentic tradition narrates that a man once came to the Prophet with a bundle and said, "I passed through a wood and heard the voice of the young of birds, and I took them and put them in my carpet and their mother came fluttering around my head." And the Prophet said, "Put them down." And when he had put them down, the mother joined the young. And the Prophet said, "Do you wonder at the affection of the mother towards her young? I swear by Him who has sent me, verily, God is more loving to His servants than the mother of these birds. Return them to the place from where you took them, and let their mother be with them."

Such environmental teachings were actually translated into environmental policies and legislation in the classical Muslim civilization. For example, the Muslims developed the notion of *ḥaram* – inviolate zones – outsides towns, near water-courses, and other areas where development was forbidden. A second type of inviolate zone was *ḥima* which applied to forests, woods, and wild habitation and was designed to conserve wildlife. Ibn ʿabd as-Salam (fl. thirteenth century) formulated the first statements of animal rights. Muslims were also concerned about the protection of the urban environment; Islamic town planning and architecture provide ample demonstrations of this. Many classic cities, like Fez, were built with the full understanding of carrying capacity and were designed so that the city's population would not increase beyond a critical limit. The debate about conservation, protection of animals and their habitats, and the Islamic teachings on environment can be clearly seen in such classics as *Disputes Between Animals and Man*, which is a part of the *Rasāʾ-īl Ikhwān al-ṣafāʾ* (The Epistles of the Brethren of Purity) written in the tenth century. The deep respect for nature and environment is also evident in Sufism, the mystical strand of Islam, both in its thought and practice. The titles of some of the classic Sufi works reflect their concern with nature. *Gulistān* (The Rose Garden) and *Bustān* (The Fruit Garden) by Saʿdi of Shīrāz, and Farīd al-Dīn ʿAttār's *Manṭiq al-ṭayr* (The Conference of the Birds) provide good illustrations.

Contemporary Muslim societies have lost much of their traditional consciousness and concerns. Both colonialism and the mad rush for modernization have played their part in this oversight, but today we can detect a minor resurgence in Islamic environmental consciousness. This is evident both in the intellectual and academic efforts to shape a contemporary Islamic environment theory – for example in the works of Gulzar Haider, Seyyed Hossein Nasr, and Othman Llewellyn – and the frequent use of traditional Islamic concepts and technologies (such as *qanat*, the ingenious system of wells drained through a network of tunnels) in developing environmentally sound practices in the Middle East and Iran, Pakistan, and Malaysia.

Equipped with the ethical insights of *khalīfa* and *amāna*, and impelled by the Quranic dictates to assume personal moral responsibility in the world of nature, Muslims have a responsibility to meet the challenge of ecology to religious consciousness and provide mankind with a healing vision of the harmony of man and nature under God. Like everything else of value in Islam, its ecological insight can be summed up under the seminal concept of *tawḥīd* (unity). *Tawḥīd*, Islam's eternal quest for the unity of life and purpose, spirit and matter, human beings and nature, law and ethics, faith and morality, implies that man does not dominate the earth or commit violence in any form.

See also: ►Religion and Science

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Environment and Nature: Japan

John A Tucker

In traditional Japan, the word *shizen*, also pronounced *jinen*, meant naturalness, or the mode of being which is natural. Its literal meaning is "from itself (*shi/ji*) thus it is (*zen/nen*)." In modern Japanese *shizen* by extension came to refer to nature, or the environment encompassing all between heaven and earth, especially the earth, oceans, mountains, rivers, flora, and fauna.

Premodern Japanese had no single word signifying nature as a unified entity. Nevertheless passages about nature abound in their ancient literature, philosophy, and religion. Words like *ten*, literally meaning heaven, and *tenka*, meaning heaven and earth, meant something like nature. An understanding of traditional conceptions of nature can be garnered by examining Japanese thoughts about aspects of nature such as heaven, earth, mountains, rivers, trees, flowers, and fields.

Ancient Japanese evinced an unabashed intimacy with the natural world in their earliest poetry as compiled in the eighth-century anthology, the *Man 'yōshū* (Collection of Myriad Leaves). Its poems spoke of the world of mountains, rivers, flora, and fauna in anthropomorphic, animistic terms, investing each entity with a living personality infused with *kami*, or mysterious spiritual energy. Mountains were deemed most divine. Indeed, in their verses the ancient poets immortalized Mt. Fuji as a peerless deity. Rivers were considered living forces, manifesting immense spirituality in their rushing flows of clean, life-giving water. The sea was viewed as a more awe-inspiring, fearful spiritual force, one supplying sustenance but also destruction. References to birds and beasts fill the poems, evoking a sense of the four seasons and the human feelings linked to them. The poems themselves were likened to the natural world: the *Man'yōshū* included myriad *yō*, or "leaves" of poetry.

The earliest histories of Japan, the *Kojiki* (Records of Antiquity, 712) and the *Nihon shoki* (Chronicles of Ancient Japan, 720), open with myths relating the Shintō cosmogony. They give the *Man'yōshū* vision of nature a strongly religious, spiritual grounding, leaving no doubt that the world of nature was the world of creative religious spirit. After heaven and earth congealed out of an undifferentiated, egg-like mass, successive generations of personified *kami* begot one another. Finally the *kami* pair, Izanagi and Izanami, created the first island, Onogorojima, by letting the brine drip off a spear they had plunged into the ocean's depths. On Onogorojima, Izanami gave birth to the elements of nature including the rivers, mountains, birds, beasts, and flowers and trees, and the forces of nature such as fire. Because of the divinity of the progenitors, Japanese traditionally considered their archipelago and all of nature within it as sacred.

According to one account, Izanagi and Izanami also gave birth to Amaterasu the Sun Goddess and her brother Susanoō the impetuous god of storms. Because both Amaterasu, a benevolent *kami*, and Susanoō, a mischievous if not malevolent one, are deemed divine beings, Japanese have not dismissed destructive forces of nature as evil. Nor have they branded acts against nature as necessarily wrong. Indeed, Shintō myths relate that Susanoō wreaked havoc in his sister's rice fields, implying that similar actions contrary to the general good of the world of nature might still have some divine sanction via Susanoō's example. Perhaps this partly explains why many Japanese, despite their close religious, poetic, and mythic ties to nature, have at times tolerated abuses of it.

Pollution, however, was considered anathema, and was dealt with via Shintō purification rites. Pollution did not necessarily mean physical dirtiness or noxious environmental conditions; however, those forms were recognized among the more spiritual nuances associated with the Shintō notion of pollution. Traditional abhorrence of physical and spiritual pollution perhaps explains the energetic opposition of many Japanese, though certainly not all, to environmental pollution.

Amaterasu and Susanoō parented the imperial line and the ancestral stock of all its human subjects. Belief in the divinity of their islands, their imperial family, and everything within their natural environment thus results from the supposed ancestry of Japanese in Izanagi and Izanami. This became a basic tenet of Shintō, one regularly repeated throughout Japanese history. In the *Engi shiki* (Religious Regulations of the Engi Period, 927) ritual prayers record a similar vision of nature as fully infused with divine spirituality. Kitabatake Chikafusa's (1293–1354) political tract, the *Jinnō shōtōki* (The Legitimate Succession of Divine Emperors, ca. 1340), opened with the declaration, "Japan is a sacred land (*shinkoku*)." Japanese Buddhists and Confucians almost unanimously have accepted the same, essentially Shintō doctrine.

Belief in the divinity of the archipelago encouraged some Japanese to xenophobia: foreigners, typically viewed as barbarians, were feared as potential agents of pollution. Japanese soil, they felt, would be violated if the barbarians were allowed on it. Since 1945, the Japanese have become more accustomed to the presence of foreigners in their country. Still their concern for nature often seems Japan-specific: some southeast Asian forests have been depleted to accommodate the Japanese preference for disposable, wooden chopsticks, even though forest conservation practices are followed within Japan.

Introduced to Japan in the mid-sixth century, Buddhism advanced various attitudes toward nature. The Four Noble Truths, the original teachings of the historical Buddha, Siddhārtha Gautama (563–483 BCE), characterize existence as suffering, implying that *samsara*, or the environment of reincarnation, was similar. Their religious solution, *nirvana*, which literally means "putting out the flame" (of existence in this world), seems to offer an escapist otherworldliness which might have permitted a relative disengagement from nature.

The Mahāyāna Buddhist ideas of the Indian thinker Nāgārjuna (ca. AD 150–250), which were accepted by most Japanese Buddhists, affirmed the natural order. Nāgārjuna equated *samsara* with *nirvana*, disallowing otherworldliness. Nāgārjuna's view was based on the doctrine that everything is empty (*sunya*). Empty here means empty of self-sustaining substance, i.e., a substance existing in and of itself. Nāgārjuna insisted that everything that exists does so through spatial, temporal, and causal relations with the remainder of the universe. Nothing exists independently of everything else. His ideas could be construed as anticipating the ecologist's belief that all life is interrelated, and that destruction of small niches endanger the entire ecosystem. Nāgārjuna's ideas surely facilitated a more positive appraisal of nature by Japanese Buddhists.

Traditional Buddhist cosmology, however, claims that the world is subject to creation and disintegration just as humans experience cycles of death and rebirth. Arguably this view could allow a cavalier attitude toward the natural environment since regardless of one's efforts the world will inevitably disintegrate and then begin anew. The Buddhist belief that attachment to things leads to suffering also might vitiate wholehearted involvement in an environmental ethic geared toward conservation of nature. The Buddhist two-level theory of truth, assigning ultimate status to *sunya*, and relegating common sense to secondary validity, allows for concern for nature but not in a primary way.

Otherworldly tendencies appeared in the popular Jōdo, or "Pure Land", School. Based on the Indian writing *Sukhāvatīvyūha-sūtra* (Discourse on Paradise), Jōdo posits both a heaven called the Pure Land presided over by Amida Buddha, and a multileveled hell where sinners suffer eternally. Yet some theorists claim that the Pure Land and hell are merely "expedients" meant to motivate non-believers to meditate on Amida Buddha as the way to salvation. If so, then the Pure Land becomes a symbol of *nirvana*, or existential extinction, while hell becomes a hyperbole of the Buddha's claim that life in this world, the world of nature, entails suffering.

Yet the ideas of many Japanese Buddhists evinced a religiously based concern for nature. The Kegon, or Flower Garland, school asserted that every particle of existence was infused with Buddha-nature, making the natural universe a spiritual one as well, one to be saved from suffering. The *Konkō kyō* (Sutra of the Golden Light), an important text in early Japanese Buddhism, claimed that rulers who promoted the Buddha's teachings would be protected, as would be their domains, by the Four Deva Kings, tutelary divinities who protected Buddhism throughout the universe. Compassion for all sentient beings, the core ethic inculcated by Māhāyana Buddhists, instilled in some a concern for the natural world.

Buddhist poets like Saigyō (1118–1190) even extolled the world of nature as the primary arena of Buddhist values. Others debated whether plants and trees, though nonsentient beings, could actually attain Buddhahood. Many Japanese Buddhists argued that they could. Some also claimed that nature possessed a healing and even soteriological capability. Probably influenced by Shintō beliefs, the Shugendō (Order of Mountain Ascetics) school had its practitioners make pilgrimages to sacred mountains to glimpse scenery foreshadowing the Pure Land. Buddhist temples aesthetically enhanced the environment. With their rock gardens, moss gardens, and vegetable gardens, temples were practically involved in local environmental improvement as a way of meditation. Zen Buddhists see enlightenment as an experience to be had in this world and in this body. Disregard of nature, therefore, cannot be allowed. Yet Buddhists are not known for authoring agricultural or environmental tracts. It was the Confucian and Neo-Confucian scholars who, in addition to admiring nature's beauty and revering it religiously, made the world of nature the focus of protoscientific research designed to conserve the environment for future generations.

Neo-Confucianism, the last major philosophical force to emerge in traditional Japan, encouraged scientific interest in and ethical concern for the natural world. Prompted by the sophisticated Buddhist metaphysics with its (to Neo-Confucians) repulsive doctrine of emptiness, Confucians reformulated their originally socio-political thought along novel metaphysical lines so as to refute the Buddhist challenge. Originally a Chinese movement of the Song dynasty (967–1279). Neo-Confucianism ultimately became a pan-Asian force decisively affecting China, Korea, Japan, Vietnam, and other East Asian areas up until the modern period. In Japan, it was a dominant force during the Tokugawa period (1600–1867).

Neo-Confucians endorsed common sense, declaring that the natural environment was both substantial and fully real. They believed that there was no other world. Rejecting emptiness, they asserted that everything consisted of a quasimaterial, psycho-physical energy called *ki*. Giving "matter" its rationale was another ontological element, *ri*, or "principle." The fusion of *ki* and *ri* accounted for the diversity within the natural world. The latter was created by heaven and earth, which engaged in constant production and reproduction as its Way. Most Neo-Confucians recognized the complementary forces of yin and yang as the cardinal modes of material being. They also admitted the five elements of earth, wood, fire, water, and metal, as essential processes defining all development within nature. Because nature and man were created by the same elements and by the same forces, Neo-Confucians reinterpreted their earlier sociopolitical ethic of humaneness in mystical terms of forming one body with the universe. This mysticism identified the human body with all that existed. Some even spoke of heaven and earth as their parents, and the myriad entities of nature, organic and inorganic, as their companions. Most Neo-Confucians declared human nature (*sei*), or the original psycho-physical disposition of human beings, to be good, not empty as the Buddhists claimed. Furthermore Neo-Confucians claimed that the nature (*sei*) of the universe, i.e., its moral character, was originally good. The human project, as defined by Neo-Confucians, was to preserve this original goodness by moral self-cultivation and by moral action in the world.

Confucius (551 BCE–479 BCE) too respected the natural world. The *Analects*, the most authentic record of his thought, states that the wise person loves water (Chinese: *shui*; Japanese: *sui*), while the humane person loves mountains (Chinese: *shan*; Japanese: *san*). This reveals that early Confucianism linked moral concerns to ecological ones. It is also artistically significant, for the Chinese word for landscape painting is *shansui* and the Japanese is *sansui*, denoting a combination of bodies of water with mountains or hills, which were the constituent elements in a landscape painting. The latter were not just idealized depictions of nature; they were equally reflections of the moral consciousness of the artist. Furthermore Confucians' and Neo-Confucians, following Confucius' views about mountains and bodies of water, believed that morality involved right behavior toward nature and humanity.

Evidence abounds revealing a practical interest in the world of nature by Confucians and Neo-Confucians in Japan. By the late-seventeenth century, forests throughout the archipelago had been depleted due to an overexploitation as a result of a boom in the construction of castles and urban residences. Confucian scholars diagnosed the environmental crisis and called for its cure. Yamaga Sokō (1622–1685), for example, argued that forests should be conserved to ensure future productivity. Sokō admonished loggers to harvest lumber only in the proper season, not to overcut, and to reforest areas they had cut. One of Sokō's disciples, Tsugaru Nobumasa, daimyo of Hirosaki domain in northeastern Honshū, claimed that the three fundamental concerns of a feudal lord were for (1) his family line, (2) his heir, and (3) his mountain forests.

In his *Daigaku wakumon* (Dialogues on the Great Learning), Kumazawa Banzan (1619–1691) argued that humane government involved afforestation, river dike repair, and other conservation practices that would maximize agricultural productivity. Noting the crisis at hand, his disciples declared that "mountains and rivers are the foundations of a country." Full of hope, despite the depleted forests that were all too evident to him, Kumazawa claimed even that bald mountains could be covered with trees again if oats and other cover crops were planted so as to retain a thin layer of soil long enough for a forest ecosystem to reappear. Ultimately, the *Dialogues on the Great Learning* advocated harnessing samurai energy for the sake of the agricultural ecosystem: Kumazawa argued that samurai should be allowed to return to the countryside to labor as farmers rather than required to live in castle towns where they fell prey to urban vices. Kumazawa's proposals were so radical, however, that they were not heeded. Generations after his death, however, his more environmentally-oriented ideas, as advocated by others, did find favor.

Kaibara Ekken (1630–1714), influenced by the Neo-Confucian call to investigate the principles of things, authored the first systematic botanical study in Japan, the *Yamato honzō* (Flora and Fauna of Japan, 1709), describing and classifying over 1550 trees, plants, flowers, birds, fish, seashells, etc., into some thirty-seven categories. Ekken's "Preface" declares that because heaven and earth produce and reproduce myriad lifeforms, scholars must study their principles. Many later studies in herbology, botany, pharmacology, and zoology were influenced by Ekken's *Flora and Fauna*. He also encouraged the research of Miyazaki Yasusada (1623–1697) which culminated in the conservation-minded *Nōgyō zensho* (Agricultural Encyclopedia, 1696). In his preface, Ekken observed that a sage government, which nourished and educated the people, was facilitated by studying the *Agricultural Encyclopedia* because through it people could understand how to assist heaven and earth by cultivating the productive forces of nature.

Some late-Tokugawa intellectuals were influenced by notions of Western science as introduced to Japan via Dutch traders permitted at Nagasaki. Satō Nobuhiro (1769–1850), exposed to Western science but also influenced by Shintō, advocated techniques of agricultural management, based on the scientific study of natural law, to improve agriculture. He argued that this would realize the divine aim inherent in creation. Rejecting such clever short cuts, Ninomiya Sontoku (1787–1856) insisted instead on following the natural, creative cycles of heaven in agriculture, and repaying the virtue of heaven with conservation techniques which would rejuvenate nature. Miura Baien (1723–89), influenced by Western science, slightly modified the Neo-Confucian project of investigating things by advocating the investigation of the rational order (*jōri*) of heaven and earth in a disinterested, objective way.

Given the dense population which appeared during the Tokugawa, and its heavy taxation of the fragile ecosystem of the archipelago, one extremely poor in natural resources, Japan could easily have become, as Conrad Totman has suggested, an eroded moonscape rather than a verdant archipelago. In the seventeenth century, Japan was well on its way to a state of deforestation. It was saved largely by Confucian and Neo-Confucian scholars who called for systematic, scientific action. Yet it would be far-fetched to deny credit to Shintō and Buddhism, although admittedly they were less conspicuous in enunciating a conservation program saving Japan's forests, and thus its mountains, rivers, and fields.

Following the Meiji Restoration of 1868, when Japan embarked upon a course of rapid Westernization, concern for the natural environment lessened as the new Meiji state presided over the beginnings of industrialization by fostering polluting industries such as railroads. Though anathema to many, the goal of the Meiji state was to match, if not surpass, the industrial prowess of the Western nations which had imposed unequal treaties on Japan during the nineteenth century. Voices of protest against the noxious side effects were either ignored or muffled until Japan had effectively modernized. Widespread water pollution caused by the Ashio Copper Mine in Tochigi Prefecture from the late 1870s resulted in a major ecological disaster and a political scandal which simmered for nearly a century, pitting farmers against private industry and the government. Though notions of "the supremacy of agriculture" (*nohon shugi*) circulated in the late-Meiji, these were frequently no more than ideological currents.

The leading twentieth century philosopher of nature was Watsuji Tetsurō (1889–1960). Watsuji's *Fūdo* (Environment, 1935) criticized Heidegger's *Being and Time*, arguing that space, i.e., natural setting, and not just time, was crucial to human culture. Watsuji correlated the latter with three environmental zones: monsoon, desert, and pastoral. Japanese culture, he claimed, emerged from a monsoon zone where climatic vagaries produced passive, forbearing, inconsistent, sentimental, intuitive, and temperamental traits.

Since 1945, a decreasing number of Japanese have chosen to remain in the countryside close to nature. Just as the Meiji state rushed to modernize, so did postwar Japan race to renew its industrial sector oblivious to air and water pollution during the 1950s and early 1960s. In Minamata, Kyūshū, a chemical factory was finally held responsible for mercury poisoning, fifteen years after the poisoning first occurred in 1953. By the 1960s, Tokyo became internationally notorious for its air pollution. Citizen's protest groups rallied in the 1970s and 1980s, forcing the government to regulate pollution. Since the 1970s, environmentalists have argued for "environmental rights" (*kankyōken*), basing their claims on the 1947 Constitution which guarantees Japanese a "wholesome and cultured life."

See also: ►Agriculture in Japan Environment and Nature in Buddhism Forestry in Japan

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Environment and Nature: The Natural Environment in Native American Thought

Annie L. Booth

> We are the land… that is the fundamental idea embedded in Native American life… the Earth is the mind of the people as we are the mind of the earth. The land is not really the place (separate from ourselves) where we act out the drama of our isolate destinies. It is not a means of survival, a setting for our affairs… It is rather a part of our being, dynamic, significant, real. It is our self…
>
> It is not a matter of being "close to nature"… The Earth is, in a very real sense, the same as our self (or selves)… That knowledge, though perfect, does not have associated with it the exalted romance of the sentimental "nature lovers", nor does it have, at base, any self-conscious "appreciation" of the land… It is a matter of fact, one known equably from infancy, remembered and honoured at levels of awareness that go beyond consciousness, and that extend long roots into primary levels of mind, language, perception and all the basic aspects of being… Paula Gunn Allen, Laguna Pueblo (1979a: 191–192)

This is how one Native American presents her understanding of the indigenous understanding of nature. As will be explored in this article, many Native Americans present similar understandings. Their reciprocal relationships with nature permeated every aspect of life from spirituality to making a living and led to a different way of seeing the world, a more "environmental" way of seeing the world. But is this a true picture? Increasingly there has been debate over the nature of the Native American's relationship to the land, both past and present. This article will examine this debate as well as examine the way in which Native Americans view nature.

Caveats

Discussing any aspect of Native Americans requires caution, caution which has not always been employed when discussing Native American relationships with nature. Clear distinctions need to be drawn.

The first necessary distinction is that much is disguised in the concept of "Native American" or "Indian". The peoples who ranged, then and now, from the Arctic Ocean to Mexico and between two oceans encompassed a vast diversity of language, custom, practice and belief. They evolved to take advantage of different natural resources, to deal with dramatically different landscapes and climates and evolved again as they moved to different landscapes. To somehow lump this vast, rich diversity into a singular term is to fool ourselves into thinking we understand something we have no clear grasp of. It is to misunderstand the nature of people we are interested in understanding. Yet we do that lumping all the time. It leads to difficulty as when we misunderstand why two native tribes may choose different, conflicting courses of action: as for Scotland and England, proximity and the lumping in as "British" does not necessarily result in shared goals. Indeed the title of Native American is most equivalent to the idea of "European". There *is* something distinctly European when compared with North American, but there are limits to the understanding we can draw from the term.

Yet there may well be a "Native American" perspective when it comes to understanding the relationship with nature, and Native Americans as well as non-native writers frequently make this argument. This article itself will present the case for a sense shared across different native cultures, but I would urge the reader to use caution when thinking about "Native Americans".

The second necessary distinction is between the modern Native American and the historical Native American. When many writers discuss the Native perspective of nature there is a tendency to lump together

Native Americans from across the recorded historical period. The problems with this approach should be obvious: none of us live like our ancestors did 200 years ago. Modern Native Americans face different challenges than did their ancestors and many of those challenges affect how they can now relate to the land. Further, there is always a question of how well "traditional" philosophy and spirituality manage to translate into the modern world. Care must be taken not to conflate what is known about the beliefs and behaviours of the historical Native American and those of today's Native, although both might be instructive. While they inherit their past, they must live in the present.

Finally, I think it is worthwhile making the distinction between listening to what Native Americans say for themselves and what others write. Both bring different agendas to the table and it is useful to recognise that agenda when assessing the information presented. The Native speaks with the voice of cultural experience, an intimate understanding of native reality an outsider can never hope to achieve. Often they are privy to information or perspectives an outsider could not easily obtain. However, people from within cultures often have difficulty examining those cultures critically and are sometimes constrained about raising controversial issues. Non-natives do not have similar constraints and can be as critical as they wish. However, they will almost always lack that essential grasp, that innate understanding of a group of people and the way they think that a cultural resident will have. As such, it can be easy to misinterpret what is going on in a culture as modern critiques of anthropological findings are demonstrating. In terms of trying to grasp the nature of the Native American relation to nature, both past and present, it is most useful to explore both native and non-native writers, keeping in mind the perspectives of both.

The Native American Relationship with Nature

Although they varied significantly among different cultures, Native American relationships with the natural world tended to preserve ecological integrity, and appear to have done so over a significant period of time. These cultures engaged in relationships of mutual respect, reciprocity and caring with an Earth and fellow beings as alive and self-conscious as human beings. Such relationships were reflected and perpetuated by cultural elements including religious belief and ceremonial ritual.

In the songs and legends of Native American cultures it is apparent that the land and her creatures are perceived as truly beautiful things. There is a sense of great wonder and of something which sparks a deep sensation of joyful celebration. Above all else, Native Americans were, and are, life affirming; they respected and took pleasure in the life to be found around them, in all its diversity, inconsistency, or inconvenience. Hughes (1983) points out that only the newly arrived Europeans considered the land to be a "wilderness", barren and desolate. To Native Americans, it was a bountiful community of living beings, of whom the humans were only one part. It was a place of great sacredness, in which the workings of the Great Spirit, or Great Mystery, could always be felt.

Standing Bear (1933), a Lakota, wrote that Native Americans felt a special joy and wonder for all the elements and changes of season which characterized the land. They felt that they held the spirit of the land within themselves, and so they met and experienced the elements and seasons rather than retreating from them. For Standing Bear and the Lakota, the Earth was so full of life and beings that they never actually felt alone.

> There was no such thing as emptiness in the world. Even in the sky there were no vacant places. Everywhere there was life, visible and invisible… Even without human companionship one was never alone (Standing Bear 1933: 14).

This statement echoes a central belief consistent across many Native American cultures – that the Earth is a living, conscious being. The Koyukon of central Alaska, for example, see the Earth as something alive and powerful, and therefore, something which must be treated with respect:

> For traditional Koyukon people, the environment is both a natural and supernatural realm. All that exists in nature is imbued with awareness and power… all actions towards nature are mediated by consideration of its consciousness and sensitivity. The interchange between humans and environment is based on an elaborate code of respect and morality, without which survival would be jeopardized (Nelson 1983: 240).

The belief in a conscious, living nature is not simply an intellectual concept for Native American cultures. For most, perception of the landscape is important in determining perception of self. Native American cultures and histories are based in the land and their lives are inseparably intertwined with it. In a most real sense, it *is* their life. This interconnection between person and land is not merely a thing of historical significance. Present-day Native Americans continue to acknowledge their ties to the land. Utes in the Southwest, faced with the question of mining on their lands are deeply troubled, for the land is more than a mere resource, as several individuals have tried to explain:

> The land is a living body with spirit and power, which contains tribal genealogy. It is necessary for

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> the people to remain in the place in which they have always been, as guardians, and as an inseparable part of that place and space.

The tribe does nt want to diminish the land, but not because of money issues. But because you diminish *us* when the land is eaten away (emphasis in original) (Romeo 1985: 160–61).

At the Tellico Dam congressional hearing in 1978, Jimmie Durham, a western Cherokee, tried to express what his people felt for a land they could no longer even live upon, but wished to preserve nonetheless:

> In the language of my people… there is a word for land: Eloheh. This same word also means history, culture and religion. We cannot separate our place on earth from our lives on the earth nor from our vision nor our meaning as a people… So when we speak of land, we are not speaking of property, territory or even a piece of ground upon which our houses sit and our crops are grown. We are speaking of something truly sacred (Matthiessen 1984: 119).

In Native American relationships with a living, conscious world, reciprocity and balance were required from both sides. Balance was vital: the world exists as an intricate balance of parts, and it was important that humans recognized this balance and strove to maintain and stay within this balance. All hunting and gathering had to be done in such a way as to preserve the balance. Human populations had to fit within the balance. For everything that was taken, something had to offered in return, and the permanent loss of something, such as in the destruction of a species, irreparably tore at the balance of the world. Thus, offerings were not so much sacrifices, as non-Natives were inclined to interpret them, but an appropriate acknowledgment of a great gift. In this way, the idea of reciprocity emerges. From the Native American perspective, as Hughes describes it, "mankind depends on the other beings for life, and they depend on mankind to maintain the proper balance" (Hughes 1983: 17).

The respect and approval is two-way: humans both give and receive value and self-worth from the natural world. Part of the idea of reciprocity is the necessity and importance of interaction. Participation in reciprocity is vital; a failure to interact, or a breakdown in interaction, leads to disease and calamity. Thus, everything that is used in everyday life is used for its part in that interaction; it becomes a symbol of sacred interaction and relationship between the people, the plants, the animals, and the land. Rituals such as those used for healing are not designed to ward off illness or directly cure the ill person. Rather, they are designed to remind the ill person of a frame of mind which is in proper relationship with the rest of the world, a frame of mind which is essential to the maintenance of good health.

An old Keres (Pueblo) song goes like this:

> I add my breath to your breath
> That our days may be long on earth
> That the days of our people may be long
> That we may be one person
> That we may finish our roads together
> May our mother bless you with life
> May our Life Paths be fulfilled (Allen 1986: 56).

The reciprocal relationship embodied in this song, the sharing of breath is the sharing of life, is one of the central insights into Native American worldviews. One does not act in isolation, but must act with respect towards the others one shares the universe with. Involved with a *living* universe, the Native American is engaged in a constant dialogue with a network of relations, human and non-human, and natural and supernatural. Sam Gill explains that Native Americans hold a "person to person" relationship with the environment as the power of life itself is personified and inextricably linked with, and identical to, the natural world (Gill 1989: 30). This sense of relationship is explicit in every aspect of life. Consider Ojibwa Winona LaDuke's (1990: 16) comments on the ordinary, mundane activity of hunting and gathering:

> Whether it is wild rice, whether it is fish, whether it is deer or turtles, when you go and take something from the land, you pray before you take it. You offer tobacco; you offer a prayer to that spirit and to the creation of a part of that. *You take those things because you have a relationship with all the other parts of the creation. That is why you are allowed to take those things*. You take that and you give something back as a reciprocal arrangement, because that is how you maintain your relationship (emphasis added).

As countless sacred rituals, ceremonies, songs and teaching stories make clear, maintaining the relationship between human life and non-human life is the heart of Native American spirituality. The Sun Dance of the Plains Indians, which has attracted considerable interest for its more gruesome aspects (including a long government ban on its performance), is not about the ability to endure pain. It is about humanity's willingness to offer blood and spirit towards the maintenance of the balance of life, as Brown's observations make clear:

> The Sun Dance… is not a celebration of man for man; it is an honoring of all life and the source of all life, that life may go on, that the circle be a

> cycle, that all the world and man may continue on the path of the cycle of giving, receiving, bearing, being born in suffering, growing, becoming, giving back to earth that which has been given, and so finally to be born again (Brown 1978: 12).

A sense of embeddedness in the rest of the world has profound implications for how one chooses to live and interact with others. It is also one reason why the displacement of Native Americans from their lands, and the subsequent damage to the land, was and is so socially and psychically devastating. As Allen points out, the despair that appears in many writings by Native Americans is the despair of having lost "that perfect peace of being together with all that surrounds one", a loss that is irreplaceable (Allen 1979a: 192). Peter Matthiessen agrees that this understanding is found consistently across a wide diversity of cultures:

> It is not a matter of 'worshiping nature,' as anthropologists suggest: to worship nature, one must stand apart from it and call it 'nature' or 'the human habitat' or 'the environment.' For the Indian, there is no separation. Man is an aspect of nature… (Matthiessen 1984: 9).

Or consider part of a sacred Navajo chant, designed to remind the person every day of their connections with life:

> The mountains, I become part of it…
> The herbs, the fir tree, I become part of it.
> The morning mists, the clouds, the gathering waters,
> I become part of it.
> The wilderness, the dew drops, the pollen…

I become part of it (Brown 1989: 20).

Momaday describes living apart from the land with horror: "such isolation is unimaginable" (Momaday 1979: 166). As Allen confirms, all poetry, ceremony, song and story remind Indians of their part in a living evolving whole by virtue of their willing participation (Allen 1979b: 226).

Part of Native relations with nature is encapsulated in traditional spirituality. Traditional Native American spirituality has been the target of attack and suppression by the European invaders since 1492 and it continues to be a significant political, legal and emotional minefield. After 500 years of suppression, some have legitimately questioned whether there is such a thing as "traditional" Indian spirituality. Much knowledge and practice was lost through genocide and through the devastating plagues that swept the New World after the arrival of the Europeans. Many Native Americans were forced, or chose, to convert to European religions, and their descendants remain faithful practitioners of Catholicism or some form of Protestantism. In both the United States and Canada what "traditional" practices remained were outlawed and remained illegal until recently. Yet in spite of everything, Native Americans themselves state that unique, viable spiritual practices continue to exist and flourish.

One key question is, what are spiritual practices intended to do? For many Native Americans, spiritual practices were part of an ongoing dialogue with the world. Lakota Deloria (1973: 102) describes it thus: "The task of the tribal religion, if such a religion can be said to have a task, is to determine the proper relationship that the people of the tribe must have with other living beings." Spiritual practices become a way of learning how to live well, and, in this case, to live well with the natural world. They are methodologies for reaching an appropriate level of consciousness, or mindfulness, of the world. Further, these practices, which interlink behaviours, feelings and ethics, are completely identified with the very survival of the people and the land.

Native Americans saw that all that existed shared in sanctity as they were all fragments of God. While Native Americans did not worship nature, they recognized that all life around them was sacred, for "each form in the world around them bears such a host of precise values and meanings that taken all together they constitute what one would call their 'doctrine'" (Brown 1985: 37). When Native Americans saw themselves in terms of community, their definition of community included the natural community. Spirituality requires that humanity and "the rest of creation (be) cooperative and respectful of the task set for them by the Great Spirit" (Deloria 1973: 96). That task is dwelling with balance and with harmony.

> Respect in the American Indian context does not mean the worship of other forms of life but involves two attitudes. One attitude is the acceptance of self-discipline by humans and their communities to act responsibly towards other forms of life. The other attitude is to seek to establish communication and covenants with other forms of life on a mutually agreeable basis (Deloria et al. 1999: 51).

Deloria (1973) has given a particularly thorough consideration to the linkage between place and spirituality, contrasting it with Christian practice. Christianity, he notes, although originating in a particular land (the Holy Land), can and does exist almost anywhere on the face of the earth without extensive modification of the central creed; i.e. the Christian god is "portable". Traditional Native American spiritual practices, however, cannot without damage be moved from a given landscape. Rather, they have evolved to incorporate and reflect particular elements of the chosen land. Where would the Navajos be without the Four Mountains, or the Lakota without the Black Hills? When poet Paula Gunn Allen writes "We are the land…," her statement, to her, is literal truth. It is who she is as a Laguna (Allen 1979a). The same sense of identification is true for Kiowa N. Scott Momaday, who writes of giving himself to the "remembered earth" (Momaday 1979: 164–165). Or for Lakotas Black Elk and Standing Bear, who speak of the devastating loss of the Black Hills to gold miners (Standing Bear 1933; Neihardt 1932, 1975). The land is who a Native American is and it affects his/her responses to the world. Consider Ronald Goodman's interpretation of what, to the American government, was merely a question of land expropriation, but to the Lakota was an attack on their spiritual integrity:

> Traditional Lakota believed that ceremonies done by them on earth were also being performed simultaneously in the spirit world. When what is happening in the stellar world is also being done on earth in the same way at the corresponding place at the same time, a hierophany can occur; sacred power can be drawn down; attunement to the will of Waken Tanka can be achieved.
>
> Our study of Lakota constellations and related matters has helped us appreciate that the need which the Lakota felt to move freely on the plains was primarily religious. (Goodman 1990: 1)

Such an indelible bond with the land, however, is clearly a deliberate construction by the tribes. Indian groups have been migrating across the North American continent for the last 40,000 years. Some are very recent arrivals; the Navajo only migrated into the American Southwest from Alaska and the Yukon about 600 years ago (Dickason 1992). They are not then, "native" to the area. They have, however, reconstructed their religion to reflect the new land in which they dwell, in part by borrowing from earlier residents such as the Hopi. From this, Deloria draws a conclusion of interest: he believes it is possible for a cultural group to "consecrate" a particular landscape, if they are capable of seeing themselves in terms of that landscape (Deloria 1973: 295).

For the Native American, all living is spiritual practice. Thus, material possessions are symbolic of sacred relationships. Moccasins remind the wearer of their connection with the earth, with the plants and animals on it, and so of the nature of reality itself. A pipe becomes a teaching tool, a history of the people, and a reminder of how all in the world are related. When smoked in a sacred manner, it is offered to "all my relations" (Lame Deer and Erdoes 1972: 12; 150–253). Activity which maintains life is also part of the ongoing sacred process; for a Native American the acts of hunting or weaving or building a house are also religious activities. Toelken (1976) also points out that Native Americans rarely distinguish between their religious life and their secular life. Instead there is nothing in life that is *not* religious. Everything from hunting to healing is a recognition and affirmation of the sacredness of life. In the weaving of a basket is the creation of the whole world. In a proper life there is never a sense of disconnectedness from the Earth. As Peter Matthiessen suggests,

> …the whole universe is sacred, man is the whole universe, and the religious ceremony is life itself, the miraculous common acts of every day. Respect for nature is respect for oneself; to revere it is self-respecting, since man and nature, though not the same thing, are not different… (Mattheissen 1981: 12).

In all traditional Native American spiritual practice the sense of the earth as alive was part of a sacred understanding of life and human obligations to life, as Deloria discusses,

> Coming last (in creation) human beings were the "younger brothers" of the other life forms and therefore had to learn everything from these creatures. Thus human activities resembled bird and animal behaviors in many ways and brought the unity of conscious life to an objective consistency (Deloria 1999: 50).

This idea reoccurs in contemporary Native Americans as well. Allen sees the distinguishing characteristic between Western and Native American thinking as the "magicalness" in Indian perception. This is not a childish magicalness but a perception of everything in the world as alive, viable and subject to the need to grow and change. An Indian, she says, is one who

> assumes that the earth is alive in the same sense that he is alive. He sees this aliveness in nonphysical terms, in terms that are familiar to the mystic or the psychic, and this gives rise to a mystical sense of reality that is an ineradicable part of his being (Allen 1979b: 233).

The vital importance of maintaining essential relationships has serious implications for how Native Americans deal with their fur-clad relatives, the animals. The idea which appears over and over is "kinship" with other living beings, as Allen comments:

> All are seen to be brothers or relatives (and in tribal systems relationship is central), all are offspring of the Great Mystery, children of our mother, and necessary parts of an ordered, balanced and living whole (Allen 1979b: 225).

Brown (1985) comments that non-humans are the links between humans and the Great Mystery. To realize the self, kinship with all beings must be realized. To gain knowledge, humans must humble themselves before all creation, down to and including the lowliest ant. Nature is a mirror which reflects all things, including that which it is important to learn about, understand and value throughout life. Further, many tribes acknowledge that humans found a world to come in to and a way of making a living as the result of conscious, caring gifts from the animals. The creation myths of tribes such as the Arapaho or the Iroquois tell of how the Creator created the world with the help of animals, from mud brought up from beneath endless waters by a muskrat or rested on the back of a willing turtle. Sacred objects are donated, as when eagle grants the use of his feathers, and food is found because holy animals offer their flesh as a gift (Harrod 1987: 51).

However, some anthropologists such as Harrod (1987) or Hultkrantz (1981), see a tension inherent in the problem of having to kill animals with whom one had a deep, intimate relationship. Looking at the Plains Indians, Harrod observes that such tensions are apparent in creation myths. The Blackfoot, for example, tell of a time when humans were hunted by the buffalo. To change this, the god taught the Indians to make bows and arrows and then to hunt. In compensation for becoming food, the buffalo and other animals became spiritual helpers which the Blackfoot were to obey. In this fashion, and through other rituals, the tension inherent in eating social equivalents is partially resolved (Harrod 1987: 44–45, 53–54).

Most Native American legends speak of other species as beings who could shed their fur masks and look human. They once shared a common language with humans, and continued to understand humans after the humans had lost their ability to speak to the animals. The animals partook of the sacredness of life, and were often the descendants of the powerful beings who had lived on the earth before humans. An animal was something more than its furry, four-footed shape, more than what was seen by human eyes. It was, says Nelson (1983: 31), a personage and a personality with a lineage far older than humanity's. Laird describes animals this way:

> It is to be remembered that the pre-human Immortals (the gods, if you will) were Animals Who Were People. These Forerunners, these Ancient Ones whose bodies shimmered as it were between animal and human forms, these denizens of the elder dream-world, have long since taken their final departure; yet they remain as the visible animals of this everyday world… Mythic Coyote, supertrickster and pattern-setter for mankind, is not [coyote], raiding fields and howling on the hills before dawn – and yet in a certain mystical sense, he is (Laird 1976: 110).

Even into the present, the Native Americans respect their relationship with animals and believe that the respect and caring go both ways. Thus, communication is possible, as Yukon Indian Irene Isaacs explains:

> You can tell them and they do it, that wolf. You tell them, "Kill something for me!" And then the wolf will. Then you come, and they are going to kill a moose and you're going to find it and have moose meat. They do that, wolves. So they understand Indians. And other animals, that's what I tell my son about that too. You've got to treat animals good (McClellan 1987: 280).

Martin, discussing subarctic bands, also notes that a sympathy builds up between the hunter and the animal persons who are hunted, a sympathy which pervades human life. At all times, there is a mutual obligation felt, an obligation to be courteous. An animal is not killed unless the hunter obtains its consent in the spiritual world; the animal must be willing to surrender itself to the hunter. Hunting gives meaning to the hunters' lives; it gives a sense of identity. It is the animal who grants this sense of identity (Martin 1978).

According to Nelson, the Alaskan Koyukon believes that animals and humans are distinct beings, their souls being quite different, but that animals are powerful beings in their own right (Nelson 1982, 1978). Consequently a complex collection of rules, respectful activities and taboos surround everyday life and assist humans in remaining within the moral codes that bind all life. Hunting, therefore, is conducted with respect and with ritual from the moment the hunt is conceptualized until the animal's remains are properly disposed of. Animals are not offended at being killed for use, but killing must be done humanely, and there should be no suggestion of waste. Nor can the body be mistreated: irreverent, insulting or wasteful behaviour could result in the future loss of the species, which would no longer make itself available for killing. Even gathering must be done respectfully. Yukon women gathering roots are pleased by the find of caches of roots already collected by mice. However, they are careful to leave some for the mice. Otherwise the mice are likely to come raiding Indian supplies during the winter (McClellan 1987: 139–140).

The practical consequences of such relationships with animals are profound. Species were not endangered or exterminated, for exterminating a species would have meant the elimination not only an essential life, but a kindred being. Hughes (1983) believes that the "ecological consciousness" of the Native American was in part due to their sense of kinship with the rest of the world.

The need to both respect *and* use animals continues today, although it can engender controversy. Whaling, for example, continues to be a controversial subject. When a west coast tribe, the Makah, decided to return to their traditional practice of whaling in 1999 it provoked outrage on the part of environmentalists and even ordinary people; it prompted immense television coverage, the attempted intervention of the Sea Shepard Society and required the protection of the US Coast Guard for the hunters (Blow 1998). However as Tom Mexsis Happynook, chair of the World Council of Whalers, argued, whaling represents a modern practice of responsibilities which integrate the native culture into the environment, which "maintain the balance within the environment and ecosystems":

> For the Nuu-chah-nulth hunters the taking of any life was looked upon as the most sacred responsibility that we have had bestowed upon us, because of this my grandfather taught me the hunters had to pay dearly for the honour of taking a life. This especially applied to the whaling chiefs because they hunted the greatest and largest mammal on earth.

People have a very important role to play in the environment which is to help maintain the balance through our relationship with the ecosystem; that one of the most important tools we have at our disposal to meet this obligation is respectful, responsible and sustainable utilization of the resources (the gray whale population on our coast is a perfect example of that responsibility) (Happynook 1999: 3).

Non-natives see an intelligent, sympathetic endangered species. Whaling Natives see the same but also a creature with which they have had a profound relationship for millennia, the hunting of which underlies who they are as a culture.

This argument has a scientific basis as well. For example, the Inuit in northern Canada have long argued that they had a better sense of the whale population, through yearlong observation, than did the visiting government whale biologist and pushed for a larger harvest quota. Subsequent non-native research has begun to confirm the greater accuracy of traditional ecological knowledge in this instance (Wohlforth 2004). It is worth recognizing that the sense of relationship, of reciprocity and of participation in the world encapsulated in Native spirituality, and as reflected in how they interacted with animals, had a very practical ecological link for many Native Americans, as Deloria describes:

> The Indian principle of interpretation/observation is simplicity itself: "We are all relatives." Most Indians hear this phrase thousands of times a year as they attend or perform ceremonies… this phrase is very important as a practical methodological tool for investigating the natural world and drawing conclusions about it that can serve as guides for understanding nature and living comfortably within it. "We are all relatives" when taken as a methodological tool for obtaining knowledge means that we observe the natural world by looking for relationships between various things in it. That is to say, everything in the natural world has relationships with every other thing and the total set of relationships makes up the natural world as we experience it (Deloria 1999: 34).

Sounds remarkably like the modern science of ecology. But were Native Americans ecologists?

The Ecological Indian?

In the last two decades the academic discussion has moved slightly in focus from what view of nature Native Americans had in the past or present, to how this might translate into action. The key question appears to have become, where Native Americans truly the first environmentalists? Were they "ecological" Indians? Or were they, as Berkes terms it, "intruding wastrels" destructive of their ecosystems, surviving only because of they moved around and had fortuitously small populations (Berkes 1999: 145). Or are they "fallen angels", former noble savages whose ancestors lived in harmony with nature but whose descendants threaten fragile wildlife populations and at-risk wilderness? This is a challenging debate within ecological and anthropological circles, one to which entire conferences are devoted. A critical discussion of this issue is provided in a Extra to this article. As this Extra indicates, "using" Native Americans as ecological "models" is difficult and potentially misleading. That said I still wish to consider how they have adapted to the land and whether the adaptations could be considered ecologically successful. While most Native Americans, I think, would have considerable difficulty in fitting themselves into a category as shallow and narrow as "environmentalist", I believe that non-Natives have something to learn about living with the land.

It must be remembered that for most Native Americans, the land and its residents has many more shades of meaning than non-Native societies are willing to consider. The land is a source of sustenance, and was exploited for that purpose. However, the land also holds other meanings for past and present Indian cultures. Nelson remarks of the Alaskan Koyukon, principally hunters and gatherers, that their land

> is permeated with different levels of meaning – personal, historical and spiritual. It is known in its finest details, each place unique, each endowed with that rich further dimension that emerges from the Koyukon mind (Nelson 1983: 245).

To picture Native Americans as people who passed through the land leaving no trace, as some environmentalists are apt to do, is to deny an ecological reality, and, in passing, to damn the Native American with faint praise (with the implication that they were incapable of making such a mark). As Hughes remarks of the Northeastern Indians,

> Like all human cultures, the forest Indians were agents of change in nature. For at least 10,000 years, and perhaps much longer, they had lived within the forest ecosystems, hunting, fishing and gathering with skill and experience. Their land was not a wilderness, but a woodland park which had known expert hunters for millennia (Hughes 1977: 7).

That the lands remained productive was in part due to Native American lifestyles that were more or less mobile (even the farmers moved to new areas when the soil was exhausted), as Cronon (1983), Merchant (1989) and Krech (1999) document. It may have also been the result, in some cases, of a sense of stewardship. Many tribes deliberately took (and still take) steps to ensure that human induced changes did not damage their source of livelihood. Among the Yukon Indians, these steps took the form of a belief in ownership of certain areas.

> This kind of ownership meant that a headman and the people who traveled with him had the first right to use the products of the local land and water, but they also had the duty of taking care of these resources… It was part of their job to see that people did not overhunt, overtrap or overfish the area, as well as to see that as far as possible everybody got enough to eat… (McClellan 1987: 151–152).

Among the Cree, efforts to conserve resources took the form of dividing the land into regions, with a hunting camp in the centre. The camp was occupied until both animal populations and resources such as firewood and green bedding boughs were reduced. Old campsites were cleaned prior to leaving to avoid offending the spirits, who would send away the animals if the land was not cared for (Tanner 1979: 74–75). Such concerns did not mitigate the ecological impacts; the game population and the camp site recovered because the Indians moved elsewhere. However, the concern for the spirits' good will, in combination with a mobile population, may have limited irreparable damage, at least where overall human population numbers were low. Such land stewardship practices can still be found in modern native cultures across northern Canada and Alaska, as well as elsewhere.

Of great concern to Native Americans, for obvious reasons, was the conservation of game animals. Harrod notes the presence of several Trickster stories amongst the Plains Indians, in which the Trickster character exploits trusting animals to satisfy an insatiable appetite. In this pursuit he is foolish enough to eliminate almost all the animals, usually missing just one:

> That Trickster is foolish and even a dangerous hunter appears in the theme of the "last animal" which runs through the narratives. As a consequence of escape, often brought on by a momentary lapse in Trickster's character, an animal survives to continue the species. Clearly the hunting techniques of Trickster are not affirmed; rather, the foolishness and potentially disastrous consequences of such activities are underlined in these stories (Harrod 1987: 63).

There appears to have been a real concern, expressed through such stories, that the animal populations not be decimated. Recent anthropological work among the twentieth century Cree and Koyukon, among others, has uncovered what researchers feel are deliberate conservation practices. Tanner (1979) and Berkes (1999) observe that the Cree are constantly assessing plant and animal population levels. Long- and short-term changes in populations are understood both in spiritual terms (the activities of the Animal Masters) and in terms of environmental factors (food supplies, water, weather patterns, forest fires, and hunter activities). The Cree govern their hunting activity on the basis of these observations.

Among the Koyukon, conservation activities are also based on their keen observation of the ecological dynamics of their lands. The people regulate their harvests in a number of ways to ensure that plant and animal populations remain healthy. The Koyukon may consciously avoid taking more individuals than they believe can be naturally replaced, or they may take special measures that they hope will enhance the productivity of a species. They avoid killing female waterfowl, bears and moose in the spring when they are breeding. Hunting activities are usually spread over as wide an area as possible. Young plants and animals are usually not harvested, but are allowed to mature. Trappers are very cautious about where and how many animals are harvested (Nelson 1983: 221–223). For example, trappers are careful when trapping the sedentary beaver.

While such practices are noteworthy, Nelson is careful to point out that there is no objective data to prove that these intentional limitations actually achieve their conservation goals. He does, however, feel that the Koyukon could be considered to be practising a "conservation ethic". Tanner is also unable to document the impacts of the Cree's conservation practices on resource populations. Berkes, however, makes an extensive case for the conservation ethic of modern Cree, although he notes it was not without many mistakes and misapprehensions.

A final issue to consider is the modern need for Native cultures to make a living from the land upon which they live. This often involves necessary, and not always satisfactory, compromise between traditional beliefs regarding nature and resource extraction. Forestry is a common industry on many Native lands in both Canada and the United States. One well known, long term industrial forest operation has been undertaken by the Menominee of Wisconsin. The Menominee have been logging on their reservation for over a century and still have a robust and healthy forest ecosystem. Their forester, Marshall Pecore, argues it is a unique balancing act.

> It is said of the Menominee people that the sacredness of the land is their very body, the values of the culture are their very soul, and the water is their very blood. It is obvious, then, that the forest and its living creatures can be viewed as food for their existence... Their story is one of successful equilibrium between harvesting and using only what the land can provide, and maximising the jobs and other economic benefits that flow from a sustained-yield harvest (cited in Davis 2000: 55–56).

However it is also not always easily achieved. The band I work with, Tl'azt'en Nation, also runs a commercial forestry operation and have done so for 20 years. They feel they have been less successful in integrating traditional values and, correctly my analysis suggests, blame it on the restrictions surrounding forestry in British Columbia, as Grand Chief Ed John indicates:

> There's a conflict right there. That one is really a conflict that we're conscious of – trying to look at a bottom line and manage in a traditional way – and we haven't really been able to marry those two successfully and our teachings… they're still there but… you know there's a real major conflict in thinking and ideology right there along with our teachings, when you go into the bush to take a plant for medicine, you return something back. And then in logging you go in there and clearcut an area, you don't put anything back except new trees… I have a concern about that, and how we do that I'm not sure right now except to try to build those traditional teachings and principles into your management plans, push those, work those. Some of those don't necessarily, are not necessarily acceptable by the (British Columbia) Ministry of Forests, so it's an ongoing struggle there too because you have different thinking about how that forest should be managed (Booth 1999: 33).

However, Natives need to make their own compromises:

> Conservation and development-policy-making and -planning often seems to assume that we, the aboriginal peoples, have only two options for the future: to return to our ancient ways of life or abandon subsistence altogether and become assimilated into the dominant society. Neither option is reasonable. We should have a third option: to modify our subsistence way of life, combining the old and the new in ways that maintain and enhance our identity while allowing our society and economy to evolve (Erasmus 1989: 229).

Conclusions

Are Native Americans ecologists? Environmentalists? Or peoples with a unique understanding of the natural world that might or might not have translated into a better way of living with the earth. Readers will need to draw their own conclusions. However, I agree with Berkes (1999: 182) when he notes that, "A fundamental lesson of traditional ecological knowledge is that worldviews [and beliefs] do matter."

> The challenge is to cultivate a kind of ecology that rejects the materialist tradition and questions the Newtonian, machinelike view of ecosystems… The indigenous knowledge systems of diverse groups, from the Dene of the North American subarctic to the Fijians of the South Pacific, provide an alternative view of ecosystems. This is a view of an ecosystem pulsating with life and spirit, incorporating people who *belong* to that land and who have a relationship of peaceful coexistence with other beings.

Native American views of nature, as articulated in this article, attract a great deal of interest as well as controversy. There is a fascinating psychological question as to why, as a society we are attracted to them, even if they are not part of our cultural heritage. Perhaps we need to believe there are ways of seeing the world that might lead to the preservation of functioning ecosystems. Perhaps this is the same basis from which others are driven to criticise the concept of the ecological Indian: we do not have to feel as guilty for our behaviour if we are all equally, inherently, destructive of nature. The problem I see is not that we are able to be inspired by Native Americans, or that they drive us to justify our actions against ecosystems, but that in doing either we lose sight of the people themselves and the complex nature of the challenges they face. We need to allow ourselves that inspiration, the critical question as well, but we need to always remember the *people* who articulate a reality that perhaps all humans can understand.

> Once in his life a man ought to concentrate his mind upon the remembered earth, I believe. He ought to give himself up to a particular landscape in his experience, to look upon it from as many angles as he can, to wonder about it, to dwell upon it. He ought to imagine that he touches it with his hands at every season and listens to the sounds that are made upon it. He ought to imagine the creatures that are there and all the faintest motions in the wind. He ought to recollect the glare of noon and all the colours of the dawn and dusk.
>
> I am interested in the way that a man looks at a given landscape and takes possession of it in his blood and brain. For this happens, I am certain, in the ordinary motion of life. None of us lives apart from the land entirely; such isolation is unimaginable. We have sooner or later to come to terms with the world around us – and I mean especially the physical world; not only as it is revealed to us immediately through our senses, but also as it is perceived more truly in the long turn of seasons and of years (Momaday 1979: 164, 166).

Extra: The Ecological Indian?

In the last two decades the academic discussion has moved slightly in focus from what view of nature Native Americans had in the past or present, to how this might translate into action. The key question appears to have become: were Native Americans truly the first environmentalists? Were they "ecological" Indians? Or were they, as Berkes terms it, "intruding wastrels" destructive of their ecosystems, surviving only because they moved around and had fortuitously small populations (Berkes 1999: 145). Or are they "fallen angels", former noble savages whose ancestors lived in harmony with nature but whose descendants threaten fragile wildlife populations and at-risk wilderness?

This interest in Native American relationships with nature has an old history. Influential members of the early American conservation movement were deeply impressed by Native Americans and their relations with the natural world (Cornell 1985). This question however came under intense consideration with the 1960s environmental movement. Former Secretary of the Interior Stewart Udall (1973) articulated this best in his influential article entitled "Indians: First Americans, First Ecologists." Interest burgeoned and works such as *Black Elk Speaks* (Neihardt 1932, 1975), *Rolling Thunder* (Boyd 1974) and the now controversial speech of Chief Seattle became cultural icons. The story of Chief Seattle's speech is somewhat instructive in how eagerly and uncritically the public embraced the idea of the Native environmentalist. While Seattle, a Dwarmish chief, did indeed make a highly articulate speech to the US government on the appropriation of his tribe's land, what has become know as Seattle's speech was actually a highly liberal adaptation written by a non-native as narration for a 1970s film (Kaiser 1985).[1]

Native Americans were not unwilling to have this part of their culture articulated. Many writers of the 1970s and 1980s articulating the Native American and nature relationship were Native Americans such as Vine Deloria, Jr., Paula Gunn Allen, John Lame Deer, Winona LaDuke and N. Scott Momaday.

By the 1980s, however, the issue came under academic scrutiny and the picture was no longer clear cut. Anthropologists and historians marshalled on both sides. People like Hughes, Nelson, Cronon, Gill, Toelken, Brown and others presented plausible cases for cultures which, while not gentle nature lovers, nonetheless maintained functioning ecosystems through cultures which integrated nature into spiritual and living practices. Many were examining historical cultures, although Gill, Brown, Toelken and Nelson were working with modern cultures. Making the case that Native Americans were not model ecological citizens were scholars such as Callicott, Martin and Krech.

The debate has not as of this writing been resolved. Both sides have over time made some persuasive cases. The "good ecological" native arguments are, simplified, based on two threads. The first thread is the ecological knowledge and "philosophy" contained in Native culture past and present. This has been discussed in the section on Native views of nature. The second thread is the ecological state of North America when European explorers discovered it. While research has demonstrated that the landscape was not unmanipulated by human residents, nonetheless after an occupation of between 10,000 and perhaps 40,000 years (Dickason 1992) North America looked like an Eden to European arrivals. Forest cover was extensive. Wildlife, including large carnivores, appeared in astonishing numbers. It was a sharp contrast to the humanized, ecologically impoverished landscape that European explorers have left behind. This is the crux of the argument of those who argue that Native Americans offer models of human–nature relationships well worth admiration and study.

Those who argue against the concept of the "ecological Indian" also draw on evidence from the pre-European era. Shepard Krech III is now one of the leaders in the move to debunk the myth of the ecological Indian and he does so in his most recent book (Krech 1999) based largely on historical activities. He also does so by defining the truly ecological Indians clearly as ones who did *not* change, damage or irrevocably alter their ecosystem. By doing so, he clearly defines what we (or at least the scholars debating the ecological Indian myth) think of as ecological or environmental behaviour: the opposite. By this definition, as Krech successfully argues, the historical Native American was not ecological or an environmentalist. There is considerable archaeological evidence, for example, that indicates many cultures did indeed damage their ecosystem through overuse of resources. Krech cites the midwestern Cahokia culture which flourished between the twelfth and fourteenth centuries. They apparently denuded their landscape so severely they needed to import wood. The earlier southwestern civilization of the so-called Anasazi may have also collapsed as a consequence of overuse of resources (Krech 1999: 76–77). Other cultures constantly altered the landscape deliberately. Cultures in the eastern woodland and the prairies fired habitats, deliberately, to alter vegetation to attract different browsers or to force animals into more easily hunted areas (Krech 1999: 105) or to produce berries. While these fires were prompted by considerable ecological knowledge of fire succession stages, these fires often got out of control and were highly destructive. Along the east coast there are still areas burned down to rock (Patterson 1988). Krech also cites the hunting of bison through massive drives into pens or over cliffs, with subsequent waste of considerable meat. As Krech does point out, there is equal evidence of careful use of all resources as well. However, what is clear in all his careful scholarship is the Native Americans used, altered and in some cases damaged nature. By non-native definition they are unecological, non-environmental. Krech confirms earlier arguments put forward by scholars such as Callicott and Martin.

Both sides make careful sophisticated arguments that interested readers should approach in their entirety and draw their own conclusions. I remain uncertain as to utility of the debate itself (not

[1] A copy of the speech and more on the controversy can be found at: ►http://www.geocities.com/Athens/2344/chiefs4.htm.

that I disagree with debate). I have done a lot of work with a Native Canadian band (the politically correct Canadian term is First Nations) in north central British Columbia, who in turn have given me a nickname: the Blonde Woman. It is said with liking. I am grateful for the name, it means people are willing to talk to me when I show up at their door; the name came with trust. What I find fascinating however, is that it reflects the most visible feature by which I am defined as *non-Indian*. I have never met a blonde Carrier native; my blondeness defines me as completely the outsider. By its measurement I am most clearly not native. That definition of who is and is not is important, even crucial to people. But the Band I work with does not make the usual corollary mistake; they do not stereotype me as *the other*, and their focus on my blondeness reflects that too. It is the least important non-native characteristic they could focus on. Instead they let me prove myself as an individual, good or bad, trustworthy or not. They do not stereotype me. It is not a courtesy we tend to return.

To talk about the "ecological" or "non-ecological" Native American is to talk of stereotype. Part of the stereotype is to assume that all Natives are alike and can be characterised as part of that larger group. One bad (or non-ecological) Indian therefore manages to spoil the bunch. To be fair we do this to other groups as well, one bad poor black inner-city dweller casts a shadow on all, but this does not make it a good practice. If we wish to assess a native group's ecological goodness we should assess only that group within its ecosystem, history and circumstance. However, this glosses over a larger problem.

When we are assessing an "ecological Indian" status we are doing what my Band does *not* do to me, blonde hair not withstanding: we hold each Native group up against our concept of Indianness and, usually, judge them lacking. Even those disputing the ecological Indian concept are rebelling against an ingrained stereotype of the Native as nature child at home in the wilderness. Those images are as old as Christopher Columbus (Berkhofer 1979; Francis 1992; Berkes 1999). There are two key problems with this stereotype. The first is that there is something like an essential Indian or Indianness. The second is the imposition of a thoroughly non-Native concept of ecological or "good" nature–human relationships.

Take the first problem identified: it is part of the problem I identified early in this article, that we take for granted there is something that is a "Native American". I once sat in a university class taught by a Cherokee. After a discussion on blood quantum, a US government measurement of whether an individual could legally qualify as an American Indian, a student asked the professor "How much of an Indian are you?" It seems to me that we spend most of our time requiring Natives always to be answering that question. We continually measure Natives by whether they meet our definition of Indian, whether blood quantum or environmental mysticism, lifestyle or economic choices, rather than allowing Natives to be people, individuals, members of a community. Our ecological Indian is a stereotype of our expectations of an Indian; he is not a real human with real human, situationally unique problems, opportunities and choices.

The second problem is that when we allocate goodness as an assessment of ecological or environmentally correct behaviour it is based on a western definition of ecological or environmental goodness. As Allen and Deloria Jr, among others, point out this definition derives more from "the exalted romance of the sentimental 'nature lovers' [or] self-conscious 'appreciation' of the land" (Allen 1979: 192).

The non-native concept of nature, and consequently good environmental behaviour, is based upon a relationship that is largely separate from a day-to-day intimate interaction with that nature. It is something outside of our everyday lives, in the sense that when we think about nature it is not the bits of grass and single struggling trees along the sidewalks in our cities, or the squirrels and cockroaches that survive with us that we think about. We imagine *Sierra* magazine vistas, forests, steams and charismatic wildlife which we may manage actually to experience once or twice a year at best. As a result of separateness, and of the ability to make a living that is removed from the land, nature becomes a sacred, remote concept. Nature is something we are deprived of, often yearn for, do not understand or know as anything other than a desire. Worse, the undeniable ecological crisis of modern culture creates an image, a truthful image, of nature as fragile, threatened, in need of protection (although this does *not* mean most of us are willing to either change our lifestyle or voluntarily stay out of natural areas). So the day-to-day use of nature by many Natives is seen as unecological, particularly if such use includes making a living through exploiting resources through mining, trapping, logging, damming, or hunting whales. However, as Berkes (1999: 154) notes, wilderness is a questionable ecological concept; there are few landscapes on earth that were not manipulated by human cultures. Native American perceptions of nature include an intimate understanding of making a living from that nature. Part of living means making a living, and we all make a living from the land. Some of us can hide that fact from ourselves better than others. If nothing else, a native perception of nature and the human relation with nature is *honest*. But it does mean that it is often difficult to call Natives environmentalists or even ecological, if by that we mean they did not live with, change and use nature.

Using people to demonstrate a point often involves forgetting that the examples are flesh and blood. Beliefs do not translate perfectly into practice. And the definition of what *is* an ecologically sound practice has changed with the circumstances. Much depends on the natural context: population densities, existing ecological damage, and outside conditions. Today there is disagreement over whether "traditional, real" Indians drive pickup trucks, snowmobiles, powerboats and use assorted firearms to hunt. There are bitter disagreements over "traditional" harvests, for example the Inuit harvest of the seriously endangered bowhead whale using modern mechanical killing devices.

Time also plays a factor, particularly when looking at Native American practices. What was ecologically acceptable 600 years ago, such as stampeding herds of the incredibly numerous bison off cliffs, is not acceptable now when bison are endangered. A less dramatic example might be the hunting of eagles for ceremonial feathers, claws, etc. Native Americans are occasionally prosecuted under endangered species laws for these spiritually necessary practices. Yet while eagle populations are on the upswing, they are far from secure, as even Native Americans acknowledge. Who is the more "ecologically sound" citizen, the spiritually motivated Native American or the pragmatic US Fish and Wildlife Service officer who arrests them?

Finally, there is the question of which Indian you chose as a "model": the safely dead "traditional" Indian or the living descendant. The dead no longer have a voice to protest over how they are used. The living is facing very difficult questions on existence in the modern world. Environmentalists often seem to prefer the dead Indian; modern Indians too often make difficult partners. On some issues, Native Americans have welcomed the help of resource rich environmental organizations. On other issues, for example oil and mineral developments on the southwestern or Alaskan reservations, Native American tribes have been on opposite sides from environmentalists. Or consider the bitter divisions that resulted after Greenpeace successfully lobbied against the trade in harp seal skins. Many northern tribes lost much of their yearly income with the loss of the sealskin market, and they are angry in their condemnation of Greenpeace's cultural insensitivity. A similar issue has erupted as animal rights activists are increasingly successful in making the wearing of fur "politically incorrect". While some furbearers are ranch-raised, many are still trapped by northern Indian communities who stand to lose a significant source of income. White middle-class environmentalists are often slow to recognize the imperative of feeding children on reservations with 60% unemployment and chronic poverty. They also raise legitimate questions on the use of animals.

To conclude, there is no easy answer regarding this issue, academically. To the living, flesh and blood Indian, the debate is also academic, as they struggle to reconcile the invasiveness of western culture and their often fierce desire to hold on to older cultures, whether "ecological" or not, if only for their children and grandchildren's sakes.

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Ethnobotany

RICHARD EVANS SCHULTES

There are numerous definitions of ethnobotany. The simplest is that it concerns the study of the uses of plants in societies. The term was first employed by John Harschberger in 1895. It was used narrowly in reference to the use of plants by aboriginal people. More recent authors believe that ethnobotany should consider not only the uses of plants but the entire range of relations between humans and plants.

Ethnobotany is a distinct field of research with a strongly interdisciplinary outlook. A number of subdivisions have developed, such as archaeoethnobotany (often called paleoethnobotany), ethnopharmacology, ethnoecology, and ethnomycology. There is even a possible subdivision which could be called "horticultural ethnobotany." With this rapid proliferation of interests, ethnobotanists have widened the definition to encompass the study of uses in aboriginal societies, native technological manipulation, classifications of the plants involved, indigenous nomenclature, agricultural systems, magicoreligious and mythological concepts connected with plant uses, and the general sociological importance of the flora in indigenous societies.

Ethnobotany itself is certainly not new. The earliest humans must have been incipient ethnobotanists. They must have classified plants in their surroundings – those of little or no utility, those which were useful in many practical ways, those which alleviated pain or otherwise ameliorated illness and those that caused illness or even killed outright. They must have wondered at the unwieldy effects of the few hallucinogenic or psychoactive species, and they could explain their extraordinary properties by assuming that they were endowed with spiritual power from supernatural forces.

It was not long before the knowledge and manipulation of the properties of plants became associated mainly with certain individuals, and the early medicine men or shamans ultimately acquired great powers over many aspects of the life and beliefs of the general population. Members of the general population, often especially women, were likewise conversant with the properties and uses of their food, medicinal, and other economic plants of daily use. Many peoples around the world are very knowledgeable about their ambient vegetation as a result of inherited knowledge, the result of hundreds of years of experimentation.

Modern ethnobotany can be of great value to many fields. Human health, new and better medicinally valuable phytochemicals, the domestication of new crop plants for food and industrial purposes, better understanding and use of plant biodiversity, and general environmental conservation – all might well reap significant advantages from proliferation of ethnobotanical investigations.

The world's flora, estimated to contain some half million species of flowering plants, have been analyzed with modern chemical techniques only on a limited scale. Tropical rain forests, which contain a greater part of the world's plant species, have been the least chemically studied even though they are extremely rich laboratories. The Amazon Valley, for example, has an estimated population of 80,000 species of angiosperms. When this wealth of species in other rain forest areas of the world is considered the opportunities for great advances in our knowledge of phytochemistry are obvious. If we consider only alkaloids, for example, the increase in our knowledge is significant. In 1950 we were aware of 2,000; in 1970 the number had increased to 4,000, and in 1990 it had reached 10,000.

If enough material of 80,000 species must be collected for chemists from such a difficult and extensive area for travel, transportation, and availability of resources, it is obvious that the task can never be completed, especially by random collecting. Ethnobotany can be a significant help.

More and more tribal peoples are succumbing to acculturation or westernization as a result of road and airport building, dam construction, increased missionary pressure, heightened tourism, or disruption from their centuries-old dwelling sites. In many areas of the great native Amazon Basin knowledge is disappearing even faster than the forests. When an Indian can get from a missionary, tourist, or commercial agent our effective and easily used drugs, this native knowledge disappears rapidly. Of the numerous subdivisions of the field of ethnobotany, none is more important than ethnopharmacology – the search for new medically valuable plants.

In the small area of the northwestern Amazonia (Colombia, Ecuador, and a small part of western Brazil), more than 1,600 species of biodynamic plants used by the Indians as medicines are considered to be an adjunct of routine cures by medicine men, or poisons (as in the manufacture of curare or arrow poisons). If chemists concentrate on those plants which Indian use has demonstrated to be in some way bioactive, understanding of the chemistry of the flora of the region can be accomplished more efficiently.

Another example of the value of ethnobotanical research lies in the Indians' familiarity with minor variations in plant species. This may be of great help in one phase of the study of biodiversity. One of the enigmas that botanists and other specialists have not had much success in understanding concerns the native's easy recognition of varieties of many of the plant species of their forests. These variants are so well established in the Indians' classifications that they usually have distinct names, in spite of the botanists' inability to see any distinguishing morphological characteristics. This skill is manifest not only in the few cultivated economic plants but also in their classification of many wild plants of no utilitarian, ceremonial, magical, or mythological importance. The Indians can usually tell at once and frequently on sight and often at a significant distance, without feeding, tasting, smelling, crushing, tearing, or other physical manipulation, to which category a plant belongs. While it is of interest to the anthropologist and psychologist, it is of extremely practical importance to chemists and botanists.

Yoco (*Paullinia yoco*, Sapindaceae) is a gigantic liana from the bark of which numerous tribes of the Colombian Amazonia prepare a very strong stimulating drink taken in the early morning before eating solids.

The drink has 3% caffeine. There are native names for at least 13 of these lianas. While several give a creamy white drink, others a slightly reddish brown product, there are no discernable morphological differences in them. Often several of the named "kinds" grow in relatively close proximity, so it cannot be due to ecological differences. Nor is it due to different parts of the liana.

Another example is ayahuasca or caapi (*Banisteriopsis caapi*, Malpighiaceae), a forest liana the bark of which is the source of an interesting vision-producing hallucinogenic drink employed widely by many tribes in the western Amazonia. Since the source plant was identified and botanically described as a species new to science in 1853 by the British plant explorer and ethnobotanist, Richard Spruce, many specialists and amateurs have written about it. We are certain now that one species of *Banisteriopsis* is used. There is now no doubt also that Indians can visually identify at a distance different "kinds" of the *caapi* liana. There is a long list of these variants, and the natives maintain that they are employed to prepare drinks of different strengths or in connection with various ceremonies or dances because of longer or shorter intoxications or because of special magicoreligious needs. There is one of the named variants from which a drink may be prepared according to the kind of animals the hunter wants to find and kill.

Could the ability of the Indian to recognize various types of *B. caapi*, often at a distance, be due to slight differences in the bark of the liana, presumed chemical diversity (which could not be seen), variation in leaf shape, ecological factors (growing in dense or open forests), or other dissimilarities? None of these can be considered logical explanations of the uncanny ability consistently to identify the named type of the liana. It remains an enigma which deserves further study.

Whatever the explanation of this perspicacity, specimens of 18 "kinds" of the ayahuasca vine were collected by Dr. E. Jean Langdon, an anthropologist who worked amongst the Siona in the Colombian Amazonia. They were submitted for botanical identification by a botanical specialist, Dr. Timothy Plowman, and almost all were referred to the single species, *B. caapi*. As Dr. Langdon states: "Further exploration between the conjunction of botany–chemistry–culture warrants further investigation."

This example of the unexplored horizon awaiting scientific investigation is typical of many other unexplained examples of the wealth of aboriginal concepts of natural phenomena awaiting technical solution around the world.

Ethnobotany, if intensified, can contribute extraordinarily to many fields of modern science, technology, and sociology, but time is of the essence in view of the worldwide uncontrolled acculturation of indigenous societies. As Prince Philip, former president of World Wildlife Fund, has pointed out: "The tropical forests and their traditional inhabitants are under very severe pressure from human encroachment, and it is sadly inevitable that many of these plant species and the tribes which understand their use are rapidly disappearing forever."

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Ethnobotany of Alaska: A Southwestern Alaska Perspective

Dennis Griffin

Alaska is the home of many diverse native peoples who inhabit a wide variety of environments. To survive and flourish in these environments it was essential for people to be aware of the wide range of plant and animal species in their area on which their survival depended. Published texts on Alaskan Natives, particularly the Eskimo (Lee and DeVore 1968), have stressed the dependence of native people on hunting in order to survive. While this dependence is undoubtedly true, the awareness and intensity of use of vegetal resources has often been overlooked. While it is impossible to summarize, in a single article, the use of indigenous plants among all native peoples of Alaska, this article focuses on one area of Alaska, that of the Southwest, in order to illustrate the range of knowledge and use of indigenous flora by the Yup'ik Eskimo. This use includes the harvest of plants for food, medicine, and utilitarian purposes. Limited ethnobotanical references for native peoples in the remainder of the state are also included.

Alaska can be divided into two principal environmental regions based on general landform and vegetation: the Interior and Coastal regions. The Interior region is bounded by mountain ranges to the north and south (Brooks and Alaska Ranges, respectively) with a gradual transition in elevation west to the Bering Sea. American Indian peoples largely inhabit the interior. While not being addressed in this article, the ethnobiology of this region can be found in Carroll (1972), Fortuine (1988), Garibaldi (1999), and Kari (1987). The Coastal region extends along the border of the state to the north and west where it meets the Bering Sea, and along the southern coastal area where it borders the Sea of Alaska. The northern and western coastal areas are generally ice-bound in winter, and comprised of low-lying tundra vegetation. The southern coastal area is generally less affected by the ocean climate with its warmer sea temperatures with vegetation changing from a tundra regime on the Alaska Peninsula to a more forested environment to the east. The Coastal region is largely occupied by Eskimoan people,[1] that are divided into two linguistic subgroups, the Yup'ik and Inuit–Inupiaq (Woodbury 1984). Yup'ik was spoken aboriginally on the coasts of the Chukchi Peninsula in Siberia and Alaska from Norton Sound south to the Alaskan Peninsula, and then east along the Pacific to Prince William Sound (Fig. 1). Inuit–Inupiaq was spoken north from Norton Sound and east across Arctic Alaska and Canada to the coasts of Labrador and Greenland (see Anderson 1939; Nickerson et al. 1973; Jones 1983 for ethnobotanic information for the Inuit–Inupiaq portion of Alaska). This paper focuses on the ethnobotany of the Yup'ik Eskimo in southwestern Alaska, an area dominated by the Yukon–Kuskokwim Delta which includes both Nunivak and Nelson Islands.

[1] The Aleut occupy the southern tip of the Alaskan Peninsula and the Aleutian Islands. Their use of indigenous flora is not discussed in this paper (see Bank 1953).

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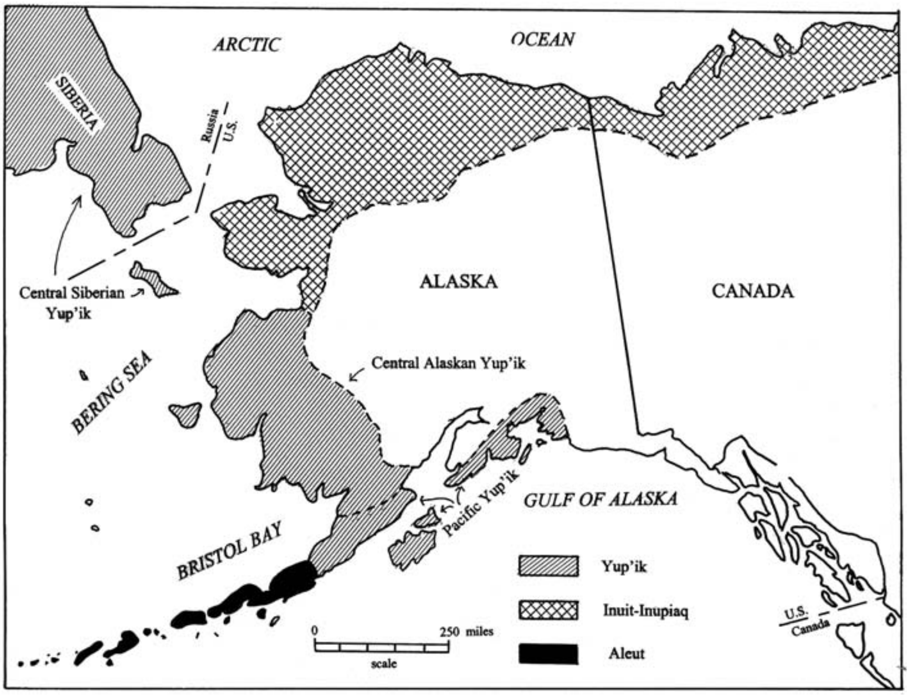

Ethnobotany of Alaska: A Southwestern Alaska Perspective. Fig. 1 Distribution of Yup'ik Speakers in Alaska.

Ethnobotany of Alaska: A Southwestern Alaska Perspective. Fig. 2 Nunawarmiut elders examining plant specimens (from left to right: Nan Kiokun, Helen Williams, and George Williams, Sr.).

Ethnobotany of Alaska: A Southwestern Alaska Perspective. Fig. 3 Nunawarmiut elders examining plant specimens (from left to right: Nona Amos and Walter Amos).

Few early ethnographic studies in Alaska have highlighted the Eskimo's range of knowledge and use of local flora. In fact the opposite was often the case, in that many observers expressed a belief that Eskimos had little knowledge of local herbs and roots (Whittaker 1937: 115). Young and Hall (1969: 43) found that the Western Eskimo were more aware of and made use of more plant species than is generally acknowledged. While the present study summarizes the known traditional use of indigenous plants in Southwestern Alaska (Central Alaskan Yup'ik), comparative data are also included for plant use among the peoples of St Lawrence Island and Siberia (Siberian Yup'ik) and the Chugach of Prince William Sound (Pacific Yup'ik), when known. This information was primarily obtained from a 12-year (ca. 1995–2006) collaborative anthropological project with the Nuniawarmiut of Nunivak Island (see Figs. 2 and 3), and a compilation of published and unpublished sources of ethnobotanical use.

Regional Setting

The Yukon–Kuskokwim Delta (Fig. 4), a geographic and cultural area historically occupied by Central Alaskan Yup'ik-speaking Eskimos in southwestern Alaska, encompasses an area of almost 81 million kilometers (31,250 square miles) or 8.1 million hectares (20 million acres). This delta region consists of a vast and largely roadless expanse of low-lying tundra that has attracted limited attention from ethnographers in the past. Native villages are located along the area's major waterways with development largely limited to commercial fishing. The degree of early contact between subcultural groups within the Delta cannot accurately be determined due to conflicting early historical data and later movements of peoples throughout the region, but villages are known to have been linked by extensive trade networks, intermarriage among village residents, and village alliances during times of warfare (VanStone 1984: 224). Ponds, lakes, streams, and sloughs, which made travel throughout southwestern Alaska extremely difficult, cover half of the Yukon–Kuskokwim Delta. Not surprisingly, the immense wetlands provide suitable habitat for millions of waterfowl, small and large mammals, and abundant flora. The seasonal harvest of marine mammals (e.g., seals, sea lion, walrus) and many species of fish (particularly salmon, halibut, whitefish, and blackfish) remains vital for local survival.

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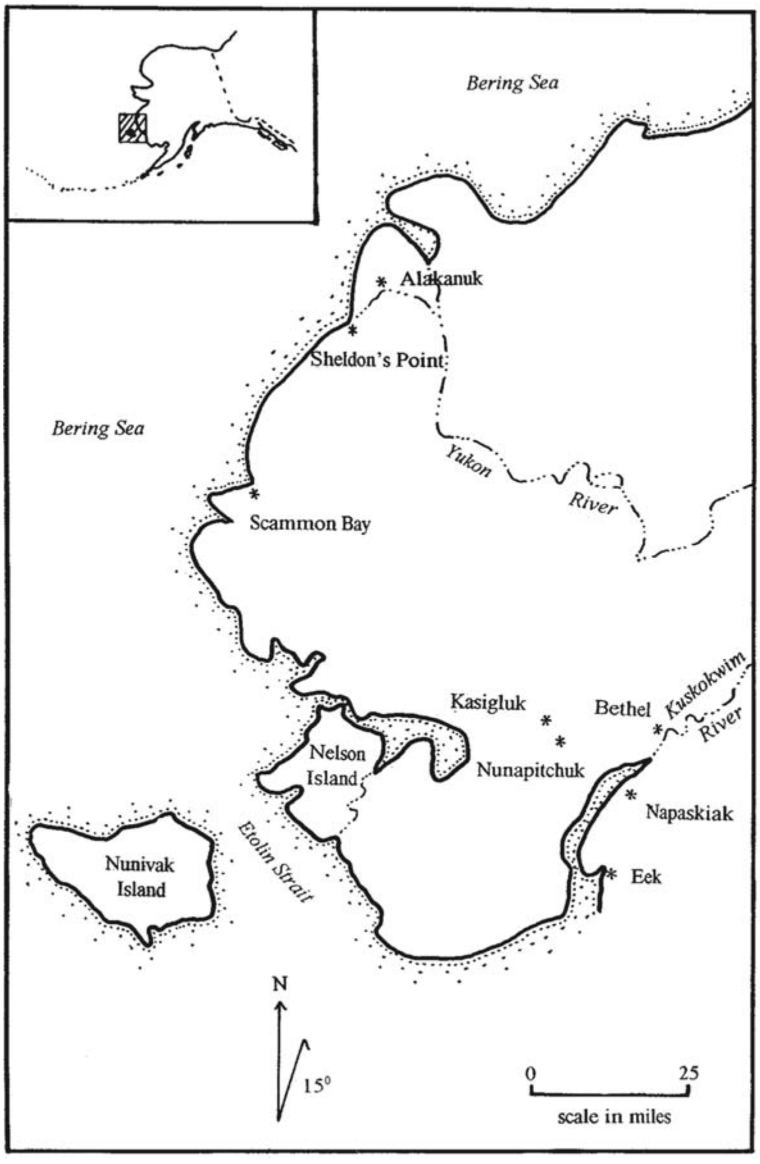

Ethnobotany of Alaska: A Southwestern Alaska Perspective. Fig. 4 Map of Yukon–Kuskokwim Delta.

The Yukon–Kuskokwim Delta is subject to a subarctic maritime climate, influenced by the surrounding sea, which produces a relatively stable temperature. Summers are generally cool and windy, with some areas experiencing frequent fog; winters are cold with both wet and dry periods. The region's mean annual temperature is −2°C (30°F) with mean daily temperatures ranging from −25°C (9°F) in January and February to 10°C (50°F) in August (Selkregg 1976, Swanson et al. 1986). Rain and snowfall is heavier on the mainland than neighboring islands (e.g., Nunivak), with islands experiencing more frequent overcast days with dense fogs. This difference between the mainland and island delta regions is due to the greater effect of the Bering Sea on the island environment. Precipitation is moderate with a mean annual rainfall of 40.6 cm (16 in.) and snowfall of 127 cm (50 in.). Vegetation throughout the region remains similar.

The Yup'ik Eskimo of southwestern Alaska traditionally practiced a hunting, fishing, and gathering subsistence economy that revolved around the harvest of the above-mentioned species, in addition to the numerous plant species that were critically important to survival. Hulten (1966, 1968) has studied the vascular flora of the Yukon–Kuskokwim Delta, Bos (1967) and Palmer and Rouse (1945) that of Nunivak Island, and Young (1968) on St Lawrence Island. The region's vegetation is predominantly comprised of Arctic tundra containing a variety of lichens, grasses, sedges, flowers, and shrubs. It is similar to vegetation found throughout western and northwestern Alaska. The tallest tundra plants are shrubby willows that can reach up to 8 ft in height along some river courses. Major vegetation types include wet tundra, dry tundra, alpine tundra, and grass–browse (i.e., grass hummock and beach grass–forb). Wet tundra is most prevalent along the coast in poor drained areas, with the dominant cover species consisting of sedges (*Carex* spp.), cottongrass (*Eriophorum* spp.), willow (*Salix* spp.), crowberry (*Empetrum nigrum*), and various species of mosses and lichens (e.g., *Sphagnum*, *Pohlia*, and *Cladonia*). Dry tundra is found on areas of sloping terrain having good drainage and is dominated by species similar to those found in wet tundra areas, in addition to bearberry (*Arctostaphylos alpine*), Labrador tea (*Ledum palustre decumbens*), woodrush (*Luzula nivalis*), bog blueberry (*Vaccinium uliginosum*), and dwarf birch (*Betula nana exilis*). Alpine tundra, found at higher elevations on hills and mountains, is similar to that in dry tundra areas, and is dominated by crowberry, alpine bearberry, Labrador tea, White Mountain-avens (*Dryas octopetala*), and moss. Grass–browse is generally found interspersed with the dry tundra subtype and along edges of streams and rivers adapted to periodic flooding. This vegetation type is dominated by fescue (*Festuca* spp.), bluejoint (*Calamagrostis canadensis*), willow, lichens, sedge, wild celery, and seacoast angelica (*Angelica lucida*).

Use of Indigenous Flora

Indigenous plants were an integral part of the year-round diet of Eskimo people in addition to their incorporation in other facets of their lives. Contrary to the popular perception of Eskimo people surviving solely on fish and meat, they utilized a large number of local plants for food, medicinal, and utilitarian purposes. An earlier Alaskan study estimated that up to 15% of the diet of Western Eskimo people (Kotzebue to Alaska Peninsula) is made up of vegetable resources (Young and Hall 1969: 43). While plant resources remained sparse on some offshore islands such as St Lawrence Island (Young and Hall 1969), on Nunivak and Nelson Islands they provided a significant addition to the Native's year-round diet.

Knowledge of the Native use of indigenous flora in the Delta remains limited. Previous ethnobotanical studies are limited to research on Nunivak Island (Fries 1977; Griffin 2001, 2004; Lantis 1946, 1959; Nuniwarmiut Taqnelluit 2006), Nelson Island (Ager and Ager 1980), the Kuskokwim villages of Napaskiak (Oswalt 1957), Eek, Kasigluk, and Nunapitchuk (Andrews 1989; Lantis 1958, 1959), and several lower Yukon Delta and coastal villages (e.g., Alakanuk, Sheldon's Point, Scammon Bay) by Fienup-Riordan (1986). St Lawrence Island and the Chukchi coastal area of Siberia are similar in landform with Southwestern Alaska in that lands are covered by low-lying Arctic tundra, although the number and variety of plant species differ between areas. Knowledge of the indigenous use of plants in these areas remains limited to few published and unpublished accounts (Young and Hall 1969; Ainana and Zagrebin, unpublished data, respectively). Ethnobotanical knowledge among Pacific Yup'ik speakers is largely limited to studies among the Chugach (Birket-Smith 1953; Fortuine 1988; Wennekens 1985) in Prince William Sound, Kodiak Island (Graham 1985), and the Alaska Peninsula (Morseth 2003). Since the flora of the first two of these areas are very different from that of the Yukon–Kuskokwim Delta (i.e., forest vs. tundra), only information on the use of similar plant species is addressed here. Several recent, regionally based publications have attempted to summarize our knowledge of the indigenous use of plants throughout Alaska (e.g., Biggs 1999; Garibaldi 1999; Schofield 1989), however the Yup'ik-speaking areas remain poorly documented.

Table 1 provides a list of the seasonal use of indigenous food plants by the Yup'ik Eskimo. This index provides data on the Yup'ik use of 43 indigenous plant species in southwest Alaska. In Table 1, species

Ethnobotany of Alaska: A Southwestern Alaska Perspective. Table 1 Seasonal use of indigenous food plants among Yup'ik-speaking Eskimo

Scientific name	Common name	Season[a]	Plant part	Storage	Location[b]
Ammodenia peploides	Sea Purslane, Seabeach Sandwort	Su	Leaves	X	Nunivak
Angelica lucida	Wild Celery	Su	Leaves, stalk, root	X	Y–K Delta, Ak. Pen., Chugach
Arctostaphylos alpina	Alpine Bearberry	Su, F	Fruit		Y–K Delta, Inuit
Boltenia ovifera	Sea Potato, Sea Onion	S, Su	Bulb		Nunivak
Caltha palustris	Marsh Marigold	W, S	Entire plant	X	Y–K Delta
Carex spp.	Sedges	F	Root, stem		Nunivak
Cladonia spp.	Lichens	S	Entire plant		Nunivak
Claytonia tuberosa	Wild Potato, Tuberous Spring-Beauty	Su	Corm		Y–K Delta, Siberia
Conioselinum chinense	Western Hemlock-Parsley	S, Su	Root		Nunivak, Chugach
Dendroa aggregate		Floats to beach	Branches		Nunivak
Draba borealis or *Draba hyperborea*	Wild Lettuce	S, Su	Leaves	X	Nunivak
Dryopteris dilatata	Shield Fern	Su, F	Fronds, fiddleheads		Nunivak
Empetrum nigrum	Crowberry	Su, F	Fruit, plant	X	Y–K Delta, Ak. Pen., Chugach, Siberia, Inuit
Epilobium angustifolium	Tall Fireweed	S, Su S	Leaves, young shoots	X	Y–K Delta, Chugach, Inuit
Epilobium latifolium	Dwarf Fireweed	Su	Leaves, yg. shoots	X	Nunivak
Epilobium angustifolium	Tall Cottongrass	Su, F	Base of stem, greens		Y–K Delta, Inuit
Fucus spp. *F. Gardneri*	Bladderwrack Rockweed	Year-round S, Su, F	Plant, young plant		Y–K Delta, Chugach
Hippuris tetraphylla or *H. vulgaris*	Mare's Tail	S, F	Leaves, stems, roots	X	Y–K Delta
Honckenya peploides major	Beach Greens, Seabeach Sandwort	S, Su	Leaves, stems	X	Y–K Delta, Siberia, Inuit
Ledum palustre decumbens	Labrador Tea	S, Su year rd.	Leaves		Y–K Delta, Chugach
Ligusticum scoticum Hultenii	Beach Lovage, "Wild Parsnip/Parsley"	S, Su Su	Roots, leaves, stems		Y–K Delta, Ak. Pen., Chugach
Lycoperdon spp.	Puffball	S, Su	Yg. fruiting body		K-Delta?, Siberia
Mertensia maritima	Oysterleaf	?	Leaves		Y–K Delta
Oxycoccus microcarpus	Bog Cranberry	Year-round	Fruit	X	Y–K Delta, Chugach
Oxyria digyna	Mountain Sorrel	S, Su	Leaves	X	Y–K Delta, Siberia, Inuit
Palmaria palmata	Seaweed, Dulse	Su, W	Blade		Nunivak
Parrya nudicaulis (?)	Wild Cabbage/Celery	Su	Leaves	X	Nunivak
Pedicularis verticillata	Woolly Lousewort	S	Flowers, roots		Y–K Delta, Siberia, Inuit

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Ethnobotany of Alaska: A Southwestern Alaska Perspective. Table 1 (Continued)

Scientific name	Common name	Season[a]	Plant part	Storage	Location[b]
Pohlia nutans/Webera nutans	Moss	S	Plant		Y–K Delta
Polygonum bistorta	Pink Plumes, Bistort	S, F	Leaves, root stalk	X	Nunivak, Siberia, Inuit, Ak. Pen.
Polygonum viviparum	Alpine Bistort, Wild Rhubarb	S, Su	Rhizome		Y–K Delta, Siberia
Ranunculus Pallasii	Pallas Buttercup	S	Leaves, stems		Y–K Delta
Rhodymenia palmata	Red Seaweed, Dulse	Year-round	Plant		Y–K Delta, Chugach
Rubus arcticus	Nagoonberry	Su	Fruit	X	Y–K Delta, Chugach, Inuit
Rubus chamaemorus	Cloudberry	Su	Fruit	X	Y–K Delta, Chugach
Rumex arcticus	Dock, Sour Dock	S, Su	Leaves, stems	X	Y–K Delta, Ak. Pen., Chugach
Salix alaxensis	Alaska Willow	S	Catkins, leaf top		Y–K Delta, Inuit
Salix pulchra	Diamondleaf Willow	Su	Catkins, leaves		Y–K Delta, Siberia
Saxifraga spp.	Saxifrages	S, Su, F	Leaves	X	Nunivak, Siberia, Inuit
Sedum rosea	Roseroot, Stonecrop	S	Flowers, plant		Y–K Delta, Inuit
Senecio pseudo-Arnica	Ragwort, Fleabane	Su	Leaves, stems, root, top of shoot	X	Y–K Delta
Streptopus amplexifolius	Twisted Stalk	S, Su	Fruit, young stalks		Nunivak, Chugach
Vaccinium uliginosum	Alpine Blueberry, Bog Blueberry	Su	Fruit	X	Y–K Delta, Ak. Pen., Chugach
Vaccinium vitis-idaea minus	Lingonberry, Low-bush Cranberry	Year-round	Fruit	X	Y–K Delta, Siberia, Chugach, Ak. Pen.

[a]Seasonality: S, spring; Su, summer; F, fall; W, winter.
[b]Location abbreviations include: Y–K Delta = Yukon–Kuskokwim Delta; K-Delta = Kuskokwim Delta; Inuit = Inupiaq-speaking area; Chugach = Prince William Sound; Ak. Pen. = Alaska Peninsula.

are arranged in alphabetical order by each species' botanical name. Details regarding season of harvest, plant part used, and if the species was stored for winter consumption/use is provided. In addition, the known range and extent of use of each species among Eskimo peoples is included.

While some researchers believed Eskimos had no knowledge of herbs or roots to combat or relieve sickness (Whittaker 1937), this has been found to be untrue. Medicinal knowledge of indigenous plants varies from area to area with over 28 plant species used in the Yukon–Kuskokwim Delta. Table 2 provides a list of medicinally used plants in the region, along with specific references to texts that provide greater detail on the collection, processing, and application of each species.

In addition to the use of plants for food and medicine, many plant species were used for a variety of utilitarian purposes. Table 3 provides details on 13 species used in southwestern Alaska. Data on plant name, season of harvest and specific use is included.

Native Plant Taxonomy

An examination of general Yup'ik terms (Jacobson 1984) provides comparative data useful in distinguishing some basic plant terminology distinctions. Yup'ik speakers (including Cup'ig speakers on Nunivak Island who speak the most divergent dialect within the Yup'ik branch) tend to divide plants into basic groups based on how plants were traditionally used, their similarity in appearance or physical characteristics. For example, on Nunivak Island, the Cup'ig plant name ***ciwassit***[2] translates to "wild greens that can be cooked" and is used to denote several distinct species that are prepared in a similar manner (i.e., *Rumex arcticus* [sour dock], *Polygonum bistorta* [bistort], and *Polygonum viviparum* [alpine bistort]. ***Kumarutet*** is used to denote all moss species (e.g., *Pohlia nutans*) based on the traditional use of moss as a wick in lamps (***kuman*** = lamp, light). Examples of plants grouped by similarity in appearance, characteristics or setting include: (1). ***elquat*** – term used to designate several varieties of seaweed (e.g., *Palmaria palmata* [dulse], *Fucus* spp. [bladderwrack]; (2) ***megtat neqiat*** – meaning bumble bee food for several local plant species (e.g., *Pedicularis verticillata* [wooly lousewort], *Sedum rosea* [roseroot]); and (3) ***agyam an'a(i)*** – used for all puffball species (*Lycoperdon* spp. and *Calvatia* spp.). In Yup'ik, ***agyam ana*** translates to meteor and meteors, which are traditionally said to turn into puffballs when they land (Jacobson 1984: 48). Still other plant names highlight distinctions within a genus such as ***qugyuguat***, which is used to refer to all *Salix* (willow) species except those exhibiting catkins, which are referred to as ***qimugkararat***. Further analysis is needed in order to fully understand the Yup'ik's concept and categorization of local flora.

A similarity of plant use and some Native plant names between Yup'ik, Cup'ig, and Inupiaq speakers (i.e., Seward Peninsula) to the north have been identified. Similarities between some Yup'ik, Cup'ig, and Inupiaq plant names (e.g., ***kavlak–kavlag–kavlaq*** [*Arctostaphylos alpine* (alpine bearberry)], ***paunraq–paunrat–paungaq*** [*Empetrum nigrum* (crowberry)], ***pekneq–pekner–pikneq*** [*Eriophorum angustifolium* (cottongrass)], ***tukaayug–tuk'ayut–tukaayuk*** [*Linguiticum scoticum* (lovage)]), and food preparations (e.g., ***akutaq–akutar–akutuq*** [Eskimo ice-cream comprised of berries, seal oil, reindeer tallow (Crisco), snow and sometimes salmon eggs]) highlight extended contact between western Alaskan peoples over time. Further research is needed to evaluate the degree of sharing between these language branches with regard to the recognition and use of indigenous plants.

Plant Harvest, Preparation, and Storage

In the Yukon–Kuskokwim Delta, women and children traditionally gathered most indigenous plants while the men were harvesting other available resources (e.g., caribou, waterfowl, seal) (Fienup-Riordan 1983; Lantis 1946). While fresh spring greens provided a welcome addition to the diet, which in winter was based largely on dried and stored foods, other greens were harvested throughout the year as they ripened, and used with some of those stored for winter use. With the melting of the winter's snow pack, local greens and berries not picked during the previous fall's harvest begin to appear and were added to the local diet. Depending on the time the ice pack began to break up, Yup'ik families began to move to their spring camps to harvest available resources. Along the coast, Yup'ik men would journey out along the ice to harvest arriving sea mammals (i.e., seals, walrus) while women would spend much of their time harvesting available plant resources (greens and seaweeds) and shellfish. Early harvestable spring food plants included: marsh marigold (*Caltha palustris*), sour dock (*Rumex arcticus*), wild celery, wild lettuce (*Draba hyperborea*), wild parsnip (*Ligusticum Hultenii*), wild rhubarb (*Polygonum viviparum*), mountain sorrel (*Oxyria digyna*), Pallas buttercup (*Ranunculus pallasii*), and Labrador tea.

After the completion of the spring hunting season, families would move to summer fish camps. Fish comprised the most prolific and essential subsistence resource for many Alaskan Natives living in the Delta

[2] Cup'ig spellings of all plant species are taken from the Cup'ig Dictionary by Amos and Amos (2003) and have been placed in bold italics. A glossary of Yup'ik and Cup'ig plant names are included in the Appendix.

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Ethnobotany of Alaska: A Southwestern Alaska Perspective. Table 2 Medicinal plant use among the Yup'ik-speaking Eskimo

Scientific name	Common name	Plant part	Plant application	Symptom	Location[a]	Reference
Achillea spp.	Yarrow	Leaves, stem	Infusion, gargle, poultice, chew, switch	Congestion, sore throat, boils arthritis, uterine evacuation, increase milk after parturition	Nunivak, Chugach	Fortuine (1985), Morseth (2003), Schofield (1989)[b], and Wennekens (1985)
Alnus spp.	Alder	Leaves, bark, branch	Poultice, switch	Cut/scrapes, arthritis, sore muscles; stool softner	Y–K Delta, Chugach	Ager and Ager (1980), Garibaldi (1999), Morseth (2003), and Wennekens (1985)
Angelica spp.	Angelica	Root, stem	Chew, infusion, switch	General ill health, seasick remedy, sore joints	Y. Delta, SLI	Garibaldi (1999), Hulten (1968), Morseth (2003), and Young and Hall (1969)
Artemisia Tilessi	Stinkweed, Wormwood	Leaves, branch, seed head, plant	Poultice, switch, infusion/decoction, hair rinse, vapor, chew	Cuts, dandruff, sore muscles, arthritis, stomach trouble, constipation, bleeding	Nunivak, SLI; Y–K Delta, Chugach	Ager and Ager (1980), Fienup-Riordan (1986), Garibaldi (1999), Griffin (2001), Lantis (1959), Oswalt (1957), Overfield et al. (1980), Wennekens (1985), and Young and Hall (1969)
A. vulgaris	Stinkweed	Leaves	Poultice	Sore joints, gas pains	Nunivak, Norton Sound	Garibaldi (1999), Griffin (2001), and Lantis (1958)
Betula nana exilis	Dwarf birch	Leaves	Infusion/decoction	Boiled for stomach problems, intestinal	Nunivak, K. Delta	Griffin (2001) and Lantis (1958, 1959)
Caltha palustris	Marsh marigold	Leaves	Infusion/decoction, chew	Constipation, diarrhea	K. Delta	Garibaldi (1999) and Lantis (1959)
Dryopteris austriaca	Shield fern	Fronds	Infusion/decoction	Boiled for stomach problems, intestinal	Nunivak, K. Delta	Griffin (2001) and Lantis (1958, 1959)
D. dilatata americana	Wood fern	Plant	Infusion/decoction	Stomach trouble	K-Delta	Garibaldi (1999)
Epilobium angustifolium	Tall Fireweed	Leaves, root	Infusion/decoction, poultice	Boiled for stomach problems, intestinal, constipation, cuts	Nunivak, K. Delta, Chugach	Ager and Ager (1980), Garibaldi (1999), Griffin (2001), Lantis (1958, 1959), and Wennekens (1985)
Equisetum spp., *E. avense*	Horsetail	Upper stem, plant	Infusion/decoction, poultice	Internal bleeding, hemorrhages, pimples	Y–K Delta, Chugach	Ager and Ager (1980), Garibaldi (1999), and Wennekens (1985)
Eriophorum spp.	Cottongrass	Flower, cotton, stem, leaves	Chew, poultice	Cuts/scrapes, ill health, sores, inflamed eyes	Nunivak, K. Delta	Garibaldi (1999), Griffin (2001), Lantis (1959), and Oswalt (1957)
Fomes igniarius	Chew ash fungus	Fungus	Infusion/decoction	Constipation, stomach trouble	K. Delta	Garibaldi (1999) and Lantis (1959)
Ledum palustre decumbens	Labrador tea	Leaves, stems, flowers	Infusion, fumigant	Bleeding/hemorrhage, TB, constipation, stomach trouble	Y–K Delta	Ager and Ager (1980), Garibaldi (1999), Griffin (2001), and Lantis (1958, 1959)

Matricaria matricarioides	Pineapple weed	Seed heads, plant top, plant	Infusion/decoction; chew	Colds/flu, stomach trouble, TB, laxative, increase milk after parturition	Napaskiak; NI, Chugach	Ager and Ager (1980), Garibaldi (1999), Morseth (2003), Oswalt (1957), and Wennekens (1985)
Nephroma arcticum	Arctic kidney lichen	Plant	Infusion	Ill health	K. Delta	Garibaldi (1999) and Oswalt (1957)
Oxycoccus microcarpus	Bog Cranberry	Fruit	Chew	Pneumonia, stomach trouble	Y–K Delta	Garibaldi (1999)
Picea glauca	White spruce	Needles, gum	Infusion/decoction, chew, salve	Cit/scrapes, cough, chest congestion	Y–K Delta	Garibaldi (1999), Lantis (1959), and Oswalt (1957)
Rubus chamaemorus	Cloudberry	Fruit	Chew	Diarrhea, skin trouble	Nunivak, K. Delta	Garibaldi (1999), Griffin (2001), Lantis (1959), and Schofield (1989)
Rumex spp.	Dock	Leaves, root	Chew, snuff, poultice	Diarrhea, constipation, headache, chill fever	Chugach, Napaskiak	Birket-Smith (1953), Garibaldi (1999), Morseth (2003), Oswalt (1957), and Wennekens (1985)
Salix spp.	Willow	Leaves, bark, catkins, cambium	Infusion/decoction, chew, gargle, poultice	Lung hemorrhage, pain, sore throat or mouth, skin sores, cut/scrapes, eye trouble	Y–K Delta, Nunivak Chugach	Ager and Ager (1980), Garibaldi (1999), Griffin (2001), Lantis (1958, 1959), Oswalt (1957), and Wennekens (1985)
S. fuscescens	Willow	Leaves, catkins	Chew, swab	Sore mouth, watery eyes	Nunivak	Griffin (2001) and Lantis (1946, 1959)
S. pulchra	Diamondleaf Willow	Leaves	Chew	Sore mouth	Nunivak	Griffin (2001)
Sedum rosea	Roseroot, Stonecrop	Leaves, flower, root	Infusion/decoction, chew	Boiled for stomach problems, intestinal, sore mouth, TB	Nunivak, K. Delta, NI	Ager and Ager (1980), Garibaldi (1999), Griffin (2001), and Lantis (1958)
Sphagnum spp.	Sphagnum	Moss	Chew, poultice	Diarrhea, cuts/scrapes	K. Delta	Fortuine (1985), Garibaldi (1999), and Lantis (1959)
Vaccinium vitis-idaea	Low-bush Cranberry	Fruit	Chew, poultice	Diarrhea, eye trouble	K. Delta	Garibaldi (1999) and Lantis (1959)
Valeriana spp.	Valerian	Unknown	Unknown	Stomach trouble, good luck	Y. Delta; SLI	Garibaldi (1999) and Young and Hall (1969)
Nicotiana spp.	Tobacco (introduced)	Leaf	Poultice	Control bleeding	K. Delta	Lantis (1959)

[a]Location abbreviations include: SLI = St Lawrence Island; Y–K Delta = Yukon–Kuskokwim Delta; K-Delta = Kuskokwim Delta; NI = Nelson Island; Chugach = Prince William Sound.
[b]Schofield's reference Tuvas of Yarrow on Nunivak Island is believed to be in error based on a misintempretation of Smith's arctic pharmacognonon (1973: 325).

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Ethnobotany of Alaska: A Southwestern Alaska Perspective. Table 3 Utilitarian use of indigenous plants by Yup'ik-speaking Eskimo

Scientific name	Common name	Season	Plant part	Purpose	Location
Aconitum delphinifolium	Monkshood	Year-round	Root	Hunting poison	Chugach, Nunivak?
Angelica lucida	Wild celery	?	Root	Hunting talisman	Siberia
Carex spp.	Sedges	F	Grass	Boot lining, socks	Y–K Delta
Cladonia rangiferina	Lichens, Reindeer moss	Year-round	Plant	Seal oil applicator	Y–K Delta
Elymus mollis	Wild rye grass	S, Su, F	Grass	Menstrual pad, basket roof thatching, mats	Y–K Delta Chugach
Empetrum nigrum	Crowberry	Su, F	Leaves	Storage pit liner	Y–K Delta
Equisetum arvense	Common horsetail	S, Su, F	Stems	Play matches for child	Y–K Delta
Eriophorum angustifolium	Tall Cottongrass	?	Reeds	Basket, mat	K. Delta
Petasites frigidus	Coltsfoot	Su, F	Leaves	Berry basket	Nunivak
Pohlia nutans/ *Webera nutans*	Moss	S, Su, F	Plant	Diaper, basket-lining, fire starter, pottery pad	Y–K Delta Chugach
Rumex arcticus	Sourdock	Su, F	Plant	Navigation aid, cache pit lining, landmark	K. Delta
Sphagnum spp.	Sphagnum moss	Year-round	Moss	Menstrual pad, diaper	Nunivak
Vaccinium vitis-idaea minus	Lingonberry	Su, F	Fruit	Dye	Y–K Delta Chugach

and its harvest would occupy the majority of the families' efforts for several months. Traditional indigenous plants would continue to be harvested as they ripened and were eaten fresh or placed in underground caches for temporary storage. By late summer/early fall, several berry species (e.g., cloudberry [*Rubus chamaemorus*], nagoonberry [*R. arcticus*], crowberry [*Empetrum nigrum*]) and local greens (e.g., sour dock [*Rumex arcticus*]) were ready to be harvested and women and children would spend most days on the tundra gathering plant resources.

Most plants were available in a variety of locales and their harvest did not dictate moving the family to specific camps. Plants that grew in abundance in specific terrain, such as several varieties of cliff greens, usually offered other resources that could be harvested at the same time (e.g., fish, Sandhill cranes). Greens such as *Rumex arcticus* could be found throughout the delta and old camp sites are said to contain buried cache pits once used for plant storage.

As an example, when harvesting "wild spinach" or sour dock, Nunivak elders state that they would stay in an area until they had harvested enough for their family's long-term needs (Amos 1991; Kiokan 1995). After picking, they would cook the spinach a little bit before placing it into a cache dug underground.

> Cook em half way, just for the leaves to just shrivel up and not take much space, and they would dig ditches and line it with a certain type of twigs and grass and put em' in there until the weather gets colder, before the ground get hard, knowing that when it freezes, that *Ciwassat* (*Rumex arcticus*) would freeze in with the earth. So before that time they would go over there again, pull the *Ciwassat* out and this time leave em' on top of the ground… They would cover them with grass, probably willows too to keep them together and they would leave them until it freezes (Amos 1991: 16).

Before placing the spinach in the caches, the cooked leaves would be drained of juice and the pit lined with woven grass mats (e.g., *Elymus mollis*). "Some people rolled them up like a ball and put them away. Each roll was made enough for one meal. They rolled the spinach ball big enough for their dinner or a snack. That's how they took them out of the ground" (Amos and Amos 1989: 25). Grass was placed on top before the cache was covered with rocks to insure it would not be disturbed until needed (Kiokan 1995). Berries were stored in much the same way, except that these pits would be lined with rocks (Kiokan 1995; Whitman 1995) and raw spinach (e.g., *Rumex arcticus*) was used

Ethnobotany of Alaska: A Southwestern Alaska Perspective. Fig. 5 Rock-lined cache pits at Nash Harbor village, Nunivak Island, Alaska.

as an inner lining (Kiokan 1995). The berries would have no juice when removed, since they would have dried out while being stored underground. In the fall, people would return to their seasonal caches and transport their stored berries and greens to their winter village. Curtis (1930: 36) describes berry caches as "a small box-like structure of flat stones lined with grass and covered with sod until air- and water-tight." Examples of such features were discovered during recent archaeological excavations on Nunivak Island (see Fig. 5).

Changes in Plant Use

While recent investigations on Nunivak Island (Griffin 2001, 2004; Nuniwarmiut Taqnelluit 2006) have added extensive details to previous knowledge of traditional subsistence procurement and storage techniques, one must keep in mind that the memories of earlier subsistence use may be affected by historic changes to native culture. The most obvious change in Yup'ik indigenous plant use, between that found in early ethnographies and at present, is the current lack of knowledge of many previously harvested plants. With the abandonment of many small Delta villages in favor of larger villages with established schools where native children were sent to be educated, and a subsequent increased reliance on western foods, fewer families rely on traditional subsistence resources. Studies (e.g., Nowak 1975) have documented a link between continued traditional subsistence activities and a family's economic position. With village centralization, the cost of purchasing and maintaining the equipment needed to continue traditional subsistence activities (e.g., boat, four-wheeler, gas) became dependent on having a steady source of income and time to pursue such activities. In time, information on earlier plant use is forgotten and influences resulting from increased contact with non-Yup'ik mainland peoples can add to or supplant earlier local knowledge. For example, in 1927 Curtis (1930: 35) recorded the use of willow leaves (*Salix* spp.) on Nunivak Island as a food and medicinal item. In 1939, Lantis (1959: 60) found only one elder on Nunivak who still recalled the earlier use of willow. Today elders routinely deny such traditional use. However, recent influence of northern Eskimos on the island population has resulted in a renewed use of the plant, although contemporary Cup'it elders believe that its use is only of recent innovation. A similar pattern of traditional versus recent use has been noted for stinkweed/wormwood (*Artemesia tilesii*).

It is easy to assume that observed Native lifeways in the early twentieth century reflect those practiced during the late prehistoric period or before. However, in spite of the evident continuity of tool use and general subsistence practices on Nunivak Island (Griffin 2001, 2004) and the Yukon–Kuskokwim Delta (Shaw 1983) throughout the past 500 years, traditional lifeways may have been different, possibly more complex, than those historically recorded. Following increased contact between mainland Native peoples (i.e., trade, intermarriage) and Euro-Americans during the nineteenth century, changes in the use of indigenous plants were probably an ongoing process, influenced by the degree and type of contact, as well as impacts from a serious loss in Native population resulting from the introduction of western diseases.

Previous research in Native communities within the Delta have focused on documenting changes to Native lifeways following the arrival of Euro-Americans to the region (e.g., Fienup-Riordan 1983; Lantis 1946). However, these studies have provided little detailed information on traditional use of indigenous plants. The collection of ethnobotanical information was rarely a focus of research efforts and a systematic analysis of Native plant use throughout the region has yet to be undertaken. Given the incorporation of western foods in Native diets and a corresponding decline in the harvest of many indigenous plants, efforts to collaborate with Native communities need to be undertaken before information on traditional use of area vegetation has been forgotten.

The degree of contact between mainland and island Eskimo people, prior to the arrival of Russian and Euro-Americans in the late eighteenth and nineteenth centuries, is unknown but would have largely been limited to trade between neighboring groups during the summer months. Having to rely primarily on locally available resources for their subsistence, the Yup'ik incorporated many indigenous plants into their year-round diet. Contrary to earlier stereotypes of Arctic peoples' sole reliance on a meat-based diet for survival,

Ethnobotany of Alaska: A Southwestern Alaska Perspective. Appendix: Glossary of Native Plant Names Yup'ik Native Plant Name Glossary

Scientific Name	Common Name	Yup'ik	Cup'ig	Siberian Yup'ik
Achillea spp.	Yarrow	punaiyulinu'kait		
Aconitum delphinifolium	Monkshood		cetegneg	
Alnus spp.	Alder	chufu'koak		
Angelica lucida	Wild celery	ikiituk	ik'itut, ik'iituq, ikkitug	
Arctostaphylos alpina	Alpine Bearberry	kavlak	kavlag	
Ammodenia peploides	Sea purslane		tukullegat	
Artemisia Tilesii	Stinkweed, Wormwood	caiggluk	neqnialngut	
Betula nana exilis	Birch, Dwarf Birch	chupuaiya'hak	cigur	
Boltenia ovifera	Sea Potato, Sea Onion		arnaut	
Caltha palustris	Marsh Marigold	allngiguaq	wivlug	
Carex spp.	Sedges		pekneret	
Cladonia spp.	Lichens	ciruneruat	qelqun'at	
Cladonia rangiferina	Lichens–Reindeer Moss	ciruneruat	ungagar, ungagat	
Claytonia tuberosa	Tuberous Spring-Beauty	ulqit	ulpit	ulkik
Conioselinum chinense	Western Hemlock-Parsley		tuk'ayug	
Dendroa aggregate	Unknown		tukurnar	
Draba borealis	Wild Lettuce		inguqit	
Dryopteris austriaca	Shield Fern	ciilavik	centurkar, ceturga'ar	
Dryopteris dilitata	Shield Fern	ceturqaaraat	cilqaarat, ilqaarat	
Elymus mollis	Wild Rye Grass	taperrnaq	taperrnaq	
Empetrum nigrum	Crowberry	paunraq	paunrat, pauner	pagungak[a]
Epilobium angustifolium	Fireweed	ciiqaaq	cilqaar	
Epilobium latifolium	Dwarf Fireweed, River Beauty		qilqaarat	
Equisetum arvense	Common Horsetail	qetgoq	kenret	
Eriophorum spp.	Cottongrass	melquruaq	melqiutet, pal'it	
Eriophorum angustifolium	Tall Cottongrass	anlleq	pekner	
Fomes igniarius	Chew ash fungus	kuma'hak		
Fucus spp.	Bladderwrack		elquat	
Fucus gardneri	Bladderwrack		elquar	
Hippuris tetraphylla	Mare's Tail	tayaruq	tayarut	
Honckenya peploides	Beach Greens	qelquayak	tukullegat	mytknagrak
Ledum palustre decumbens	Labrador Tea	ayuq, ai'yut	ay'ut	
Linguiticum scoticum Hultenii	Beach Lovage, Wild Parsnip	tukaayuq	tuk'ayat, ciukarat	
Lycoperdon spp.	Puffballs	agyam anaa	agyam an'a(i)	atykyrygak[a]
Matricaria matricariodes	Pineapple Weed	atsu'koak		
Mertensia maritima	Oyster Leaf	Tumaglir	ciunertur pag	
Nephroma arcticum	Arctic kidney lichen	kus'koak		
Oxycoccus microcarpus	Bog Cranberry	uingiar, tumagliq		
Oxyria digyna	Mountain Sorrel		quulistar	kugylnik
Palmaria mollis	Seaweed, Dulse		elquat, elquarnar	
Parrya nudicaulis	Wild Cabbage		inguqit	
Pedicularis verticillata	Wooly Lousewort	ulevleruyak	megtat neqiat	kakykak[a]
Petasites frigidus	Coltsfoot	qaltaruaq	lal[a]ngagguar	kamgyak[a]
Picea glauca	White spruce	mingkot'moak		
Pohlia nutans	Moss	kuma'hotit	kumarutet	
Polygonum bistorta	Bistort, Pink Plumes	cuassaaq	ciwassat	siukl'iak
Polygonum viviparum	Alpine Bistort		ciwassat	siukl'iakyak
Ranunculus Pallasii	Pallas Buttercup		aggulunguat	
Rubus arcticus	Nagoonberry	puyuraaraq	puyurarag	
Rubus chamaemorus	Cloudberry, Salmonberry	atsalugpiaq	atsar atsakutag	akavsik
Rumex arcticus	Sourdock, "Wild Spinach"	quagciq	ciwassat	al'kyhkak
Salix spp.	Dwarf Willow	nuwi'longok	inaqac'it	okviuk
Salix alaxensis	Alaska Willow		qugyuguat	kukunat[a]
Salix fuscescens	Willow		qimugkararat	
Salix pulchra	Diamondleaf Willow		qugyuguat	kukunat
Saxifraga spp.	Saxifrages		quulistat	siknak[a]
Sedum rosea	Roseroot, Stone crop	cuqlamcaraat	megtat neqiat	nunivak

Ethnobotany of Alaska: A Southwestern Alaska Perspective. Appendix: Glossary of Native Plant Names (Continued)

Scientific Name	Common Name	Yup'ik	Cup'ig	Siberian Yup'ik
Senecio pseudo-Arnica	Ragwort, Fleabane		qugyugguat	
Sphagnum spp.	Sphagnum moss	uruq		
Streptopus amplexifolius	Twisted Stalk		atsarrlug	
Vaccinium uliginosum	Alpine Blueberry, Bog Blueberry	curaq	cur'at	siugak
Vaccinium vitis-idaea	Lingonberry, Low-bush Cranberry	tumagliq	tumaglir	kitmik
Valeriana spp.	Valerian			ahseukpuk

[a]Name references same species but possibly different subspecies.

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local flora was routinely incorporated into the Yup'ik diet in addition to Native pharmacology and utilitarian tasks.

There are few native elders with knowledge of traditional plant use in the Yukon–Kuskokwim Delta, and younger generations have not expressed a strong interest in preserving this data. Except for the continuing harvest of a few popular plant species (e.g., *Angelica lucida* [wild celery], *Rumex arcticus* [sour dock], *Caltha palustris* [marsh marigold], *Rubus chamaemorus* [cloudberry]), much traditional knowledge is not being passed on and will likely disappear with the passing of today's elders. It is important that additional research efforts to record traditional use of plants occur before knowledge of such use is forgotten.

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Ethnobotany of the Aztecs

JAN G. R. ELFERINK

Scope

The Aztecs represented the ruling empire in Mexico when the Spaniards arrived there in 1519. It was their culture that came in close – and for the Aztecs disastrous – contact with the Europeans. The Aztecs were a rather young culture. Starting as a small tribe in the thirteenth century, they developed into the ruling culture in Mexico. At the arrival of the Spaniards in 1519, the Aztecs ruled Central Mexico from their splendid capital Tenochtitlan, situated at the place where Mexico City is now located.

Ethnobotany in its broadest sense is the part of botany that deals with the use of plants in religion, medicine, all aspects of social life, and their interrelationships. The Aztecs used a very large number of plants. We know that because a lot were written down in the early years after the conquest. Because of space limitations, only a few aspects of Aztec ethnobotany will be dealt with in this article. The focus is on some plants that were especially important for the Aztecs. The relationship between medicinal plants and religion will also be discussed. A number of publications provide more detailed information about Aztec ethnobotany. These include the works of Ortiz de Montellano, Martínez, several articles in the work of Schultes and von Reis, and the comments by Emmart in the *Codex Badianus*. See also: ▶http://www.lib.utexas.edu/benson/bibnot/bn-92.html and ▶http://maya.ucr.edu/pril/reprints_agp/raiceetn.html. For the pre-Columbian use of plants in criminal practices see ▶http://www.drugtext.org/library/articles/elferink01.htm.

Ethnobotany of the Aztecs. Fig. 1 In the Mexican codices plants (especially flowers) are often depicted, such as here in the Codex Nuttall. They are probably connected with medicine, but their exact meaning is often unclear.

Sources

A number of sources deal with the use of plants by the Aztecs. These works are more detailed than for the Mayas or Incas, so we know a lot about their plant use. By far the most extensive source is the work of Hernández. He focused on medicinal plants; he described about 2000 of them, but he also gave information about a large number of other plants. Hernández was the personal physician of Philip II of Spain. Philip sent him in 1570 to Mexico with a quite clear and specific order: to get as much information as possible from the indigenous herbalists, physicians, and other people involved in medicine. The work of Bernardino de Sahagún, a Franciscan monk, is by far the most valuable source of general information about the Aztecs. His work deals with all aspects of Aztec culture, but it also includes a lot of information about the use of plants. The importance of Sahagún lies not only in the abundance of information which he wrote down. It is especially his reliability, because of the procedure that he followed using Aztec informants. The *Codex Badianus* is an Aztec herbal, written by an Aztec physician in honor of and for Charles V of Spain. It contains colored figures of plants, and a description of the treatment of several groups of diseases. The importance of magic in Aztec medicine is quite clearly illustrated in this manuscript. For understanding the role of religion and magic in the use of medicinal plants two chroniclers are of special importance. These two, Hernando Ruiz de Alarcon and Jacinto de la Serna, wrote their works in the seventeenth century. This might seem late, but the mere fact that they tried to eradicate the ancient customs and beliefs demonstrates that they dealt with the beliefs and attitudes of the ancient Mexicans. In both works ample attention has been paid to the use of *ololiuhqui*, *peyotl*, *picietl* and other plants in medicine and religion. In addition a number of other chroniclers mention the use of plants, but mostly their contribution is modest as compared with those mentioned before (Fig. 1).

The Aztec Interest in Plants

Botanical Gardens

The appreciation of the leading Aztecs for botany, and especially for medical botany, is demonstrated by the presence of botanical gardens in ancient Mexico. Their wealth in species and choice was so large that the Spanish conquerors were deeply impressed. One of the most important gardens was near the palace of the ruler Montezuma. He did not want any food plant or fruit tree in his garden. Those, he believed, were for slaves and merchants. The garden contained medicinal plants, beautiful flowers, and odorous trees and herbs. Montezuma ordered his physicians to use the medicinal plants for the nobles at court (Cervantes de Salazar 1971: 320). According to Solis the botanical gardens contained herbs for all types of diseases and ailments, and although the Aztec physicians had little knowledge of the cause of diseases, they knew quite well with which plants certain diseases had to be treated. The medicinal plants from these gardens were distributed freely to all those who suffered from diseases (Solis 1996: 172).

The king of the city-state Texcoco (which had a treaty with the Aztec capital Tenochtitlan) was Nezahualcoyotl; he lived in the fifteenth century. He is described as a constructor, a poet, a wise and clever statesman, and a righteous ruler who codified a number of laws (Clavijero 1970: 115). He was also a special expert on medicinal plants. Those plants which he did not have in his vicinity – Texcoco is situated near present-day Mexico City at an altitude of about

2000 m – were painted. Hernández used these paintings when he prepared his treatise on the materia medica of Mexico; in the original version he meticulously copied figures of plants.

Clavijero (1970: 231, 232) states that there were many botanical gardens in ancient Mexico. He mentions as the most important those of the capital Tenochtitlan, and that of Texcoco, and of the lords of Iztapalapa and of Huaxtepec. Cortés and Bernal Diaz expressed their admiration for the garden of Iztapalapa, and Hernández described a number of the plants from this garden. More important and also much larger than the garden of Iztapalapa was the botanical garden of Huaxtepec. The garden not only contained local plants but also many which were imported from regions far away. After the conquest the Spaniards conserved the garden for many years, and used the medicinal plants in the hospital which they had established in the region (Clavijero 1970: 232). Clavijero stressess that many of the plants in this garden were taken from remote areas. The transportation of several types of trees from remote areas to the core of the Aztec empire was only one of the many classes of products which were transported. The conquered tribes had to pay a lot of tribute consisting of a large variety of goods, to the Aztecs. In addition the Aztec merchants, who traveled a lot abroad, transported valuable items (which could be plants) from the region where they practiced commerce, to the capital.

Medicinal Plants

Knowledge of medicinal plants was essential for the Aztecs because their treatment of diseases relied heavily on their use. The principal quality or application of the plant determined their nomenclature. That could be a color, the place where it was found, the beauty of the flower, but also its preferential application against a certain disease. The Aztecs often gave a plant the suffix *patli* when it was used as a medicine; *patli* means "medicine," but gives by itself no further specification. The reference to a disease or target was often given in the remaining part of the name. In this nomenclature the plant *axixpatli* was a medicine which caused urination (a diuretic). In the same way the plant *atonahuizpatli* was a remedy against fever. In such a name the ability of the plant to act as a medicine against fever is stressed, but it does not necessarily mean that the plant had no other properties. Sometimes a large number of different plants had the same name. The disease *nanahuatl*, probably syphilis or a related disease, was very important in ancient Mexico (Fig. 2). Hernández gives not fewer than eight different plants which were called *nanahuapatli*. The Aztecs also had a medicine called *nanahuaquahuitl* or "tree against *nanahuatl*," and *nanahuaxochitl* or "flower against *nanahuatl*."

Ethnobotany of the Aztecs. Fig. 2 It is striking that the *Guayacum officinale* or *guayacan* was not described as one of the *nanahuapatli* (medicines against syphilis). The guayacan became a major medicine for the Europeans who suffered from syphilis. This picture is from *Köhlers Medizinal-Pflanzen*.

The Aztecs had a clear idea about the origin of their knowledge of medicinal plants. They were convinced that they had inherited this knowledge from the Toltecs, a tribe that resided in the valley of Mexico before the Aztecs arrived, and to whom the Aztecs were related. About the Toltecs Sahagún writes:

> …the Toltecs had much experience and knowledge, they knew the properties and virtues of herbs, they knew which were harmful and poisonous… and through the large experience they had [of these plants] they passed on [the knowledge of] those which are now used for curing, because they were the first physicians, and especially the first of this kind who were called Oxomoco, Cipactonal, Tlaltetecuin, and Xochicauaca who were so competent in knowing medicinal herbs that they were the first inventors of medicine, and the first physician–herbalists…(Sahagún 1969: 10-XXIX).

The description underlines the importance of medicinal plant knowledge, in a way that demonstrates that medicine and botany could not be separated.

Plants in Religion and Medicine: Divine Plants

The Aztecs venerated a large number of gods, and a number of them had a close relation with plants. The goddess Toci was venerated by all those who had a profession related to medicine (Sahagún 1969: 1-VIII and IX). She was the goddess of medicines and medicinal plants. Like other social entities in the Aztec society the pharmacists venerated their own deity. This was primarily the goddess Tzapotlatena. The fact that she had invented the *uxitl*, a highly appreciated medicinal resin derived from pines, was the reason that the pharmacists venerated her. For the invention of the resin she was immortalized and incorporated in the Aztec pantheon of gods and goddesses. Because of the importance of maize as a food plant, some gods were especially associated with maize: Cinteotl, and the related deities Xilonen (Fig. 3). Aztec tobacco or *picietl* was also closely linked to religion. It was believed that tobacco was the body of a goddess called Cihuacoatl (Mendieta 1973: 66, 67).

Some time after the conquest a number of priests tried to eradicate the ancient beliefs of the Aztecs (Ruiz de Alarcon 1953; Serna 1953). These priests reported about their activities, and from these reports we can learn how high the Aztecs appreciated a number of plants. In fact, the priests described these plants as divine plants, because they were venerated as (minor) gods. They were invoked by means of incantations or prayers, for help with diseases. Among these were *ololiuhqui* (*Rivea corymbosa*), *peyotl* (*Lophophora williamsii*), *picietl* (*Nicotiana* sp.), *huauhtli* (amaranth, A*maranthus leucocarpus*), and *yauhtli* (*Tageta lucida*). They had in some way or other a connection with the supernatural. Some of them were hallucinogens, and could be used to get into a trance to make contact with supernatural powers (Fig. 4). These hallucinogens were used not only for divination purposes, but also in medicine. The religious relevance of the plants varied; the ololiuhqui was especially venerated as a kind of god. On the other hand, the picietl (tobacco) was used most frequently against a variety of diseases. The peyotl was mostly considered in conjunction with ololiuqui, while the yauhtli could sometimes substitute for picietl. Yauhtli (more correctly spelled: iyauhtli) was considered an important medicinal plant (Elferink 1988) (Fig. 5). Hernández mentions more than 20 applications in Aztec medicine. A priest who asked the plant for a cure especially invoked picietl. At the same time it was applied to the patient. Occasionally other medicinal plants were invoked for special complaints. For example, the *poztecpatli* was a medicine against bone fractures. It was invoked in an incantation while the priest–physician applied the plant in the form of a plaster (Ruiz de Alarcon 1953: 189).

A plant that was not hallucinogenic but nevertheless highly venerated by the Aztecs was *huauhtli*. The connection of huauhtli with religion was complex. It derived its importance not from incantations but from a special application in Aztec religion. From huauhtli a dough was made that was called *tzoalli*. From this tzoalli statues of gods were made. The statues were venerated and subsequently consumed in religious ceremonies as a kind of communion. Huauhtli was also an important food plant, and used against diseases such as eye complaints, swellings and pain in the chest.

Some hallucinogenic plants, namely ololiuhqui and picietl, had still another connection with medicine. They were principal ingredients of *teotlaqualli*. This

Ethnobotany of the Aztecs. Fig. 3 One of the maize goddesses, named Xilonen, depicted in the Codex Nuttall.

Ethnobotany of the Aztecs. Fig. 4 Besides the hallucinogens mentioned in the text the Aztecs used *teonanacatl*, the divine mushroom. In the lower part of the picture (Codex Nuttall) the mushroom is depicted, as well as a man who eats it and an unknown deity.

Ethnobotany of the Aztecs. Fig. 5 The Aztecs sacrificed many humans, as depicted here in the Codex Nuttall. On a few occasions they were stunned before they were sacrificed. According to Sahagún the *yauhtli* was used for this purpose.

was an unction that was offered to the gods, for whom it served as food. The Aztec priests smeared themselves with this unction, to dispel fear and to reach the appropriate state of mind to serve the Aztec gods. A few cases are reported in which the Aztec emperor or soldiers were smeared with teotlaqualli. It is suggested that the black color of some Aztec deities, as depicted in the codices, was due to an ointment with teotlaqualli. In addition to its use for psychoactive purposes, teotlaqualli was applied in medicine under the name *teopatli* (Elferink 1999).

Some Plants with Special Interest for the Aztecs

Maize

The name maize comes from the language spoken in the Caribbean; the Aztec name was *tlaolli* (*Zea mais*). It was by far the most important food plant of the Aztecs. Its importance can be derived from the large number of Aztec gods that were associated with maize. Its use in medicine was rather limited, although a number of chroniclers had a different opinion. They were convinced that the consumption of maize products was the cause of the low incidence of kidney and bladder complaints among the Aztecs. From maize a porridge called *atolli* was prepared. It was usually prepared together with other plants, and so a large number of different types of atolli were known. The *chillatolli*, for example, was atolli mixed with chili pepper. This atolli was an aphrodisiac, probably due to the pepper. Hernández describes nearly 20 different types of atolli, some of which were applied in medicine. It is hard to say whether their supposed medicinal action was due to maize or to the other added products.

Picietl

There are few plants which played such a decisive role in Aztec medicine and religion as the *picietl* (*Nicotiana sp*.). *Nicotiana rustica* is often given as identification of picietl or Aztec tobacco, but the properties of *N. rustica* do not correspond with those of picietl. This refers especially to the mind-altering properties of picietl, and these properties especially determined its role in religion, magic, and curing with medical incantations as mentioned before. Many chroniclers have noted these psychoactive properties, so that there is little doubt about this property in ancient times. It is therefore not surprising that diviners used picietl to get intoxicated, so that they could make divinations. In addition to magic-religious applications in medicine, picietl was just applied as a medicinal plant. Hernández mentions its use against more than 20 different ailments, particularly ailments associated with pain. An interesting application was the use of tobacco as an antidote against the bite of various poisonous animals and the cleansing of wounds with tobacco juice. A particular application of tobacco was the stunning of dangerous snakes with tobacco powder, so that they could be caught for religious purposes (Elferink 1983).

The Aztecs considered tobacco a sacred plant, and it was highly appreciated because of its use in medicine and its psychoactive properties. In this context it is relevant to realize that the Aztecs did not use the tobacco for recreational purposes as we use tobacco today. The Aztecs did not experience the negative effects of smoking, although they knew too that excessive use was dangerous.

Metl

The name *metl* or *maguey* was used for several Agave species. The metl was in more than one respect an important plant. It provided fiber that could be used for preparing clothes, sandals, and other materials. It was used to prepare a good quality of paper. The thorns were used as needles. A specific application of these thorns was the pricking in the ears or genitals to obtain blood for an offering to the gods. Metl was the basis for the preparation of *octli*, today better known as the *pulque*, an alcoholic drink made by fermenting a honey-like secretion of the plant. Although the use of alcoholic beverages was forbidden under normal conditions, octli was so important in Aztec society that several Aztecs gods were associated with it. It was frequently used as an offering. Consumption of octli occurred mainly during festivities of some octli-gods. Both metl and octli were applied in medicine, the octli mainly as vehicle for the intake of other medicines. Pregnant women were allowed to consume octli outside religious festivals, because of the supposed strengthening action of the beverage (Fig. 6).

Ethnobotany of the Aztecs. Fig. 6 From maize a beverage was prepared that was called *octli* (later it got the name *pulque*). Its consumption was forbidden under normal conditions but during some religious feasts it was taken in large quantities. Here the preparation and consumption of octli, as depicted in the Codex Nuttall.

Ulli

Ulli or *hule* was the resin of the *olcahuitl* (or *holquahuitl*) tree (*Castilla elastica*), one of the rubber-producing trees of the Aztecs. It had a number of applications. The hule was the product from which balls were made for the ritual ball game. It was further used in a number of religious customs. One of them was related to medicine. If someone recovered from a disease he wanted to honor the god who was associated with the disease. For that purpose he went to a soothsayer-priest to select a suitable day. On that day the former patient burnt in his home pieces of paper on which the soothsayer had painted with ulli the picture of the god who had to be venerated (Sahagún 1969). The use of ulli as an offering to the gods is confirmed by other chroniclers (Durán 1967: Calendario, V). The ulli was sold in the markets by special vendors, who sold nothing except ulli (Sahagún 1969: 10-XXIV). One of the most important medical applications of the ulli was to treat dysentery and diarrhea (Hernández 1959; Relaciones Geográficas México 1985: 318; Relaciones Geográficas Tlaxcala 1984: 271). For that purpose the ulli was often mixed with cacao. It was further used against a number of other ailments such as abscesses, eye diseases, inflammations, intestinal problems, urinary complaints, colic, pain, headache, and eye diseases (Sahagún 1969: 11-VI; Hernández 1959). Hernández describes a peculiar application of the ulli, which he apparently had learnt from indigenous physicians. Mixed with *axin* it was taken to improve the agility and speed of the joints. The informants told him that the bones were loosened in a sense that turns and movements were facilitated so that acrobatic abilities were obtained (Hernández 1959).

Coanenepilli

Another plant, which is often mentioned by the chroniclers because of its frequent use by the indigenous population, is the *coanenepilli*. The name “serpent tongue” refers to the form of the leaves which are bilobed (Emmart, in *Codex Badianus* 1940: plate 59). As might be expected, the name was used for completely different plants, namely *Dorstenia contrayerba*, and a *Passiflora sp*. For medicinal purposes the first one was by far the most important. In the *Codex Badianus* coanenepilli was prescribed against obstruction of the urinary tract. An important application of coanenepilli was its application as an antidote. For that reason it was called *contrayerba* by the Spaniards. If a snake or a scorpion bit someone, the Indians anointed the bite with the coanenepilli, while the juice of the plant was drunk (*Relaciones Geográficas México* 1986: 150; *Relaciones Geográficas Michoacan* 1987: 43). Another important application of coanenepilli was against fever (*Relaciones Geográficas México* 1985: 280, 306, 312). The Aztec informants of Sahagún stress the ability of the coanenepilli to purge: bad humors were expelled by mouth and via stool (Sahagún 1969: 10-XXVIII).

Shortly after the conquest it was also applied against typhus (*Relaciones Geográficas Tlaxcala* 1985: 205; Serna 1953: 283; Mendieta 1973: 98). The Aztecs desperately tried a number of medicines against the new diseases which were imported by the Spaniards. These diseases decimated the number of Indians, and caused depopulation of large parts of the country (see chapter XIII). Among the few medicines used by the Indians against these new diseases, the *Relaciones Geográficas* mentions the coanenepilli. The frequent application of this plant could suggest that the Indians had some benefit from it. On the other hand, the number of casualties could hardly have been higher than it was, so the new drug had only a limited curative value (*Relaciones Geográficas Tlaxcala* 1985: 51, 54, 59). The reason for the use of this plant against epidemics was probably that the coanenepilli was regarded as a good remedy against feverish conditions. Because the postconquest epidemics were accompanied by fever, the choice for the coanenepilli was evident (*Relaciones Geográficas Tlaxcala* 1985: 84, 205).

Coanenepilli was popular in the combined treatment of diseases with medicinal plants and magic-religious incantations. If someone experienced chest pain because of an accident, the powdered root of coanenepilli was applied, and the patient had to drink a potion of the plant thickened with ground maize. At the same time an incantation was spoken where the coanenepilli was invoked in the name of the god Pahtecatl (Andrews 1984: 177–178). Combined with magic incantations the coanenepilli was further applied against fever and against cutaneous eruptions (Serna 1953: 292, 293, 283, 289; Andrews 1984: 195–199).

Iztauhyatl

The *iztauhyatl*, in Mexican folk medicine called *estafiate*, is botanically known as *Artemisia mexicana*. According to the Florentine Codex the plant was a remedy against many diseases (Florentine Codex 1950–1969: 11-VII). Relapsing fever, cough and anxiety are mentioned. The plant was useful for treating anxiety (Sahagún 1969: 11-VII). It was also a part of complex medicines. In the Codex Badianus the iztauhyatl was part of a remedy against some diseases which we do not always know exactly what was meant: weakness of the hands, ailment of the fundament, injury of the feet, lassitude, excessive heat, lightning stroke, and phthiriasis of the head (Codex Badianus 1940: plates 43, 61, 65, 66, 79, 91, 102). Hernández indicates that the name iztauhyatl was used for more than one plant. In most cases, however, the plant described as iztauhyatl was *Artemisia mexicana*.

Magic power was ascribed to the iztauhyatl, and it was considered a sacred herb (Aguirre Beltran, 1987: 124–126). According to Aguirre Beltran the name of the plant is derived from *iztahua* (deity of the salt), and *atl* (water). The indigenous physicians called *techichinani*, who cured by sucking the illness from the body, chewed the iztauhyatl before they started the sucking of the disease. As a sacred plant the iztauhyatl was invoked in cases of troubles in love affairs. The magic power of the iztauhyatl was called for assistance when a pregnant woman or her husband wanted to trespass some rules, such as leaving the house during the night. The result was quite nasty for the child to be born who would cry a lot or become ill. To prevent these dangers the woman had to wear a bag with some copal or iztauhyatl, and the man had to wear a bag with picietl, when they went out during the night (Serna 1953: XIII; Sahagún 1969: 5-XIX).

Against one of the most severe epidemics of the postconquest time, mostly referred to as *cocoliztli*, no medicines were available. Among the few which were tried with unknown success were the iztauhyatl. Some of the authors of the *Relaciones Geográficas* mention the plant as a remedy; it was put in water, and the water was used to wash the patient (*Relaciones Geográficas Mexico* 1986: 135).

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Ethnobotany in China

Georges Métailié

Ethnobotany is the study of the links that human beings, as individuals or societies, have maintained and maintain with plants. China is a country with more than 50 different national minorities, with very different traditional cultures, languages, food habits, etc. Chinese ethnobotany could thus be the juxtaposition of the different ethnobotanies of all the ethnic groups living in China. On the other hand, one generally understands "Han" when one says "Chinese." This term, which is the name of the second dynasty after unification of the empire (206 BCE–AD 220) is also the name of the main ethnic group in China, with about 96% of the population. It is the ethnobotany of the Han Chinese that we are going to present here.

With 3,692,000 square miles, China is about the same size as the United States. Its relief can be roughly compared to stairs going down from the western plateaux to the plains of the east and the south. Its climate is under the double influence of a huge continental mass and the strong impact of the summer monsoon: generally the winters are cold to very cold – except for the extreme south-east – and dry. The summers are very warm with high rainfall and moisture. The diversity of climates and reliefs has probably favored a particular richness in vegetation. With about 25,000 species of higher plants, 2,600 species of ferns, 2,100 species of mosses and liverworts, and some 5,000 species of fungi, China has the third richest flora of the world after Malaya and Brazil.

In Chinese mythical history, the beginning of the relation between man and plants is so strong that it is considered the first step into "civilization." Speaking of Shennong, the Divine farmer, one of the three mythical emperor creators of the Chinese civilization, one says that "before him, men did not know cereal grains, they ate animals and drank their blood. Then Shennong tasted the herbs, sorted cereals, and taught the art of tilling to the people. Then he tasted herbs again and sorted simples to save the people from illness." Eventually, the Yellow Emperor, successor of Shennong, taught cooking and medicinal prescriptions. In the Chinese tradition, the access of mankind to civilization was achieved when man became a tiller and a gatherer; agriculture supplied what was needed for basic food, and gathering gave access to the complementary plants, medicinal, and pot herbs. Actually, the local biodiversity appears to have been rather well appreciated and exploited all through Chinese history, because China is one of the main centers of domestication of plants and possesses a very rich *materia medica*. The local richness did not prevent a great interest in plant introduction. However, introduced plants, like corn, sweet potato, tomato, and potato, have been used mainly as complementary food and never caused any fundamental change in food habits, as happened in Europe, for instance, with American plants. Among the 116 botanical species cultivated as vegetables today in China, at least 37 would have been locally domesticated. Also, considering the cultivars – which are the form under which these species are cultivated – their number amounts to several thousands. As for trees and shrubs, more than 300 species are exploited today – even if they are not all cultivated – for their fruits, eaten fresh or, more frequently, after transformation or preparation.

There is a traditional opposition between crops cultivated on dry lands – millets, wheat, barley, sorghum – in Central and Northern China, and rice and various tubers cultivated in irrigated fields of the south. Nowadays, thanks to agricultural hydraulic development, rice is also cultivated in northern parts of the country, where climatic conditions permit it. On the other hand, corn, following irrigation development, replaced traditional millet crops. The ordinary diet consists of large amounts of a basic food, called *fan*, made from steamed or boiled grains, such as rice, millet, or sorghum, or various kinds of noodles made from wheat, pulses, rice, etc. It is accompanied by *cai* (dishes), generally made from vegetables and soya bean in the form of *tofu*. Among these dishes, fish or meat, important for special occasions, are still not very frequent in everyday life, especially in the countryside.

As for clothing, even if today synthetic fibers, wool and silk have become more and more important, in the sixties, in mainland China, cotton was the only material used for common suits and even shoes. In the countryside, some work clothes, sun hats, and raincoats are still frequently made of bamboo or palm leaves. They combine several advantages: since they are not heavy, they provide good shelter and allow the air to circulate freely. The use of wood for buildings is entirely limited by the resources of the environment: it is a wooden framework which bears the roof of the traditional standard Chinese house, the nonweight-bearing walls being made of brick or tamped earth. However, from its shoots eaten as a delicacy, to the chopsticks used to eat, from the scaffolding, drill-hafts and brine conduits of the salt-fields in Sichuan to irrigation flumes, and from ordinary furniture to the most exquisite pieces of wickerwork, bamboo is probably the member of the vegetable kingdom which plays the most important part in the material life of the Chinese.

Traditional Chinese medicine uses as *materia medica* some 4,773 products of plant origin, 740 of animal origin, and 82 minerals.

Chinese people are also very interested in the beauty of plants. Varieties of some 12 ornamentals are particularly valued: tree-peony (*Paeonia suffruticosa* Andr.), Japanese apricot (*Prunus mume* Sieb. et Zucc.), hybrid roses, camellias, rhododendrons, Wintersweet (*Chimonanthus praecox* Link.), Chrysanthemums [*Dendranthema morifolium* (Ramat.) Tzvel.], orchids (*Cymbidium* sp.), daffodils (*Narcissus tazetta* var. *chinensis* Roem.), hybrid gladioli, pinks (*Dianthus caryophyllus* L.) and Indian lotus (*Nelumbo nucifera* Gaertn.). Besides a great number of other "traditional" ornamentals like bamboos or cockscombs (*Celosia argentea cristata*), new varieties appear frequently. Grafted succulents became very popular and, more recently, Kaffir lilies (*Clivia* sp.). Just for the pleasure of watching new flowers or to be photographed in front of a blossoming magnolia or plum, crowds of people will visit public parks in the spring, while in autumn it would be unthinkable not to go and admire the red leaves of maples in the nearby hills of the city of Nanking, for instance.

Plants obviously play a very important part in the life of the Chinese people, but one may wonder whether there is any particular kind of relation which would define a "Chinese ethnobotany." A first striking point, which can be well appreciated in agriculture and horticulture, is the closeness of the human-to-plant relation. This is obvious with a crop like rice where, after the nursery stage, every seedling in the paddy is transplanted to the field where it will ripen. Propagating other plants like yams or taros also necessitates the individual handling of every cutting. The sowing of all the plants cultivated in gardens, like cucurbits and beans, is individual, and even for crop plants like millets or wheat it is remarkable that a sowing machine allowing seed by seed control has existed at least since the thirteenth century. Grafting seems to have begun during the first centuries AD but it became very important in horticulture as early as the sixth century and was much used for fruit and flower production. Professional horticulturists have used grafting since the Song dynasty (960–1279) when it was believed it could create new varieties of flowers (tree-peonies and chrysanthemums) for amateurs who would pay fortunes just to watch the most beautiful. Another example of individual treatment of a plant is the technique of tree-potting (*penzai, bonsai* in Japanese): to keep the tree in small proportions, it is necessary to prune its branches and roots every year and to look after it day after day.

In ancient China, scholars also developed a very exclusive relation with plants. They would rank them from the most precious to the lowest. Following their personal taste, men of letters would develop real "friendships" with the ones they appreciated most and which would live in their studios, along with "the books and the cithar (zither)." Joseph Needham and Li Hui-Lin have shown that this interest in special plants led to various monographs on them. Plants have also been a favorite theme for literature and poetry. Since the thirteenth century several encyclopedic books have been composed entirely with quotations from texts dealing with plants. One famous book, published in 1231, *Portraits of the Plumflower*, is devoted only to the Japanese apricot (*Prunus mume* Sieb. et Zucc.). The author, Sun Boren, through a hundred ink drawings, each accompanied by a poem, evokes the feelings that he experienced watching the flower, from its bud stage to the fall of the last petal. Actually, in the painting of flowers, Chinese artists were more concerned with emotion than representation. Using a brush and black ink, they were looking for the essence, more than for the true form of, bamboos, pine trees, orchids, or plum-flowers. Zou Yigui (1696–1772), a famous painter, criticized the Western paintings he had seen at the imperial court as being too realistic, and he considered their authors not painters, although they possessed skill, but simple artisans.

In ancient China, plants as medicine were not distinct from minerals or animals and belonged to a system of classification where the whole *materia* *medica* was separated into three ranks, *san pin*, for nonpoisonous products, good for the health and used to “nourish life,” to very active products, generally highly toxic and used only under very strict conditions. During the sixth century, Tao Hongjing, a famous physician, developed this classification: within each of the three grades, plants were subdivided into herbs, trees, grains, potherbs, and fruits. At the end of the sixteenth century, another physician, Li Shizhen (1518–1593) in a famous book called *Bencao gangmu* (Classified Pharmacopaeia, 1596), changed the basis of this classification. Considering almost obsolete the three ranks system, he reorganized the whole materia medica “from the lowest to the most precious,” from minerals to man. He kept the five categories mentioned above for plants but in a new order – herbs, grains, vegetables, fruits, and trees – and divided those into 33 subgroups following various criteria like ecology, taste, and toxicity. Besides this learned system, created and used by physician–scholars, there was a folk taxonomy not exclusive from the previous classification, where the ethnobotanical data were distributed into six ranks. Following Brent Berlin’s vocabulary, they are:

– *Kingdom* marked by two words meaning plant, *caomu* (herb tree) and *zhiwu* (planted thing);
– *Life-form* with three main taxa, *cao* (herb), *mu* (tree) and *teng* (vine) and the ambiguous statute of *chu* (bamboo) “neither herb nor tree”;
– *Intermediate* where groups are named by juxtaposition of terms used for taxa of generic rank, like *tao-li* (peach-prune), *song-bai* (pine-cypress);
– *Generic* marked by monosyllabic terms like *tao* (peach), *xing* (apricot), *zao* (jujub);
– *Specific* where one finds some of the monosyllabic terms also used for generic taxa but with a narrower meaning like *xing* (apricot: *Prunus armeniaca* L.). However, terms of this rank are generally polysyllabic. They may be *secondary plant names*, lexical extensions on the basis of a generic term, like *yinxing* (silver apricot: *Ginkgo biloba* L.), or *jiazhutao* (narrow bamboo peach: oleander, *Nerium odorum* Soland.). They may also be *primary plant names* like *Lu meiren* (the beautiful lady of Lu: poppy, *Papaver rhoeas* L.), *mudan* (male cinnabar: tree peony, *Paeonia suffruticosa* Andr.);
– *varietal* a system, already described in the first encyclopedia *Erya* (third–second centuries BCE) is still effective today.

The long tradition of observation, culture, and use of plants along with a fair knowledge of plant life never led to a systematic approach. Among the rich literature about plants one cannot find anything like a primer of botany. Up to the middle of the nineteenth century, plants, in China, were considered in their cultural environment. Besides horticulture, agriculture, or art, concern with plants was philological: considering plant names with obscure meanings occurring in ancient texts, literati would try to find which plants would fit these names. To do so, they compared textual evidence or interpretation with the results of inquiries they made among their contemporary countrymen. Chinese traditional scholars’ plant knowledge can be described as cultural botany.

See also: ►Food Technology in China, ►Agriculture in China, ►Bamboo, ►Li Shizhen

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Ethnobotany in Ethiopia

Mesfin Tadesse

Ethiopia is located in the horn of Africa between 3°N and 15°N latitude and 33°E and 48°E longitude. Generally the central parts of the country are mountainous with the highest mountain peak, i.e., 4,620 m, being at Ras Dejen (Ras Daschen) in the Semien Mountains.

The coastal areas are low-lying plains. An area in the northeastern part of the country called the Afar depression is about 115 m below sea level.

Botany

The beginning of an organized study of the plant resources of Ethiopia can be traced to about 1,850 when Achille Richard (1847–1851) described the first flora of the country. *Tentamen Florae Abyssinicae* consists of descriptions of about 1,700 species of plants from particularly the northern parts of the country. This was followed, a hundred years later, by the work of Cufodontis (1952–1972), *Enumeratio Plantarum Aethiopiae Spermatophyta*. Almost 20 years after the completion of this checklist, the *Flora of Ethiopia* and later on the *Flora of Ethiopia and Eritrea* was started. This is still in progress although most of the volumes have been published (Hedberg and Edwards 1989, 1995; Edwards et al. 1995, 1997, 2000; Hedberg et al. 2003). What was and is being attempted in the above-cited publications is the documentation of the higher plants of Ethiopia and Eritrea, with the *Enumeratio* also providing information on plants found in Somalia.

Ethnobotany

The focus of this article is not on the total plant life of Ethiopia but only on the cultivated plants, i.e., the domesticated, wild and semi-wild food and medicinal plants. This usually falls under the umbrella of agronomy in agriculture and ethnobotany in plant biology. In order to understand the origin of ethnobotany in Ethiopia more completely, one has to look into the beginnings of agriculture. This, however, is a broad subject and will not be attempted here. (Ed. note: see Alexia Smith's article on Ancient Methods of Agriculture in this volume.)

Cultivation and domestication of plants have taken place in a number of spots in the world. Although naturalists like Darwin (1868) and De Candolle (1882) had written about cultivated plants, the first person to provide extensive documentation was the Russian scientist, Vavilov (1935), between 1926 and 1937. Vavilov considered the Ethiopian highlands as one of the eight centers of origin of cultivated plants with the major plants being Abyssinian hard wheat, poulard wheat, emmer, Polish wheat, barley, grain sorghum, pearl millet, African millet, cowpea, flax, sesame, castor bean, garden cress, coffee, okra, myrrh, teff, pea, and indigo.

In an overview of the origin of agriculture, Harlan (1998) wrote:

> From our review of the agricultures of the world, they seem to be centered on the Near East, Ethiopia, sub-Saharan Africa, China, Mesoamerica, highland South America, and lowland South America. Each has its own suite of cultivated plants. People associated with them, their cultures and religions, are closely intertwined with the main crops they grow. This appears to be the pattern on a global scale.

This view does not differ very much from the patterns described by Vavilov. A little bit has been added here and there but the overall conclusions are very similar.

It is believed that the first cultivated plants were selected from wild plants for their desired values and then domesticated (i.e., manipulated for purposes of mass production, a process of selective breeding). Domesticated plants are often associated with humans and do not occur in the wild, e.g., maize, tobacco, soybeans; others are still found as wild or semiwild plants, e.g., coffee, niger seed (noug), etc. Here I will select only five of these plants from Ethiopia to illustrate their use and how some of them spread to other countries. Further reading material is also provided after the references.

Coffea arabica L.: Rubiaceae (*Bunna* in Amharic)

The southwestern Ethiopian highlands (in Illubabor and Keffa) are believed to be the centers of proliferation and probably also of origin of *C. arabica* (Richard 1847–1851; Meyer 1965a, 1965b, 1969; Fernie 1966). As early as 1848, Richard considered arabica coffee as spontaneous in forests in Ennarya and Keffa and introduced elsewhere in Ethiopia. Other contenders of origin are the Boma Plateau in adjacent southern Sudan (Thomas 1944), Mt. Marsabit in Kenya and the highlands of Yemen. From all the available evidence and from theories regarding the place of origin of plant and animal species, it is believed that arabica coffee originated within the confines of present-day Ethiopia in general and the Keffa–Illubabor region in particular and then it was taken first to Yemen.

The coffee seeds or seedlings that were taken from the Ethiopian highlands were planted in the irrigated fields and terraces in Yemen (Old Arabia Felix). It appears that Yemen had been the only supplier of cultivable coffee to the world, and the Netherlands the first European country to acquire the first planting material from Aden in 1690. But it is also known that earlier on, in 1616, a coffee plant was taken to Holland from Mocha (Haarer 1962). The Dutch started planting coffee in Sri Lanka (formerly Ceylon) in 1658. Wellman (1961) wrote that the Portuguese had also introduced coffee into Sri Lanka before 1600. Wrigley (1988: 39) indicated that "Baba Budan, a Muslim saint," is believed to have taken a few seeds (seven according to Wellman 1961) into India (Malabar) around 1600. Plants were shipped from Malabar to Java in 1696. These supplied the first commercially grown beans to Europe. In 1706, a coffee plant was sent to the Amsterdam Botanical Garden from Java and seeds and seedlings that were produced from this single introduction were distributed to the major botanical gardens in Europe (Haarer 1962) and South America.

How did the drinking of coffee spread? This aspect is closely related to the brewing of coffee but as there are conflicting views on where the brewing started, it is also assumed that there will be similar hypotheses about the spread of coffee drinking. May be it is best to start with how coffee was utilized at first.

From a questionnaire survey made in 1989–1990 by the author in many coffee growing areas in Ethiopia, it appears that the earliest use of coffee in Ethiopia was in the form of small balls from roasted ground beans. These were then mixed with butter and kept in the mouth, between the cheek and the jaw, while making long journeys. While at home or in the vicinity of home, roasted coffee beans that were dipped in butter were chewed. This practice goes together with other rituals such as thanksgiving, celebrating the birth of a new child, etc., in this part of Ethiopia even to the present day. It also appears that this habit did not cross the borders of present-day Ethiopia. Similar modes of use have been reported for other species of plants, e.g., the early use of coca (*Erythroxylon coca*) in the Andes of South America (Brucher 1989: 175; Simpson and Ogorzaly 1986: 363–364).

Genetically, *C. arabica* is tetraploid, meaning that it has four times the original (haploid) number of chromosomes. It is believed to have originated by polyploidy, a process of speciation by doubling chromosomes, from a diploid ancestor. However, up to now no diploid plant has been found in the wild and the parents that might have given rise to it are assumed to have become extinct.

Brucea antidysenterica J. F. Mill: *Simaroubaceae* (*Waginos in Geez*, or *Yedega Abalo in Amharic*)

The root barks of this plant have been used since a long time ago in northern Ethiopia to treat dysentery. Today, there is a lot of useful information on the medicinal value of this species. Antitumor chemicals and cytotoxic antileukemic alkaloids have been isolated from it (Fukamiya et al. 1986).

There is an interesting story about how this species became popular. According to Pankhurst (1982) a Scottish traveler called James Bruce who stayed in Ethiopia from 1769 to 1771 was attacked by dysentery when he was about to leave Ethiopia. He tried to cure himself with the help of the medicines he had brought along from Europe but was not successful. When observing that he would not be able to make it to Europe traveling through the hot landmass of Sudan and Egypt, the Chief of Ganjar of Shanquilla informed him to take a well-established local drug known as *Waginos* (Geez name, the root of the current Amharic and Tigrigna languages of Ethiopia) or *Yedega Abalo* (name in Amharic, the official language of Ethiopia). The root bark of this plant was cleaned, dried in the sun, and ground into powder. James Bruce was then made to take two spoonfuls of the powder with camel's milk. After the sixth or seventh day, Bruce regained his health and was able to continue his journey to England. On his way back, he took some of the powder and fruits of Waginos. He used the powder whenever he or his companions fell sick on the way. The fruits were delivered to a botanist at the British Museum of Natural History called Daniel Solander, who, noting that it represented a species not known in Europe then had it planted in several British gardens. The plant was later named by Miller *Brucea antidysenterica* to commemorate James Bruce with the specific epithet indicating the medicinal property of the plant.[1]

Hagenia abyssinica (Bruce) J. F. Gmel: *Rosaceae* (*Kosso* in Amharic)

This is a large tree with smooth flaking bark known from Ethiopia, Kenya, and Uganda. The plant produces male and female flowers on separate clusters. The female flowers, known as *Kosso*, are used in eliminating tapeworm from human intestines. First the flowers are sun dried and an infusion of half an ounce is prepared in a glass of water. This should be drunk early in the morning before breakfast. The patient is not allowed to take food during the day, and, if the bowel movement is not free during that day, a physic should be taken at night.

Here there is also an interesting story on how the plant was introduced into the international world of medicine as an age-old tested medicament. According to Pankhurst (1975), "the first foreign medical man to interest himself in Kosso" was a French physician called Dr A. Brayer around 1816. Brayer's first acquaintance with Kosso was from a contact he had with an old Armenian merchant called Karabet in Constantinople (now Istanbul) who told him that the "…Ethiopians cured themselves with the aid of the flowers of a plant which…was known by the word which also signified the taenia itself." The plant was then called *Brayera anthelmintica* Kunth to commemorate the physician, Dr Brayer, and also to indicate its anthelmintic (antiworm) properties. Today, the chemistry is well known and the active compounds are Brayerin (a bitter, acrid resin), volatile oil, and tannin.

[1] More information on the chemical constituents of *Brucea antidysenterica* may be obtained from the *Journal of Natural Products,* e.g., Fukamiya et al. (1986) and Imamura et al. (1995); *Current Medicinal Chemistry*, e.g., Jung et al. (2000), and medicinal databases.

Since *B. anthelmintica* described by Kunth in 1824 is preceded by *Banksia (Bankesia) abyssinca* described by Bruce in 1790, the first name applied to the Kosso plant, today we use the later specific epithet transferred from *Banksia* to *Hagenia* (1791) following the International Code of Botanical Nomenclature. The genus name *Banksia* was published in 1781 by the son of Carolus Linnaeus (often called the father of botany) for an entirely different plant and thus could not be used in conjunction with the specific epithet of the Kosso plant. Hence, the next available genus name in the *Rosaceae* is *Hagenia*.

Guizotia abyssinca (L. F.) Cass.: Asteraceae (*Noug* in Amharic)

This is an annual herb that usually grows between 50 and 100 cm, but it may grow up to 2 m. It produces small yellow flowers at the apices of branches and stems. The marginal flowers are 6–8 in number (rarely up to 15) and strap-shaped, while the central flowers are numerous and tubular. It is from these centrally located flowers that the oil-producing fruits are obtained. The fruits are black, a few millimeters long, up to 1-mm wide and without hair when fully mature. Six out of the seven species in the genus (Mesfin Tadesse 2004) are found in Ethiopia; it is assumed that the genus originated in Ethiopia.

Noug has been domesticated in Ethiopia for a long time. The oil is used in cooking and as a source of candlelight. The cake is used as part of animal fodder. The plant was introduced in India, where it is also grown as an oilseed crop plant, and in other countries. In Australia, it has been found growing around overseas shipping containers areas. In the United States (Wisconsin), the Winnebago Company introduced it as wild bird seed, and in Ohio (Butler County), it was found as a weed in flower beds, near where bird feeders had been over the preceding winter. In Ethiopia, it is grown as an oilseed crop on a rotational basis with cereals and pulses. "It constitutes about 50% of Ethiopian and 3% of Indian oilseed production" (Getnet and Sharma 1996). Today it is reported as being used in paint and soap production as well.

James Bruce was the first person to take the fruits of *Guizotia abyssinca* to Europe. The earliest name applied to plants grown from these fruits in gardens in Paris was *Verbesina oleifera* by Buchoz in 1775, probably as part of a polynomial (cf. Baagoe 1974: 3). Consequently this name is invalid, but it indicated the property of the plant as used then and now. A plant cultivated in Sweden from among the fruits supplied by James Bruce formed the basis for the first valid name applied to this oil-bearing plant, i.e., *Polymnia abyssinica* L. f. (1781). For a thorough analysis on how the present name was adopted, the reader is referred to the works of Baagoe (1974).

Eragrostis tef (Zucc.) Trot.: *Poaceae* (*Teff* in Amharic)

This is one of the economically most important members of the grass family in Ethiopia. It is an annual plant widely cultivated in Ethiopia as a staple cereal crop, but it also occurs as an escape from cultivation. It is easily recognized by "its panicle of oblong, nonshattering spikelets full of plump grains retained within the swollen florets" (Phillips 1995). A large number of cultivars have been recognized based on the color of the grains with the major types being white, red, or black.

The genus *Eragrostis* consists of about 350 species (Phillips 1995). *Eragrostis tef* is an allotetraploid ($2n = 4x = 40$) and its origin is as yet unknown although it is closely related both morphologically and genetically to the widespread and weedy *Eragrostis pilosa* (Ingram and Doyle 2003).

The grains of *Eragrostis tef* are finely ground or milled and Ethiopians prepare thin and flat pancake- or chappati-like "bread" called *injera* or *yetef injera* from the flour. Injera is utilized throughout highland Ethiopia and currently also it is being utilized in certain low-lying parts of the country, e.g., among the Somali population in eastern Ethiopia. Outside of Ethiopia, the Borana people (Oromo ethnic group) of northern Kenya use the grains as a staple food.

The chaff is also used mixed with clay in the construction of wall material for mud houses in Ethiopia. It is also used as feed for domestic animals. Thus no part of this plant is wasted. This latter use of the plant has recently gained ground in other countries. Teff is now widely grown in South Africa and Australia for hay production and in India as a green fodder. It is also grown as a health food product and as forage for livestock in South Dakota and Montana (Stallknecht et al. 1993) in the USA. The immigrant Ethiopian community in the USA also utilizes the grains of plants mostly cultivated in Idaho in the preparation of injera.

The specific epithet *tef* is taken from the Amharic vernacular name Teff. The first cultivated teff plant in Europe was in the botanical gardens at Firenze (Florence) in Italy from grains collected by James Bruce in Ethiopia. It was subsequently named *Eragrostis tef* by Zuccagni in 1775. A large number of studies have been published on the biology and chemistry of *Eragrostis tef* (Ingram and Doyle 2003; Ketema 1997; Bekele et al. 1995 (as Bekele, Endashaw in ref.), as examples).

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Ethnobotany of the Incas

Jan G. R. Elferink

The conquest of America resulted in a considerable enrichment of the number of plants that could be used by Europeans in medicine and nutrition. Important examples are the potato, maize, beans, cacao, chili pepper, quinine, and so on. All these plants were widely used by the pre-Columbian peoples, among which were the Incas. The Incas were only one of the many highly developed civilizations that developed in the Andes and the Peruvian shore of the Pacific Ocean. Like the Aztecs in Mexico, the Incas were a young culture, starting their development in the thirteenth century. When the Spanish conqueror Pizarro arrived in Peru in 1531, the empire of the Incas was enormous, stretching from what is now Colombia in the North, to the middle of Chile in the South.

Information about the use of plants in all aspects of daily life by the Incas (i.e., Inca ethnobotany) comes mainly from the Spanish chroniclers who accompanied or followed the Spanish conquerors. Unfortunately their information is far more limited than of the chroniclers of the Aztec region. As a consequence we know less about Inca ethnobotany than about Aztec ethnobotany. The chronicler Cobo gave the most extensive description of Inca plants. Some indigenous chroniclers, such as Poma de Ayala, gave some original applications of plants by the Incas. A very late work by Losa contains material that was mostly derived from ancient sources (including Cobo), and thus provides information about the use of plants that is probably of pre-Columbian origin. Besides the information written down by the chroniclers, an increasing quantity of information comes from archeological findings.

Although the amount of information about the use of plants by the Incas is limited, the amount is far too large to cover in a short paper. Therefore only a restricted number of items of Inca ethnobotany will be dealt with. These items come from the use of plants in medicine, and in connection with their role in magic and religion. There is excellent additional information about Inca ethnobotany. These include the works of Yacovleff and Herrera, Towles, Alarco de Zadra, Bastien, Brack Egg, Valdizan, and Maldonado. Unfortunately some of these works are not easily accessible. A very good website about the potential economic applications of Inca food plants is ►http://www.nap.edu/books/030904264X/html/.

Medicinal Plants

The Inca Herbalist-Physician: Hampicamayok

In his description of the Inca physician, Cobo (1964: 256) underlines the importance of the knowledge of medicinal plants for this profession.

> …Their physicians were in general old people and highly experienced… They had little knowledge about the nature of the diseases and about their specific names… [They knew] many herbs to cure them. They had more knowledge about wounds and sores… and the particular herbs to cure them. They never used complex drugs, they cured with simple herbs, and between them there were many great herbalists… from whom we learned the virtues of many plants which we now use in our cures. With these simple drugs they also used to make fomentations and perfumes, which they applied in fever and other ailments…

Other chroniclers such as Garcilaso confirm the importance of knowing plants among the Inca physicians. Though Garcilaso is sometimes contradictory in his descriptions of the medical abilities of the Incas he praises the herbalists. There were "great herbalists who were very famous in the days of the Incas. These herbalists learned the virtues of many herbs and taught them by tradition to their sons; they were regarded as physicians…" (Garcilaso 1966: 121).

The most common name for this type of physician was the *hampicamayoc*, literally "official in charge of medicines" (Poma de Ayala 1980; Gonçalez Holguin 1952; Morua 1946: 113). Calancha states that the (h) anpicamayos, who were called *oquetlupuc* in some coastal regions, were physicians with good reputations (Calancha 1974: 1248).

Besides Cobo some other chroniclers made statements which give an idea of the knowledge about medicines of the indigenous herbalists. Without referring directly to the herbalist, Blas Valera stresses the large number of medicinal plants of the Incas. He says that if they were all known there would be no need to bring herbs from Spain or elsewhere, but that the Spanish doctors set so little store by them that even those which were known to be used by the Indians have in the main been forgotten (Valera 1992: 132). It is not quite clear if the Kallawayas, the traveling herbalists of the Andean regions in Bolivia and Peru, knew the hampicamayok. About these Kallawayas (or Callawayas or Callahuayas) a large amount of information is available concerning their role in folk medicine of the last few centuries (Bastien 1987).

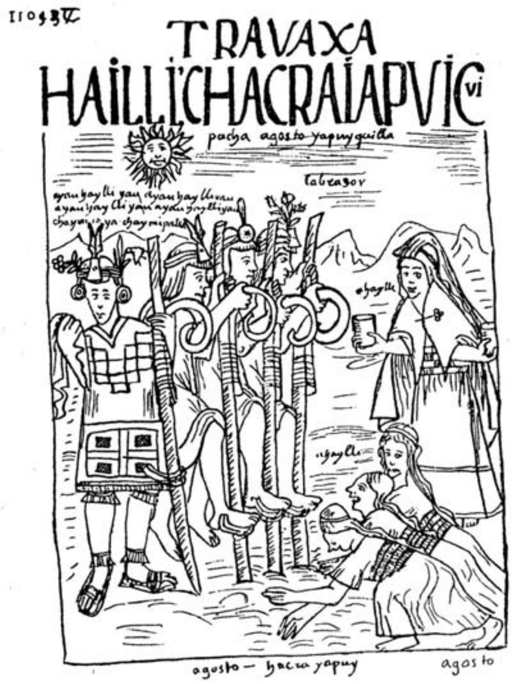
Plants Used in Medicine

In contemporary Peruvian folk medicine a very large number of medicinal plants are used, but the chroniclers described only a relatively small number of them, only a few hundred. That does not mean that the Incas did not use them. It is more an indication that the chroniclers for the Inca region were far less competent than those of the Aztecs. Cobo has especially described many Inca plants. Among these were a few that were

Ethnobotany of the Incas. Fig. 1 Maize or *sara* was an important food plant. According to the chroniclers, the consumption of maize products was the reason for a low incidence of gout among the Incas. This and the other botanical pictures are from *Köhlers Medizinal-Pflanzen*.

more important in Inca medicine than others. Maize or *sara* (*Zea mais*) was not only an important diet staple but was also an important medicine, as was the slightly alcoholic beverage called *chicha* that was prepared from maize (Fig. 1). According to several chroniclers the consumption of maize and chicha was the reason that they saw very few kidney and bladder complaints among the Incas (Fig. 2).

In the work of most chroniclers only a few plants are mentioned. It seems likely that those few plants mentioned repeatedly by different authors were of special importance and widely used. If this reasoning is correct then *molle* (*Schinus molle*) was one of the most used medicinal plants (►http://www.herreros.com.ar/melanco/elferink.htm). Contreras y Valverde (Contreras y Valverde 1965: 11, 12) states that the Indians considered the molle as a universal medicine against all their ailments. The differential use of molle is a good example to show that Inca physicians were quite aware that the eventual medicinal effect was dependent on preparation and means of application. The tree exudates a resin that was taken as a purgative and against melancholy; the resin in wine was against dropsy (Lizarraga 1968: 81; *Relaciones Geográficas* 1965: I-349; Vazquez de Espinosa 1969: 432). To cure leishmaniasis the resin and the bark of the tree were boiled in water until the water remained colored, and from this fluid the Indians took a portion on an empty stomach, and a second portion in the afternoon (Cobo 1964: 6-LXXVIII). The



Ethnobotany of the Incas. Fig. 2 Ploughing by special implements as preparation for sowing maize was ceremonially initiated by the Inca ruler and his family, recognizable by the large earrings.

Ethnobotany of the Incas. Fig. 3 *Datura stramonium* or *chamico* was used in medicine and in malevolent practices.

dried and pulverized resin was applied against ulcers. Lizarraga describes the resin as an excellent remedy for diseases of the respiratory system; he had tried the resin on himself (Lizarraga 1968: 81). The leaves, cooked and applied in a bath, were used for gout, and the crushed leaves were applied on wounds (Cobo 1964: 6-LXXVIII). The liquid made by boiling the leaves in water was a good remedy for eczema (Garcilaso 1966: 504). From the leaves a kind of oil was prepared that was useful for pain in the joints and for ailments of the stomach (*Relaciones Geográficas* 1965: I-349). A decoction of the leaves was applied as a bath for the treatment of the swollen legs of dropsy patients, and for gout. A plaster of the fruits was supposed to be effective for stomach complaints (Cobo 1964: 6-LXXVIII). The fruits of the molle were crushed and the juice gave a beverage that was taken for kidney and bladder complaints (Garcilaso 1966: 504). The fruit was also used to prepare a kind of *chicha*, which was more intoxicating than the chicha made from maize, and which was highly esteemed by the Indians (Cobo 1964: 6-LXXVIII). Besides medicinal properties the molle possessed some other qualities. Its wood was preferred as the basis for charcoal. This was the reason that it lost its importance in colonial times. Before the conquest the tree was very common, but a few years after the conquest it had decreased dramatically (Garcilaso 1966: 504) because of the need of charcoal for brasiers.

Another plant with widespread application was the *quinua* (*Chenopodium quinoa*). The plant was an important food-plant; it was especially attractive because it grew at high altitude. It was also used in medicine for a number of ailments such as stomach complaints, inflammations, spasms, swellings, fever, liver complaints and so on (Losa 1983: 71, 72; Calancha 1974: 138; Garcilaso 1966: 500). Another attractive feature was the possibility of preparing a good quality of inebriating chicha.

The *chamico* (*Datura stramonium*) was a strongly hallucinogenic plant (Fig. 3). In low doses the plant was used against fever, insomnia, inflammations, and to abate pain. According to Cobo the chamico was taken to get inebriated. Higher doses were used in criminal practices, a custom that has persisted till modern times. According to Cobo the chamico was secretly administered to victims who became intoxicated, and thus could be robbed easily. The chroniclers do not report about the use of chamico in religion, in contrast with other psychoactive plants.

Some plants, such as *coca*, *sayri* (tobacco) and potatoes were especially important in social life as food plants or in religion as offerings (▶http://www-personal.umich.edu/~jlvoris/thesis.html). However, all of them were also used as medicine. Chewing of coca leaves was practiced to ease hunger, thirst and tiredness, and this habit became especially important after the conquest (Fig. 4). Coca leaves were applied

Ethnobotany of the Incas. Fig. 4 The coca plant played a role in Inca religion and medicine. Its use in pre-Hispanic times, however, was strongly regulated by the Inca ruler.

externally to strengthen broken bones and to cure wounds and ulcers. The decoction was taken against diarrhea and to combat stomach complaints. The dried pulverized leaves were used for asthma. Coca was added to tobacco and chewed maize in an ointment to treat the bites of poisonous animals (Lope de Atienza 1931: 75). Two types of tobacco were distinguished: a cultivated and a wild form. It seems likely that these two forms correspond with *Nicotiana tabacum* and *Nicotiana rustica*, respectively (Wilbert 1987; ►http://www.hoboes.com/html/Politics/Prohibition/Notes/Shamanism.html). Both were used in medicine, but mostly it is not indicated which form was used. The root of the wild form was called *coro*, and was especially suited for a number of diseases, including syphilis. Tobacco was usually smoked, but the Indians used the tobacco also as snuff (Cobo 1964: 4–LVI). Tobacco was used to treat headache and migraine, and to improve sight. Poma de Ayala states that tobacco, in the form of snuff, was used against fever and cold (Poma de Ayala 1980: 769). One of the main applications of tobacco was to treat bites of poisonous animals (Apuntes 1987: 14; Maroni 1988: 157). The medical applications of potatoes were limited. Cooked potatoes were applied against gout. Potatoes were freeze-dried for conservation, and the resulting product was called *chuñu*. The chuñu was considered an excellent remedy against ulcers, spasms, pain of syphilis, and verruga (Cobo 1964: 4-XIII). The Incas knew many tubers that were very important as food plants. All these plants, among which are potato, *oca* (*Oxalis tuberosum*), *maca* (*Lepidium meyenii*), *ulluco* (*Ullucus tuberosum*) and *añu* (*Tropeaolum tuberosum*), were also applied in medicine. About the economic aspects of these plants an excellent internet source is available (►http://www.nap.edu/books/030904264X/html/).

Procreation and Plants

A number of plants were used to modulate fertility, or to induce sterility. The use of plants was mostly combined with magic. Among the plants that were applied to induce fertility were the *cabega*, the *vilca* (*Anadenanthera colubrina*), the *espinco* (*Medicago hispida*), and the *mocomoco*. Murua (1987: 435) states in a general way that the Indians used many plants and potions, not only to procure fertility, but also to induce sterility. In a society where having children was important, the administration of sterility-inducing plants was a severe crime that was punishable by death (Casas 1939: 147; Elferink 1999). Because those who induced sterility saw few reasons to be communicative, the chroniclers write in general terms about it and give no concrete names of plants. A colonial source reports that the Peruvian Indians considered the consumption of an infusion of the leaves of the *sogue* (*Salix humboldtiana*) a means to cause sterility in women (Losa 1983: 110). It is noteworthy that the Incas used the plant for several medicinal purposes, but that for these applications the infusion of the leaves was not taken orally.

Both plants and magic were applied to increase or to decrease libido (Elferink 2000). Acosta warned that the excessive consumption of *uchu* or *ají* (chili pepper, *Capsicum annuum*) by youngsters was undesirable, because of the aphrodisiac action of the plant (Fig. 5). This pepper was applied frequently to spice meals. Its use was so common that abstaining from consuming ají was considered fasting. Other plants described as an aphrodisiac were the *cuchuchu*, the *siaya*, the *tocoracas* and the *itapallo*. The *añu*, presently better known as *mashua* (*Tropaeolum tuberosum*), has been described as an anaphrodisiac (Cobo 1964: 171; Garcilaso 1966: 501). The Inca ruler gave the roots of the plant (it is an important food plant) to their soldiers as food, so that they forgot their wives. A later source describes the plant as an aphrodisiac (Losa 1983: 133). From the plant called *pencácuc* (*Mimosa* sp.) a male and a female form existed. Cobo describes the aphrodisiac properties of this plant, and he states that only the roots of the male form of the plants were stimulating; the roots of the female form had the opposite effect. A comparable peculiar difference between the male and female form of a plant has been ascribed to the *chutarpo* (or *huanarpo*). The male form, *huanarpo macho* (*Jatropha*

Ethnobotany of the Incas. Fig. 5 *Capsicum annuum* or chili pepper was an important food plant. It was considered a medicine and also an aphrodisiac.

macrantha), was known to act as an aphrodisiac. The female form, *huanarpo hembra* (*Cnidoscolus peruvianus*), acted in the reverse way, and could be used as an anaphrodisiac to annul the effect of the former (Santa Cruz Pachacuti 1992). Although the effects of these plants have not been investigated, the description suggests that the plants possessed a magic action rather than a real one. However, in contemporary folk medicine the huanarpo macho is still used as an aphrodisiac for men, while the huanarpu hembra is considered an aphrodisiac for women and a desaphrodisiac for men (Brack Egg 1999: 145). The *maca* (*Lepidium meyenii*) is a plant that has gained a lot of interest in recent times because of its supposed aphrodisiac and other properties. Because it can stand low temperatures, it was a favorite food plant of high altitudes. Descriptions about its use as an aphrodisiac in ancient Peru are scarce. Cobo (1964: 4-XVI) suspects that the relative increase of the population in the province of Chincha-cocha was due to the "hot" properties of this plant.

Magic Plants

Plants–Religion–Magic

A few plants played roles in Inca religion because they were used as offerings. Coca and tobacco were most frequently used (Fig. 6). Much information is available about coca and the Incas. The plant was important, but mainly for the upper social classes, because common men were not permitted to chew coca except with the ruler's permission. In some regions the *espingo* was

Ethnobotany of the Incas. Fig. 6 Tobacco was considered a medicine rather than a recreational drug. Two types of tobacco were used. The wild tobacco was probably identical with *Nicotiana rustica*.

frequently used as an offering (Arriaga 1968: 211). In many burial mounds of the Chimus (the Chimu kingdom was conquered by the Incas) strings of espingo seeds have been found. Priests used espingo in chicha to get very drunk, suggesting that the plant had psychoactive properties. The identification of the plant is not certain. In an indirect sense maize was the most important plant in religion, because chicha prepared from maize was used by all important and not-important ceremonies as an offering. Furthermore, maize was the basis of *sanco*, a kind of dough or bread that was used in religious ceremonies as a kind of communion.

Maize, coca and potatoes were so important that figures were made from them. These were called *saramama*, *cocamama*, *papamama* (or *axomama*), respectively, and were venerated as objects with supernatural powers. The veneration had a practical background: it was meant to have a good crop of the product from which the figure was made (Arriaga 1968: 200, 204, 205, 273; Albornoz 1988: 165). The religious importance of these plants is probably connected with the appreciation that the Incas had for these plants: coca as a psychoactive plant, and maize and potato as important food plants. In addition, all three plants were used in medicine.

Divination

Some plants played a decisive role in Inca divination. To obtain an idea about the importance of divination in Inca society we only have to look at the different types of diviners described by the chroniclers: more than 50 Quechua names are reported. The absolute number of diviners was also very large, as indicated by Acosta (1954: 172) and others (Morua 1946: 72; *Relación de los Agustinos* 1992: 8) who simply state that there were innumerable diviners. Cobo confirms that there were many diviners of several types (Cobo 1990: 160–163). In every town there were many of them, a statement that earlier was also made by Cieza de Leon (1962: LV). Citing another source, Cobo gives the figure of 475 people in Cuzco who had no other occupation than just divining. Intuitive divination was among the principal types of divination, and was often mediated by oracles in the form of *huacas*. A number of (mostly psychoactive) plants were applied to facilitate contact with the supernatural. Diviners called *yacarcaes*, who recruited spirits from fire, took coca leaves. They pronounced spells with which they summoned the spirit of the person from whom they wanted information. After a few other rituals the "devil" (as the chroniclers describe it) came and without being seen spoke to the attendants. He told them that he was the spirit of the person to whom they wanted to speak (Cobo 1990: 169). The procedure was followed in divinations where potential dangers for the Inca ruler or the empire were determined. That could be threat of rebellion or a plot against the Incas. The procedure resembles the one that was used by Inca sorcerers in love affairs. Here tobacco in combination with coca was applied. The person who wanted the love of another went to these sorcerers with a piece of clothing of that person. The sorcerers used coca and tobacco to get into a trance and raise the spirits of persons who had to become the beloved one.

Vilca (*Anadenanthera colubrina*) was very popular among diviners, who consumed the drug in the alcoholic beverage chicha (Cobo 1990: 169), to get intoxicated and attain the right psychic condition to make divinations (Fig. 7). According to Acosta (1954: 172) vilca, alone or in combination with chicha, was applied for all types of divinations. Among the questions which had to be answered, were predicting future events such as the outcome of certain enterprises, whether one would stay healthy or become ill and die. Another purpose was to find stolen or lost goods. For the same purposes the *achuma*, now better known as San Pedro cactus (*Trichocereus pachanoi*), was used. Murua has described the divination ceremony.

> To perform these superstitions and divinations they locked themselves in a house that was closed from within. There they started to drink and to get intoxicated until they lost their senses, and after a day they gave answers to the questions. To reach this effect they smeared their body with certain ointments. The sorcerers first talked with the devil in an obscure place in a way that the people heard a voice, but did not see who talked. They performed many ceremonies and offerings, and answered the questions with yes or no, as they liked it. For this purpose they used vilca or achuma. (Murua 1987: 432–434).

Ethnobotany of the Incas. Fig. 7 A number of psychoactive plants were used in divination practices. Among these was the *vilca* or *Anadenanthera colubrina*. Vilca was also the name of certain idols. Here the Inca ruler talks with the vilcas and huacas.

Currently some other psychoactive plants such as *ayahuasca* (*Banisteriopsis caapi*) are used in divination, in addition to those mentioned before. It is not sure however, if ayahuasca was used in Inca times.

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Ethnobotany in India

N. C. Shah

Ethnobotany is the use of plants in material or abstract form among ethnic communities or tribal people. Sometimes, it is regarded as ethnographical or anthropological or tribal botany. India is a vast country with a variety of topographies, climates, vegetation, and people. When discussing ethnobotany in India, we can consider two groups of people, those living in small cities or rural villages and tribal peoples who live in remote villages. India has a population of 102 million, out of which about 50 million people belong to 550 tribal communities. There are 325 total languages with a large number of dialects spoken within the country, of which 18 are official including English, Sanskrit, and Urdu.

Ethnobotany is a combination of ethnography and botany. Ethnographers describe the people of a region including their race, language, and their uses of plants:

- Food and its methods of preparations
- Medicine
- Extraction of fatty oils
- Edibles and non-edibles
- Condiments and spices
- Seasoning material for food
- Drinks and beverages
- Incense
- Household furniture
- Agricultural tools
- Utensils

In abstract form plants can be used in socio-religious and socio-cultural ceremonies, in worship, songs, sayings, similes, riddles, proverbs, and in mythology.

In the study of ethnobotany, native or regional names are collected with their phonetically correct pronunciation known as *transcription*. The native or cultural names are deciphered, etymologically and philologically with the help of local guides or linguists. This adds interesting information about the plant. As an example, in Ladakh, *Erigeron alpinus*, a small herb, grows near the glaciers and is locally known as *Kukling kukling chi bhando*. It is said that a particular type of insect eats only this plant. An interesting folk tale is attributed to the naming of this plant. Once, the insect that eats it did not get this plant, and when he was coming back after the day's toil, another insect asked him whether he got his favourite plant to eat. He replied, "Kukling kukling chi bhando" (Yes I got it but it was too bitter) (Shah 1994a). The botanical names of the plants, with their synonymy and family, habit and habitat, distribution within the region, and phenology (time of flowering and fruiting), are usually given.

Ethnobotany in India started when the British botanists came to India and searched for plants to study and also noted the native uses of the plants. Roxburgh (1832) described the use, the vernacular names, and the botanical identification of plants. Describing the use of *Tylophora asthemetica* leaves for asthma and their roots for dysentery are part of his ethnobotanical contributions (Shah and Kapoor 1976).

In 1873, Sir George Watt studied the economic plants of the Manipur and Burma (Myanmar) border for 10 years. In 1883 he was put in charge of an exhibition on Indian economic products sponsored by the then government of Bengal (now West Bengal and Bangladesh). Plant exhibits from all parts of the country were obtained and, after he obtained proper botanical identification, vernacular names and information on various uses, they were exhibited in Calcutta. This was the first workshop on Indian ethnobotany. Sir Watt published, with the help of the material from the exhibits, his monumental work, *Dictionary of the Economic Products of India*, with an index of 3,000 vernacular names and various uses from different parts of India. He also supplied the plant product names in different languages including Arabic, Persian, Sanskrit, Hindi, Bengali, and the South Indian and tribal languages and dialects such as Bhils, Gonds, Nagas, Santals, and Bhotias. In his publication he reported various uses of plants such as indigenous dye plants, such as *Indigofera tinctoria* (Neel), *Saccharum officinarum* (Ganna or cane sugar), and 190 plants as indigenous detergents and substitutes for soap, as well as 500 fodder plants from different parts of the country. He also mentioned sacred and traditional uses of plants, which had no economic significance. He listed *Butea frondosa*, describing its traditional and medicinal uses, the use of its wood and twigs in *Homa* or sacrificial fire and its leaves as plates in the Hindu thread ceremony for eating (Watt 1889–1896). His work is the first true collection of ethnobotany in India.

Actual study on ethnobotany was initiated by Dr. S. K. Jain, who conducted ethnobotanical surveys in Madhya Pradesh and reported various uses of plants (Jain 1963a): as medicine and food (Jain 1965a); for making musical instruments by the Gonds tribe of Central India (Jain 1965b), and in magico-religious rites, taboos, and beliefs among the Adivasi of Bastar in Madhya Pradesh (Jain 1963b, 1964).

Thereafter, there were a number of sporadic studies (Jain and Tarafder 1970; Shah and Joshi 1971). In the first work, the use of medicinal plants by the Santal people, earlier reported by Bodding (1925, 1926), was explained. In the second work, the ethnobotany of the Kumaon Himalayas was reported with various uses of plants, such as for medicines, food, condiments, or incense, along with the etymology and philology of the vernacular names and a brief introduction to the tribal people and their communities.

The subject of ethnobotany was made official in 1982 after the establishment of the Society of Ethnobotanists. A newsletter was brought out and seminars, symposia, training courses, and workshops were held. Later on, in 1990, a journal *Ethnobotany* was published. In 1983 an All India Coordinated Research Project on Ethnobiology was initiated at the Regional Research Laboratory in Jammu. It was a multi-disciplinary, multi-institutional, and action-oriented research program for generating and documenting the multi-dimensional perspectives of the culture, traditions, and knowledge of tribal life.

Work on the ethnobotany of different regions and tribes was published for Central India, Madhya Pradesh, Bihar, Orissa, North Eastern India, Arunachal Pradesh, Assam, Meghalaya, Maharashtra, Nilgiris, etc., in the proceedings of seminars and training courses and in other compilations (Jain 1981, 1987, 1990). The work was summarized by Binu et al. (1992), Maheshwari (1996), and Jain (2001). There are a number of institutions and universities where ethnobotanical field work was conducted: Botanical Survey of India, Howrah; Regional Research Laboratory, Jammu; National Botanical Research Institute, Central Institute of Medicinal and Aromatic Plants and Central Drug Research Institute at Lucknow; Tropical Botanical Garden and Research Institute, Trivandrum. Many Ph.D. theses were awarded in ethnobotany at a number of universities such as University of Calcutta, University of Kumaon, and University of Rajasthan.

Ethnobotany in India can be explained under the following headings.

Food Plants

Three species of *Amaranthus*, *A. caudatus*, *A. hybridus* ssp. *hybridus* and ssp. *cruentus* are cultivated for their seeds. They have been grown along the whole length of the Himalayas, from Kashmir to Bhutan above 1,500–3,000 m and also on the South Indian hills. Amaranths are fast-growing, cereal-like plants that produce high-protein grains in large, sorghum-like seed heads. The origin of *A. caudatus* is the Andes in South America and of *A. hybridus* is Mexico and Central America. However, the crop has declined to almost a vanishing relic in its homeland, and more Amaranth grain is now produced in Asia especially the hill regions of India, Nepal, and Bhutan than in America (Shah 1987).

The young leaves and seeds are used as food. These are called *Marca*, *Scu* or *Cu* or *Kedari-cua* (Himachal Pradesh and Uttaranchal), *Bustanfroz* (Kashmir), or *Ramdana* (Hindi). The etymology of *Scu* and *Cu* is obscure, *Kedari-cua* meaning *cua* of Kedarnath, *Marca* possibly after the name of Marca, a Bhotia tribe. However, it is interesting to note that *Amaranthus* sp. is called *scul* in Mexico (Berlin et al. 1974: 158), which is phonetically very near to the local names *Scu* or *Cu*. In the Himalayas the seeds are parched and then made into flour for making bread or *capati* and the young leaves are used as vegetables. It is one of the commodities Hindus use for breaking the day's fast in Uttaranchal and other parts of the country, and it treated as sacred (Shah 1987).

Fagopyrum tataricum is cultivated in higher altitudes, from 2,500 to 3,500 m, throughout the Himalayan region. Known as *Fafar* (Bhotia) *Fagopyrum esculentum* is cultivated from 1,500 to 2,500 m throughout the Himalayan region and in the Nilgiri hills. The leafy vegetable is known as *Oogal*; the seed grains are known as *Kotu* (Kumaoni), *Kannuja*, *Palti* (Garhwal and Bhotia), *kotu* (Trade name), and buckwheat (English). Its flour is used by the Bhotias in various sacred functions and ceremonies. They believe that it warms the body. The nuts are also used for making local drinks and are also traded to people in the plains. They have a high commercial value as the flour is baked or fried into bread and eaten by Hindus to break their fast (Shah 1987).

Tribal communities throughout the world use yams, *Dioscorea* spp. In the Kumaon region, the bulbils and root tubers of *Dioscorea bulbifera* (Gethi) are used as food. There is a Kumaoni saying, "Khaunhi ne gethi kamar bandhi peti" ("Dioscorea is not available in his house to eat and even then the person poses himself as a big guy"; Pandey and Pande (1999).

Another species, *Dioscorea melanophyma* known as *Tarur* or *Tikhun* (Kumaoni), is the staple food of the Rajis. This tribe is apparently of non-Aryan affinities and is commonly known as Ban Raut, Ban-Manus. Earlier they were known as cave dwellers, but they now live in well-built houses in the Pithoragarh district, Uttaranchal. The present population of the tribe (in 1993) is 556.

The Rajis are known for their craftsmanship in making wooden utensils (bowls) from the wood of a small tree, *Boehmeria rugulosa* (Genthi). Net bags are made for collecting the wild growing root tubers of *Dioscorea* from the fibres of *Boehmeria macrophylla* (syn. *B. platyphylla*), known as *Gargilla*, with a special digging tool known as *Bheku* (Figs. 1 and 2). The Rajis believe that eating *Tarur* rhizomes alleviates hunger (Shah 1987, 1994b). In Uttaranchal and other parts of the Indian Himalayas, another crop which is cultivated on non-irrigated land is *Eleusine coracana*, commonly known as *Ragi* or *Madua* (finger millet). In Uttaranchal, also growing in the wild, are *Urtica parviflora* and *U. dioeca*, Himalayan stinging nettle and stinging nettle, which are collected along with other fodder grasses and locally called *Shishuna* (Kumaoni) and *Kaldiya* (Gahwali). Its young offshoots are used as a vegetable. The Himalayan stinging nettle and finger millet are both designated as poor man's food.

There is a saying in the Kumaoni language, "Madua ka roti shishona ka sag, Khale rankara yo tero bhag" (O lad! what a pity on your poor fate that you have to eat the cooked vegetable of stinging nettle with a bread of finger millet). *Shishuna* tastes like spinach. Another interesting seed crop, which is cultivated throughout the Kumaon region, is *Glycine max*, locally known as *Bhat mas* or *Bhat*, black soy or black bean. This is a most interesting crop, introduced from China as the

Ethnobotany in India. Fig. 1 A Raji boy showing *Japi*, a net bag made up of fibre from *Gargilla* (*Boemehria platiphylla*) and also holding *Bheku* a digging tool for *Dioscorea* spp. (photo by N. C. Shah).

Ethnobotany in India. Fig. 2 A Raji girl stripping fibres from *Gargilla* (*Boemehria platiphylla*) to be used for knitting a net bag known as *Japi* (photo by N. C. Shah).

wild Soya bean, *G. soya*. It is found only in China from Heilong to Taiwan to Tibet, Japan, Korea, and Russia (Shah 2002 and 2006).

The local name was possibly coined because of the sound, Bh..a..tt, which emerges when the black bean is parched (Shah 1987).Various recipes are prepared, such as *thatwani* or *rasa*, *dubka*, *curkani*, and *jaula*. They are prepared in an iron bowl known as *karahi*. These recipes are very nutritious and they are prepared in every house of Kumaon (Shah 2002 and 2006). Hymnowitz (1969) conducted a survey in Kumaon to collect a germplasm of the species, when he noted that kwashiorkor, a disease caused by protein deficiency, was not found amongst the children of the Kumaon hills.

Incense, Condiments, Seasonings, and Narcotics

Burning of incense has long been part of Indian culture. It is not clear why the incense is burned. *Aquillaria malaccensis* (*A. agallocha*) is a tree found in Arunachal Pradesh and Assam. The fungal-infected highly aromatic wood is used as incense and known as *Agru* after which the common Indian name *Agar batti* (incense stick) was coined. In ancient times, it was an important commodity of export from India and it is the costliest aromatic wood in the world. The current rate for the wood is ca. US $2,000 per kg, and now it is banned both for collection and export.

Nardostachys jatamansi, *Jatamansi*, or spikenard, was known not only in India, but also in Assyria, Egypt, Greece, Rome, and Arab countries as an important import from India. It was known for its various uses such as incense, a nerve tonic and for its use in hysteria, epileptic fits, heart palpitations, etc. The rhizome of *Nardostachys jatamansi* grows in the high Himalayas in Uttaranchal, Nepal, Bhutan, South China, and Tibet. It is used by the Bhotias as incense and for medicinal use. It has religious as well as cultural sanctity. In Kumaon a song is sung in its praise usually in fairs and festivals (Shah 1987, 1994d). In Mesopotamia, it has been recorded in cuneiform-shaped script (Speiser 1951). Its association with Alexander the Great has also been established (Rücker and Glauch 1967), and it was mentioned in the holy Bible (Modenke 1954). Akbar the Great used it as a royal perfume (Jarett 1948), and the Monpas (Arunachal Pradesh) (Dam and Hajra 1981), Santals and other tribals of South India also recorded using it (Jain and Tarafder 1970).

Jurinea dolominaea (syn. *J. macrocephala*) is locally known as *Dhup* in Kashmir and the Punjab Himalayas and *Guggul* in the Kumaon Himalayas. *Dhup* means incense. The rhizomes and roots are collected and traded, to be used mostly in sacrificial fire or *homa*. The herb was also used in royal cosmetic preparations during the reign of Akbar the Great (Shah 1994a).

Cannabis sativa is commonly known as *Bhangãlu*, *Bhangãu* (Kumaoni), *bhangah*, *gangika* (Sanskrit), hemp or marijuana (English). *Bhangãu* or *Bhangãlu* are derived from the Sanskrit word *Bhang*. The root of these words, “ang” or “an”, recurs in all Indo-European and modern Semitic languages (De Candolle 1886: 148). In Uttaranchal, local people recognize two types of *C. sativa*: the cultivated one, known as *Ghar-bhangau*; and the wild one, *Kath-Bhangau*, which usually grows near habitations, mostly near cattle sheds known as *khattas*. *Kath* and *Ghar* mean wild and domestic. *Ghar Bhangau* are cultivated tall plants, 1.5–4 m high, grown mainly to procure edible seeds and fibre; *Kath Bhangau* are wild, comparatively short, 0.5–1.5 m, and are used to collect hashish and crude resin. In Uttaranchal, their seeds, seed oil, stems, fibre, leaves, inflorescence, and resin are used (Shah and Jain 1988). The fibre is used for making cordage or ropes and the pith of the stem is used as torchwood. The seeds are used as food (Shah 1997a, 2001).

The plant is also used as a narcotic. The plant produces three types of narcotics. (1) Hashish (*bhang*) consists of the dried leaves and flowers of male and female shoots. In the northern plains, a preparation of *bhang* is used as a beverage and sold Varanasi, Lucknow, and Allahabad. (2) *Ganja* consists of dried inflorescence specially from female plants without any leaves. (3) *Attar* or *charas* is the crude resin, which appears on the stem and inflorescence and is the strongest part. Cannabis is often seen growing around abandoned and dilapidated houses and is used abusively. When the Kumaoni people want to curse someone, they say, “Teri kuri bhangau jam jo”, which means, “May hemp grow in your house”, i.e. “May your house be ruined and damaged to such an extent that Cannabis will grow there”. People of Garhwal also name their male children after the intoxicant resin, *attar* obtained from the plant such as *Attar Singh* (Shah 1997a).

Liquor Producing Plants

There are a number of cereals which are used for producing liquor with or without fermentation in the Himalayas and other parts of the country. Some are *Hordeum vulgare*, *Juar*, or barley; *Eleusine coracana*, *Madua*, *Ragi*, or finger millet; *Echinocloa frumentacea*, *Jhungra*, *Madira*, or Japanese barnyard millet; and *Panicum miliaceum*, *Ceena* (*Kangi*), or common millet.

There are also trees from which liquor is produced. Most important among them is *Madhuca India*, commonly known as *mahua*. The fleshy pericarp is fermented and liquor is produced by fermentation. This is a common practice in central parts of India among the tribal and village people. The dried fleshy pericarp is ground to produce flour and bread is produced. The seed of this plant is used to produce edible oil.

Another tree is *Caryota urens*, known as *Mari*. The sap is collected in a pot which is hung and tied to an incised tree. The sap so collected is known as *Toddy*. It is used like a beer or it is fermented and then distilled to yield an alcoholic liquor.

Medicinal Plants

Rauvolfia serpentina is generally known as *Sarpagandha*, the local people used the roots in folk medicine in snakebite and to calm troubled people, in Bihar it was called *Pagal ki Dawa* (“the medicine of the insane”). The drug was adopted first in the Unani system of medicine and consequently in Ayurveda. Because of the alkaloid reserpine found in the root, antipsychotic and hypertensive properties are attributed to it, and it was included in modern medicine in the early 1950s (Shah 1995).

Recently, scientists at the Tropical Botanical Garden and Research Institute (TBGRI) found that the Kani tribes of Kerala use *Trichopus zeylanicus* ssp. *travancoricus* (*Trichopodaceae*), locally known as *Arogyapacha*. It is used as a health food to maintain vitality and as an immunomodulator to increase resistance against diseases in the body, as is ginseng. The extract of the leaves was commercialized by a pharmaceutical company and exported to Japan, Germany, Malaysia, and Indonesia. From the net profit obtained from the sale, 2% was shared between TBGRI and the Kani tribes of the region. It was the first model in the world of recognition of an Intellectual Property Right (IPR) pertaining to ethnobotanical and medicinal plant knowledge (Bagla 1999).

Socio-Religious and Socio-Cultural Plants

Plants have so deeply influenced the life and culture of the people of the Indian subcontinent that a number of plants are worshipped like deities (Gupta 1971; Gandhi 1989). In India, there are two kinds of worship: *Havan* or sacred fire, which means the act of oblation and sacrificial offering to Gods and Goddesses through fire. The Aryans used to offer their deities animals, butter and milk, cakes of barley, and the Soma plant, a divine plant not yet convincingly identified. A number of plants have been considered, such as Ephedra, Sarcostemma, Cannabis and Amanita muscaria, the fly agaric mushroom. (Mehdihasan 1963; Shah and Badola 1977 and Shah 2005). The latest speculation points more clearly to Ephedra as the likely species. People now usually use *Ephedra* species. There are a number of plant materials which are used in the oblation. These are cereals, sugar, raisins, dates, coconut, sesame (*Sesamum indicum*), and a number of medicinal and aromatic plants. *Puja* is a pre-Aryan practice and ritual, in which cooked food, vestments, ornaments and other materials like flowers, leaves, and water are offered to deities. The people burn incense and wave light in front of an idol, e.g. Arti. They also chant mantras. The word

Puja is derived from the Dravidian word *pu* meaning, flower, and *ja* meaning, "to do", so it is a flower ritual or *pushpakarma* (Shah 1994c).

There are many plants worshipped by the Hindus in India. *Ficus religiosa*, commonly known as *Peepal* (sacred banyan), is worshipped on every Sunday on every Somvati Amavasya of the year that is on the non-lunar day of the Hindu month known as Shravan, usually falling in July or August. Each part of this tree is considered sacred. In most Hindu and tribal communities, the bride is first married to a tree and then to the bridegroom. A Hindu never cuts the tree and cutting is equated with killing a Brahmin (Dube 1995). Every part of the plant is also considered medicinal, and Santals. Bodding et al. reported 16 therapeutic uses of the plant parts (Jain and Tarafder 1970).

In the month of Jeth (May–June), on a day with a full moon, the *F. benghalensis*, commonly known as *Vat* (banyanan tree), is worshipped. In Bhado (August–September) on Durva-ashtimi day, *Cynodon dactylon*, Hindu women worship the *Doob* grass and they also fast on that day. Doob grass is always used in performing *Pooja*. *Ocimum sanctum*, *Tulsi* (holy basil), is the highest venerated plant among the Hindus; it is believed to be an incarnation of a Goddess. It is always kept in every house and worshipped daily. It is used in cough and cold and fever as a household remedy. Some claim that it can cure cancer. *Curcuma longa*, *Haldi* (turmeric), is used as an important condiment in every house and in various religious ceremonies. It has a number of therapeutic properties, some of which have undergone scientific studies (Shah 1997b). There was a lot of hue and cry when some NRI Americans (Non-Resident Indians living in the United States) patented the use of turmeric for healing fresh wounds, which is quite a common use in India. After a long fight in the American courts, the Council of Scientific and Industrial Research (CSIR), New Delhi won the case after they presented documentary proofs of its uses in fresh wounds from old medical treatises. Last, but not least is *Azadirachta indica*, the Neem tree. All parts are regarded as medicinal for day-to-day ailments and diseases. It is sometimes called a "home tree doctor". It is not worshipped, but it has socio-cultural significance. On the first day of the Hindu calendar year known as *Samvatsar*, which is a festival usually falling in March, early in the morning a few leaves of Neem are eaten with a belief that the person will remain healthy throughout the year (Dube 1996).

The Indian subcontinent consists of separate linguistic communities each of which share a common language, traditions, and culture. If we want to learn the use of plants by a community, then we have to probe through their language as a tool.

A. Barrea, one of the first promoters of ethnobotany in Mexico, states:

> The best ethnobotanist would be a member of an ethnic minority who, trained in both botany and anthropology, would study the traditional knowledge, cultural significance, and the management and uses of the flora. And it would be even better for him and his people if his study could result in economic and cultural benefits for his own community (Martin 1995).

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Ethnobotany: Malay Ethnobotany

ROHANI LONGUET

Is There Such a Thing as Malay Ethnobotany?

It is surprising that in a country as rich in floral species and knowledge as Malaysia, Malay ethnobotany – the knowledge that the indigenous Malays have of their flora – has not been studied as such. Lists of plants and their uses have been compiled, but not many systematic approaches on the perception of the flora by the local inhabitants have been made. That is probably because of the diversity of influences to which the country has been submitted through history. Complexity may be perceived as a lack of unity.

One must distinguish between the Malays living in Malaysia and the rest of the "Malay peoples" who have inhabited not only the Indonesian archipelago, but also areas from the Pacific to the Indian Ocean, from Madagascar to New Zealand and Taiwan. It is possible to cover the subject by considering the particular heritage of the Malays that are presently living in Malaysia. These Malay groups have developed a common indigenous system of botanical knowledge. Their system refers to a worldview and a perception of nature that is steeped in the great Asian traditions, but has a particular local terminology and an indigenous use of native – or imported – species. Such an enterprise is useful because, together with the other Malaysian citizens of various ethnic origins, the Malays of that country have to face the problem of the possible disappearance of their natural and cultural heritage.

Malaysia's Botanical Richness

Malaysia is located at the heart of the Indo-Malesian system, one of the biggest rainforest systems on the planet. Rainforests are defined as "evergreen, hygrophilous (living or growing in moist places) in character, at least 30 m high, but usually much taller, rich in thick-stemmed lianas and in woody as well as herbaceous epiphytes[1]" (Shimper 1903, in Dunn 1975). Diversity, splendour and luxuriance characterize the original flora of the country.

Malaysia itself is divided into two parts separated by a shallow sea. The West part comprises the Southern Malay Peninsula, and the East part comprises the Northwestern part of the island of Borneo. Almost 95% of the plants present in Borneo and Sumatra – which belong to the same geological area – are present in the Peninsula, a significant feature for the permanence of botanical knowledge among migrating peoples.

Both parts of the country have a "main range", a series of hills culminating at 2,187 m in Gunong Tahan for the Peninsula and 4,094 m in Mount Kinabalu for Borneo. From the hills, streams run down on limestone boulders to merge in majestic rivers that end in large estuaries where villages have settled. Up until the 1960s, forest covered 85% of the soil (Polunin 1988). A relatively small country, Malaysia has a rich density of species: 8,000–10,000 (compared to, say, 11,000 in India). Botanist Keng calculated that the Malaysian flora has 2.96% of the gymnosperms and 2.79% of the angiosperms of the world.

Three factors have contributed to the floral richness (Deverre 1985).

The climate, which is hot and humid, with rain all year round;

Geological stability from the beginning of the tertiary; and

The encounter and interpenetration, in the Peninsula, of two kinds of flora, from the Asiatic continent in the North and Malesian flora from the South.

Various floral landscapes create a rich pool of environmental resources for the inhabitants to draw from. There are mountains, hill forests, lowland forest, fresh water swamps, coastal beaches, saltwater swamps and agricultural lands.

The major botanical families are

1. The Dipterocarps. They are so large that a *cengal* tree in the state of Terengganu needed eleven men to circle its girth.
2. Palms. There are five times the number of native palms than in all of Africa.
3. Eugenias. They align the hill slopes with the bright red of their young leaves
4. Tall gingers, mostly strongly scented.

Malaysia is also home to half of the world species of Nepenthes, who digest insects in their receptacles, and to other botanical stars like the *Raflesia Tuan Muda*, the world's biggest flower, many species of orchids and prehistoric species like the *Gnetum gnemon* and the giant fern-looking *Cycas*.

[1] Epiphytes are plants that grow on other plants mainly for support. Examples of these in tropical rainforests are orchids and ferns. Epiphytes are sometimes also known as "air plants".

The Geographical and Historical Components of the Malay Knowledge of Plants

The botanical lore of the Malays reflects the Peninsula and Borneo's floral composition. But Malaysia was at a crossroads of maritime routes that brought in science and culture from three great civilizations: India, China and the Arab world.

First were the years of early trade. The people of the Peninsula collected and sold the fragrant *gaharu* (*Aquilaria Agallocha*), dammars (from various *Dipterocarpacea*) and camphor (from *Dryobalanocarpus camphora*); this trade was recorded in the Chinese chronicles (Weatley 1980). The Peninsula remained for centuries within the sphere of influence of the Indianized empires, Funan, Sri Vijaya and Majapahit. Its inhabitants may have benefited from early initiation to Ayurvedic botanical knowledge. Some common village native plants like *gandarussa* (*Justicia gandarussa*) and *patarwali* (*Tinospora crispa*) still bear Sanskrit names.

From China came Buddhist scholars. In the wake of Admiral Cheng Ho, a Chinese community settled in Malacca. Chinese *sen seh* and settlers established medicinal gardens around temples and houses, sharing knowledge on small tropical herbs such as the *empedu bumi* (*Andrographis paniculata*) (also an Indian plant) *getang* (*Spilanthes acmella*), and the *pegaga* (*Centella asiatica*).

Malays have also benefited from Arabo-Persian medicinal and botanical knowledge that included the value of spices as medicine as well as food flavouring and preservatives. They brought in plants names such as *limun*, *henna* and *halba*.

There was a permanent influx of visitors and settlers: from the South – Achenese, Minangkabau, Javanese, and Bugis; from the North – Pattani Malays and Chams, carrying Chinese, Vietnamese and Cambodian knowledge. For instance, Mohammed Yusoh is a well-known roots and leaves seller from the East Coast of the Peninsula. He claimed to have had Arabic, Javanese and Chinese "gurus". He was also so familiar with some aboriginal tribes that he was dubbed "Mat Sakai" (Mat of the aborigines). The term *Sakai* has since become derogative, and is now replaced by *Orang asli*, literally the "original people". The life source of the *orang asli* tribes is the forest. They are the ones who would have transmitted knowledge on dangerous species like the Antiaris dart poison, the *tuba* Derris to kill fish or the *susu harimau*, a contraceptive mushroom.

Like pharmacists, aboriginal people provided the medicines; like medical doctors, Malay *bomoh* or traditional healers would tune the prescriptions to their patients. Some Malay peoples – proto – or deutero – Malays like the Jakun – belong to the *orang asli* group. However, generally for the Malays, the forest is considered dangerous. It is a vast, inexhaustible store of resources to be exploited. Villagers on the forest fringes, hunters, martial art gurus, herbalists and animal traders make expeditions in the forest from the base of their village.

One difference between the forest dwellers and the Malay settlers is the level of intervention that the Malays have introduced in nature. They tended to select and "grow" their natural environment in settled villages while aboriginals made use of everything they needed on the large tracks of forest they knew, without changing the natural composition of species. Malay villagers encouraged the growth of *nipah, nibong, pinang* and coconut palms. They planted crops on the outskirts of their villages and fruit trees around their houses.

Another example of a transmitter of botanical knowledge is Tuk Ku Paloh – Syed Abdul Rahman (1818–1918), a religious teacher of Arabic lineage and a political advisor to three successive sultans of Terengganu. He planted orchards of *jambu* (*Eugenia* sp.) and *rambutan* (*Nephelium* sp.) fruit trees in his vast ashram-like compound. He even created a spice garden for medicinal use.

Species native to drier and cooler regions were acclimated. In the Northern states, a *Zyziphus* (*bidara*) used in religious rites (also belonging to the Chinese materia medica) is planted around mosques and cemeteries. The pomegranate, dear to Arabo-Islamic tradition and a symbol of fertility for the Chinese, is grown in some Malay gardens against climatic odds.

Concepts and Philosophy of Malay Ethnobotany

Researchers have been puzzled by the apparent contradictory and overlapping beliefs of the Malays. A traditional healer would summon spirits from the animist past, chant a Hindu *mantra*, wrap up the incantation in a Muslim *doa* prayer and prescribe a plant preparation. The Malays do not seem to have perceived a contradiction in their multi-layered spiritual interpretations of the relationship of man with nature.

Mohd (1995), writing about the passage from animism to Hinduism, suggests that the Malays "merely transferred their beliefs in spirits and in nature to the various Hindu gods." Subsequently, one could surmise that the belief in Shiva, a Hindu creator god, introduced the concept of a unique force behind nature, separate and above it, perhaps preparing for the Muslim concept of *tawḥīd:* the oneness of God.

During the nineteenth century, compilations of medicinal and botanical knowledge were made in *jawi* script or translated, giving lists of therapeutic plants. These, like the *Tajul Mulu"* (Medical Book of Malayan Medicine) or the *Ilmu Tabib* contain lists of charms and references that place them in traditional healing systems. The role and the effect of the plants were described according to their relation with the balance between the four elements, the humours and "hot or cold" or "wet or dry" states. Studies are still needed to identify to which tradition(s) they actually owe their formulas.

Today, the idea of an indigenous perception of nature – how the Malay villagers see themselves in relation to the plant world – can be found in interviews with villagers and forest workers, especially in remote areas. They have a strong sense of a reciprocal link between all living things as *insan* (creatures of God). "The growth of trees toward the sky is their prayer to God," explained an elderly lady. Plant collectors in the forest believe in the "signature doctrine". Just like the *Qurʿān* Holy Book, nature is knowledge revealed (*ilmu naqli*).

Villagers have long maintained a symbiotic relationship with nature. Plants are found everywhere in art and crafts; twirling *Cucurbitacea* and Ipomeas are found on carvings on *cenggal* wood verandahs (Said 2000). Flowers enliven the batik sarongs worn by the villagers. In *pantun* poems (Daille 1990), fragrant flowers of jasmine and *Michelia cempaka* decorate love promises. In cemeteries sweet smelling Plumeria species alleviate sadness. The Muslim paradise is pictured as a garden, so gardens also have religious significance. Even today, the Malays try to arrange some flowers to compose a welcoming entrance to their house (Nor 2003).

Malay Classification and Exploitation of Botanical Materials

In the vernacular system, plants in general – herbs, shrubs, climbers and epiphytes – are *pokok* (which means "tree" – in lay language). The "trees" are subdivided into *akar*, which means roots and climbers, *rumput* (herbs) and *paku pakis* – "nails" – for ferns.

The Malay floral nomenclature is pragmatic and empiric. It does not refer to a phylogenic organization of the floral kingdom; nor does it refer to Arab, Indian or Chinese classifications. Plant species receive their names by reference to their aspect (morphology) or their use (ergology/phytopharmacology) (Table 1).

A name sometimes evokes both aspect and use. *Tongkat* is "cane". In *Tongkat Ali*, it refers to the aspect of the straight growing *Eurycoma*, a shrub with a deep, hard-to-dig root. The word indicates the use: like a cane, it supports failing strength. *Putar* means "to turn" in Malay and Sanskrit. *Patarwali* (*Tinospora Crispa*) is

Ethnobotany: Malay Ethnobotany. Table 1 Examples of forest species familiar to the Malays and their vernacular names

Malay names	Translation	Botanical name	Reputed traditional use
Gajah beranak	Elephant giving birth	Goniothalamus	Post partum decoctions
Penawar hitam	Black medicine	Schortechinii	
Tongkat Ali	Ali's staff, sky pointer	Eurycoma longifolia	Febrifuge, sexual tonic
Teja lawang	Specific name	Cinnmonum	All medicinal decoctions
Aji Samat	Haji Samad	Jackia ornate	Tonic
Tengkok biawak	Neck of monitor lizard		
Betek hutan	Forest papaya	Renellia sp.	Nasal and sinus troubles
Setawar hutan	Forest antidote	Costus speciosus	Mostly decoration
Dedawai	Wiry one	Smilax callophyllum	Tonic, diuretic
Tongkat Ali	Ali's staff		
Kacip Fatimah	Fatimah's scissors	Labisia pointiana	Feminine health
Kerbau melawan	Fighting buffalo	Shefflera sp.	Sexual tonic
Gajah tarik	Pulling elephant	Strychnos intai	Tonic, hypotensor
Hujung atap	Tips of roof thatch	Baekia fructexcens	Postpartum
Mas secotet,	A spot of gold	Ficus deltoidea	Tonic for women
Telinga kera	Monkey's ear		
Tonkat Ali biru	Blue Ali's staff	Polyaltia bullata	Heart tonic
Cengal	Specific name	Neo balanocarpus heimii	Mostly building material
Resdong	Nose inflammation	Ervatamia	Nasal and sinus troubles
Telinga beruk	Bear's ear	Thothea	Diarrhea, colic
Mengkudu bukit	Hill Morinda,	Renellia speciosa	In medicinal decoctions
Ginseng Melayu	Malay ginseng		
Akar sarsi	Sarsaparilla	Cinnamonum ebracteum	Fragrant, diuretic

a spiralling climber. That name is also pronounced *putrawali*. *Putra* means "son"; *wali* is "representative". So the *Tinospora* in Malay is "the whirling plant that helps to get a male descendant". The pretty Tetracera climber is called *mempelas* – sandpaper – as its rough leaves are used to polish wood and metallic surfaces.

There are also specific species names, sometimes derived from the ancient Malay or Melano-Polynesian vocabulary. For instance, the sea Hibiscus is *Bebaru* from the island of Madagascar.

Composite plant names are formed by adding a qualificative identifying the individual species within the vernacular genus: *Limau* is for citrus, *limau purut* is *Citrus hystrix* and *limau nipis* is *Citrus aurantifolia*. A qualificative may indicate the degree of effectiveness of the material, either as a timber or medicine. *Tongkat Ali* is "Ali's own cane". Ali's name, the Prophet Muhammad's cousin, carries a connotation of effectiveness and strength. Other tonics for men are associated with Ali. Plants good for women refer to Fatimah, the Prophet's daughter.

Evocative qualificatives are drawn from the animal kingdom: elephants, bear, tigers, monkeys and buffaloes help characterize plants. The aerial *Paku langsuiyr* is the "vampire fern" – an *Asplenium* which hangs its large and long dishevelled leaves on the fruit trees at the back of a house. Information on location, origin or gender is frequent: "Female" often means a large variety and "male" a smaller one (noted by British forester Watson as early as 1928).

Like the *limau*, some plants names correspond a to modern botanic genus: *Uncarias* are *kekait*, some *Eugenias* are *kelat*, a word referring to the tart taste of their wood. The edible Eugenia are *jambu. Cinnamonun* species are known as *teja* with various qualificatives: *jantan* (male), *bulu* (hairy). The more poisonous ones are often called *medan* and may be used as insecticides. Misleading appearances or similarities are signalled by a repetition: *Annonacea* are *pisang pisang* – false bananas or the qualificative *hantu* (ghost).

Some plants are so specific to some ailments that they are called by the name of what they cure: there is "ring worm medicine" (*Cassia alata*) and the "sinusite trees" (*Ervatamias*). Or they may be known by the illness they cause. *Excoecaria agallocha (bebuta)* is the "blinding" or "blind one" because of its latex, which is harmful for the eyes.

Plant collectors and healers are familiar with the principal names and the alternative names of the most famous floral species. The confusion of species perceived by botanists as they noted the existence of synonyms and substitutes is not relevant within the pragmatic system that gives priority to the use of the plants. Plants that share the same use and same look will be designated with the same names. For instance, leaves from the *Leucopogon Malayanus* – an

Epacridacea – may conveniently replace the other similar looking *Cucur atap* (roof leaves) species, *Baeckia* and *Leptospermum*, in the herbalist post-delivery tea (Yusof 1985).

As the main criteria for designating plants is their use, a few very useful and well-known species change names. *Oriza sativa* is rice *(nasi)* in the plate, *beras* in the shop and *padi* in the field. *Aquilaria Agalocha* is the *tengkaras* timber of the foresters, the *chandan* tree of collectors and becomes *gaharu* when the precious fragrant wood is found in the tree.

The vast range of use of plants in Malay ethnobotany run from the rites accompanying protection ceremonies to the criminal use by thieves sending *Datura* smoke through the floor boards of houses on stilts. There are building materials, dyes, mats, food, flavourings, wrappings and cosmetic, soaps, talcum, perfumes – a complete shopping mall (Table 2).

Coherent, pragmatic and didactic, the Malay system of vernacular botany was based on the villagers' needs. About 20 years ago Malay gardens in villages were good illustrations of the familiarity of their owners with the local flora. (See Extra: "Plants on a Day in a Village 20 years ago")

The Future of Malay Ethnobotany

Today, Malay vernacular botany shares the fate of other ancient knowledge in the world. It vanishes because it is written on vanishing material supports. One of these supports is the memory of the elders. Records have been made and translated into modern Malay and scientific botanical terminology; the most recent are those of Pr. Kamarudin Mat Salleh at the University Kebangsaan Malaysia and of Pr. Roland Werner at the University Malaya). However, behind the names, has the frame of mind and the worldview of the indigenous botanists been documented enough? Can translation render the esoteric yet powerfully suggestive context? The second support of botanical knowledge is the flora of Malaysia. In the process of development, the diversity and quantity of plants species are reduced. In consequence "hands on" knowledge of species which were previously common is on the way to being lost.

On the other hand, the relationship of the Malays with the world of plants still runs deep. Beyond the country's political and scientific interest for biotechnology (see Extra "Three Malaysian Plants in the Hall of Fame"), it has been found (Said 2000; Nor 2003) that modern Malays grow species from their past in the small gardens of their suburban terrace houses. They have a desire to continue combining esthetics, ethnic heritage and function, in the plants they display in their new environment.

Extra: Plants on a Day in the Village, Twenty Years Ago

In the Malay village, a young mother woke up on her mat made of Pandanus, with the smell of the Euphorbia ambers still warm under her special post-delivery sleeping platform. There was a light fragrance from the surrounding *belukar* secondary forest: the astringent *Rutacea Glycosmis*, frothing *Cinnamonum* and camphor. These contained plants prepared for her morning bath. Her newborn had his umbilical cord cut with a bamboo *sembilu* and later he would be circumcised with same type of disposable knife.

The mother is having a breakfast of sweet potatoes sprinkled with grated coconut. She will take a tonic *majun* pill made mostly of spices and ginger (*rempah ratus*) mixed with honey collected from nests on the gigantic forest Compassia tree. She set aside a large basin of *ubat periok,* a decoction based on *akar kayu* (jungle roots and trees) bought from herbalists at the market (*Annonacea*, *Cinnamoum*, a bitter *Eurycoma*, the slim leaves of *Baekia fructescens*, and a modest beach creeper, *Vitex trifolia*).

The forest smell pervades the house built in cool timber (*seraya or cengal* Dipterocarps) with a *nipah*-thatched roof. The midwife performs a thorough massage of the young mother with coconut oil, applying lime juice on her stomach, wrapping her in a tight batik (dyed cloth) corset and finally applying the heat of stones wrapped in large *Morinda* leaves to help the recovery process.

Meanwhile, the men are at sea on a *chengal* made boat. The sails are made of *sekecut* sedge from the paddy fields mounted on bamboo battens from the *belukar*. They pull ropes made of coconut husks and prepare a *gala gala* caulking made of jungle resin and *minyal kuin* oil in case the deck needed it. The seams on the flanks of the boast rarely leak as they are built with strips of the bark of tannin rich *gelam Melaleuca leucadendron* (from the swamps) fixed during the construction on the *pasak* "nails" *Mesua ferrea* (from the forest) that join the planks of the boat. If a new crew member became seasick, he could use an oil distilled from the leaves of the same *gelam* tree.

In the village, in the afternoon, sitting on a platform in the garden, the great grand mother is sewing a pillow stuffed with floss from the *kekabu* tree. Her daughter gathers *ulam* greens and *daun serai* (*Cymbopogon*) to perfume the sauces for the next meals. A group of young girls ask permission to take some *inai* leaves from the Henna tree for an elder sister who is going to be married soon. She may look at the *bidara* (*Zyziphus*) and the cotton tree which are used during the funeral rites. A small *jambu* (*Eugenia*) has been planted where foetal membranes of the new grandson are buried. Life stages are written in the garden around the elderly lady. The presence of the plants helps preserve practical knowledge as well as spiritual beliefs. The next generation naturally learns from them.

Extra: Three Malaysian Plant Species in the Hall of Fame

A Criminal Tree?

Recently, for as long as six weeks, a battle was fought in the news (*Utusan Malaysia* November and December 2004) around a *Rubiacea* species, the *Mytragyna speciosa* (*ketum* in Malay). Journalists reported that police officers had felled an old *ketum* tree in Perak, causing a stir among nature lovers. The police explained that villagers had called them as the tree attracted drug addicts to the area. In fact, the police in Terengganu had previously felled hundreds of them. Addicts use the leaves of ketum to calm the effects of their drug craving, as it was explained in other articles. The tree is placed, just as in Thailand, on the list of forbidden substances.

The ketum or biak, endemic to Northern Malaysia and Southern Thailand, was traditionally used by villagers in post-partum teas to ease afterbirth pains and by workers who faced long hours of work in

Ethnobotany: Malay Ethnobotany. Table 2 Some species found in Malay villages and their use

Source	Malay name	Botanical name	Traditional medicine			Food	Building material, dyes, etc.	Ornamental	Cosmetics	Fragrance	Rites	Poems and songs
			M	C	I							
W	*Kaduk*	*Piper sarmentosum*	/	/		Vegetable						
F	*Nibong*	*Oncosperma tigillarium*					House posts	/				
W	*Keduduk*	*Melastoma malabathr.*	/	/		Fruit	Indigo					
W	*Bemban*	*Donax*						/				
W	*Capa*	*Blumea balsamifera*	/	/			Camphor		Bath			
W	*Pulai*	*Alstonia scholaris*					Carving					
F	*Putrawali*	*Tinospora crispa*	/	/	/			/				
P	*Inai*	*Lawsonia inermis*	/	/	/					/	/	/
P	*Kecubong*	*Datura fastuosa*	/	/	/			/				
P	*Empedu Bumi*	*Andrographis paniculata*	/	/	/							
F	*Cengal Pasir*	*Hopea odorata*					Boats masts	/				
P	*Meninjau*	*Gnetum gnemon*				Candied chips		/				
p	*Bidara*	*Zyziphus jujuba*	/	/	/						/	/
W	*Gelenggang*	*Cassia alata*	/	/				/				
W	*Bebuas*	*Premna integrifolia*	/			In fish sauces		/				
W	*Bebaru*	*Hibiscus tilliaceus*					Ropes	/				
F	*Mengkudu*	*Morinda elliptica*	/	/	/	Leaves, fruit						
W	*Getang*	*Spilanthes acmella*	/	/								
P	*Belimbing besi*	*Averrhoa belimbi*				Coconut sauces	Cleans blades					
P	*Kenanga china*	*Artabotrys odorata*								/		
P	*Bunga cina*	*Gardenia jasminoides*								/		
P	*Duku*	*Lansium domesticum*				Fruit						
F	*Buluh*	*Bambusa sp.*				Young shoots		/				
W	*Dedalu*	*Loranthus ferrugineus*	/	/				/				
W	*Sisek naga*	*Drymoglossum heteroph.*										
P	*Cempaka*	*Michelia cempaka*						/	In hair oil	/		/
F	*Gelam*	*Melaleuca leucadendron*	/				Charcoal, caulking					
P	*Penaga lilin*	*Mesua ferrea*					Treenails					
W	*Ketola hutan*	*Aristolochia tagala*										
P	*Ceri*	*Lepisanthes alata*				Fruit						
F	*Terajang*	*Lapisanthes kunstleri*	/				Soap					
F	*Asam Jawa*	*Tamarindus indica*	/			Fruit in sauces	Cleans brass					

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Ethnobotany: Malay Ethnobotany. Table 2 (Continued)

Source	Malay name	Botanical name	Traditional medicine			Food	Building material, dyes, etc.	Ornamental	Cosmetics	Fragrance	Rites	Poems and songs
			M	C	I							
P	*Sentul*	*Sandoricum indicum*				Fruit						
P	*Dedap*	*Erytrina indica*						/			"Time to sail"	
P	*Jambu air*	*Eugenia aquea*				Fruit						
W	*Jambu arang*	*Erioglossum rubiginosum*				Fruit						
P	*Jambu batu*	*Psidium guava*	/			Fruit			Showers			
F	*Jambu golok*	*Anarcadium occidentale*				Fruit, leaves						
P	*Limau kasturi*	*Citrus microcarpa*	/			Fruit						
P	*Limau nipis*	*Citrus aurantifolia*	/			Fruit						
P	*Limau purut*	*Citrus hystrix*	/			Fruit, leaves			Shampoo			
P	*Belimbing*	*Averrhoa carambola*				Fruit						
P	*Kekabu*	*Ceiba pentandra*					Stuffing floss					
P	*Kapas*	*Gossipum brasilense*					Coton				Funerary	
W	*Paku langsyir*	*Asplenum nidum*						/				/
W	*Rambut puteri*	*Cassytha filiformis*							Shampoo			
P	*Bunga raya*	*Hibiscus rosa-sinensis*	/					/				
W	*Mata pelanduk*	*Ardisia crenata*	/			Leaves						
P	*Binjai*	*Mangufera caesia*				Fruit						
P	*Sireh*	*Piper betel*	/	/	/	Masticatory		/				
P	*Misai kucing*	*Ortosiphon stamineus*	/	/	/							
W	*Terape*	*Glycosmis citrifolia*						/				
W	*Teja pasir*	*Neolitsea zeylanica*										
F	*Cekur manis*	*Sauropus andronysus*				Vegetable						
F	*Beluru*	*Entada phaseolides*										
P	*Pandan*	*Pandanus*				Flavour, colour						
F	*Mengkuang*	*Pandanus*				Flavour						
P	*Serai*	*Andropogon citratus*				Flavour						
P	*Kunyit*	*Curcuma domestica*	/	/	/	Colour, flavour						
F	*Bonglai*	*Zingiber cassumar*	/									
P	*Halia*	*Alpinia officinale*	/	/	/	Flavour						
F	*Nipah*	*Nipa fructicans*				Fruit, salt, sugar						
W	*Gurah*	*Euphorbia*					Charcoal					

W	*Tapak Suleiman*	*Elephantopus scaber*										
W	*Kemunting Cina*	*Vinca rosea*	/	/	/	Fruit		/				
F	*Kerekup*	*Flacourtia jangomas*										Songs
W	*Setebal*	*Fagrea racemosa*	/					/				
W	*Mempelas*	*Tetracera indica*					Sandpaper					
P	*Kari*	*Murraya koenigii*				Leaves,						
P	*Delima*	*Punica granatum*	/	/		Fruit		/				/
P	*Senna*	*Cassia angustifolia*	/	/								/
F	*Bogor*	*Lagerstroemia speciosa*						/				
W	*Urang aring*	*Eclipta alba*	/	/					Shampoo			
P	*Ulam raja*	*Cosmos caudatus*				Fresh greens						
W	*Bayam serasi*	*Emilia sonchifolia*				Greens						
F	*Kangkong*	*Ipomea aquatica*				Vegetable						/
P	*Merunggai*	*Moringa oleifera*	/	/	/	Vegetable						
P	*Bayam merah*	*Amatantus gangeticus*				Vegetable						
P	*Jenjuang*	*Cordyline fructicosa*	/	/				/				
P	*Setawar hutan*	*Costus speciosus*	/	/				/			/	
W	*Teratai*	*Nelumbium nelumbo*						/				/
W	*Putat*	*Barringtonia*				Greens						
F	*Rukam*	*Flacourtia rukam*				Fruit						
P	*Lengkuas*	*Alpinia pupurata*	/	/		Sauces						
W	*Serunai*	*Wedelia biflora*										
P	*Pinang*	*Areca catechu*	/	/								
P	*Melor, melati*	*Jasminum sambac*						/		/		
P	*Tanjung*	*Mimusops elengi*						/		/		
P	*Setawar*	*Bryophyllum pinnatum*	/	/								
F	*Gandarussa*	*Justicia gandarussa*	/	/	/							
F	*Timba tasek*	*Clerodendron serratum*	/					/				
P	*Pemangil*	*Clerodendron paniculat*						/				

M = Malay, C = Chinese, I = Indian (indications not exhaustive especially for Indian data).
W = Wild, P = Planted, F = favoured (refers to how villagers find the species and not to an imported or native botanical status).

E

the forest. A few times in the past, it had received attention from researchers in Malaysia and abroad. Other species of Mytragyna grow in Africa; they have been studied for their alkaloid contents and are used there in traditional compound medicine for mental illness. Malaysian scientists agreed that the plant did have a potential as a methadone substitute and that it had a mild analgesic effect. It acts on opiate sensitive receptors in the brain.

Researchers at Chiba University in Japan (Journal of the Pharmaceutical Society of Japan Oct. 2003) have published analyses on plants gathered in Malaysia and Thailand. Among the newly identified compounds, one of them, a mytragynine pseudoindoxyl, was found to be much more effective than the same amount of morphine.

Tongkat Ali, the "Malay Viagra"?

This shrub or small tree with a particularly thick, deep and straight root is not easy to collect. It used to be very common on the slopes of forest hills in Malaysia. It is also found in Indochina and Indonesia. But now it is becoming rare, and forest officers mark trees because their fame as a source for a sexual tonic has triggered harvests of commercial proportions.

The bitter tongkat or Eurycoma longifolia was studied at Malaysian universities and found to be effective, as traditionally claimed, as a febrifuge (a substance that lowers fever) and anti-diabetic. It has a testosterone-like effect on mice, which produce a plethora of male progeny. It does not seem to have harmful secondary effects. Under Malaysian law, it is on the list of protected and non-exportable species.

With academic endorsement, and following Good Manufacturing Procedure (GMP), entrepreneurs in the country are now using extracts of tongkat Ali in very successful "power" drinks together with coffee and ginseng. To face the oncoming shortage of wild material, the Eurycoma is now grown commercially.

Sarawak Tree in the Race to Find a Medicine for AIDS

During pharmacological screenings for anti-cancer activity of medicinal plants from Malaysia, a team of US scientists identified an interesting substance in a species of Calophyllum (bintangor in Malay). It had prospects as an immune system booster and even as a treatment for AIDS patients. The scientists formed a research company and entered into a partnership with the state of Sarawak to create a drug from the particular variety of Calophyllum that had been collected and is not very common. The Government participated in funding the first stage of the research in exchange for returns on the sales of the end product medicine for AIDS.

Calanolide – and other compounds from Calophyllum species – have passed the tests on their effects on the HIV virus, and calanolide is at the clinical phase. But the competition is fierce and it has to be shown to be better than other candidates supported with equally motivated teams. More information is available at ►http://www.forestry.sarawak.gov.my/forweb/research/fr/ip/eco/calophys.htm, "The Calophyllum Story".

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Ethnobotany in Mesoamerica

RICHARD EVANS SCHULTES

The ethnobotany of Mesoamerica is extremely rich. The region is the original home of many useful plants. Amongst the numerous species, maize (*Zea mays*), avocado (*Persea americana*), henequen (*Agave fourcroydes*), maguey (*Agave cantala*), and chili pepper (*Capsicum frutescens*) immediately come to mind. All of these are inherited from aboriginal peoples who domesticated them long before the arrival of Europeans.

Perhaps the ethnobotanical aspect most typical of the region was the medicinal and ceremonial use of psychoactive or hallucinogenic plants. The Indian populations of Mesoamerica discovered and still employ in their magic and medicine many species with psychophysical properties. Even more significant is the evidence that from ancient times these plants have been considered sacred. That explained why the few plants with these unworldly effects amongst the half-million species in the world have such weird effects when ingested; they must be endowed with spiritual power, according to the belief of the aboriginal people. They are capable, through visual, auditory, or other hallucinations and related bioactivity, of allowing the medicine men or even ordinary individuals to communicate with ancestors or the spiritual forces who govern the affairs of the world below and who are able, if not propitiated, to inflect sickness, suffering, death, or calamities on people or on whole tribal groups.

We know much today about the use of bioactive plants for magico-religious and medicinal purposes from archaeological finds, ancient monuments, petroglyphs, codices, missionary reports, and other early publications. It is obvious from all of these and other sources that the use of plants capable of producing physiological and psychological alterations has had deep significance amongst native peoples in many parts of the world, especially in Mesoamerica.

In view of the great importance of psychoactive plants in the life of Indians of Mesoamerica, a brief discussion of the cultural importance of several of the numerous psychoactive plants employed by the Indians of Mexico and Guatemala in ancient and modern times will best indicate this particularly significant aspect of Mesoamerican civilizations.

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Peyote (*Lophophora williamsii*)

The hallucinogenic peyote cactus has a long history in Mexico as a sacred plant employed in numerous medicinal and ceremonial ways. Peyote is a low, spineless cactus. It is still used ceremonially by Indians in central and northern Mexico, particularly the Huichol, Tarahumare, and Cora. The Huichols each year make a sacred pilgrimage to the peyote deserts and cut off the tops of the peyote plants, leaving the roots in the ground to regenerate tops. The tops are dried and taken back for use throughout the year. It is the dried top, known as the "peyote button" that is eaten during their ceremonies and dances.

Early reports, mostly by post-Conquest ecclesiastical writers, usually condemned the use of this innocuous hallucinogen as the work of the devil, and they tried, unsuccessfully, to exterminate this pagan religious ceremony. One report equated the eating of peyote to cannibalism. One of the early writers intimated that the Chichimecas and Toltecs were acquainted with peyote as early as 300 BCE, but the accuracy of this dating depends on interpretation of native calendars.

Recently, however, excellently preserved archaeological findings in Trans-Pecos, Texas, and Coahuila, Mexico, have confirmed ceremonial use of peyote. Identifiable remains of peyote buttons in great abundance and in a context suggestive of ritual use have been dated by Carbon 14, and they span 8,000 years of intermittent human occupation. In Coahuila, ceramic bowls dated from 100 BCE to AD 200–300 depict significant use of peyote; four peyote-like ornaments and a hunch-backed man holding a pair of peyotes are depicted in these bowls. There can be little doubt that peyote is the most important psychoactive plant still utilized in the dry regions of Mexico.

Of the many alkaloids (30 or more) in the peyote cactus, only one, mescaline, is responsible for the richly colored, kaleidoscopically moving visions induced when peyote buttons are ingested.

Red Bean or Mescal Bean (*Sophora secundiflora*)

Together with the archaeological cache of peyote in Texas, two other plants were discovered. One is the red bean or coral been (*Sophora secundiflora*); the other is a suspected psychotropic plant known today as the Mexican buckeye (*Ungnadia speciosa*).

An early Spanish explorer of Texas, Cabeza de Vaca, mentioned mescal beans as an article of trade amongst Indians of the southern regions of North America in 1539.

Sophora secundiflora was employed in northern Mexico until recently in certain ceremonies, but, as in the southwestern United States its use as an intoxicant has disappeared. According to the Stephen Long expedition of 1820, the Arapaho and Iowa tribes were using the large red beans as medicine and a narcotic. A well-developed mescal bean cult existed amongst at least 12 tribes of the United States. There are so many parallels between the peyote cult and the former Red Bean Dance that the origin of the ceremony must have had a southern or Mexican origin.

The active principal of *S. secundiflora* is cytisine which is common in the legume family. This alkaloid belongs to the same group as nicotine; it is a strong poison, attacking the phrenic nerve controlling the diaphragm. Death can occur from asphyxiation. It may possibly be because of the great danger in cases of overdosing with the red bean that its ceremonial use has disappeared. It is of interest, however, that the "road-man" or leader of the peyote ceremony today always wears a necklace of the red beans during the peyote ceremony, undoubtedly as a reminder of a once sacred plant.

Ololiuqui and Badoh Negro (*Turbina corymbosa* and *Ipomoea violacea*)

Early Spanish ecclesiastical chroniclers, writing at the time of the conquest of Mexico or slightly later, described the medico-religious use of a brown lentil-like seed which the Aztecs called *ololiuqui*, coming from a plant known as *coatlxoxouhqui* (snake plant), indicating a vine with heart-shaped leaves and a tuberous root, clearly a member of the Morning Glory family. Its present botanical name is *Turbina corymbosa*, but it has also been known as *Ipomoea sidaefolia* and *Rivea corymbosa*.

We know much about the preconquest use of this hallucinogenic plant. Furthermore, there are clear, although crude, illustrations of ololiuqui in the codices. The plant is depicted in mural paintings showing the water goddess with a stylized vine reminiscent of this sacred vine.

But even more scientifically meaningful is the report and illustration of ololiuqui in a most extraordinary book: *Rerum Medicarum Novae Hispaniae Thesaurus, seu Plantarum Animalium, Mineralium Mexicanorum Historia* (Medical Thesaurus of New Spain or the Story of the Plants, Animals, and Minerals of Mexico). Shortly following the conquest, the King of Spain sent his personal physician, Dr. Francisco Hernández, to live with the Aztecs and study their medicines. His notes did not appear as a book, however, until 1651, although some of Hernández' notes were published as early as 1615 by Ximénez, who wrote of ololiuqui, without identifying it, because, he stated "it will not be wrong to refrain from telling where it grows, for it matters little that this plant be here described or that Spaniards be made acquainted with it." Another report, dated 1629, stated that "…when drunk, the seed deprives of his senses him who has taken it, for it is very powerful." Still another source said that "it deprives those who use it of their reason… The natives communicate with the devil… and they are deceived by the various hallucinations which they attribute to the deity which they say resides in the seeds" (Ruiz de Alarcón 1629).

Besides being a hallucinogen, ololiuqui was used as a magic potion with reputedly analgesic properties. Aztec priests, before making human sacrifices, rubbed the victims with an ointment of the ashes of insects, tobacco, and ololiuqui to benumb the flesh and lose all fear. The seeds were venerated and placed in idols of the ancestors.

Mexican botanists identified ololiuqui correctly in the last century, but doubts arose, since intoxicating chemical constituents were unknown in the morning glory family. In 1911, a German specialist, Christian Hartwich, suggested that ololiuqui might be a species of the Solanaceae, and in 1915, an American ethnobotanist, William Safford, assuming that the chroniclers had been misled by the Indians, definitely identified it as a species of the solanaceous genus *Datura*. There were voices of protest. Not until 1939, however, were actual specimens collected in Oaxaca and used in Mazatec rituals.

It is now employed by more than six tribes and in many Oaxacan villages the morning glory is planted "as an ever present help in time of trouble." When employed ceremonially as a medicine, the patient must himself collect the seeds, and they are ground and made into a beverage by a virgin, usually a child.

In 1960, the seeds of another morning glory, *Ipomoea violacea* (formerly called *I. tricolor*), was identified as a sacred hallucinogen amongst the Zapotecs of Oaxaca. These seeds are black – thus the local name *badoh negro* – and larger than those of *T. corymbosa*, with which the badoh negro, usually employed alone, may be mixed. It has been suggested that these black seeds represent the ancient Aztec narcotic seed called *tlitliltzin*, a term in Nahuatl derived from the word for black with a reverential suffix. An early chronicler, Pedro Ponce, had written of "ololiuqui, peyote, and tlitliltzin," indicating that three different inebriating agents were represented (Wasson 1963).

The seeds of both ololiuqui and badoh negro contain a number of ergoline alkaloids, chemically related to the synthetic D-lysergic acid diethylamide (LSD).

Toloache (*Datura inoxia, D. discolor, D. Wrightii, D. kymatocarpa, D. ceratocaula*)

Species of *Datura* have a long history in both hemispheres as a genus valued as medicines and hallucinogens. The main center of ceremonial use of *Datura*, however, lies in the Southwest of the United States and Mexico where a number of species are employed. All are known as toloache in Mexico (Fig. 1).

Today, many Indians believe that they can acquire supernatural helpers through the drug, and much secret knowledge is thought to be gained during the ceremonial intoxication. In tribes of northern Mexico boys who are studying to be medicine men must undergo *Datura* intoxication once a year. Modern Tarahumare add *D. inoxia* to *tesquino* (a drink prepared from maize) to make it strong and to induce visions. Some Mexican Indians consider toloache an hallucinogen inhabited by a malevolent spirit, unlike peyote.

All species of *Datura* owe their activity mainly to their active constituent scopolamine.

Puffballs (*Lycoperdon marginatum, L. mixtecorum*)

More ethnobotanical research must be carried out on the use of two species of puffballs amongst the Mixtec Indians of Oaxaca. The first of these two species is known by the Mixtec name *gi-i-wa* (fungus of first quality), the second as *gi-i-sa-wa* (fungus of second quality).

Lycoperdon mixtecorum causes a state of half sleep in which voices and echoes are heard and, according to the natives, voices respond to questions posed to the spirits.

Ethnobotany in Mesoamerica. Fig. 1 Two species of *Datura*: *D. Inoxia* and *D. ceratocaula*. From *The Badianus Manuscript; an Aztec Herbal of 1552*. Edited and translated by Emily Walcott Emmart, 1940. Reprinted by permission of the Johns Hopkins University Press.

There is a puffball, still unidentified, reportedly employed by the shamans amongst the Tarahumare.

The active chemical in these fungi with auditory activity has not been identified. There are, however, medical records attesting to this physiological activity amongst patients who ate puffballs in North America and were rushed to hospitals hearing voices.

Mushrooms (Teonanacatl) (Conocybe, Panaeolus, Psilocybe, and Stropharia species)

Undoubtedly the most important hallucinogenic plants employed from ancient to modern times from central and southern Mexico and Guatemala involve a number of species of several genera of mushrooms.

The Spanish conquerors of Mexico were disturbed by the religious and ceremonial use of "diabolic mushrooms" known by the Nahuatl name *teonanacatl* (divine flesh). As with other native religious rites, the early clerics tried to stamp out such a loathsome religion that venerated mushrooms. It has been said that there was little that Christianity could offer comparable to the supernatural power of teonanacatl. One of the early Spanish writers reported: "They possessed another method of intoxication which sharpened their cruelty; for it they used certain small toadstools… they would see a thousand visions and especially snakes… and in this wise with that bitter victual by their cruel god were they hassled" (Sahagun 1829). The King of Spain's personal physician, who studied the medicines of the Aztecs shortly after the conquest, reported in a more scientific vein three intoxicating mushrooms that "cause not death but madness that occasionally is lasting, of which the symptom is uncontrolled laughter… There are others which, without inducing laughter, bring before the eyes all kinds of things, such as wars and the likeness of demons."

There is plentiful archaeological evidence indicating a long use of teonanacatl. Frescoes from central Mexico made at least 1,700 years ago unmistakenly refer to these intoxicating mushrooms (Fig. 2). Clay figurines from Jalisco about 1,800 years old have mushroom effigy "horns." In Colima, a clay artifact dated between AD 100 and 300 illustrates figures dancing around a mushroom. Stylish mushrooms decorate the pedestal of the statue of Xochipili, the Aztec god of sacred flowers whose body is decorated with a number of intoxicating plants. This statue was discovered on Mt. Popocatepetl and dated about AD 1450.

In Guatemala, however, the deep roots of mushroom use in ceremony go back to the famous "mushroom stones" dated between 300 and 900 BCE. Consisting of an upright stem with either an anthropomorphic or animal figure and crowned with an umbrella-like top,

Ethnobotany in Mesoamerica. Fig. 2 Teonanacatl ("flesh of the gods"): the Aztec sacred, hallucinogenic mushrooms. Painting by a Mexican artist of the sixteenth century, showing an Aztec-looking devil encouraging an Indian to eat the fungus. From the *Magliabecchiano Codex*, Biblioteca Nazionale di Firenze, Italy. Used with permission.

Ethnobotany in Mesoamerica. Fig. 3 Animal effigy mushroom stone. Highland Guatemala, Protoclassic Period (100 BCE–AD 300). Collection of the Museo Nacional de Guatemala. Photograph by G. Kalivoda, courtesy of R.M. Rose.

they are now thought to have been associated with the sacred Mesoamerican ball game ritual (Fig. 3).

It was nearly five centuries after the arrival of Europeans that serious ethnobotanical research on the sacred mushrooms of Mexico began. Since in this period of time the ceremonial use of these fungi had not been seen, W.E. Safford, an American ethnobotanist suggested, in 1915, that the Aztecs had misled the chroniclers and that, since he assumed that the dry brown top of the peyote cactus superficially resembled dried mushrooms that *teonanacatl* and *peyote* were synonymous and referred to the same plant. Unfortunately, this "identification" received some acceptance, despite voices of protest. It was not until specimens of the mushrooms were collected in the Mazatec country of Oaxaca that the first of many species – *Panaeolus sphinctrinus* – was botanically identified. Later ethnobotanical and anthropological research in a series of expeditions to the same region has led to the identification of more than 30 species of Psilocybe, Stropharia, and Conocybe ceremonially employed by at least nine tribes in southern Mexico.

Intensive research on these fungi has led to a tremendous increase in ethnobotanical, mycological, chemical, and anthropological knowledge and to an extensive bibliography. Not only have many new species of mushrooms been described, but also chemical investigation of these plants has led to the discovery of the active alkaloids, psilocybine, and psilocine.

This relatively recent discovery and research on what perhaps is a most significant aspect of Mesoamerican ethnobotany has been certainly an important factor in stimulating ethnomycological and even general ethnobotanical investigation in Mesoamerica as well as in other areas in both hemispheres.

See also: ►Crops

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Ethnobotany in Native North America

Daniel E. Moerman

Native American peoples developed a sophisticated plant-based medical system in the ten millennia before the European conquest of America. Although there were significant differences between the systems developed by the many native groups, about which many fine works have been written, there were also many broad similarities which will be detailed here. There are approximately 28,000 species of plants in North America. Native Americans used about 2,500 of them medicinally (Moerman 1996, 1998); a convenient database of all of these plant uses is available at ►http://www.herb.umd.umich.edu. The utilized portion (the medicinal flora) is a distinctly nonrandom assortment of the plants available. The richest sources of medicines are the sunflower family (*Asteraceae*), the rose family (*Rosaceae*) and the mint family (*Menthaceae*). By contrast, the grass family (*Poaceae*) and the rush family (*Juncaceae*) produce practically no medicinal species. This remarkable volume and extraordinary selectivity demonstrate without any doubt the falseness of demeaning claims which suggest that native American medicines were chosen at random, that they "just used everything and stumbled on something useful once in a while."

Health and Disease

To understand the character and effectiveness of a medical system, one must understand the health status of the people who use it. Native American peoples generally did not suffer from the heart and circulatory diseases of modern times; their diets were rich in fiber and carbohydrates and low in fats. They lived vigorous lives which provided hearty exercise on a daily basis. They experienced little cancer. Cancer is largely a disease of modern civilization. Although the situation is obviously very complex, an apparently necessary condition for cancer is carcinogens which are largely products manufactured by industrial societies (organic chemicals and dyes, nuclear radiation, etc.). Even into the current day there is evidence that the Navajo have lower rates of cancer than surrounding people (Csordas 1989).

In addition, they suffered little from the classic infectious diseases which ravaged European society over the past two millennia. In large part, this seems to be due to the fact that most such diseases (plague, typhoid, smallpox, cholera, etc.) are zoonoses, diseases of animals which, under conditions of domestication, underwent massive evolutionary change and subsequently affected the human keepers of these animals. Native Americans never domesticated animals to any significant degree (the guinea-pig and llama of Peru were apparently only coming under domestication in the few hundred years before European contact). Once these diseases were introduced into North America, they devastated native populations which had no immunity to them. However, until the sixteenth century, while Europeans underwent successive epidemics which regularly killed a quarter or half of the population, native Americans were spared this devastation.

What medical problems *did* native Americans face? In the southeast and southwest, there is evidence of a decline in health status after the invention of agriculture when the diet became simpler, which apparently led to some deficiency diseases. Hunting and gathering peoples avoided that problem, but they, like Europeans, may have experienced some zoonotic infections particularly from beaver, and some trichinosis from bears. These would have been direct zoonoses which individuals contracted directly from the infected animal, not remote zoonoses which, once passed to one human being, were subsequently passed from person to person. Like rabies, a terrible disease for the individual who contracts it, these direct zoonoses are not serious threats to a whole society because they are not contagious in the ordinary sense of the term.

Native Americans probably paid a price for the vigorous life they led. Accidents, sprains, broken bones, cuts, lacerations and the like were common. There was a range of arthritic conditions, some probably the result of injury like those just mentioned, and perhaps some similar to rheumatoid arthritis. There is ample evidence that native peoples engaged in warfare; this would have been a source of serious medical problems. There was a range of occasional problems associated with menstruation, pregnancy, childbirth, and lactation which required attention. Living in smoky houses, it is not surprising that they had a broad range of treatments for irritated eyes: they also treated colds, headaches, cold sores and bruises, the normal insults of daily life everywhere (Vogel 1970).

Drugs

To address this range of problems, native Americans inevitably resorted to drugs based on various plants. There were some nonplant substances used medicinally. *Castorecum* from beaver was utilized for various conditions, and some minerals and clays were used as well, but by far the preponderance of medicinal substances came from plants. Every native American group for which we have any information had a botanical pharmacy. While some were quite small (the Inuit had few plant resources on which to rely) most were quite elaborate with hundreds of plant drugs used for a broad range of conditions.

This straightforward proposition raises a number of much more challenging questions. Native American healers, even into the early twentieth century, regularly knew the identity of 200 or 300 medicinal plants which they could readily distinguish from the 3,000 to 5,000 species which grow in any particular area. Among 100 sophisticated and well-educated modern Americans, it seems unlikely that very many could identify 200 species of plants of any kind unless they were professional botanists (or perhaps gardeners). How did nonliterate people, without reference to botanical keys or floras compiled by professionals, maintain this extraordinary amount of knowledge (Berlin 1992)?

Another challenging question is this: Why is it that plants might be of medicinal value in any case? Why do poppies (*Papaver*) (Fig. 1) or nightshade (*Solanum*) (Fig. 2) induce unconsciousness? Why does willow (*Salix*) bark tea relieve headaches? Why does wormseed (*Chenopodium*) kill intestinal parasites? Why does milkweed (*Asclepias*) (Fig. 3) cause vomiting? Although there are many obstinate details yet to understand, the broad outlines of an answer to this question may be sketched. Plants often produce substances of a variety of sorts to protect themselves against browsers (most often insects or worms, but also vertebrates), to defend their space against other plant competitors, or for a wide variety of other particular purposes. These substances share one character: they are somehow biologically active. In using them as medicine, people appropriate these (usually) defensive chemicals to induce reactions which they desire. They are usually toxic; they are therefore customarily used in moderation (for example, by "prescription").

Ethnobotany in Native North America. Fig. 1 Poppy, *Papaver somniferum*.

Sometimes the answer to particular questions seems fairly straightforward: the toxic cardiac glycosides in milkweeds (*Asclepias* spp.) discourage browsing by insects, worms, deer, or other vertebrates. However, for people who want to induce vomiting, to clear their systems of foul humors or the like, such plants are ideal medicines. Similarly, the substances in wormseed which deter various worms from eating the roots also kill intestinal parasites in human beings. There are nonhuman analogues to these uses of drugs which are of great interest. In the case of milkweeds, an insect, the monarch butterfly, might be said to use the plant medicinally as well. By virtue of a complex evolutionary adaptation, they manage to tolerate the milkweed toxins, sequestering them throughout their bodies, making themselves in turn unpalatable to predatory birds, notably blue jays (Brower and Glazier 1975). In a case similar to the human use of goosefoot as an anthelmintic, there is evidence to indicate that occasionally chimpanzees, when they appear not to feel well, seek out the leaves of a particular species of *Aspillia* which has anthelmintic properties. Otherwise, the species is ignored (Wrangham and Goodall 1989).

Some cases are less clear-cut. Salicin is a substance found in the leaves of most species of willow; the chemical is named after *Salix*, the genus of willows. This water-soluble substance washes off the leaves during rain, and acts as an herbicide on plants growing around the tree. It is also the chemical precursor of acetylsalicylic acid, a synthetic drug which we know

Ethnobotany in Native North America. Fig. 2 Nightshade. *Solanum americanum*.

Ethnobotany in Native North America. Fig. 3 Milkweed or Butterfly weed, *Asclepias tuberosa*.

as aspirin. Various naturally occurring salicylates (also found in certain birches, in the common ornamental *Spiraea*, and in wintergreen) have the same general biological effects as aspirin (named after *Spiraea*) relieving headache and reducing inflammation and fever. The advantage of aspirin is that it is less toxic than the natural chemicals. All of the salicylates seem to work as a result of their inhibiting effect on a class of substances known as the prostaglandins which are involved in all these biological processes. The prostaglandins are also involved in the maintenance of the mucous layer in the stomach and intestine; this is why aspirin (and the other salicylates) can cause stomach upset. What is not clear is why a herbicide should have this effect on mammalian biochemistry. Many similar cases remain to be understood.

Psychological Drugs

There is little evidence of native American use of drugs for recreational purposes. In addition, there is only very little evidence indicating the use of drugs in religious or other ritual. This differentiates native North American peoples from indigenous peoples of Mexico, Central and South America, and many other places as well. The one significant native American use of a consciousness altering substance involves peyote in the Native American Church. This, however, is a recent development of the twentieth century with no obvious precursors. There are a number of highly active drugs available for such uses, among them various members of the Solanaceae family (particularly nightshade and jimsonweed), as well as a number of hallucinogenic mushrooms, most notably *Amanita muscaria*. The one drug of this sort which was widely used was tobacco (*Nicotinia* spp.). Uncured native tobacco is a much more powerful drug than the highly processed modern variation. In Mexico, powerful tobacco concoctions were ingested in a number of ways to induce substantial transformations of consciousness. This seems not to have happened north of the Rio Grande. All accounts of its use in North America indicate that it was utilized very sparingly: individuals sat in a circle and shared the smoke from an ounce or so of tobacco. Its function was clearly more symbolic than biological. There may be a few exceptions to this generalization, but they are all either controversial or very poorly documented. When native American peoples wanted to transform consciousness – in the vision quest, for example – they did so with disciplines like starvation, concentration, isolation, and sleep deprivation.

Some Interesting Medicinal Plants

Here are some notes on several interesting plants used medicinally by native peoples of north America. St John's Wort, *Hypericum hypericoides*, (Figs. 4 and 5) is a very useful plant. Recently, a number of double blind controlled trials have shown that several substances in the plant work to reduce mild to moderate depression. There is little evidence to indicate that native peoples suffered from this common modern scourge; Vogel's authoritative account, *American Indian Medicine*, never mentions it except as a possible effect of European *Arnica montana* taken internally (Vogel 1970: 261). Instead, it was used, primarily by peoples of what is now the southeastern United States (Alabama, Cherokee, Choctaw, Houma, Natchez) for a variety of purposes: an infusion of the whole plant taken for dysentery; decoction of the root taken for severe pain especially in childbirth; an infusion of the leaves used as a wash for sore eyes.

Another important plant is yarrow, *Achillea millefolium* (Figs. 6 and 7). With 258 recorded uses as a drug (Moerman 1998), it is the most utilized of all native American medicinal plants (second: *Acorus calamus*, sweetflag, with 219 uses; third: *Artemisia tridentata* ssp. *tridentata*, basin big sagebrush, with 166). Yarrow is one of the most widespread plants in

Ethnobotany in Native North America. Fig. 4 Wild St Johns Wort, *Hypericum perfoliatum.* Copyright D. Moerman. All rights reserved.

Ethnobotany in Native North America. Fig. 5 Garden St Johns Wort, *Hypericum* sp. Copyright D. Moerman. All rights reserved.

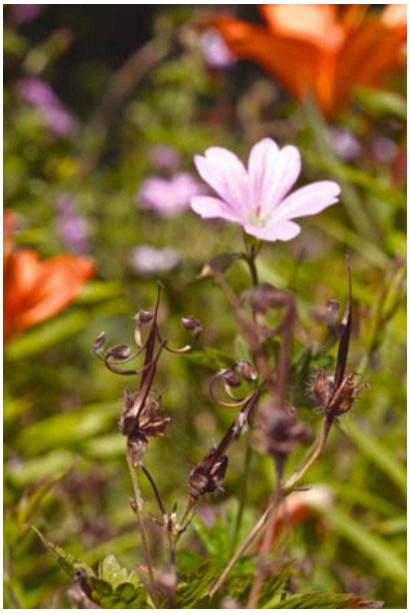
Ethnobotany in Native North America. Fig. 6 Wild Yarrow, *Achillea millefolium.* Copyright D. Moerman.

Ethnobotany in Native North America. Fig. 8 Cranesbill or Wild Geranium, *Geranium maculatum*. Copyright D. Moerman.

Ethnobotany in Native North America. Fig. 7 Garden Yarrow, *Achillea millefolium*, with garden sage, *Salvia officinalis.* Copyright D. Moerman.

the world, found over most of the northern hemisphere, and in temperate regions of the southern hemisphere as far south as Peru and Tanzania. Wherever it grows, it is used to treat wounds, infections, burns, swellings, sores, pimples, insect bites, and other problems of the skin. The ancient Greeks attributed the discovery of the virtues of *Achillea* to Achilles after whom it is named. He, trained in the arts of medicine, war, and diplomacy by his tutor, Chiron the Centaur, used it to heal a festering wound in an old enemy to establish an alliance against the Trojans. Native Americans also used it internally for a range of conditions: as a diuretic, for fevers, colds, coughs, internal pains, and for diarrhea, among others.

Finally, among the 49 American species of crane's-bill, or wild or hardy geranium, the one most favored as a medicine by native peoples was *Geranium maculatum*, the spotted crane's-bill (Fig. 8). A favorite of a number of Midwestern tribes – Menominee, Meskwaki, and Ojibwa used it for diarrhea, sore gums and toothache – its use by the Iroquois can show us some



Ethnobotany in Native North America. Fig. 9 Cranesbill or Wild Geranium, *Geranium maculatum*; hooked seeds. Copyright D. Moerman.

important elements in the medical thinking of non-western peoples (Herrick and Snow 1995). As it goes to seed, *Geranium maculatum* develops a series of very distinctive hooks from its peduncle which hold newly formed seeds (Fig. 9). These hooks, for the Iroquois, were distinctive and important, putting it in a special category of plants with "hook-like or ensnaring features," along with a number of other plants like the Canadian anemone, *Anemone canadensis* which has spiky hooks on its seeds, as does the purple avens, *Geum rivale*, and a number of other species. The Iroquois utilize most of these for conditions of eversion, or looseness, or escape, like cold sores, or diarrhea. The idea is that the hook-like, ensnaring quality of the plant will engage, or grab, or capture the looseness and pull it back, and so a tea of the roots is used to wash a chancre sore, and a poultice of dried root is applied to the unhealed navel of an infant. And so the ethnopharmacologists are happy when they find that the geranium root contains substantial quantities of tannin which is a strong astringent, hence "validating" this usage. But the wild geranium has more uses than that. Suppose one suspected that his wife were having a flirtation with another man. Putting a bit of geranium root or flower in her food or drink might capture her, and bring her back. Likewise if you are trying to sell some baskets, you could sprinkle them with geranium root tea to ensnare a buyer (and I can attest that books with drawings of wild geraniums included in them sell better than ones that don't). There is more to medicine than chemistry (Moerman 2002). In addition, no garden is complete without an assortment of wild geraniums (Figs. 10–14) .

The medicinal knowledge of native North American peoples is extraordinary. Just how this knowledge was developed remains a mystery. Native American peoples came from Asia; the flora of Asia is in many ways similar to that of North America (Duke and Ayensu 1985). It is quite likely that the first migrants to the New World brought with them detailed knowledge of medical botany, much of which was applicable to this new flora.

Most remarkable, however, may be this: I am unaware of any significant medicinal use of any indigenous American plant species which was not used medicinally by one or another native American group. An interesting example involves recent research on taxol, a substance of great medical value found in the common yew, *Taxus brevifolia*, and the Canadian yew, *Taxus canadensis*. Taxol has shown substantial effect in the destruction of tumors in a number of forms of cancer, particularly ovarian cancer, until now a highly refractory form of the disease. Native Americans did not use yew to treat cancer (see above), but they did use it for a variety of other conditions, among them skin problems, wounds, rheumatism, and colds.

Ethnobotany in Native North America.
Fig. 11 Horticultural Hardy Geranium. Copyright D. Moerman. All rights reserved.

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Fig. 12 Horticultural Hardy Geranium. Copyright D. Moerman. All rights reserved.

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Fig. 10 Horticultural Hardy Geranium. Copyright D. Moerman. All rights reserved.

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Fig. 13 Horticultural Hardy Geranium. Copyright D. Moerman. All rights reserved.

Ethnobotany in Native North America. Fig. 14 Spring garden dominated by Horticultural Hardy Geraniums; also columbines, *Aquilegia canadensis*, and poppies, *Papaver somniferum*.

In general, if one were interested in finding potentially useful botanical chemicals from the North American flora, it would clearly be wise to focus first on that portion of the flora which had been used by native Americans. Their experience and knowledge can yet guide our scientific efforts to enhance human health.

See also: ►Medicine of the Native North Americans

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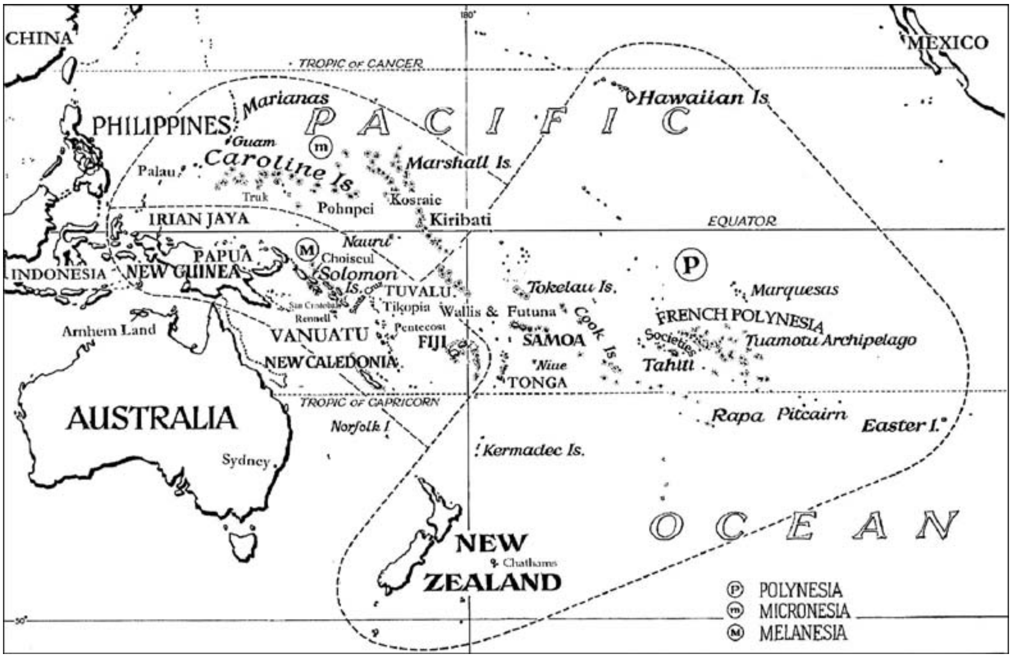
Ethnobotany in the Pacific

YADHU N. SINGH

The island communities of the Pacific, sometimes collectively known as Oceania, are inhabited by indigenous peoples from three major cultural or ethnic regions: Polynesia, Melanesia, and Micronesia (Fig. 1).

Because they lacked a written language of their own at the time of first contact with Europeans in the eighteenth century, much of the earlier information on the ethnobotany of the area has been constructed from the journals and other records of explorers, missionaries, and anthropologists. The increasing westernization of the islands has led to a greater reliance on imported food, clothing, fibers, and other materials, resulting in a decline in the use and specialized knowledge of native plants and agriculture. Fortunately, this influence is greatest in the urban areas and many of the traditional practices continue to flourish in the more rural and isolated communities. Some practices or items of material culture have lost their original roles, but instead have since acquired social, cultural, or historical significance, and consequently are being perpetuated by the present generations. A considerable body of plant lore still exists among the aged chiefs and inhabitants, and several anthropologists and ethnobotanists have strived to document this information. Because of space shortage, only a brief synopsis is presented and the reader is directed to the bibliography for a more complete treatment.

One popular theory on the origins of the Pacific islanders contends that their navigator ancestors migrated eastward from the Indo-Malay area, carrying with them from island to island the plants they needed for food, social, and cultural purposes. The food plants include all of the starchy perennial plants which are propagated vegetatively, including the taro, *Colocasia esculenta* (Fig. 2) and other nourishing *Araceae* of the genera *Alocasia, Amorphophallus*, and *Cyrtosperma*; the various yams, *Dioscorea* spp., whose numbers of cultivated species decrease from west to east; the breadfruit, *Artocarpus altilis*, (Fig. 3) of Captain Bligh and the mutiny on HMS *Bounty* (Fig. 4) fame, and for



Ethnobotany in the Pacific. Fig. 1 Map of the Pacific Ocean showing the three cultural regions of Melanesia, Micronesia and Polynesia. Modified from *Fiji in Color* by Jim Siers, and reproduced with permission from the author.

Ethnobotany in the Pacific. Fig. 2 Taro (*Colocasia esculenta*) plants and tubers.

Ethnobotany in the Pacific. Fig. 3 Breadfruit (*Artocarpus altilis*).

which the greatest number of cultivated varieties are found in eastern Polynesia; the principal bananas, *Musa* spp. (Fig. 5); also sugar cane, *Saccharum officinarum* (Fig. 6), which provides a nourishing drink; and the kava plant, *Piper methysticum* (Fig. 7), the source of the kava beverage which is used for many different activities in the islands.

Throughout its long history, the Pacific most certainly witnessed modification of its vegetation as its inhabitants adapted to the new environment and improved their techniques, and as waves of new migrations of humans arrived with new methods, ideas, and plants. Two important plants which fall into this category are the sweet potato, *Ipomoea batatas*, and the manioc or cassava, *Manihot esculenta* (Fig. 9), being cultigens which were introduced from the American

Ethnobotany in the Pacific. Fig. 4 HMS *Bounty* model (from Wikipedia). Pitcairn Island stamp depicting the *Bounty.*

Ethnobotany in the Pacific. Fig. 5 Banana (*Musa* × *paradisiaca*).

Ethnobotany in the Pacific. Fig. 6 Loading a harvest of sugar cane (*Saccharum officinarum*). Reproduced from inflight magazine of *Air Pacific* with permission.

tropics in the last century, and which have become important components of the local diet.

The most widely reported uses of plants in the Pacific are for food and utensils, medicine, ceremony and rituals, general construction, fuelwood, boat and canoe building, cordage and fiber, fish poisons, woodcarving, tools, weapons and traps, mats, clothing, dyes and pigments, and perfumes and oils.

The dominant food economy is based on the cultivation of the small number of starchy perennial plants mentioned above, which are propagated by vegetative means and which provide tubers and starchy fruits. They are usually embellished for taste, flavor, and variety by various condiments and complimented by seafoods and other plants and shrubs. They include the coconut tree, *Cocos nucifera*, which is unquestionably the most utilized of all plants in the Pacific (Fig. 10).

By one count as many as 125 different uses have been reported. Food uses include eating the soft flesh of immature nuts as an important weaning and adult food; drinking the juice of immature nuts as a nutritious and refreshing local beverage which is often sold and is considered a sacred offering to visitors in Kiribati; using the kernel of the endosperm of the mature nut raw, cooked, or fermented in a variety of ways as a staple food and as a major food for chickens and pigs, as well as an ingredient in locally produced commercial livestock feeds. It is also used for fish and rat bait. The kernel is dried to make copra from which coconut oil is obtained for use in cooking, soap making, as scented oil and in perfumery, and in medicinal potions. The sap from the flower spathe is used to make fermented and unfermented toddy and syrup, which are of considerable nutritional importance in Micronesia and on the atolls. Also, the husks of some cultivars of green nuts are eaten in atoll Polynesia and Micronesia. Other parts of the plant serve as a major source of fuel, for construction and fiber and cordage (Fig. 11), Recently, the fibers from the tree trunk have been pressed into materials suitable for making furniture (Fig. 12).

Young and mature leaves are used for weaving baskets, food containers and parcels, table mats for

Ethnobotany in the Pacific. Fig. 8 *Cordia subcordata* habit, leaves and flowers.

Ethnobotany in the Pacific. Fig. 9 Cassava (*Manihot esculenta*) plants and crop.

feasts, to beat water during fish drives, and for pounding and stabilizing banks of taro beds. The shells are used to make drinking cups for water and kava (Fig. 13).

Small bowls, cooking vessels, funnels, storage utensils, fish hooks and lures, and various types of body ornaments were also made of shells. Other supplementary food sources include using the pith of the trunk of the sago palm, *Metroxylon* spp., Polynesian arrowroot, *Tacca leontopetaloides*, mature seeds or drupes, aerial root tips, and hearts of meristem of the screwpine, *Pandanus* spp. (Fig. 14), seeds and flesh of ripe fruit of the tropical or beach almond, *Terminalia catappa* (Fig. 15), seeds of the cycad, *Cycas circinalis* (Fig. 16), and the young fronds of many ferns and tender shoots of a wide range of species.

The beverage called kava, prepared as an infusion from macerated stems and rhizomes of the kava plant, *Piper methysticum*, is probably the best known and most distinctive item of the material culture of the Pacific. It continues to occupy a central place in everyday life in the islands, although its role has been somewhat diminished by time and outside influences. Besides being the social beverage of chiefs, noblemen, and more recently of commoners, it has also been used to welcome distinguished visitors at formal gatherings, at initiation

Ethnobotany in the Pacific. Fig. 7 (a) A kava plant (*Piper methysticum*). (b) Dried kava roots for sale in Suva, Fiji. Reproduced from inflight magazine of *Air Pacific* with permission. (c) A kava party in Fiji. The bowls (above and below) are usually made of *Cordia subcordata* (see Fig. 8). Bowls and cups (below) on display at Expo 86 in Vancouver, Canada.

Ethnobotany in the Pacific. Fig. 10 Coconut (*Cocos nucifera*) tree. Drying coconut flesh to make copra.

Ethnobotany in the Pacific. Fig. 11 Coconut fiber coir sinnet. Photograph courtesy of Fiji Museum.

Ethnobotany in the Pacific. Fig. 12 All furniture, including the sofa, coffee table, dining table and chairs were made using pressed coconut tree trunk fiber. Photograph courtesy of Mr. Prakash S. Nagra.

and completion of work, in reconciling with enemies, in preparing for a journey or an ocean voyage, for installation in office, validation of titles, ratification of agreements, celebration of important births, marriages, and deaths, as a libation to the gods, to cure illnesses and to remove curses, as a prelude to tribal wars – in fact, in almost all phases of life in the islands.

Despite the gradually declining reliance on traditional medicine, over 120 different plant species are

Ethnobotany in the Pacific. Fig. 13 Picture of coconut shell kava cups. Photograph courtesy of *Kava Kauai*.

reportedly used for medicinal purposes. Herbal preparations and potions are used to treat a wide variety of ailments, although not always identified with the equivalent Western disease names. Some of these ailments are shown in Table 1. Among the plant species of most widespread medicinal importance are the beach almond, coconut, pandanus, *Vigna marina, Centella asiatica* (Fig. 17), *Premna taitensis, Ageratum conyzoides, Hernandia nymphaeifolia, Entada phaseoloides, Triumfetta procumbens, Morinda citrifolia* (Fig. 18), *Guettarda speciosa*, and *Terminalia catappa*.

Traditional practitioners and midwives continue to play an important role in healthcare delivery and, with the rapidly rising costs of Western medicine, there is renewed interest in herbal cures and practices. Presently, an extensive literature on the past and current medicinal practices is being assembled by anthropologists and ethnobotanists. However, the active chemical components have been identified for only a small number of the herbal potions.

Also of medicinal value are species used as fumigants or insect repellants, soap substitutes, shampoos or hair

Ethnobotany in the Pacific. Fig. 14 Screwpine (*Pandanus tectorius*). The hearts of the ripe meristem (right) are savored by many communities. Pictures courtesy of University of Hawaii Botany Department.

Ethnobotany in the Pacific. Fig. 15 Beach Almond (*Terminalia catappa*) flowers and fruits.

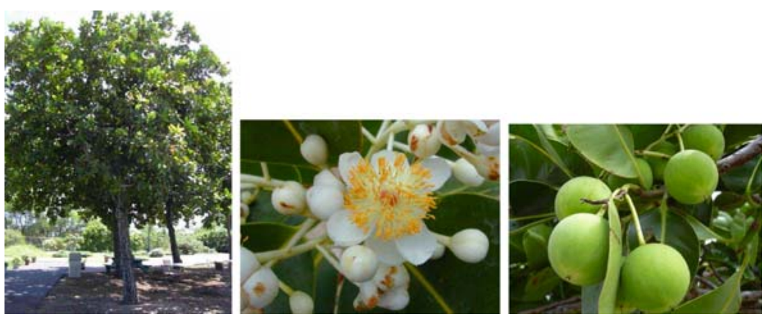
Ethnobotany in the Pacific. Fig. 16 Cycad (*Cycas circinalis*).

Ethnobotany in the Pacific. Table 1 Ailments treated with traditional herbal preparations and potions

Arthritis and joint pains
Bleeding
Bone fractures
Cardiovascular disorders, muscular diseases
Cuts and bruises
Diabetes
Gastrointestinal and kidney disorders
General incontinence
Obstetric and gynecological conditions
Pain, fever and inflammation
Parasitic and microbial infections
Postpartum care and nursing
Pulmonary disorders like asthma
Skin disorders
Vomiting and nausea

Ethnobotany in the Pacific. Fig. 17 Gotu kola (Centella asiatica).

Ethnobotany in the Pacific. Fig. 18 Noni (Morinda citrifolia) leaves, ripe and raw fruit, and a commercial noni preparation.



Ethnobotany in the Pacific. Fig. 19 *Callophyllum inophyllum* habit, flowers and fruits.

conditioners, and antitoxins. Of the soap substitutes, *Colubrina asiatica* is used almost universally for this purpose. Among those used as antitoxins, or to treat puncture wounds from marine animals or jellyfish stings are *Avicenna maritima, Cassytha filiformis, Excoecaria agallocha, Sophora tomentosa*, and *Tournefortia argentea*. The seeds of *Calophyllum inophyllum*, the heartwood of *Santalum yasi*, and the leaves of *Vitex* spp. are burned as mosquito repellants.

Tree trunks and timber from about eighty different species have found multiple uses, including for house, canoe, and boat building, tool and weapon making, woodcarving, fishing equipment, food utensils, furniture, games, toys, and musical instruments.

Various items for the tourist industry made from wood and plant materials. From left: warclub, comb, cannibal fork, box and fan.

General construction purposes utilize sawn or hewn timber for house poles, beams, rafters, flooring, walls, pilings, bridges, wharves, etc. Some of the more commonly used species include *Bruguiera gymnorhiza, Calophyllum inophyllum* (Fig. 19), *Casuarina equisetifolia, Cocos nucifera, Guettarda speciosa, Hibiscus tiliaceus, Inocarpus fagifer, Intsia bijuga, Pandanus tectorius, Rhizophora* spp. (Fig. 20), *Terminalia catappa*, and *Thespesia populnea*. For thatching purposes, various grasses, and the leaves and fronds of coconut palms and pandanus are extensively used.

Ethnobotany in the Pacific. Fig. 20 Red mangrove (*Rhizophora mangle*).

Ethnobotany in the Pacific. Fig. 21 Coconut fiber coir cord and wooden fishing hook. Photograph courtesy of Fiji Museum.

The timber and woody parts of many of the same species are used to construct warclubs, spears and spearpoints, bows and arrows, fishing poles, fish traps, fish hooks (Fig. 21), floats, paddles, digging sticks, needles and awls, adzes and tool handles, tapa cloth beaters, bowls, including kava bowls, ladles, spoons, stirrers, mortars and pestles, coconut huskers, bread-fruit splitters, and food containers.

For toys and games, the seeds or fruit of *Abrus precatorius, Barringtonia asiatica, Caesalpinia bonduc, Erythrina variegata*, and others, are used for small balls, marbles and lagging pieces, while the wood of *Gardenia taitensis* is carved into marbles and cricket balls in some Polynesian islands. Pandanus leaves are made into kites and whistles while parts of the coconut palm are made into toy windmills, toy boats, rattles, sledges and clappers. The thin epidermis of pandanus leaves serves as a substitute for cigarette paper for handrolled cigarettes.

A basket and a mat made using dried pandanus leaves.

Musical drums (like the *lali* of Fiji) and the slit-gongs (of Vanuatu) (Fig. 22), beside being musical instruments, are still extensively used for summoning people to village meetings or to church services, the most favored species for this purpose being *Cocos nucifera, Guettarda speciosa, Pemphis acidula, Terminalia catappa*, and *Thespesia populnea*.

Ocean going crafts of diverse structures and sophistication were developed to serve specific functions such as for transportation between the islands, for fishing, as racing outrigger or war canoes, and chiefly for voyaging. The components of such crafts, most of which were obtained from plants, include hulls, keel and prow pieces, outriggers (Fig. 23) floats, booms, ribs and spreaders, planking, platforms, shelters, masts and mastheads, paddles, steering oars, and sails, bound together with fiber cordage.

Ethnobotany in the Pacific. Fig. 22 A lali (arrow, and sculpture, left picture) and a slit-gong from Vanuatu located on the Suva (Fiji) campus of the University of the South Pacific.

The hull and keel pieces were composed of extremely strong and durable timber. *Calophyllum inophyllum* has been favored for the hulls of the larger Polynesian and voyaging canoes. Other species also used for this purpose include *Cordia subcordata, Intsia bijuga*, and *Hernandia nymphaeifolia*. Sails were plaited together from pandanus or coconut leaves and other species were used as adhesives and for caulking. Cordage and fiber for lashings on crafts, housing, weapons, fishing lines, stringing fish nets, and in various handicrafts are obtained from the husk fiber or coir of the coconut (Fig. 24), the bast fiber of *Hibiscus tiliaceus* (Fig. 25), and the leaves of the pandanus. These three materials are also used for straining coconut cream, kava, and other liquids, and for stuffing and caulking. The dried fibrous pandanus drupes, coconut coir and *Hibiscus tiliaceus* bast fiber are used as brushes for painting the tapa cloth, other ceremonial clothing, and handicrafts.

Ethnobotany in the Pacific. Fig. 23 Outrigger canoes used in the tourism industry.

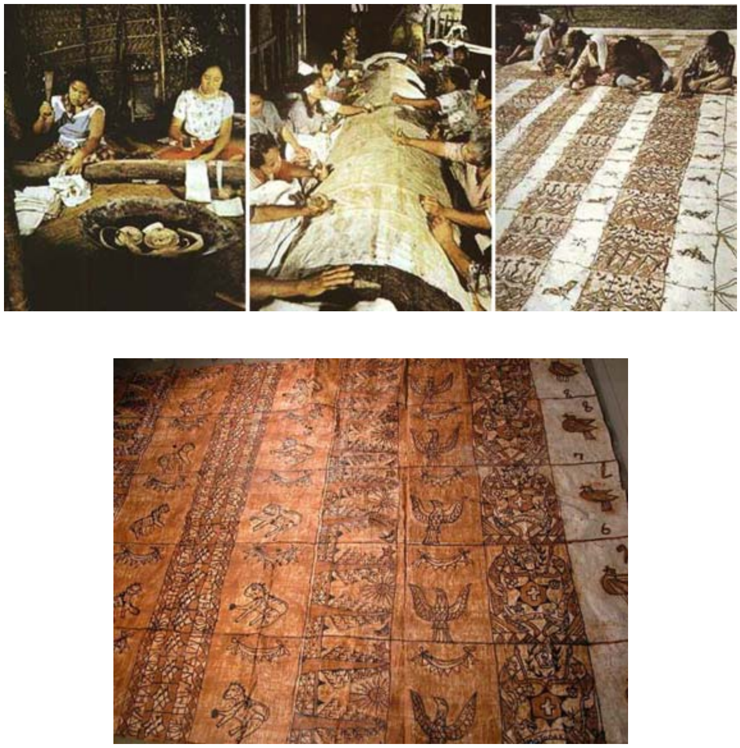
Ethnobotany in the Pacific. Fig. 24 Coconut fiber coir.

Of the various species used in the production of clothing and handicrafts, the most important are the coconut palm, pandanus, breadfruit tree, *Hibiscus tiliaceus*, and the paper mulberry, *Broussonetia papyrifera* (Fig. 26). The leaves of the first two and the bast fiber of *Hibiscus tiliaceus* are used throughout the Pacific for making hats, ordinary and ceremonial mats and garments, fans, and a wide array of handicrafts. The bark of *Broussonetia papyrifera* and the breadfruit tree are processed to make the cloth called tapa which is best known in Fiji, Tonga, and Samoa (Fig. 27). Dyes, pigments, and preservatives, obtained from a number of species, in particular *Ficus tinctoria, Bruguiera gymnorrhiza, Morinda citrifolia* and *Rhizophora* spp., are used for dyeing, painting, or strengthening and preserving bark cloth, mats, baskets, and other plaited ware, hats, breechcloths, grass skirts, canoe sails, and for decorating parts of the human body on ceremonial occasions. The dyes and pigments are obtained from the bark and, less commonly, from leaves, roots, flowers, sap, fruit, and seeds.

Although most wood species are used as firewood, some are particularly favored because of their high heat

Ethnobotany in the Pacific. Fig. 26 Paper mulberry (*Broussonetia papyrifera*) habit and tree trunk.

Ethnobotany in the Pacific. Fig. 25 Beach hibiscus (*Hibiscus tiliaceus*) habit, flower, and strainer from the bark in use for kava making.



Ethnobotany in the Pacific. Fig. 27 (a) Tapa making in Tonga. Most commonly the bark of the paper mulberry or breadfruit tree is used. The bark is stripped from young saplings, and the white inner layers are peeled off for the tapa. These narrow strips are soaked in water until softened (in the bowl in the foreground), then they are pounded with grooved mallets, which spreads the bark into increasingly wider strips until they are about ten inches wide. The edges are then overlapped and glued with cassava root juice, breadfruit, or arrowroot starch to make wide sheets. Then, on a long log, the tapa is stretched over a series of these design plates, and the tapa is rubbed with dye to stain the surface in areas where the design is raised (middle picture). Finally, after the tapa has dried, dark outlines and details are hand painted, using crude brushes made from sticks with frayed ends. A variety of natural plant dyes are used (right). Natural brown dyes, for example, have been made from clay and tree sap. (b) The finished tapa cloth. Photographs courtesy of the Government of Tonga.

Ethnobotany in the Pacific. Fig. 28 *Derris elliptica* leaves and vines.

content (*Pemphis acidula, Suriana maritima, Premna serratifolia*), ability to cook slowly and produce slow-burning charcoal (*Bruguiera gymnorhiza, Rhizophora* spp., *Casuarina equisetifolia*, coconut shells), or provide a desired taste to foods. All parts of the coconut palm are used for fuel, and it is by far the main source of fuel in the atoll countries, as well as in some of the larger low-lying islands.

Sophisticated fishing gear used by coastal communities has been complemented by fish poisons or stupificants, with some ten species being used for this purpose. The fruits, roots, or vines are pounded and the juice is scattered in a tidal pool or the lagoon. The suffocated fish rise to the surface and are gathered in baskets woven from coconut leaves. The poisons do not affect the edibility of the fish. The most commonly used species are *Barringtonia asiatica* (fruits), *Tephrosia piscatoria* (roots), and *Derris* spp. (roots and vines) (Fig. 28). The use of these fish poisons has recently been outlawed in many countries.

See also: ►Coir

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Ethnobotany in Pakistan

Zabta K. Shinwar, Anwar Nasim

Ethnobotany is a very broad discipline and covers all types of human–plant interactions. It is the study of how the people of a particular culture and region make use of plants. However, there are also other definitions, such as the use of plants in early societies.

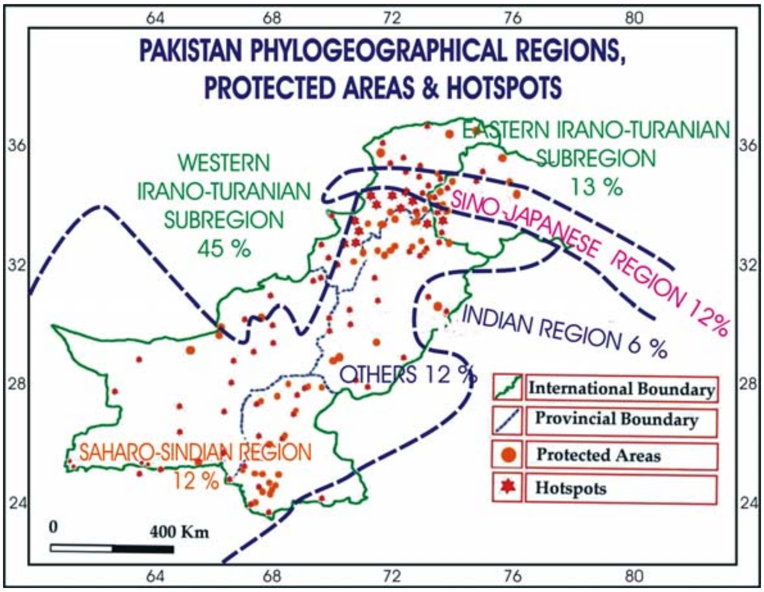
One cannot separate poverty from threats to biodiversity conservation. Pakistan is a developing country with 150 million people. Each child born inherits an average debt of Rs. 4,400 (US $80). About 32% of Pakistan's population has a monthly income of Rs. 650 (US $11). Infant mortality is 83.3 per thousand (compared to Thailand's 28, Indonesia's 41, Bangladesh's 60). Global borrowing, shrinking incomes, diseases, lower average ages, and greater mortality are all moving the majority of the world's population to desperation.

Pakistan has varied climatic and ecological zones and topography along with vast floral diversity. It contains nearly 6,000 species of flowering plants of which 70% are uniregional. Pakistan has four phytogeographical regions (1) Irano-Turanian (46% of species confined to Pakistan), (2) Sino-Himalayan (10%), (3) Saharo-Sindian (9.5%), and (4) Indian element (4.5%). Despite the Saharo-Sindian Region being the biggest area, the diversity of species confined to this area is lowest for any phytogeographical region (Ali and Qaiser 1986) (Fig. 1).

Ethnobotanical plant resources can be divided into two broad categories:

1. Ethnobotanical resources: plants used directly by local communities for food, forage, fiber, timber, medicine, ceremony, symbol, or income.
2. Phytogenetic resources: plants processed or manipulated to extract genes or DNA for crop improvement, cells for tissue culture, or chemicals as precursors of pharmaceuticals.

Local communities in different regions of Pakistan have centuries old knowledge concerning traditional uses of



Ethnobotany in Pakistan. Fig. 1 Pakistan phylogeographical regions, protected areas and hotspots.

most of the plants in their areas. Some of the important plants are commercially harvested for the extraction of various types of active ingredients. Even though the systems of *Unani* and *Ayurvedic* medicines are largely based on plants, the precious wealth of indigenous knowledge is in danger of being lost. The use of traditional knowledge must also reflect the values embedded in the traditions upheld by elders, especially with regard to medicine. Practitioners know that respecting plants is essential to the efficacy of medicines, which should be seen as having curative energy that draws its medicinal qualities from a relationship between the plants and the people (Juden 2003).

Overharvesting of medicinal plants for commercial purposes has threatened their abundance, and even their occurrence. Detailed surveys were conducted to document species of priority for commercial harvesting. Priority species chosen by the Ministry of Food, Agriculture, and Livestock (MINFAL), and two major herbal facilities in Pakistan (Hamdard and Qarshi) are listed in Tables 1–3.

The plant hotspots of Pakistan are spread over 13 natural regions from alpine pastures to mangrove forest. More than 10% of the flora is endangered (Shinwari et al. 2000, 2002) (Fig. 2). This is because of environmental problems including population pressure, poverty, and poor quality of the natural resource base, breakdown of social institutions, lack of land-use plans, and lack of enforcement of existing rules.

Global efforts to conserve and protect the natural environment are a recent phenomenon, though efforts to conserve economically important natural resources have a long history. Ethnobotany and conservation are inseparable and conservation is one of the most-valued tasks of ethnobotanists. In addition to conservation techniques, communities also need to be educated on the importance of conservation of local ecosystems, and with that, their socioeconomic conditions.

There is a rising trend to shift resources from allopathic to traditional healthcare systems. For example in Japan, a Society of Oriental Medicine Studies was established by 98 members interested in Kampo (traditional Japanese medicine). Today, it has about 10,000 members of whom 80% are allopathic doctors. Back in 1967, health insurance companies approved only four Kampo prescriptions. Today, there are more than 200 approved prescriptions.

There is a need to cultivate medicinal plants (MPs). In Lucknow (India), medicinal plants worth Rs. 90 million are grown annually. In China, in the year 2000, the total output value of the pharmaceutical industry was 233 billion yuan (US $28 billion). By the year 2010, the share of traditional Chinese medicine in the international market is projected to improve from 3 to 15%.

Ethnobotany in Pakistan. Table 1 Priority species by MINFAL

Scientific name	Local name
Apium graveolens	Ajmood
Carum copticum	Ajwain
Cassia angustifolia	Sana-maki
Cassia senna	Sana-Makki
Curcuma zeodaria	Aania Haldi
Foeniculum vulgare	Sonf
Hyocyamus niger	Ajwain Khurasani
Lawsonia inermis/alba	Barg-e-Hina
Matricaria chamomilla	Gul-e-Baboona
Nigella sativa	Kalonji
Rosa damasena	Gul-e-Surkh

Major Issues Pertaining to Medicinal Plant Cultivation, Conservation, and Income-Generation in Pakistan

Following are the major issues concerning medicinal plants in Pakistan:

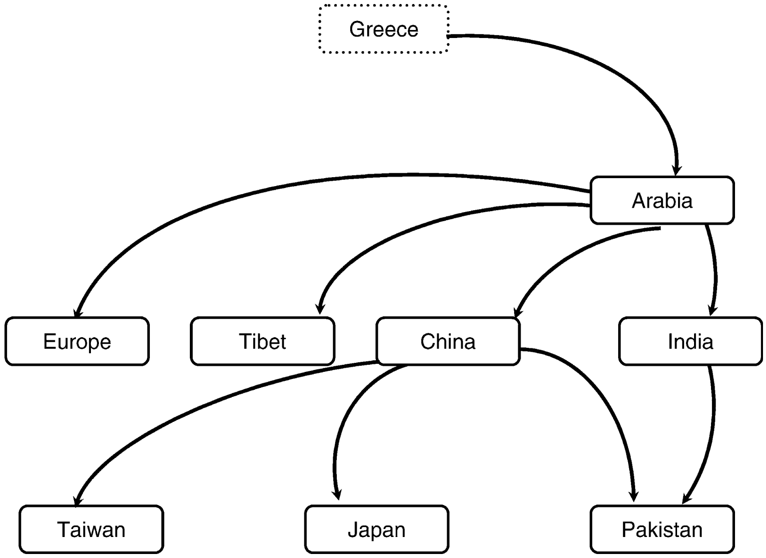
- Potential of medicinal plants: commercialization, economic growth, and prosperity
- Increasing demand of herbal medicines globally
- Illegal collection/extraction from wild populations with the reduction of many valuable species
- Traditional healthcare system and extinction scenario
- Policy issues relating to promoting large-scale cultivation and conservation

Ethnobotany in Pakistan. Table 2 Species, prices, quantities, and values of medicinal plants (Hamdard Laboratories (Waqf), Pakistan)

Scientific name	Common name	Average price (Rs. per kg)	Quantity collected (kg)
Lavandula officinalis	Ustukhuddus	320	3,000
Achillea millefolium	Baranjasif	285	6,000
Viola odorata	Gul-e-Banafsha	550	2,000
Carum carvi	Zeera siya	495	2,500
Onosma bracteatum	Gul-e-Gaozaban	290	1,500
Berberis aristata	Zarishk	238	2,000
Polypodium vulgare	Bisfaij	250	4,000

Ethnobotany in Pakistan. Table 3 Species, prices, quantities and value of medicinal plants (Qarshi Industries (P) Limited, Pakistan)

Scientific name	Common name	Average price (Rs. per kg)	Quantity collected (kg)
Plantago ovata	Ispaghol Musallam	225	2,300
Achillea millefolium	Saffron	30,000	5
Viola odorata	Gul-e-Banafsha	550	2,000
Carum carvi	Zeera siyah	400	2,500
Lavandula officinalis	Ustukhuddus	320	3,000
Onosma bracteatum	Gul-e-Gaozaban	290	1,500
Berberis aristata	Zarishk	238	2,000
Polypodium vulgare	Bisfaij	250	4,000



Ethnobotany in Pakistan. Fig. 2 Trade chain of medicinal plants showing its possible origin from Greece.

Ethnobotany in Pakistan. Table 4 Medicinal plants of Pakistan

Total species of higher plants (medicinal and nonmedicinal)	About 6,000
Species used as medicine	(10%) > 600
Species available in the market	>300
Wastage from collector to consumer	>50%
Price difference from collector to consumer	>100%
Availability of quality material	Questionable
Trained collectors	None

Twelve percent of Pakistani flora is used in medicines, and more than 300 medicinal plants are traded (Table 4). The ten leading Dawakhanas (herbal manufacturers) of Pakistan annually consume more than 2 million kg of 200 medicinal plants (Table 5). Some of the medicinal plants in the Unani system seem to have originated in the medicine of ancient Greece (Fig. 2).

Almost all medicinal plants in Pakistan are wild. Local collectors are sometimes unaware of the best collection procedures. Medicinal plants from the sites of collection to the national and international markets pass through various middlemen. Consequently, the prices of the crude drugs increase more than 100% along the trade chain. The flora of Pakistan is also threatened because of rapid infrastructural development (roads, building construction), population explosion, spread of irrigation systems, and pollution.

Twenty-two species of medicinal plants worth Rs. 14.733 million were traded in 1990; in 2002, this value rose to more than Rs. 122 million. In 1990, 95 species were consumed worth Rs. 36 million while in 2002, medicinal plants worth Rs. 218 million were consumed (Shinwari et al. 2002).

Ethnobotany in Pakistan. Table 5 Annual consumption of important medicinal plants used by ten leading Dawakhanas (data from 1990, published by NIH-Pakistan)

Category	Average consumption (million kg)	Total value (million Rs.)
20 species used >10,000 kg year^{-1}	0.33	5.6
80 species used >1,000 kg	0.26	8.2
100 species used <1,000 kg	0.05	1.4
Total 200 species	0.63	15.2
Estimated production 4–2 million kg	1.27	30.4

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Ethnobotany in Pakistan. Table 6 Total flora and medicinal plants of the hotspots of Pakistan and their current status

Region	Size of flora (number of species)	Total number of medicinally important species	Threatened flora (number of species)
Chitral	±1,600	800	150
Kashmir	1,500	900	200
S. Waziristan	425	323	??
Sindh	1,185	700	100
Hazara	1,759	>1,000	??
Swat	1,550	500	87
Balochistan	1,330	700	>150
Kurram Agency	1,200	>600	>100

Deforestation in the Himalayas is generally attributed to demographic pressure and other related effects (1) increase in demand for land for cultivation, (2) livestock population, and (3) use of the remaining forest to meet growing needs for fodder, fuelwood, and timber. On the other hand, social issues, such as social relationships, perceptions and values about natural resources as seen by different social groups, issues of access to and control over resources, and issues of power in relation to deforestation, have rarely been discussed in current literature as possible driving forces to deforestation (Saxena et al. 2001).

Thousands of Afghan refugees have taken shelter in Pakistan. They are dependent on plants for their daily domestic needs. The Ghamkol Area, Peshawar Road in Kohat, for example, was rich in *Berberis lycium* and *Delphinium kohatense*. The Ghamkol Refugees Camp was established in the early 1980s. Today, *Berberis lycium* and *Delphinium kohatense* are lost from the area (Shinwari et al. 2002). Because of such trends, many of the species, especially those having medicinal values, are becoming threatened (Table 6).

According to Chaudheri and Qureshi (1991), nearly 37% (266 species) of the total of 709 endangered species are endemic to Pakistan. A recent study has revealed that there are over 600 endemic species of Indo-Pakistan (Shinwari et al. 2002) (Table 7). The center of evolutionary radiation is Kashmir, northern Balochistan and Chitral (northern Pakistan).

Ethnobotany in Pakistan. Table 7 Endemic plants of Pakistan (Modified from Ali and Qaiser 1986)

Area	Number (%)
Endemic in Kashmir (both the sides of the divide)	Over 600 (37%)
Endemic in Alpine-Hindukush	76 (20%)
Endemic species in Pakistan	Over 400
Bi- or triregional	Over 100
Uniregional	Over 300
Irano-Turanian	125
Sino-Himalayan	115
Saharo-Sindian	60
Mountainous areas	78%
Other regions	22%

The rapid loss of floral and cultural diversity and the poverty of 30% of the people in Pakistan make it urgent that we find solutions to their problems and to take active roles in making decisions about the management of natural resources and about the legal status of their traditions and knowledge.

WWF-Pakistan is playing a leading role toward conservation and sustainable management of plant resources. Keeping in view the floristic richness, local uses, danger of loss of knowledge, conservation status, and endemism, the Ethnobotany Project (then headed by one of the authors of this report), introduced Ethnobotany as a subject at M.Sc., M.Phil., and Ph.D. level in various universities.

A project initiated in 1997 as a collaborative effort between WWF-Pakistan and the People and Plants joint program of UNESCO, WWF, and the Royal Botanical Gardens Kew had the aim of developing an applied ethnobotany project to investigate the status of fodder and fuelwood management at Ayubia National Park (ANP) and in its periphery. The project, currently known as Ayubia Ethnobotany Project, also aimed at providing recommendations for improvement of fodder and fuelwood management systems, as well as implementing some activities to contribute toward greater sustainability of plant resources at ANP and in the surrounding forests. The overall objectives of the People and Plants program in Pakistan were to (1) strengthen the capacity for work in applied ethnobotany in Pakistan through a program of training of young professionals and students, and (2) achieve better integration between conservation and development at selected field sites.

The work conducted at ANP and in the surrounding forests was thus developed in order to provide a model, where the aim is to improve the management of forests including fuelwood and fodder resources outside the National Park. The aim was also to encourage agreements between communities from local villages and the Forest Department for joint management of forests in which communities have certain rights of use. This would reduce pressure on plant resources in the National Park.

Major Developmental Issues in Pakistan

Pakistan is the tenth most populated country in the world with 144 million people. Major national developmental issues are to alleviate poverty through increasing agricultural productivity and through improvement of other sectors such as industrial development and trade and tourism (UNEP and WTO 1998). In the forestry sector, programs of afforestation have been implemented to try and meet the country's timber and fuelwood needs. Timber harvesting through (unsustainable) logging is threatening environmental quality including supplies of some resources required by local communities (WWF-Pakistan 2000). Local cultural and social systems are progressively fading and, with them, local knowledge of resource management (Shinwari et al. 1996). National healthcare support at the village level is poor due to lack of facilities and qualified staff. The use of medicinal plants is therefore a necessity in many rural areas.

Women are usually responsible for fuelwood, fodder collection, and water carriage besides a host of agricultural activities. Access to fuelwood and fodder and other nontimber forest products (NTFPs) is also decreasing due to decreases in forest cover and also mismanagement of existing forests. Besides being overwhelmed by fuelwood and fodder collection tasks, education of young girls is also affected by lack of schools for girls. As is generally recognized in South Asia (Gururani 2002) and based on our own assessment of the situation at ANP, the link between women and resource management requires particular attention (Aumeeruddy 1996).

Conservation Priorities

Forest cover represents only 5.2% (4.58 million ha) of the country's area, but the country is highly dependent on trees as well as on NTFPs (Shinwari and Khan 2001). Scarcity of biological resources is a major concern because it represents the livelihood for a large portion of the population. Biodiversity is endangered through increase in population, timber harvesting beyond the productive potential, overgrazing in forest undergrowth as well as in pastures, unsustainable collection of NTFPs such as medicinal plants, for trade, and unsustainable collection of fuelwood (Government of Pakistan 1998). Fuelwood is still the main source of energy in Pakistan with 90% of the rural population and 50% of the urban population mainly relying on it.

International NGOs such as IUCN and WWF are working on natural resource management with a strong emphasis on the role of local communities. IUCN has been involved in recording traditional management of medicinal plants in Bomberet Valley in Chitral (Ali and Khuwaja 2003). Among local NGOs, the Agha Khan Rural Support Program is regionally recognized for its experience related to natural resource management involving local populations in afforestation programs, cultivation of medicinal plants, and social forestry. International agencies such as the European Union (EU) and a German aid agency (GTZ) are also involved in major projects in close collaboration with the Forest Department: the European Union project "Environmental Rehabilitation in NWFP and Punjab" and GTZ Joint Forest Management project in Mansehra (NWFP).

Priorities for Capacity Building in Ethnobotany

Ethnobotany is a multidisciplinary science encompassing botany, anthropology, economics, and linguistics that studies the way in which a society relates to its environment and particularly to the plant world. These relationships can be social, economic, symbolic, religious, ritualistic, commercial, or artistic (Aumeeruddy-Thomas and Pei Shengji 2003). In the early 1980s, there was an increased focus on local management practices by ethnobotanists as a result of greater global concerns about the environmental crisis. A great number of ethnobotanists were then engaged in studies to understand the rationale for such practices, the functioning of local institutions relating to management practices, as well as their impact on the conservation of biodiversity (Aumeeruddy-Thomas 2004).

An introductory workshop was organized in September 1996 that showed that ethnobotany in Pakistan had mainly focused on people's use of medicinal plants with relatively little concern for other plant resources. However, the practicalities related to resource management, aspects related to tenure, ownership, rights of access, methods of harvesting had not yet been investigated. Consultation during the workshop with conservation managers, academics, NGO representatives, and practitioners such as *hakeems* (traditional doctors) showed that there is much interest in using ethnobotany as a tool to learn more about people's needs and perceptions, in order to design better conservation approaches.

Ayubia National Park: An Example

ANP was chosen for the project in applied ethnobotany because it is representative of many situations encountered in other forested areas in NWFP—high pressure on resources due to high energy needs (because of prolonged winters and nonavailability/scarcity of alternate sources), mismanagement due to unclear access and tenure regimes, and a high level of conflict between local communities and the Wildlife and the Forest Departments.

Most of the vegetation in and around the Park is heavily influenced by people. The vegetation of ANP, which seems fairly well preserved in places, is dominated by coniferous species principally Blue pine (*Pinus wallichiana*) and Spruce (*Abies pindrow*) mixed with scattered broad-leaved tree species such as Oak (*Quercus dilatata*), *Aesculus indica*, Elm (*Ulmus wallichiana*), *Prunus padus*, etc. Populations of broad-leaved trees have declined. Blue pine and fir have colonized large areas, leaving seemingly little space for broad-leaved species to grow and relatively poor vegetation in the understorey. Outside the Park, forested areas are almost entirely composed of fir in the northern aspects and blue pine elsewhere.

Conservation and Developmental Issues at ANP

Forests are important in the Himalayan foothills for catchment's protection. At present, poorly regulated collection is leading to degradation of the resource base, both within and outside the Park. Tree populations are decimated and regeneration is highly affected. Women have to walk very long distances to collect fuelwood and fodder, and a situation of conflict persists between the women and the Park guards. Guzara forests (outside the Park) do not have a clear tenure regime and wild plant resources have greatly declined due to mismanagement, the absence of clear rules of control and access to resource. A critical social issue at Ayubia is that women are the main harvesters and users of natural resources but are also the least represented in decision-making processes. It is men who control the influential networks taking decisions regarding access to resources, tree planting, or timber harvesting.

Unlike in many other traditional societies, there is no well-developed classification or folk taxonomy. Moreover, knowledge and practices especially relating to fodder and fuelwood are not linked to cosmology or larger cultural beliefs. Beyond ethnobotanical knowledge, they also have some ethnoecological expertise, such as knowledge of bird nesting or over-flying the area, and habits and habitats.

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Wild Vegetable and Mushroom Collection in the National Park

Types of mushroom collected were mainly different species of morels, locally known as *Kali* (black) and *Surkh* (red) Guchi (*Morchella esculenta*), Narela, Begar Guchi (*Morchella* sp.). Kali and Surkh are phenotypic variations of *M. esculenta*, the only mushroom collected for sale. For women, collection is associated with fodder or fuelwood collection trips.

The main vegetables collected are *Kunji* (*Dryopteris stewartii*), *Mushkana* (*Nepeta laevigata*), *Kandhor* (*Dryopteris blanfordii*), *Mirchi* (*Solanum nigra*), and *Tandi* (*Dipsacus inermis*). Parts collected are young leaves for all species. The most collected vegetables are the two *Dryopteris* species, followed by *N. laevigata*. It should be noted that two of these three species are ferns. Collection season for wild vegetables is between April and the end of June (Aumeeruddy et al. 2004).

Conservation Practices

Conservation of plants involves more than plant protection and controlling access to plant resources. Conservation also demands collection of baseline data on social, economic, and ecological parameters, to be incorporated into a comprehensive management strategy. Effective conservation also requires extension activities and education about the importance of plants as well as strategic cultivation initiatives. Moreover, conservation requires the involvement and support of the communities that ultimately depend on these plant resources.

A notable lack of available information on propagation and management of important species limits the increased cultivation of plants. This lack of information is exacerbated by a paucity of quality planting materials. By increasing both the amount of available information and the quantity of local nursery-based stocks, the project hopes to leverage a substantial reduction in the pressure on wild populations of plants. Whatever information exists on the cultivation of plants is not readily available to the farmers who actually could use it.

Selection of species for study must be based on several criteria: degree of endangerment in the wild, actual or potential market value, and the availability of existing information. To harvest medicinal plants sustainably, training of collectors, training in nursery techniques, and removal of some of the middlemen from the trading chain are essential.

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Ethnobotany in South America

Ingrid Roth

Historic Considerations

Ethnobotanical investigation started in Venezuela with the first description of useful plants by Humboldt and Bonplan (1799–1804).

The original population of South America, the Indians, came from Asia about 23,000–10,000 years ago. Today, hundreds of Indian tribes still exist, each comprising a 1,000 people or less and each with its own language or dialect. They accumulated a knowledge of the native flora over centuries or even thousands of years. Almost every primitive society has its own pharmacopoeia. The Amazon area, extending over Colombia, Ecuador, Brazil, Perú, and Venezuelan Guiana (Schultes and Raffauf 1990), supports the most extensive tropical rainforest in the world, and rainforests are ecosystems with the greatest wealth of plant species.

The Indians searched mainly for medicinal plants which cured stomach and intestinal problems, inflammations, skin diseases, intoxications, gynecological disorders and parasites. For about 5,000 years, the Indians searched for useful plants and cultivated a large number of them. The most ancient archeological findings of plants used by Indians are Cucurbit seeds about 14,000 years old, and avocados about 10,000 years old. Cultivation of plants and agriculture were started, at the latest, about 5,000 years ago (Brücher 1989). South and Central American Indian tribes improved the yield and quality of numerous crop plants which today enrich our daily diet. Indians carried out experiments for possibly hundreds of years, but they may also have been accustomed to certain poisonous substances or more resistant to local drugs.

Indians not only supplied us with valuable goods, but also transmitted their language.

On the Origin of Common and Some Latin Plant Names

In tropical regions, plant identification is most difficult. Most of the plant families have their own specialist somewhere in the States, in the Netherlands, or in other countries so that the material has to be sent to them where it may rest for years or decades until identification is settled and sanctioned. In the meantime, one is dependent on the local and common names which – in many cases – are very useful and unmistakable. In Venezuelan Guyana, there was a peasant without any scientific training who could distinguish most of the 280 collected specimens, even separating the species from one another, relying thus only on common names. A binary nomenclature is frequently used so that sometimes a perfect correspondence between scientific and common names is maintained: *Guamo*, for example, corresponds to the genus *Inga*; and each species also has a species name. *Inga alba* carries the vernacular species name *colorado,* which means colored (*Guamo colorado*). *Inga capitata* is called *Guamo negro* (black Guamo), *Inga rubiginosa* corresponds to *Guamo terciopelo* (velvety Guamo), and so on. The complication which arises from this nomenclature is its regional restriction, so that a species called *Guamo colorado* in Venezuelan Guyana may have a completely different name in other parts of Venezuela. Also, the name *Guamo colorado* may be applied for two completely different species belonging to different families in geographically different regions. Great caution in the application of these names is therefore indicated, and information about the geographical origin of the species in question is indispensable.

Within the mixed-up jungle of common names, this author made the observation that some words were obviously of Spanish origin while others had an Indian sound. After the conquistadores had entered the country, many of the original Indian plant names were altered. A *palo de Maria* (*palo* = pole, stem; in Venezuelan Spanish, it is a tree) corresponding to *Tachiglia paniculata,* or Santa Maria (*Triplaris surinamensis*), San Jose (Saint Joseph = *Jacaranda obtusifolia*), or Nazareno (from *Nazareth* = *Peltogyne pubescens*) certainly resulted from attempts to Christianize the Indian world. A great part of the common names are thus of Spanish origin, created soon after the colonizers arrived. Names were given by using personal names such as Don Juan, or recognizing special characteristics of the plants such as *azucarito* (sugary) or *espina de erizo* (spine of the hedgehog). The Spanish name *sangrito* (bloody, bleeding) for *Pterocarpus* refers to the red secretion from the bark; *cenizero* (ashtray) relates to the old powdery bark; the name *jabón* (soap) comes from the smell of the fresh bark. The name *kerosen* indicates the propensity of the cork to catch fire when lit with a match; the *zapatero* (shoemaker) has a fruit in the shape of the sole of a shoe. Other names refer to characteristic colors, geographical origin (*montanero* = from the mountains, *sabanero* = from the savanna), to similarities and comparisons with animals (*pata de zamuro* = claw of the vulture; *burro muerto* = dead donkey; *cabeza de mono* = head of the monkey); and many other designations which are more remarkable for their oddity than their characterization of the plant. Some names, however, such as *conserva* (canned food), certainly a very recently applied name, have little or nothing to do with the appearance of the plant. Many species, on the other hand, were compared with the indigenous European plants and some of them recognized more or less correctly by the Spanish colonizers, such as certain Lauraceae of the genera *Aniba*, *Endlicheria*, *Ocotea*, and *Nectandra* which received the generic name Laurel (for example: yellow Laurel, black Laurel). However, it may be possible that some of these names were given relatively recently by people already trained in Botany. Rollet's Laurel, certainly, is a very recent creation in honor of Dr Rollet. *Higuerón* (fig) for *Ficus* is also correct. Most of the comparisons with the indigenous European plant species, however, are very unsuccessful falsifications which have nothing to do with the European genera or species after which they were named. *Cedro dulce* (the sweet cedar) is *Eriotheca*, Bombacaceae; *Crudia*, Caesalpiniaceae, is called *algarrobo* (carob); *Caryocar nuciferum*, Caryocaraceae, became an almond (*almendra*); *Platymiscium*, Papilionaceae, was made an oak (*roble*); and *Swartzia schomburgkii*, Papilionaceae, was transformed into an olive tree (*olivero*). The name *uvero* (grapevine) for *Coccoloba,* Polygonaceae, refers to the clustered grape-like infrutescence of this tree. *Touroulia guianensis*, Quiinaceae, is called *palmito*, but it has nothing to do with palm trees, and *helecho* (fern) corresponds to *Dilodendron,* Sapindaceae, which has no relationship with ferns.

As mentioned above, in many cases we can only guess in which historical period names were given, whether soon after the conquistadores had entered the country (Christian names) or only recently by botanically trained people (as Laurel Rollet). Some species of *Sapium,* Euphorbiaceae, are, for example, designated as *caucho* (rubber), probably a name of Indian origin.

Many of the originally applied Indian names may have been much more meaningful than the later Spanish names. In the jungle of names even some of

Arabic origin appear; these were first assimilated from the Arabs by the Spanish people and came from Spain via the conquistadores to South America. *Jebe* (*Lonchocarpus sericeus,* Papilionaceae) is an Arabic name. Checking a complete plant list with over 270 species the author found that about 50% were of Indian origin. But it is very difficult to find them out. Not all names which mean nothing in Spanish are Indian names.

Within the approximately 370 known Indian tribes, 125 different language families are distinguished, not counting dialects and individual languages. The fact that no fundamental language type unites all these different tongues complicates any investigation. Best studied are probably the Mexican Indian languages. Indian plant names from Mexico sound different from Venezuelan names. In Venezuela, however, philological studies of Indian languages are hardly cultivated. Checking a dictionary of Yanomami, no word referring to a plant name could be found. However, some names of very different Indian origin, such as Chibchua, Quechua, Náhuatl, Taino, Caraibic, Guarani, Araucanic, Tupi, or Guaicurü (from Mexico, Brazil, Peru, Chile, and the Caribbean) were adopted in other South or Middle American countries and are now known all over the world. From the Taino came such common words as *maiz*, *tabaco*, and *sabana*. From Náhuatl (Mexico) we have *aguacate* (avocado), *cacao*, chocolate, tomato, potato, and chicle. *Colibri* (a bird) comes from the Caraibic (or Caribic); *ananas* is from the Guarani. Quechua has contributed the words quinine and cocoa, while petunia comes from Tupi.

Some Indian words may easily be recognized by their prefixes or suffixes. The prefix *gua-* always indicates Indian origin, as in *guamo, guatacare, guacharaco* or *guaraunera*; Guatemala is also an Indian name). -*Gua* also appears at the end of the word in *majagua*, or in the middle of the word, as in *masaguaro*. The suffix -*cua* in Nicua or -*guo-* in Purguo is used frequently. -*Guay-* or -*guaya-* in *guayaba* and *guayabito* are other forms of Indian vocal music rich in vowels. Double vowels like ua, ue, and uo are frequently represented in Indian words such as *carruache, arahueque,* and *bocsuo* or *merguo*. The *puig* rich in vowels may be a creation of the Caribbean area, being used in Northern South America and the Caribbean Islands. In some words one may perceive the Indian onomatopoeia as in *paují*, a bird name. Double vowels are also characteristic of such words as *copey* (the Christian-Social party of Venezuela has chosen this as its party name which is adopted from the copey tree, a *Clusia), cozoiba, cacaito,* or *yigüire*. The ending –*mán* is frequently found in such Indian words as *baramán, cajimán, samán*. The suffix –*i*, otherwise frequent in certain Indian languages, is seldom found in Venezuelan Indian names. However, the accentuated ú is not infrequent, as in *cacú*. The ending -*ey* as in *araguaney* and *merey* also indicates Indian origin. The ending -*tl*, on the other hand, as frequently found in Mexican Indian (Náhuatl, for example), seems to be missing in Venezuelan Indian. A repetition of a word, a twin word, is usually a reference to the Indian in such word compositions as *sun sun, marimari*, or *yarayara*; in Yanomami Yare means "gone with the wind" and may be the origin of the name *yarayara*, eventually referring to seed dispersal. Some of the Indian names became part of the scientific nomenclature. Examples are *samán (Samanea saman), ceiba, simarouba,* Cacao *(Theobroma cacao),* and many others. The meanings of the Indian names are unknown. For some cultivated plants or plants of high economic value, however, the significance of the names is known. The name caucho or *caoutchouc* (*rubber*), in Indian *cau-uchu*, means the weeping tree which sheds tears of latex. Dozens of English words thus have their origin in one or another Indian language.

Transmission of Information

Botanical knowledge was transmitted to the present population mainly orally. It is based on the experience and experiments of Indians for hundreds or even thousands of years. It is estimated that at least 20 alimentary plant species were cultivated on the continent by Indians before the arrival of Columbus in 1492. The Andean Incas trained pharmacognosts specialized in the search for new natural drugs. In the Maya culture, illustrated books called codices were elaborated in which preparations of medical plants are described. The oldest book dates back as far as the tenth century. Dr M. de Cruz had already described 250 curative plants in 1552. The Incas, however, unfortunately did not draw the plants.

Inca Medicine

Inca medicine was divided into a magic-religious branch administered by the priest of the Temple of the Gods and an empirical branch practiced by the *curanderos* (healers) (*Primera nueva cronica y buen gobierno* of Felipe Poma de Ayala in 1613) (Albornoz 1993).

Illness and death were connected with religion and mysticism. Indians believed that they were caused by magical sources. Consequently, shamanistic use of hallucinogenic plants was well developed. Healing was accompanied by ritual dances, dances imitating animals, black magic, exorcism, faith healing and the use of amulets. Astrology was integrated into the healing methods of the ancient Indians. Medicine men collected roots and other vegetable parts in the woods while singing and praying. They applied the theory of signatures, just as Paracelsus did in the sixteenth century, suggesting that each plant resembled the part of the human body which it could cure (Albornoz 1993).

Sick people were cured with massages, suction, vapor blowing, or cataplasms. Shamans acted as intermediates between people and the gods. The Indians used plants in rites and religious ceremonies; the plants are important as they open the entrance to the spiritual world and enable the person to communicate with ghosts and gods and to develop spiritual power (Fig. 1). Species of *Nicotiana* (tobacco) were used to prepare stimulants and narcotics, as well as for medicinal, ritualistic, and hedonistic purposes. Shamans and priests employed nicotine to enter into ecstatic trances. Today, nicotine is also used as an insecticide.

Hallucinogenics of *Ebena* were smoked with blowpipes. The action of the active alkaloids started only a few minutes later, when the spirit abandoned the body to enter the world of ghosts. In this way, shamans expelled the bad ghosts from the body of the patient. *Ayahuasca* (*Banisteropsis*) alkaloids enable telepathy and prophecy. Pictures painted under the influence of ayahuasca are rich in vivid and bright colors, in symbolism and details.

Cacao was called the Food of the Gods (Figs. 2 and 3). The Indians have domesticated it since 2,000 years ago. They developed the art of planting and selecting cacao. The Indian emperor Moctezuma (Montezuma) is said to have drunk 400 cups of hot xocolatl (chocolate) a day. Cacao contains stimulating alkaloids.

Cocaine (*Erythroxylum coca*) has been cultivated in the Andes since 7000 years BCE The coca shrub contains the alkaloid cocaine, used as a remedy for hunger and fatigue. Indians masticate the leaves. The hydrochloride of cocaine is used as a local anesthetic. The function of the brain is altered by the use of psychoactive plants. The use of drugs is, however, prescribed by religious instructions of the tribe.

The native population can utilize almost every plant growing in their environment. The discovery of South America brought a large number of new plant species to Europe and in this way profoundly altered European habits. As a consequence of the discovery of America, such products as maize, cocoa, potato,

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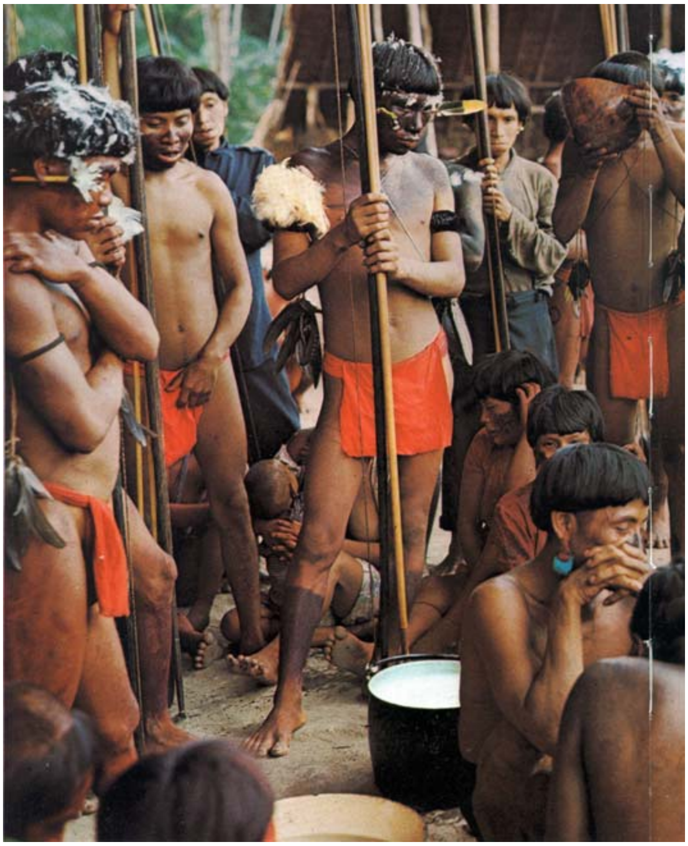
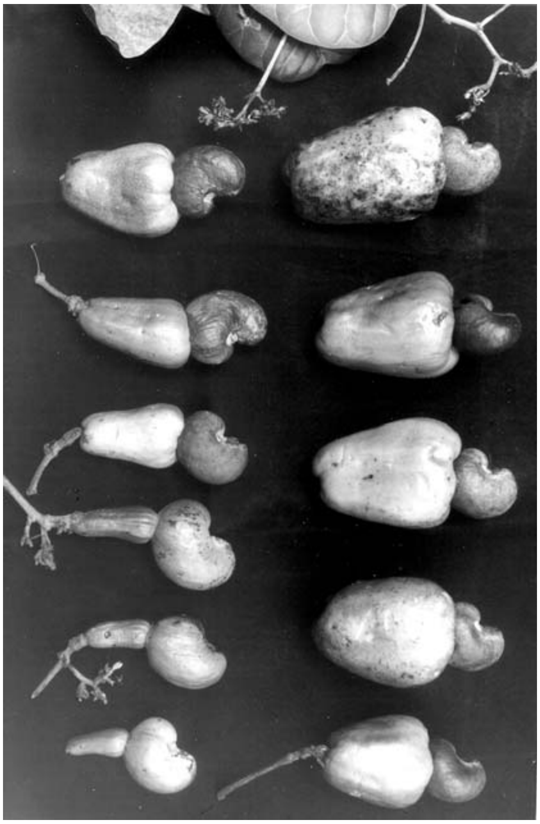


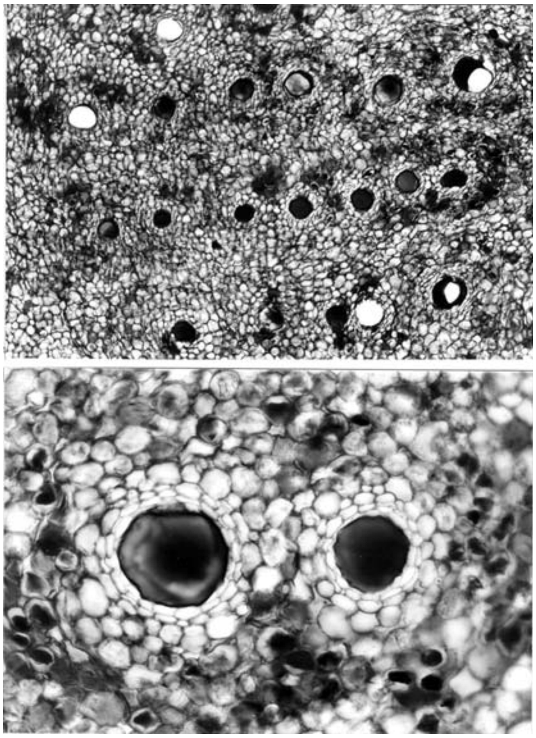
Ethnobotany in South America. Fig. 1 Ritualistic ceremony of Yanomami Indians with dances and a banquet (Courtesy Luis Cocco 1970).

Ethnobotany in South America. Fig. 2 Cacao flowers and fruits emerging from the stem (Roth and Lindorf 2002).

Ethnobotany in South America. Fig. 3 Right: a longitudinal section of cacao fruit with seeds (Roth and Lindorf 2002).



Ethnobotany in South America. Fig. 4 Double fruit of *Anacardium occidentale*: a nut develops from the real fruit; the stalk below transforms into a fleshy pseudofruit (Roth and Lindorf 2002).



Ethnobotany in South America. Fig. 5 *Anacardium occidentale*, transection of the fleshy false fruit with resin canals (Roth and Lindorf 2002).

tobacco, and beautiful orchids improved the European standard of living. *Hevea brasiliensis* supplied the latex rubber.

Utility of South American Plants

Indians used plants to make fermented drinks, syrup, jam, and marmalade from fruits, baskets and cloth from fibers, vessels from calabashes, and housing, canoes, musical instruments, arrows, and bows, furniture and carved objects from timber. For hunting, they used fish and arrow poisons extracted from plants (curare). Timbers resistant to termites were particularly useful. Some plants supply perfumes or even insecticides. Oils, resins and balsams, wax, cork, gum and rubber, glycosides, saponins, alkaloids, flavonoids, coumarin, tannins, carbohydrates, pectins, lipoids, and tars are found in South American plants. Enzymes, lectins, vitamins, vegetable sweeteners, antidotes, antibiotics, cytostatics, immunostimulants, immunosuppressives, antiallergens, and laxatives may be extracted from many plants, as well as antimicrobial substances, antioxidants, cholesterol-reducing and glucose regulating or anti-inflammatory and antiphlogistic substances. Some plants not only contain a single substance, but some contain as many as 70 different alkaloids or dozens of active substances with similar effects.

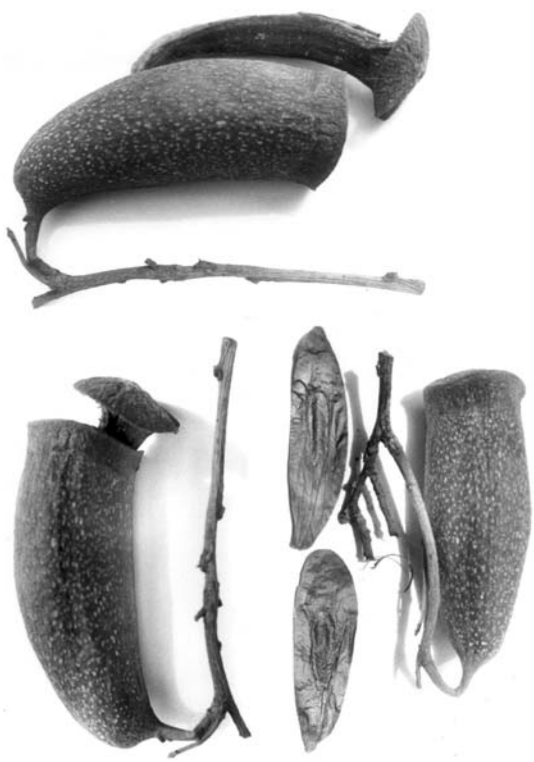
A large number of tropical plants have a variety of uses. Most medicinal plants cure quite a few diseases. These plants may also have other uses.

Other not-curative substances obtained from plants are edible plant parts, cloth, material for construction and transportation, condiments, perfumes, soap, stimulants, fibers, cork, tannins, timber, and natural dyes. The Indians also used these dyes to paint their bodies (e.g. red with *Bixa orellana*) and were consequently called red skinned people. Seeds of the cacao tree were used by Indians as currency: with 100 beans one could buy a slave. Further objects of exchange were condiments, timber, and textiles (Figs. 4–22).

Preparation of Herbal Drugs

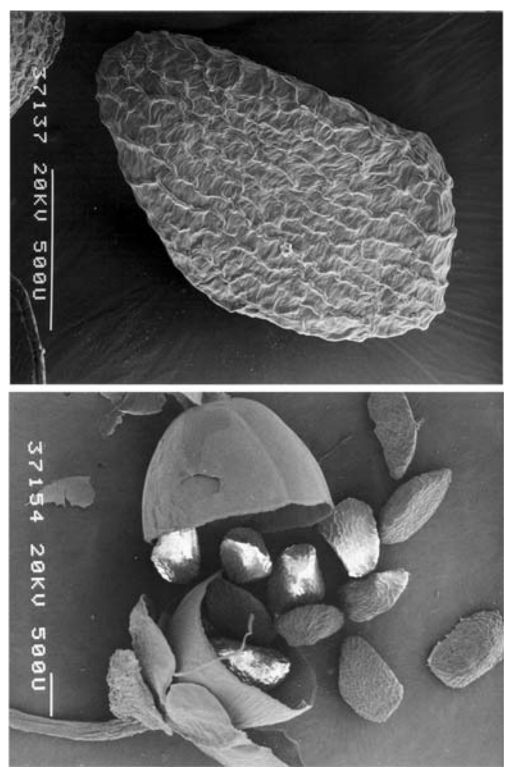
Natives frequently use crude herbs. They put fresh leaves on wounds for disinfection or on the forehead to soothe headaches. Fresh fruits, seeds, and leaves may be eaten raw or plant parts may be cut to pieces, broken, shredded, crushed, ground, or pulverized. For external use, cataplasms are prepared by crushing and grinding.

Ethnobotany in South America. Fig. 6 Fruits of palm trees (Roth and Lindorf 2002).



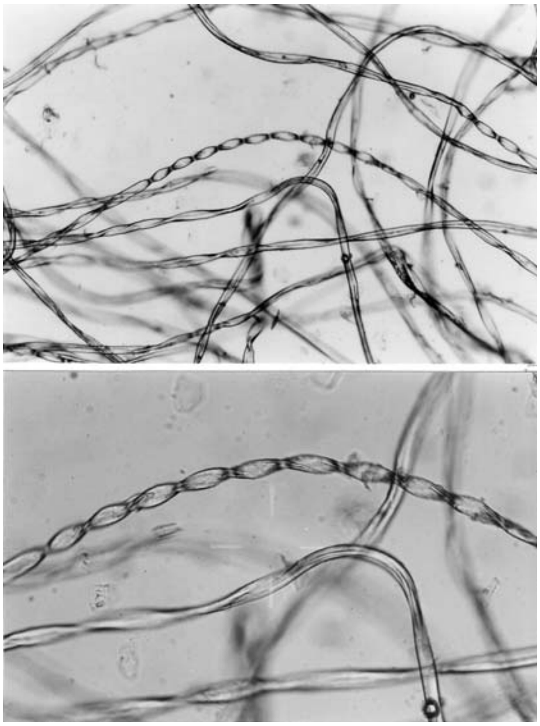
Ethnobotany in South America. Fig. 7 Pipe-like fruits of Lecythis with seeds (Roth and Lindorf 2002).

Ethnobotany in South America. Fig. 8 *Coccoloba uvifera*. Above: shrub growing at the beach; below: infrutescences (agglomerations of fruits) (Roth and Lindorf 2002).



Ethnobotany in South America. Fig. 9 *Plantago major*. Above: fruit, below: opened fruit with seeds. The mucilaginous seed coat has laxative effects (Roth and Lindorf 2002).

Ethnobotany in South America. Fig. 10 Prepared and compressed bark of fig on which natives painted an Indian motive, the quetzalcoatl, or king of the birds (Roth and Lindorf 2002).



Ethnobotany in South America. Fig. 12 Fibers of Barbados cotton under the microscope (Roth and Lindorf 2002).

Ethnobotany in South America. Fig. 11 Picture painted by Indians on the bark of a fig (Original).

Ethnobotany in South America. Fig. 13 Woven purse made of cotton fiber with alligator motif (original).

For internal use, a tea, decoction or infusion is prepared.

Women and Beneficial Use of Plants

Women had and still have a good knowledge of useful herbs. They know the places where to find and collect them and how to prepare them. Mothers pass their

Ethnobotany in South America. Fig. 14 Poncho (jacket) with typical Indian design (original).

Ethnobotany in South America. Fig. 15 Indian basket made of fibers of a palm tree with typical geometric design (original).

Ethnobotany in South America. Fig. 16 Rosettes of the Andean plant *Espeletia*. The leaves are very hairy and may be used to manufacture cloth (Roth and Lindorf 2002).

Ethnobotany in South America. Fig. 17 Balsa woodcarving, representing a daisypod of the rain forest (original).

Ethnobotany in South America. Fig. 18 Opened fruit of a Mahagony tree with brown seeds. Mahagony is a very fine and expensive timber used for elegant furniture (Roth and Lindorf 2002).

knowledge on to their daughters. Many useful plants are cultivated by women in special house gardens around the house (Silva 1999). Women likewise play their part in agriculture and are aware of the biological diversity of plants. In many places they maintain the agricultural system called *conuco* carried out in the form of small plantations (Royero et al. 1999).

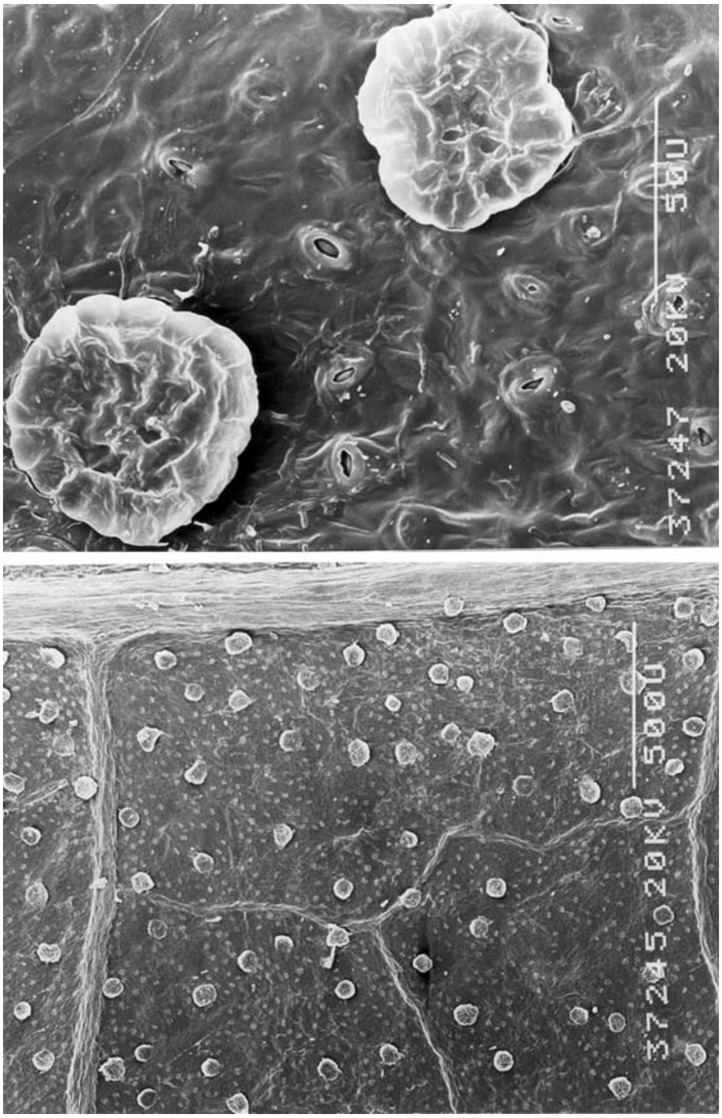
Actual Use of Medicinal Plants

In 1884, the first school of pharmaceutical studies was founded in Venezuela. Although in the twentieth century interest in natural medicine declined abruptly, due to the development of chemotherapy and synthetic products, native people who live far away from urban centers, e.g., in the Orinoco delta or in large forests where no public transportation is available, plants are still the best and the most inexpensive medicine available for everybody all the time. In underdeveloped countries, 3.5 million people depend on phytopharmacy. Natural medicines also have the advantage of having been tested by Indians for hundreds of years.

Further Possible Investigation and Recommended Bibliography

The first place to find information about medicinal plants would be the *herbolarios*, open stands where healing plants are offered. They are scattered all over

Ethnobotany in South America. Fig. 19 Woodcarving representing a llama with its shepherd (original).

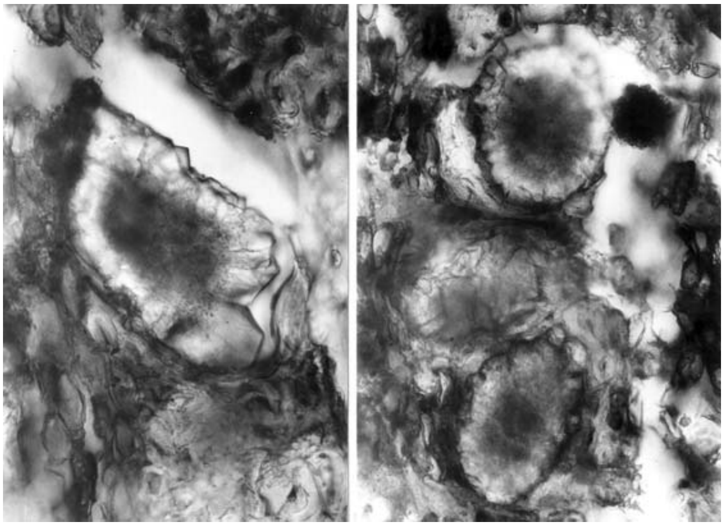


Ethnobotany in South America. Fig. 20 *Bixa orellana* leaf with glands in surface view. The seed coat of Bixa is industrially used as a dye for food, adding a brilliant orange color (Roth and Lindorf 2002).

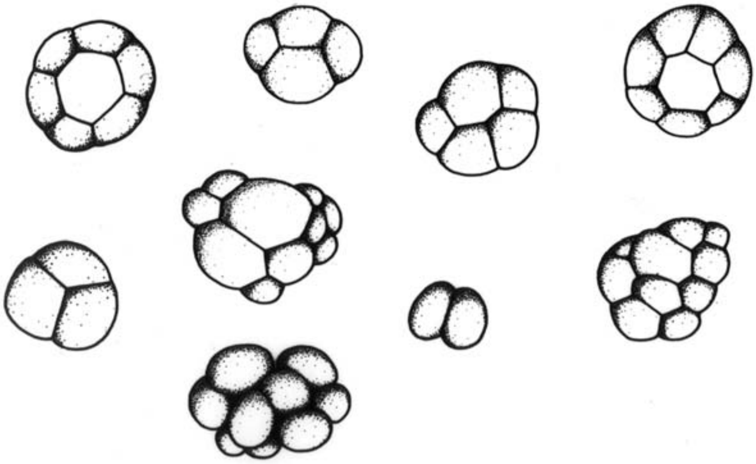
the country and staffed by native experts on healing plants. These people preserve the knowledge of useful plants transmitted to them by their ancestors. They know exactly the right plant species, the organs which have to be used, the methods to prepare the drugs and the way to administer the medicine. They also are informed if the plant was collected wild or whether it was cultivated, and they know their vernacular and local names. Drugs of this kind have to be handled with care. Native people are accustomed to these drugs over as many as hundreds of years; other people may react in very different ways. Caution is advisable. The *herbolarios* are often found along highways or at local markets. Perhaps the most authentic information is found with the living Indian tribes, who know not only healing plants, but also narcotics (Schultes and Raffauf 1990).

In most cases, healing substances are only found in one or another organ, or are enriched in determined organs. When buying drugs at the pharmacological stalls, only plant parts or organs are handed over to the buyer, who then has to find out which plant species is the donor and which taxonomic name the plant has, as plants are usually sold by their vernacular names.

The collection of SECAB is one of the most valuable compilations of medicinal plants which includes the flora of Bolivia, Colombia, Chile, Ecuador, Panama, Peru, and Venezuela. Pittier (1926) contributed a great deal to the knowledge of the useful Venezuelan plants. Gupta (1995) studied 270 Ibero-American medicinal



Ethnobotany in South America. Fig. 21 *Coccoloba* with large crystals of calcium oxalate in the bark (Roth and Lindorf 2002).



Ethnobotany in South America. Fig. 22 Compound starch grains of the edible root of *Arracacia esculenta*, a relative of the cellery (Roth and Lindorf 2002).

plants. Schultes and Raffauf (1990) deal with the healing forest of the northwest Amazon region. Brücher (1989) treated the genetics of neotropical useful plants. Interest in tropical useful plants has been growing steadily, so that several books dealing with taxonomic description, chemical contents, pharmacology, use (including recipes), ecological requirements and cultivation of medicinal plants have appeared, written by native botanists, pharmacists, experts on human nutrition, chemists, etc. Uphof provides a good survey of useful and medicinal plants of the world up to 1968. Exhaustive information on South American medicinal and useful plants can be found in Roth and Lindorf 2002.

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Ethnomathematics

Marcia Ascher

Ethnomathematics, as a field of inquiry, began in about 1970, although the term itself did not come into use until about 10 years later. Its basic tenet is that mathematical ideas are cultural expressions embedded within cultural contexts. The emergence or elaboration of mathematical ideas follows no necessary or universal path. The ideas that are stressed, their expressions, and their applications vary depending on the culture. Whether an idea arises within a culture or is stimulated by contact with another culture, it becomes enmeshed in the complex of ideas particular to the culture. This perspective is of particular importance because mathematics had long been viewed as culture-free or culture-neutral.

Ethnomathematics calls for a definition of mathematical ideas that is broader in scope than just those associated with modern mathematics. By modern mathematics we mean the category so designated by professional mathematicians worldwide and spread through Western-style schooling. Modern mathematics itself is the confluence of ideas from people in many cultures which became merged through translation, media, and standardization of expression. Mathematical ideas, however, whether or not they fed this stream, are those ideas involving number, logic, spatial configuration, and more important, the organization of these into systems and structures. To fully appreciate the ideas, they must be viewed in their cultural and ideational contexts.

The number of different cultures existing during the past 300 years, using the criterion of mutually exclusive speech communities, is in the range of 5,000–6,000. Although today there is an overlay of a few dominant cultures, traditional cultures still exist, in some cases blended with, or within, the dominant cultures. Moreover, there are, particularly within large or small industrialized nation-states, subcultures, part cultures, and composite cultures which have developed shared ideas and particular ways of doing things. To learn about the mathematical ideas of cultures that had no writing systems or whose traditions are no longer extant, we must depend on information that can be gleaned from artifacts or from reports of observations left by others. Even where the ideas are current, they are often implicit rather than explicit, and so must be obtained through the interpretation of observations and conversations. Thus, the study of mathematical ideas in their cultural contexts often interacts with or draws upon such fields as archaeology, ethnology, linguistics, culture history, and cognitive studies.

For some, the primary goal of ethnomathematics is to broaden the history of mathematics to one that is global and humanistic. For others, the pedagogical implications and uses are paramount.

Through a discussion of planar graphs and concepts of space/time, the sense and perspective of ethnomathematics will be made more specific.

Planar Graphs

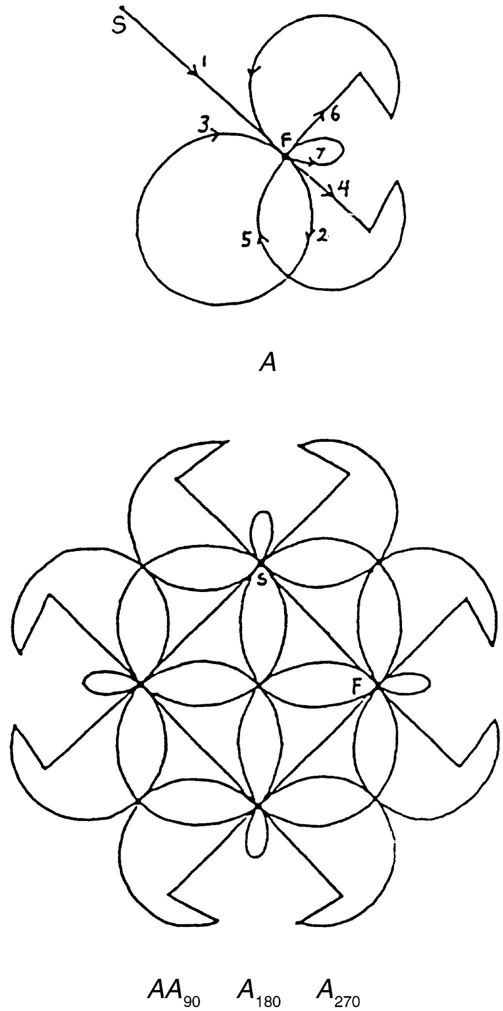
The mathematical idea of tracing figures continuously is found in several diverse cultures. Just as the contexts for the tracings differ from culture to culture, so do the associated geometric or topological ideas.

In modern mathematics, the concept of continuous figure tracing falls within graph theory. Described geometrically, graph theory is concerned with arrays of points (called vertices) interconnected by lines (called edges). The question said to have inspired the founding of graph theory by the mathematician Euler was: "For a graph, can a continuous path be found that covers every edge once and only once? Also, if such a path exists, can the path end at the point it started?" According to the story, there were seven bridges in Königsberg, Prussia where Euler lived. The townspeople wondered if, on their Sunday walks, they could start from home, cross each bridge once and only once, and end at home. Between Euler in 1736 and Hierholzer some 130 years later, a complete answer was found. The answer depends on the degrees of the vertices – the degree of a vertex is the number of edges emanating from it. First of all, not all graphs can be traced continuously covering every edge once and only once. Such a path exists if the graph has one pair of vertices of odd degree, provided that you start at one of them and end at the other. Also, if all vertices have even degree, such a path can be traced starting anywhere and ending where you began. There can be no such path when a graph has more than one pair of vertices of odd degree.

Much the same question was of concern to the Malekula who live in Oceania in what is now the Republic of Vanuatu. There, however, the issue is getting to the Land of the Dead. According to the Malekula, when a man dies, in order to get to the Land of the Dead, his ghost must pass a spider-like ogre who challenges him to trace a figure in the sand. He must trace the entire figure without lifting his finger or backtracking and, if possible, ending at the point he started. If he cannot meet the challenge, he cannot proceed to the Land of the Dead.

From the ethnographic literature about 100 figures and the exact tracing paths used by the Malekula are known. Analysis of the tracing courses corroborate the Malekula's concern for the problem and their adherence to its stipulations and solution. However, in addition, the tracing courses demonstrate the use of systematic procedures involving general systems that extended beyond individual figures to groups of figures. There are three or four of these extended systems, one of which is briefly described here.

For each figure in the group, there is an initial procedure, namely some ordered sequence of motions (call it A). This is followed by the same procedure modified by formal transformations. Call a transformed procedure A_T. For the group of figures, only a particular set of transformations is used: rotation through 90°, 180°, 270°; horizontal reflection; vertical reflection; each alone or in combination with inversion. Inversion is the reversal of the order of the procedure. One figure and its initial procedure, A, are shown in Fig. 1.



Ethnomathematics. Fig. 1 A Malekula sand tracing. Top: A; bottom: $AA_{90}\ A_{180}\ A_{270}$.

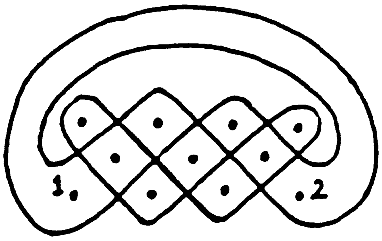
In terms of A, the figure can be succinctly described as $AA_{90}\ A_{180}\ A_{270}$.

The figure exemplifies the Malekula interest in symmetry combined with graph theoretic constraints and formal, systematized tracing processes.

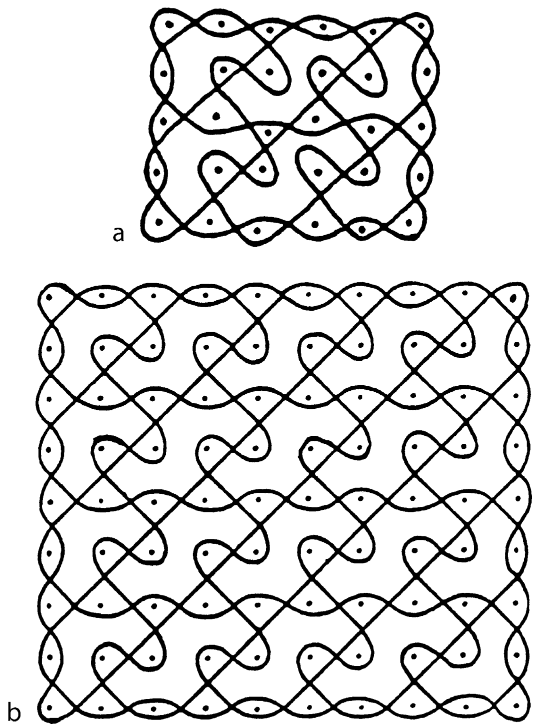
The study of the mathematical ideas embedded in the Malekula sand tracing tradition leads to an appreciation of this as an intellectual endeavor. However, the global history of mathematics is also enriched. The question of continuous figure tracing is seen as one that arises in different human settings and that has intrigued and challenged quite diverse people. As such, it has been used in the teaching of modern mathematics to create a more inclusive and humanistic view of mathematics.

Another, quite different, sand tracing tradition is found among the Tshokwe of what is now the Angola/Zaire region of Africa. In this tradition, a rectangular array of dots is first constructed. Then a skilful storyteller intrigues his audience by drawing a continuous figure around the dots as the story related to the figure emerges. Some of the stories highlight the topological fact that the resultant figure defines regions in which certain dots are isolated from others.

In Fig. 2, for example, dots 1 and 2 represent a husband and wife; the other dots are their neighbors. The husband built barriers to keep his wife from the neighbors so that she would attend to her chores instead



Ethnomathematics. Fig. 2 A Tshokwe sand tracing.



Ethnomathematics. Fig. 3 Tshokwe sand tracings. (a) *Top*; (b) *bottom*.

of visiting. A large collection of these figures and their stories have been made during the past 50 years. The collection is rich and varied. There are, for example, sets of figures sharing general characteristics of shape but differing in a construction parameter. For example, compare Fig. 3a, b.

Again, exploration of this tradition has increased our appreciation and enriched the global history of mathematics. In addition, however, now having several instances of continuous figure tracing, we see that a particular mathematical idea can lead to different elaborations through combination with a different assortment of mathematical ideas.

Concepts of Space/Time

All cultures define time and the space around them by the physical and mental imposition of order. Because these orderings play such a significant role in how experience is perceived and interpreted, it is extremely difficult to comprehend that others may define them differently. Western concepts of time and space are an intimate part of modern mathematics. We briefly describe another view, that of the Navajo of North America, with particular emphasis on points of contrast with the Western view.

In Western culture, until the late nineteenth century, Euclidean geometry was believed to describe truths about the physical world. Basic to Euclidean geometry are points, lines, surfaces, and solids, and the belief that they can be used to separate space into parts. For example, a line can be separated into two parts by a point, or a surface can be separated into parts by lines. It is also assumed that space has three dimensions, it has no gaps (continuous), it extends in all directions without bound (infinite), it has zero curvature, and neither size nor shape are changed if something is in one place rather than another (uniform). At the end of the seventeenth century – particularly because of the work of Isaac Newton – the three spatial dimensions were augmented by time as a fourth. This time dimension, however, is distinct from the space dimensions. That is, a configuration in space may change with the passage of time but spatial properties are absolute and not affected by time. Mathematicians now understand that Euclidean geometry is a mental construct and that, under other assumptions, there are other geometries. Also, for the physical universe, time and space have become interrelated by Einstein's theories of relativity and by the cosmological theory that space itself has been undergoing expansion since the universe began as a single point. Nevertheless, the Euclidean model (with an augmented time dimension) still underpins the worldview incorporated in modern mathematics and science.

For the Navajo, space and time are so inextricably interwoven that one cannot be discussed without the other. They see the universe as dynamic, made up of processes rather than objects and situations. They do not conceptualize things as wholes made up of clearly distinguishable static parts. We, for example, see the body as a physical unit which has distinct parts with specific locations and specific boundaries. For us, arms, legs, teeth, and eyes are part of the body but, say blood pressure, is not. To the Navajo, on the other hand, the body is a dynamic whole, that is, a *system* of interrelated parts. To be a part of the body means to be involved in making the body work. Blood pressure then, without a static specific place, is as much a part of the body as an arm or leg.

For the Navajo, of course, specific locations and spatial boundaries do exist. However, while we view a location as where something *is*, the Navajo view it in terms of process – an object is in process of being in a specific place as the result of the withdrawal of motion. Spatial boundaries, as well, have dynamic components: some interrupt action but the action can continue once the boundary is surmounted; others require that actions be modified.

Another contrast is the description of two overlapping surfaces. We see as significant that the surfaces have a region in common. Since our focus is on the region as a set of spatial points, we can describe the region with no concern for time or motion. The Navajo see the overlap as part of an active, ongoing process. What is of primary significance is whether the same or different elements are in contact and, hence, are defining the region. If, for example, the surfaces that overlap are a snake and a rock, the overlap is different in kind if the snake is sleeping on the rock or if the snake is slithering over the rock.

As contrasted to focusing on when and where something is, the Navajo focus on its motion – whether it is coming or going, getting faster or slower, or moving purposefully or aimlessly. Distance, too, is conceptualized in terms of movement with respect to markers.

In the Navajo worldview, space is continuous, has three dimensions, and is finite in that the universe is expanding outward but will eventually shrink back to its starting point. However, above all, interrelatedness and motion are ever present, incorporating and subsuming both space and time.

Differences in worldview have ramifications for approaches to solutions of problems as well as to their contents. The analytic approach is fundamental to mathematics and its teaching. Problems are broken up into subparts in the belief that the solution is the sum of the solutions of the subparts. Furthermore, the steps used in mathematical problem solving superimpose processes on what are viewed as static entities and fixed relationships, in the belief that these processes have no effects on the entities or relationships. By contrast, Navajo problem solving is holistic and focuses on the problems' dynamic interrelationships.

Ethnologists and linguists in the first half of the twentieth century discussed the Navajo culture and worldview. However, only much more recently have studies concentrated on their mathematical ideas and on the ramifications of their worldview for school learning of mathematics (Moore 1993; Pinxten 1983). From these studies we have gained insight into how very deeply mathematical ideas are embedded in culture. The ethnomathematical perspective, which views mathematical ideas as cultural products, provides an enlarged framework within which there can be more than one worldview, making clearer contrasting underlying assumptions and enabling diverse contributions.

The ethnomathematics endeavor has drawn together researchers and educators from many parts of the world. For example, Claudia Zaslavsky's seminal book on African mathematical ideas and practices inspired further investigations by many African scholars. Notices of their work appear in an ongoing newsletter published by the African Mathematical Union's Commission on the History of Mathematics in Africa. The newsletter is available at ►http://www.math.buffalo.edu/mad/AMU/amuchma_online.html.

And, in Mozambique, Paulus Gerdes, a mathematics educator, has made extensive use of the Tshokwe figures discussed earlier, using them as a basis for introducing students to a variety of numerical, topological, and algorithmic ideas. The association of these and other ideas with indigenous traditions is being used by him (Gerdes 1993, 1999) to underscore the premise that mathematics is not the exclusive product or province of an outside, dominant culture. More anthropologically based studies continue to enlarge the global history of mathematics and mathematical ideas. See, for example, Ascher (1991, 2002), Washburn and Crowe (1988) and Frank (1992, 1999). The intimate relationship between language, cognition, and mathematical ideas continues to be explored. A thoughtful overview and discussion of this can be found in Barton and Frank (2001).

The International Study Group on Ethnomathematics serves as a focal point for those primarily concerned with the pedagogical implications of ethnomathematics. It has a large international membership primarily made up of elementary mathematics educators who teach in non-Western settings. Reports of activities and projects of the organization and its members can be found in their newsletters, which are available through their website ►http://www.rpi.edu/~eglash/isgem.htm.

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Ethnomathematics of the Inkas

Thomas E. Gilsdorf

Under the shade of a tree some women are sitting. They are watching over several children, but at the same time their bodies are subtly swaying and their hands are busy moving threads. These women are weaving. As they talk among themselves, calculations are occurring: 40 × 2, 20 × 2, 10 × 2, etc. On their weaving tools symmetric patterns of geometric and animal figures are slowing emerging, produced from years of experience in counting and understanding symmetric properties. The procedures they follow have been instructed to them verbally as has been done for thousands of years, and they follow it precisely, almost subconsciously. In fact, these women are doing *mathematics*. They are calculating pairs of threads in blocks of tens (10, 20, and so on) and determining which colors of threads must go in which places so that half of emerging figures will be exactly copied across an axis of symmetry. These women, and likely some girls who are learning from them, are not writing down equations or scratching out the calculations on a notepad. Remarkably, the weaving is done from memory.

Weaving has existed in most cultures around the world, so the events and hence the mathematics in the previous paragraph could occur almost anywhere. In our case, we are going to consider the mathematics of the South American cultural group of the Quechua-speaking Inkas (Incas). As with weaving, we will see that Inka mathematics is intimately tangled with Inka culture.

Before we can jump into the details of their mathematics, we must take some time to understand who the Inkas were, and some small picture of what their culture was like. Backing up even further, the first term we must clarify is "Inka," by which we refer to a collection of many groups who had a common government, religion and language, but were of distinct cultural origins. When we speak of the "Inka Empire," we refer to the territory controlled by the Inka from about 1400 to 1560 (CE). The first Inkas started near Cuzco in present-day Peru and persistently moved on neighboring groups, forming an enormous empire that included part or all of Peru, Ecuador, Bolivia, Chile, Argentina, and southern Colombia (Fig. 1).

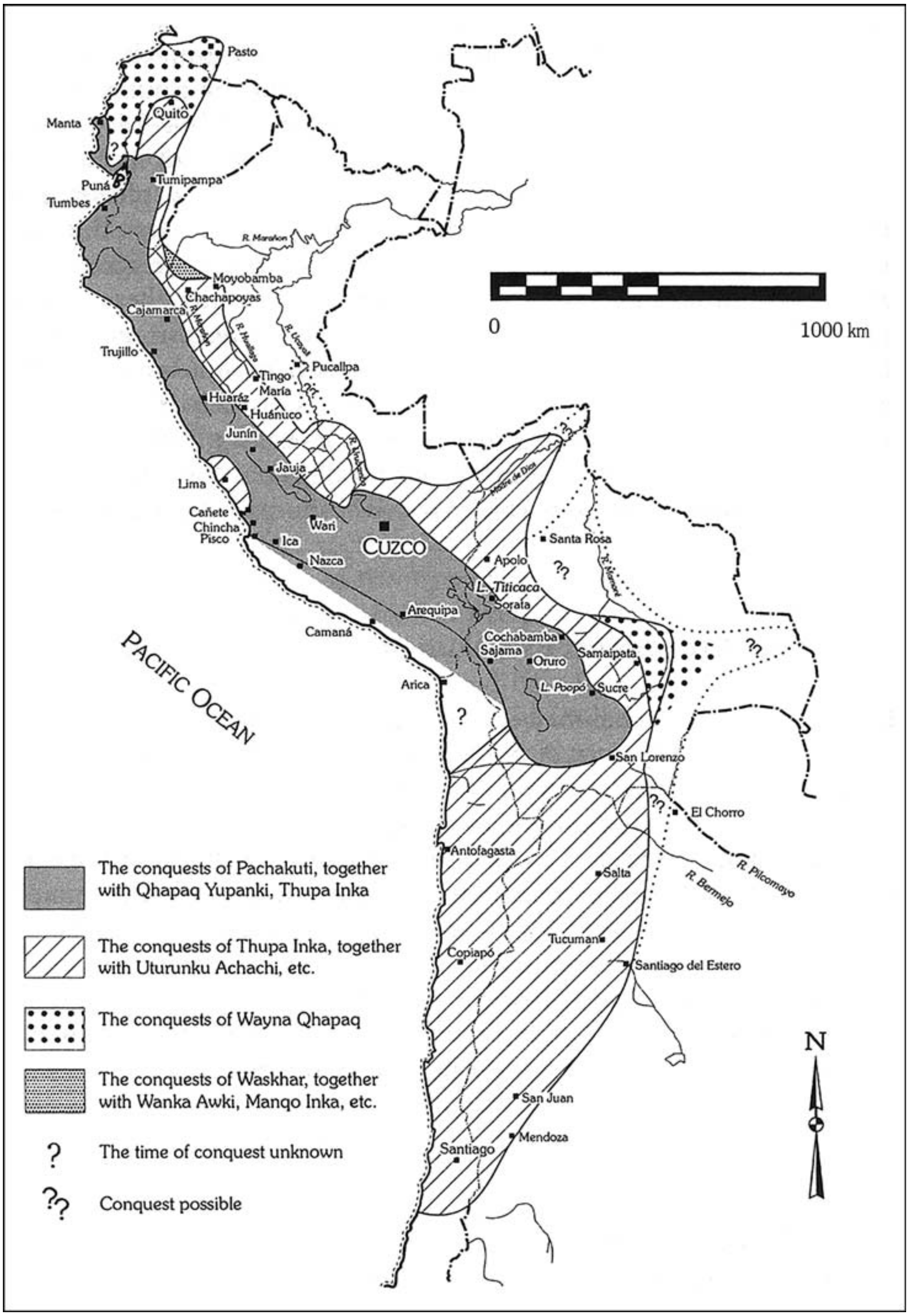
We have seen that there is mathematical thought occurring in weaving, but as we proceed, we can also observe factors such as geography that may have influenced the development of Inka mathematics.

Geographic, Climatic, and Environmental Aspects of Inka Mathematics

The Inka territory included regions of widely varying geography: coastal desert, high rugged Andes, the Lake Titicaca inter-mountain area, seacoast along the Pacific, and jungle on the eastern edge of the Andes as they descend into the vast Amazon basin. From pages 24–32 of D'Altroy (2003), we can get a glimpse of the situation, by noting that a 200 km trip by air from ocean to forest in central Peru would cross 20 of the world's 34 major life zones. In addition, the Andes range contains many areas that are rugged enough to be inaccessible even by horseback.

In terms of weather, there are numerous, unstable climate and geological patterns such as earthquakes, droughts, floods and the corresponding effects of periodic occurrences of el Niño.

These geographical aspects indicate several needs for mathematics. For example, all successful groups in the dry regions had to have some kind of effective water control in the form of irrigation and aqueducts. Next,



Ethnomathematics of the Inkas. Fig. 1 The Inka Empire. From D’Altroy, *The Incas*. Oxford: Blackwell Publishing, 2003: 66. Used with their kind permission.

those in the high altitudes had to have some form of flexible mountain agriculture, such as terrace farming. Moreover, in many parts of the Inka territory, the groups there had to construct bridges to cross deep canyons and difficult mountain areas. In effect, civil, and agricultural engineering were crucial elements of survival. Finally, as in almost any cultural group, knowledge of astronomy is important in terms of predicting planting and harvesting seasons, approximating weather changes, and general time keeping. Mathematics is, of course, necessary for all of these activities.

A Few Relevant Cultural Groups

As alluded to previously, there were many groups that formed what we are calling the Inkas, and we would like to mention just a few of them. The relevance is that these groups had their own mathematical concepts and practices, and as the Inkas absorbed these groups into their system, they almost certainly made use of some of that mathematical knowledge. A quite complete general reference on the various groups and their interactions with the Inka is in Moseley (1992).

Of the many competing cultural groups in what became Inka territory, we can first mention the Moche of the northern Peruvian coast, from about 100 to 700 CE. Later, in old Moche territory a substantial group called the Chimú arose, forming the Chimor Empire with its capital city of Chan Chan. The Moche-Chimú group was the largest Inka rival, and they inhabited the northern Peruvian coast during the Early Intermediate period to the Late Intermediate period (about CE 0–1470). They practiced river valley agriculture along several of the rivers that descend from the Andes to the Pacific, including the Moche River. They were not overcome by the Inkas until 1470.

Another group is the Huari of the central Andean highlands of Peru during the Early Intermediate and Middle Horizon periods (about CE 600–1000). The Huari engaged in advanced irrigated terrace farming and had quite mathematical artwork.

Next, we can mention the Aymara kingdoms of the Lake Titicaca region of the Late Intermediate period (about CE 1000–1400). The Aymara themselves consisted of several groups, e.g., the Colla and Lupaqa groups. Also, the Aymara had their own language group, and some dialects of Aymara are still spoken today. The Aymara also had extensive terrace agriculture as well as domesticated llamas and alpacas.

The last of this sampling of groups that we mention is the Nazca of the southern Peruvian coast of the Early Intermediate period (about BCE 400–CE 500). Some indication of Nazca understanding of geometry and astronomy can be seen in the lines and figures they created in the desert. It is still not clear what the lines represent, but there are connections between many of the lines and both astronomy and ritual of the Nazca. The interested reader can get some idea of this topic in the book edited by Aveni et al. (1990) and in the article on Nazca lines in this encyclopaedia. Of course, we cannot exit the Nazca topic without mentioning in passing the inspiration to mathematics teachers in the name of Maria Reiche (1903–1998). Reiche was a German-born teacher who made a daring career move in 1932 by moving to Peru. By the end of her career, she had played a crucial role in the preservation and study of the Nazca culture and lines. See her collected works in Reiche (1993) for more details.

All of the above groups had some knowledge of mathematical ideas. The *khipu* that Marcia Ascher will discuss in detail elsewhere in the encyclopedia existed long before the rise of the Inkas and was known for example, to the Huari and Aymara; see Chap. 10 of Quilter and Urton (2002). As the Inkas grew to control territory, their control and/or interaction with these groups must have played into their own mathematical understanding and development. We could even go much farther and say that this little piece on Inka ethnomathematics is only a peek into the larger realm of mathematical interaction, history, and culture of Andean societies, most of which has yet to be carefully researched.

Understanding Preconquest Inka Culture

Tahuantinsuyu, "Land of the Four Quarters," is the word the Inka used to describe their territory. We would like to know a little about what Inka culture was like before the arrival of the Spanish in 1532. However, it turns out that it is not so easy to reconstruct an ancient culture.

First, although the Inkas were indisputably advanced in many regards, they did not use a writing system as we know it. In fact, the subject of how the Inkas created and maintained complexity in terms of society, government, and economy without communication through what we would consider a writing system is one of active debate. The khipu represents a mathematically based system of information keeping that could well have served in place of writing. Meanwhile, however, it is also the case that the Inka groups made use of oral tradition, whereby information, history, and social practices are passed along via oral descriptions. See Schneider (1994) for a general description of oral tradition. Also, an interesting description of Inka culture and literature can be seen in Lara (1960).

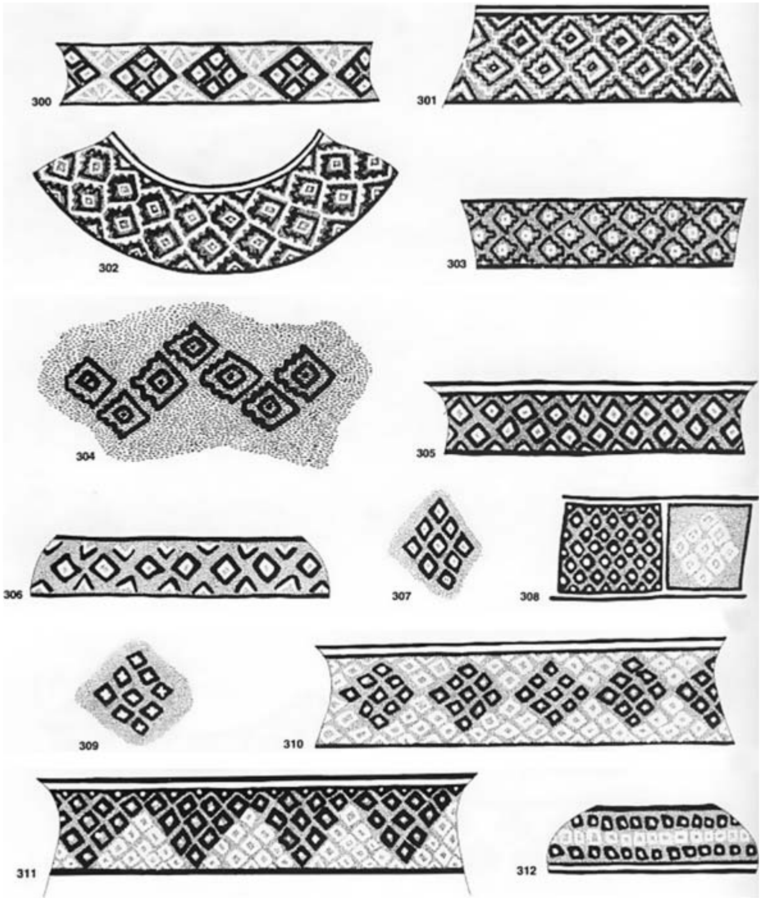
Next, there are problems with accuracy of information on the history of the Inkas. Because the only studies of Inka culture took place after the Spanish conquest, information about the Inkas is either substantially culturally biased, as in the case of most Spanish chroniclers, or is a study of a group that has changed significantly in nature, as is the case in studying present-day descendants of the Inkas. Thus, accurate information is difficult to obtain. For our purposes, two sources considered to be relatively accurate are those of Pedro Cieza de León and Felipe Guaman Poma de Ayala. In Ascher and Ascher (1981: 3), the reader may find a detailed description of original works and translations of Cieza de León's work, and in the bibliography here we have listed a reference to the works of Guaman Poma (1936). Guaman Poma is particularly known for the many drawings of Inka culture that he made, a few of which are presented in Fig. 19. From sources such as

Ethnomathematics of the Inkas. Fig. 2 (a) Bolivian textile pattern. From Tamara E. Wasserman and Jonathan S. Hill, *Bolivian Indian Textiles, Traditional Designs and Costumes*. New York: Dover Publications, 1981, Plate 11. (b) Bolivian textile pattern. From Tamara E. Wasserman and Jonathan S. Hill, *Bolivian Indian Textiles, Traditional Designs and Costumes*. New York: Dover Publications, 1981, Plate 17. (c) Bolivian textile pattern. From Tamara E. Wasserman and Jonathan S. Hill, *Bolivian Indian Textiles, Traditional Designs and Costumes*. New York: Dover Publications, 1981, Plate 17. (d) Bolivian textile pattern. From Tamara E. Wasserman and Jonathan S. Hill, *Bolivian Indian Textiles, Traditional Designs and Costumes*. New York: Dover Publications, 1981, Plate 13.

these, we can explain a few aspects of Inka culture that are relevant to our theme of mathematics.

One feature of the Inkas worth mentioning is that as they expanded into regions of other groups, they allowed those groups a certain amount of local control. There are two advantages to this attitude. One is that the subjugated groups would not be as likely to reject Inka rule. The other, relevant to our theme of mathematics, is that by allowing the conquered groups to retain some original culture, the Inkas could use and improve mathematical and engineering ideas of those groups, such as astronomy and agriculture. This last comment implies that some of the mathematics of the Inkas was probably diffused from other groups.

Also relevant to the development of mathematics in the Inka region is that of economy. Starting with very



Ethnomathematics of the Inkas. Fig. 3 Ica design patterns. From Dorothy Menzel, *Pottery Style and Society in Ancient Peru*. Berkeley: University of California Press, 1976, Plate 26. Used with their kind permission.

early organized groups and extending even to the present, trade has been an important factor in the societies in the Inka region. In addition, the Inka economy included an extensive taxation system. Later, we will see that this taxation, among other activities, could be recorded on the Inkas' khipus. A good reference to the ideas of trade and interaction of the various groups can be found in Moseley (1992).

Quechua Number Words

Our first mathematically close look at the Inkas comes by way of discussing Quechua number words, which reflect Inka numeration. In a study of numbers in cultural mathematics, there are two distinct aspects that we must consider: Number words and number symbols (representation). These two concepts are not the same.

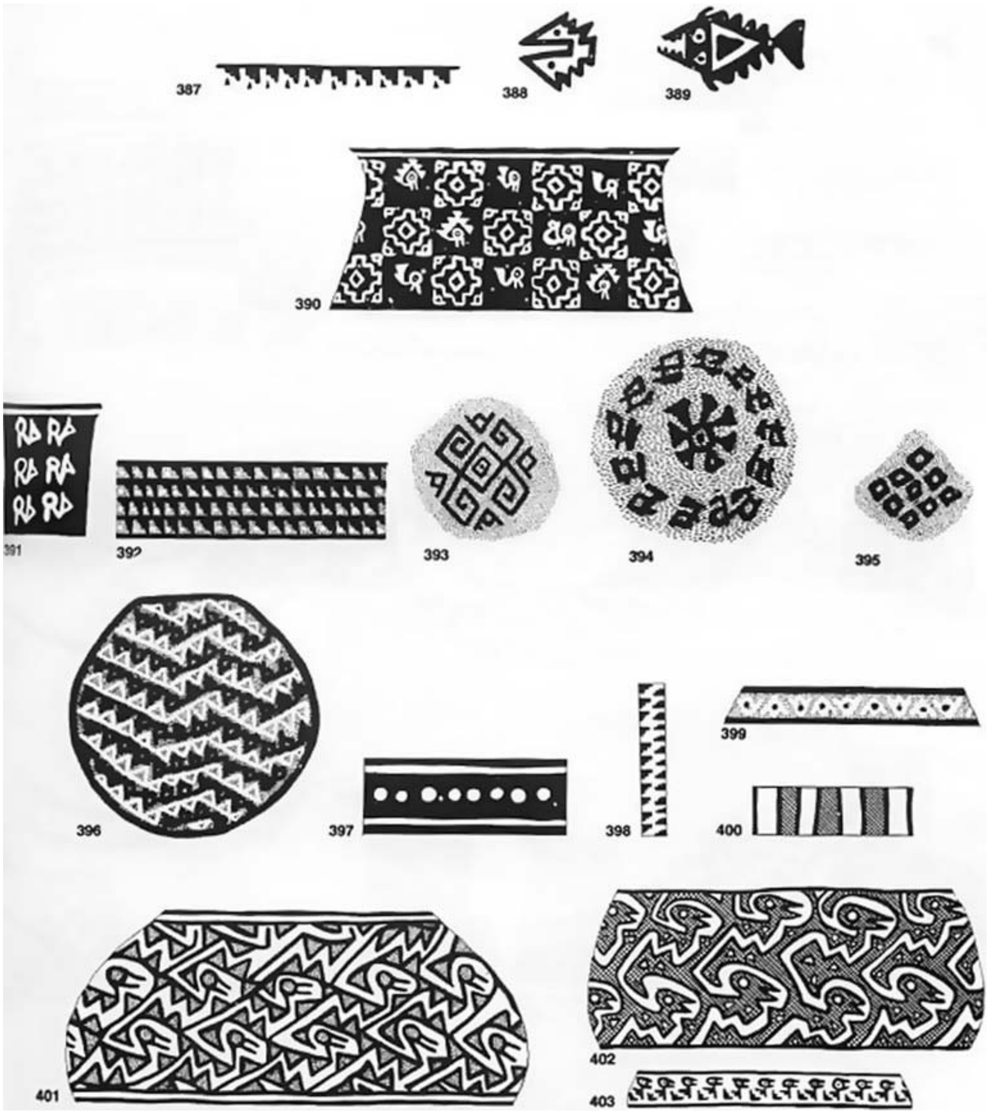
The first things we must clarify have to do with Quechua, the language used by the Inka. Until the 1960s, it was commonly thought that Quechua originated and spread with Inka expansion. In Mannheim (1985), Mannheim (1991), Stark (1985), Urton (1997), and Weber (1989), the reader may find explanations and references indicating that Quechua in fact originated in northern central Peru and later split into essentially two branches. For our intentions, we take as our model Weber's description of Huallaga (Huánuco) Quechua, which is often referred to as *Quechua I* or *Quechua B* in the references. As Weber indicates on, Huallaga Quechua seems to have suffered fewer changes than some other Quechua dialects, which implies that our discussion here of number words should have some accuracy.

Here is a short list of number words from Huallaga Quechua:

huk – 1, *ishkay* – 2, *kimsa* – 3, *chuska* – 4, *pichqa* – 5, *soqta* – 6, *qanchis* – 7, *pusaq* – 8, *isqon* – 9; *chunka* – 10, *pachak* – 100, *waranqa* – 1000.

The format of more complex number words is the following:

[multiplier] {nucleus} (adder).



Ethnomathematics of the Inkas. Fig. 4 Ica design patterns. From Dorothy Menzel, *Pottery Style and Society in Ancient Peru*. Berkeley: University of California Press, 1976, Plate 31. Used with their kind permission.

The nucleus is always a power of ten. For the examples that follow below, we will employ the above notation, namely, multipliers – [], nuclei – {} and adders – ().

Example 1: *isqon pachak*: [9] {100} = 9 ¥ 100 = 900.

Example 2: *qanchis chunka pichqa*: [7] {10} + (5) = 75

Example 3: 347,002: [[3] {100} ([4] {10} (7))] {1000} (2).

kimsa pachak chuska chunka qanchis waranqa ishkay.

From the number words and the examples above, we can deduce that the Inkas counted in base ten; i.e., they used a decimal system.

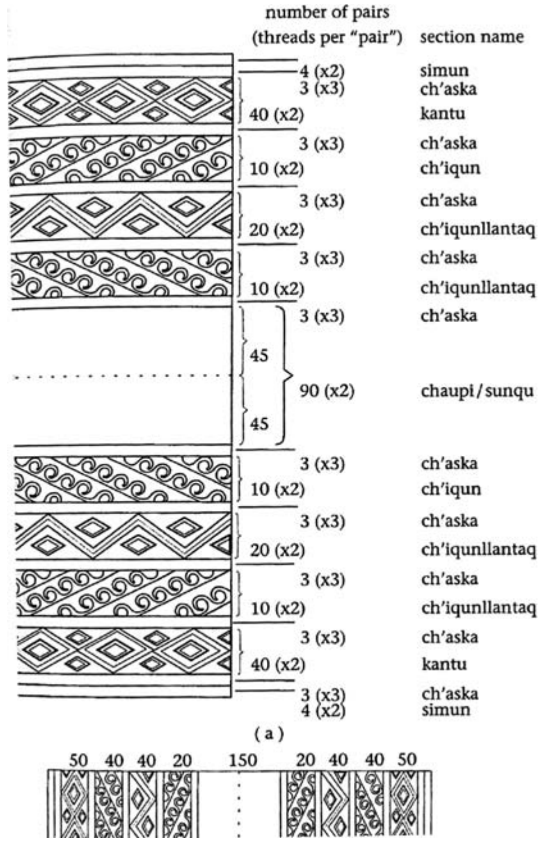
Looking Deeper: Weaving, Symmetry, and Counting

The previous section describes some basic facts about number words of the Inkas. However, that information tells us little about the cultural context of Inka mathematics. Such contexts between mathematics and culture pull us into the field of ethnomathematics. Good places to start in the study of ethnomathematics in general are with Selin (2000), Ascher, (2002), Closs (1986), Pacheco (1998), Urton (1997), and Zaslavsky (1973). What comes out of ethnomathematical considerations is the understanding of how a particular culture perceives and interprets mathematics. It is often surprising to learn that some cultural activity of a particular group

Ethnomathematics of the Inkas. Fig. 5 Ica design patterns. From Dorothy Menzel, *Pottery Style and Society in Ancient Peru*. Berkeley: University of California Press, 1976, Plate 45. Used with their kind permission.

involves elegant mathematics that are not easy to see until we look closely and think differently. Moreover, although modern Western mathematical notation of the mathematics being used may not make sense to people of the group, it becomes clear that they nevertheless understand the concepts. The interesting part is that the Western and non-Western interpretations can be dramatically different. We will next examine some such activities for the case of the Quechua-speaking Inkas.

Let us look more carefully at the situation of the women who were weaving, described at the beginning. The first mathematical observation we can make is to notice the symmetry patterns that evolve from the weaving process. In chapter six of Ascher (1991), we find a careful discussion of decoration and various translations, reflections and rotations that reveal a cultural emphasis of the Inkas on formality, precision, and repetition. Fig. 2a–d show some examples of weaving patterns of the Inka and some other cultural groups eventually controlled by the Inkas. In Fig. 2a for example, we can observe many types of symmetry. One such symmetry is horizontal: Imagine a horizontal line drawn halfway through the figure. Then we see that the pattern in the upper half is exactly repeated in the lower half. Similarly, if we draw a vertical line down the middle of the figure, then the pattern on the left half is exactly repeated on the right half, so the figure has vertical symmetry. Now let us look at Fig. 2b. Except for slight displacements of some of the smaller parts of the figure, it has horizontal symmetry. It does not have vertical symmetry, however: Observe that if we draw a vertical line through the middle of the rectangular spirals part of the figure and reflect the figure across that line, then the spirals will appear in a different orientation; that is, we will not see the same pattern repeated. On the other hand, the rectangular spirals pattern appears again in Fig. 2c, which although it does not have vertical symmetry, has rotational symmetry: Imagine putting a tack in the middle of the strip pattern and rotating the figure 180°. The rectangular spirals then appear in the same orientation as in the original unrotated figure. Now let us look at ceramics, namely the item marked "300" from Fig. 3. It has several symmetry properties including vertical, horizontal, and rotational symmetry. On the other hand, item 311 of



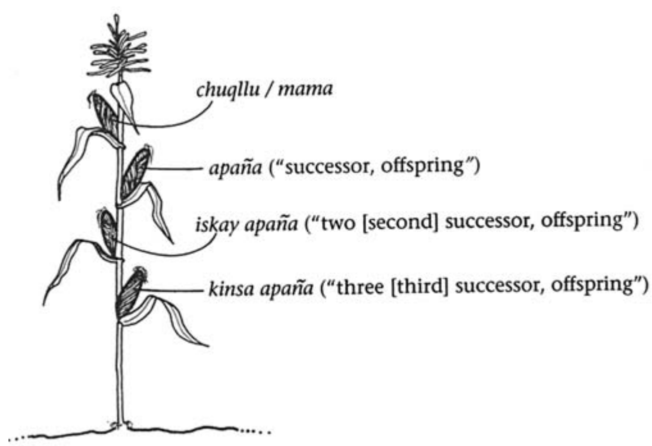
Ethnomathematics of the Inkas. Fig. 6 Warp counts on two axsus from Candelaria. From Fig. 4.6, pg. 121 of the *Social Life of Numbers: A Quechua Ontology of Numbers and Philosophy of Arithmetic*, by Gary Urton with the collaboration of Primitivo Nina Llanos, @1997. By permission of the University of Texas Press.

Fig. 3 only has vertical and translational symmetry (translational symmetry means the pattern is repeated if we slide the figure to the right or to the left). Next, item "401" of Fig. 4 only has translational symmetry.

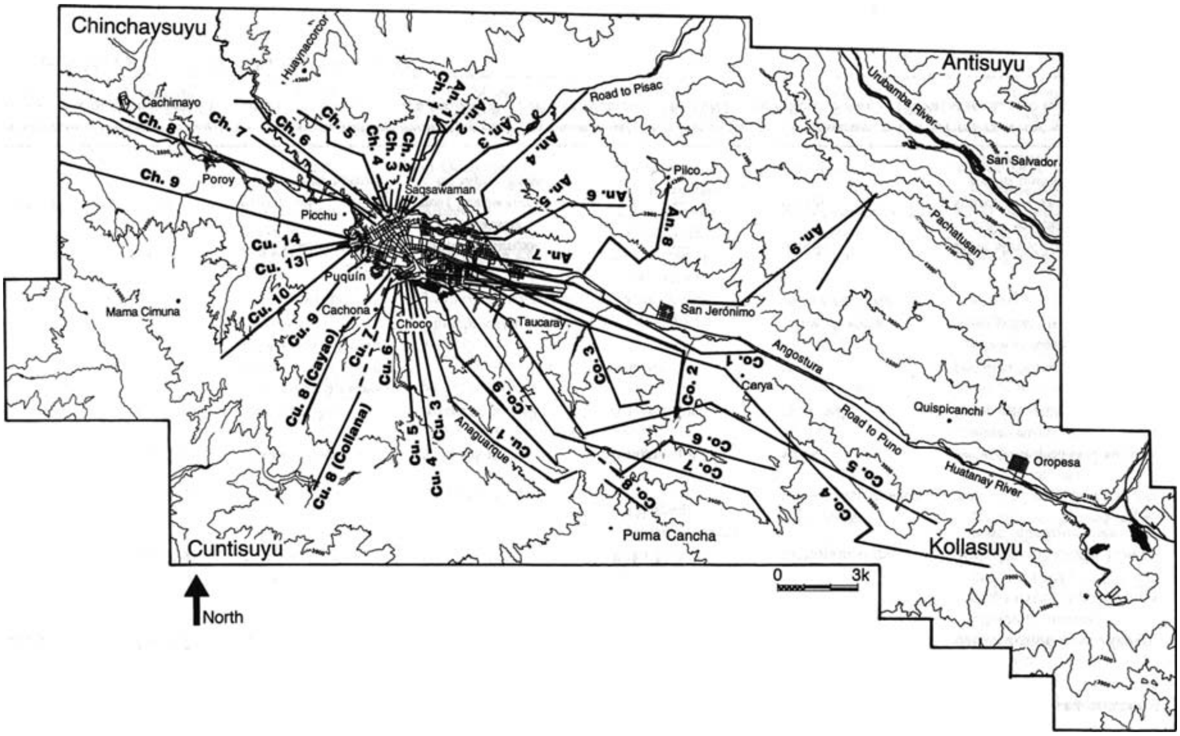
Furthermore, symmetry can appear in contexts other than weaving. Go get yourself a snack or something refreshing to drink while you ponder the symmetry properties in Figs. 3–5. If you want to look even deeper into more types of symmetry properties, you can read Ascher (1991), Chapt. 6.

The above is good practice for learning about symmetry patterns in general, but we must get back to the cultural part of this. We can ask questions like: What can we deduce from the symmetry properties used in a particular cultural group? In the case of the Inkas, we see the repeated preference for a lot of symmetry. This preference indicates a strong sense of order and precision in Inka culture and mathematics. This corresponds with our general knowledge of the Inkas as being a culture that kept careful records via their *khipus.*

Here is another question: how do the weavers know how to construct the patterns in order that they have such symmetry? Even in the case of what at first appears to be a simple shawl having several stripes of varying widths, we can ask as to how the weaver knew how to obtain the widths from the threads. Look at Fig. 2a again. In these questions we are in fact asking about mathematics. The people (mainly women) who weave such items must in fact count (*yupa*: "to count or account") threads. For the case of stripes, the number of say, red threads for the first stripe must correspond in some way to the number of red threads that might appear later in the pattern, so that the two red stripes have the



Ethnomathematics of the Inkas. Fig. 7 The 'birth order' and naming of ears of corn. From Figure 3.3, pg. 86 of the *Social Life of Numbers: A Quechua Ontology of Numbers and Philosophy of Arithmetic*, by Gary Urton with the collaboration of Primitivo Nina Llanos, @ 1997. By Permission of the University of Texas Press.



Ethnomathematics of the Inkas. Fig. 8 Cuzco's ceque system. From Terence D'Altroy, *The Incas*. Oxford: Blackwell Publishing, 2003. Fig. 7.1, page 160. Used with their kind permission.

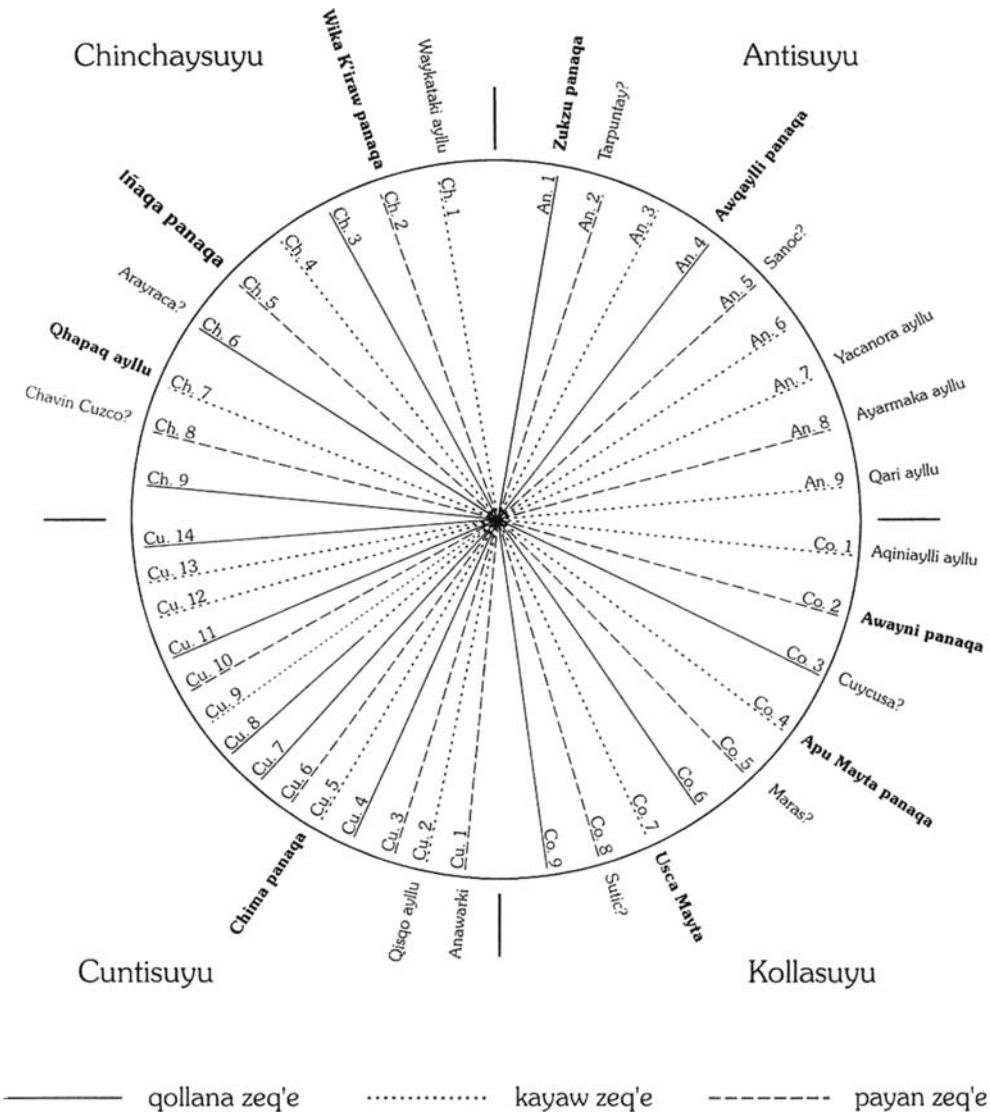
same width. The numbers of threads to be counted in each step of a weaving process is often complicated, and must be decided upon ahead of time. Indeed, the weaver must know in advance what the entire pattern will look like. Once the process starts, what is remarkable is that the weaver does the counting of threads mentally. A detailed discussion of how groups of threads are counted by Inka (Quechua) weavers can be found in Chapter four of Urton (1997). In our context of ethnomathematics, we can observe some mathematical properties in Inka weaving. One such property described in Urton (1997) (see Fig. 6) is that thread counts are usually done in blocks of 10 and 20, and that in general what is being counted are values of pairs of numbers of threads. Notice the influence of the decimal system. The complex geometric or animal motifs are created by a process called *pallay*- "to pick up."

It is worth mentioning that the master weavers or *Mamas* are women who most likely started weaving when they were girls and reached a high level of expertise. They were treated with special respect. Their abilities in counting, understanding patterns of symmetry, and in geometry were part of that expertise. The ethnomathematical aspect of this situation is this: if we asked one of these women to explain geometric or symmetry properties in terms of lines, rotations, polygons, and so forth, they probably would not be able to explain them. Yet, they clearly understand these mathematical concepts; the difference is that their understanding comes from the perspective of a weaver who must create a pattern.

A Bit More About Counting, Pairs, and Even Numbers

In Quechua culture, counting is closely tied to important cultural aspects. Kinship and social organization, as explained by Urton (1997), represent one such aspect. On page 85 for example, he tells us that ears of corn on a stalk are carefully named in the order in which they appear, with the first representing the "mother" and others being defined in accordance to the first as offspring of the mother (Fig. 7).

Note that the order of the counting is as important as the counting itself. As for the subject of pairs, it turns out that the Inkas view the property of being even in a count as extremely important. In fact, we could go so far as to say that odd numbers are considered as incomplete pairs. We saw above that the counting of threads in the weaving process is done in pairs of threads. There are many more instances in which one counts pairs in Quechua society. The perception of even versus odd numbers is in fact one of the main themes of Urton's (1997) book. The cultural impetus



Ethnomathematics of the Inkas. Fig. 9 Schematic diagram of Cuzco's ceque system. From Terence D'Altroy, *The Incas*. Oxford: Blackwell Publishing, 2003. Figure 7.2, page 161. Used with their kind permission.

for this viewpoint is that the Inkas constantly strive to have proper order in their world. Such order even extends to contexts like social situations. If a person has done something inappropriate, then something must be done by him or by the community so that proper social order is regained. This can be thought of as completing an incomplete pair. By the way, notice that this persistence of order and proper organization appeared in the symmetry patterns, too.

A Few Remarks About Astronomy

Inkan astronomers knew about the solar, lunar, and Venusian cycles. They had a solar calendar and festival calendar based on 12 lunar cycles, plus adjustments to account for the difference necessary to make a full 365 day year.

Throughout the city of Cuzco there are remains of some of about 400 markers, called *huacas,* along imaginary lines called *ceques* (also *zeq'e*). These lines originate from the center of Cuzco. Figs. 8 and 9 show some details of the system, though you will have to read Chapt. 7 of D'Altroy (2002) to fully understand the figures. These huacas had ritual and social significance. Some had connections with astronomy, hence mathematics. In particular, the Inka used several of the ceque lines as part of astronomical observations such as the June solstice. Furthermore, the ceques and huacas were crucial components of the Inkan religious ceremonies and in fact the huacas are more accurately described as sacred shrines. For more details about Inkan astronomy and the ceque lines, see for example, Moseley (1992), pages 78–79, Chapt. 7 of D'Altroy (2002), or Urton (1981), and the article on Quipus in this encyclopaedia.

Astronomy and culture quickly become intimately involved with each other. We know that astronomy and mathematics also have a close relationship, so we can conclude here that astronomy, culture, and mathematics of the Inkas are intertwined.

Yupana

The Inka performed rather complicated computations. The khipu was a record keeping device not used for calculating. In fact, most of the knots on known khipus are tight, implying that the values on them were usually intended to be fixed. This leads us to ask the question: How did they make the computations? The answer to this question is still not completely understood. One possibility arises in the first of the drawings of khipus made by Guaman Poma. (See Ascher's article on the Quipu.)

The rectangular grid of solid and unfilled dots appears to be a kind of counting board; however, Guaman Poma gives no explanation of the grid. Certainly there would be reason to believe that the grid has mathematical meaning because of its appearance with a khipu. A curious aspect of the grid is that each row contains 11 dots, something that obviously does not coincide with a decimal counting system. In addition, because Guaman Poma's work occurred after the Spanish conquest of Peru, the grid does not necessarily represent a device of the Inka.

On the other hand, proposals of mathematical uses of the grid have been given, with the term *yupana* (Quechua for the verb to count) used to denote it, such as appears in Mackey et al (1990), Higuera (1994), and Burns Glynn (1981, 1990).

The mathematical methods for counting that are presented make logical sense, such as filling the 11th dot as a placeholders for powers of ten. Included are photos of three-level rectangular stone figures that resemble counting grids in some ways that could have served as abaci for counting. There are descriptions by Spanish chroniclers of observations of Inkas counting on these rectangular forms, but here we encounter the problem of accuracy. A conclusive explanation of the grids and rectangular forms still has not been given. However the works cited here point toward possible patterns of counting or symbols.

See also: ►Nazca Lines, ►Environment and Nature in the Andes

Acknowledgements

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Faience in Ancient South Asia

Blythe McCarthy

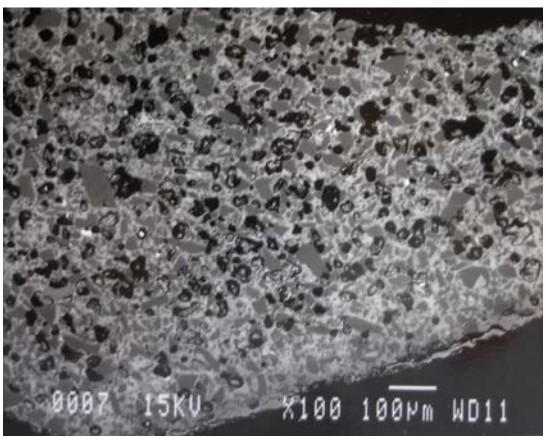
The term faience when refering to ancient materials describes a man-made material of mineral grains, generally quartz or sand, that are bound together by varying amounts of glass, often with a layer of glass (a glaze) on the surface. The material can be very friable and crumble easily or can be hard and dense, depending on the amount of glass present. Several terms have been used to describe this material including glazed quartz frit, glazed paste, glazed composite bodies, blue-glazed whiteware, fritware, and siliceous paste. Faience is however the term most commonly used. Although faience is most often associated with ancient Egypt there was also a well-developed faience industry in the Indus Valley as well as in ancient Mesopotamia. The faience industry in South Asia dates to the third millennium BCE while that from Egypt dates to the first half of the fourth millennium BCE and Mesopotamia from the late fifth millennium BCE (Stone and Thomas 1956; Moorey 1985).

Faience using quartz for the mineral grains first appeared in South Asia during the Kot Diji phase (2800–2600 BCE or Nausharo I). It is seen at Nausharo and Mudigak in the form of beads (Barthélemy de Saizieu and Bouquillon 1997). Beads were primarily small in size and shaped as cylindrical rings during the early Harappan period, Kot Diji phase; however small tubular, spherical and diamond shaped beads have also been found. There are also beads, lenticular and biconical in shape, from this period at Harappa (Kenoyer 2000). Some of the faience from the end of this phase appears similar to compact faience seen in the later mature Harappan phase. Beads continue to constitute a large proportion of the faience into the mature Harappan phase (►http://www.harappa.com/indus2/174.html). There is a concentration of ellipsoidal beads, but larger and more complex beads, such as segmented and multicolor beads, are present as well. Faience beads form a small part of the bead corpus with steatite beads accounting for the majority. At the site of Nausharo only faience beads and small amulets made of faience have been found. In addition to beads, bracelets, buttons, spindle-whorls, gamesmen, animal figures, and small jars made of faience have been found at the sites of Harrappa, Chanhudaro, Lothal, and Mohenjodaro among others. Fig. 1 shows some fragments of bangle bracelets of varying diameter, as well as vessel fragments. Small faience jars have been found in all faience containing strata at Harappa. Several of the vessels have textile impressions (Kenoyer 1998: 159).

Faience is occasionally found in sites of periods later than the Harrappan period. A microbead hoard was found in a black slipped ceramic at the site of Agiabir (Mirzapur), Uttar Pradesh (Singh 2002) dated to the Northern Black Polished Ware (NBP) culture (600–200 BCE). Occasional faience beads were recovered in two earlier periods at the site, that of the Narhan culture (1300–900 BCE) and Pre-NBP with Iron (900–600 BCE). Singh states that it was similar to the high strength faience of the Indus Valley civilization. Faience bangles also continue after the Harappan period and may lead to the introduction of glass bangle technology in the early historic period (600 BCE) (Kenoyer 1994).

Two types of quartz faience have been identified for the Indus Valley Civilization. One, coarse with 50–100 μm quartz grains, is speckled in appearance, with a glass binder and colorant. This material was used for beads and small tokens (Barthélemy de Saizieu and Bouquillon 1997). A second type is fine with a compact structure, evenly colored with quartz grains less than 30 μm in diameter. This dense, homogeneous form of faience was determined to have been formed by multiple cycles of heating, to a temperature between 1,000 and 1,100°C, and grinding an initial mixture of alkalies (salts), clay, and quartz. This produced faience of uniform color due to a very homogeneous glass phase and very small quartz crystals as seen in Fig. 2. The addition of alkalies in the final step where the objects were fashioned resulted in a thin surface glaze through an efflorescence glazing process (McCarthy and Vandiver 1990). In this process, the alkalies migrate to the surface during drying, react with the quartz particles at the surface and form a glass (►http://www.harappa.com/indus3/255.html). This type of faience manufacturing results in a material of higher strength than other forms which may account for its use in bangle bracelets and vessels unlike the other forms of

Faience in Ancient South Asia. Fig. 1 Compact faience bangle bracelet and vessel fragments from the site of Harappa.



Faience in Ancient South Asia. Fig. 2 Backscattered electron image from a scanning electron microscope of a cross section of a faience bangle bracelet from Harappa. The dark gray grains are quartz, the light gray matrix is the glass phase. The exterior of the bangle runs along the lower edge of the photomicrograph and a thin glaze layer is visible along part of the length at the lower right.

Indus valley faience which are primarily used for beads. Faience can be manufactured in this manner without the addition of glass, i.e., with only salts and sand; however, this forms a glazed material with a very friable interior.

A workshop was found at the site of Harappa in 2001 (Kenoyer 2003) that included debris from faience manufacture (►http://www.harappa.com/indus3/246.html). Steatite tablet molds, carved in reverse, were uncovered as were firing containers, kiln supports and a yellow green slag. The clay containers were lined with crushed bone and steatite. (See slides 250–253 at ►http://www.harappa.com/indus3/slideindex.html.)

To date, no traditional kilns have been found that can be linked to faience manufacture. Recent experiments have resulted in a plausible method for the firing of the small faience objects found in the Indus Valley culture. Replication of the containers, setters and faience material similar to that found in the workshop were made and used to fire faience and steatite. The filled containers were set in a bonfire. The temperature in the containers reached 935°C and glazed faience resulted. (See slides 254–257 at ►http://www.harappa.com/indus3/slideindex.html.)

The color of South Asian faience varies. When a pure quartz mineral is used for the grains and there is no colorant in the glass phase a white material results. This may have a colored glaze layer and so appear colored if not broken. If a colorant is present in the glass binding material, such as copper that produces a blue color, or iron oxide particles, that produce a red color, the interior of the faience has that color. When weathered, faience appears similar to weathered glass and the two materials can be easily confused. Colors include white (colored by high calcium), black (colored by manganese), deep blue (colored by copper or cobalt and manganese), yellow, brown and red-brown (colored by iron), and brilliant red. Faience with multiple colors has been used to imitate banded agate and agate or carnelian eyebeads, white with brown, black or red-brown (Kenoyer 1998; Barthélemy de Saizieu and Bouquillon 1994). Lead has been found in the glazes of two Indus period faience beads from Nausharo (Barthélemy de Saizieu and Bouquillon 1995). This is 1,000 years before the earliest known lead glazes, but the small number of beads containing lead may indicate that it was an experiment.

Dayton theorized that spent metallurgical molds made of steatite were used to form the first faience (Dayton 1989). Bouquillon and Barthélemy de Saizieu identified such steatite faience in four cylindrical beads from the pre-Indus period at Mehrgahr dated to around 3000–2800 BCE where a steatite glazing tradition was in place as early as the Chalcolithic period (Barthélemy de Saizieu and Bouquillon 1995). This date places the manufacture and use of this material earlier than siliceous faience in South Asia. In this form of faience, ground steatite is used for the mineral grains. The steatite faience makes up less than 1% of the steatite objects recovered from the site. The compositions of the glazes on the steatite faience are similar to those found for glazed steatite from the pre-Indus period.

The development of faience occupies an intermediate step in the technological progression that led to glassmaking in South Asia. The earliest step was that of heating and glazing of stones (steatite), followed by manufacture of faience, first one of crushed steatite, then of quartz grains, progressing finally to glass manufacture.

See also: ►Beads

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Fengshui

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Along with acupuncture, the best known representative of Chinese science in the West today is *fengshui*. The term is often translated as "geomancy," though the two graphs that comprise the term simply mean "wind" and "water." The practices associated with *fengshui* have been informed by ambiguity since their early beginnings – between a practice encouraging charlatanry based on mystification and a set of practical recommendations grounded in sensitivity to the natural environment. This article will ignore the mantic and divinatory aspects of *fengshui*, and the associated panoply of arcane symbolism of colors and animals and planets and stars, all of which distract from its more down-to-earth applications.[1]

It was not until the 1950s that Western scholars began serious investigation of Chinese sciences, as signaled by the first volumes of Joseph Needham's monumental *Science and Civilization in China*. Needham devotes large sections of his second volume to the philosophies of nature found in Daoism and "the school of Naturalists" (the so-called *Yin-Yang* thinkers), the theory of the five elements (*wuxing:* better translated as "five phases of transformation"), symbolic correlations and correlative thinking, and the system of the *Yijing* (Book of Changes).

We have here for the first time a comprehensive, scholarly, and open-minded account of the philosophical and scientific background from which *fengshui* emerged. The practice of "geomancy" itself, however, Needham relegates to a chapter on "the Pseudo-Sciences," considering it under the heading "Divination" along with such practices as scapulimancy (prediction of good or bad fortune on the basis of the behavior of ox and deer shoulder-blades when subjected to heat), astrology, chronomancy, cheiromancy, and the

[1] For a more detailed treatment of *fengshui* is its broader context, see Parkes (2003) and see Geomancy in China in this Encyclopaedia.

like. Operating on the straightforward definition of *fengshui* as "the art of adapting the residences of the living and the dead so as to cooperate and harmonize with the local currents of the cosmic breath [*qi*/*ch'i*]," he devotes four pages to a brief history and description of the practice.[2] After remarking on its advantages and drawbacks, he concludes that "all through, [*fengshui*] embodied a marked aesthetic component, which accounts for the great beauty of the siting of so many farms, houses and villages throughout China" (Needham 1956: 2:361).

But if one considers the continuities between the basic features of the Chinese worldviews from which *fengshui* arose – the understanding of the world as a dynamic play of forces, or *qi* energies, rather than an aggregate of material things, with a corresponding emphasis on *becoming* over being, or *process* rather than substance – the scientific components of the practice will become as apparent as the aesthetic aspects.

The historical beginnings of *fengshui* are shrouded – appropriately for such an enigmatic science – in mystery. Marcel Granet cites as perhaps "the first mention of beliefs that are at the origin of geomancy" a passage in the *Book of Songs* (Shijing; ninth to fifth centuries BCE) where the founder of a town is said to have observed "the shadows" (which would indicated south) and also "the surrounding yin and yang." Feuchtwang remarks in this connection that the application of *fengshui* principles to the layout of towns and cities is apparently much earlier than to houses and graves (Feuchtwang 1974).

Another indication of an awareness of *fengshui* principles comes from a story concerning Meng Tian, the Qin Dynasty general who supervised the building of the first part of the Great Wall. Construction was begun in 221 BCE: "He… built a Great Wall, constructing its defiles and passes in accordance with the configurations of the terrain. It started at Lin-t'ao and extended to Liao-tung, reaching a distance of more than ten thousand li."[3] Thanks to its following the contours of the land, the Wall is traditionally seen as resembling a great dragon, which is an image that comes to refer in *fengshui* to any important topographical formation. Meng Tian is also credited with the invention of the camelhair writing brush, which eventually revolutionized the writing of Chinese characters. Thus in addition to being responsible for a good part of a 2,000-mile long "dragon" in the form of the Great Wall, he facilitated the production of countless smaller dragons – the image that characterizes calligraphy executed with especially vital energy – in the centuries since his death.

In 210 BCE, upon the death of his patron the first Qin Dynasty emperor, Meng fell victim to a dastardly political plot and was ordered to commit suicide. On hearing the news, he is said to have cried out in uncomprehending lamentation over this cruel stroke of fate. Then, on reflection, he said gravely: "I am guilty, and assuredly should die… A moated wall of more than 10,000 li; in the course of this work I cannot have avoided cutting through the earth's veins [*di mo*]: this is my guilt." He thereupon swallowed a lethal dose of poison (March 1968: 260–261). The *mo* of *di mo* ("earth's veins") corresponds to something in the human body like veins, or arteries, or pulses, but more closely to the acupuncture meridians, since no physical "envelope" for the flow is perceptible.

In a survey of the history of *fengshui* the Ming Dynasty author Wang Wei writes: "The theories of the geomancers have their sources in the ancient Yin-Yang school. Although the ancients in establishing their cities and erecting their buildings always selected the sites (geomantically), the art of selecting burial sites originated with the *Burial Book* [Zangshu] in 20 parts, written by Guo Pu [276–324] of the Qin Dynasty" (cited in March 1968: 261). Central to the *Zangshu*, also known as the *Book of Funerals*, is the idea that certain sites are blessed with flows of especially vitalizing energy known as *shengqi* ("vital breath," "life energy"), which is a phase of the larger circulation of cosmic energies: "When the *qi* of yin and yang breathes out it is wind. When it ascends it constitutes the clouds, and when it falls it is rain. It travels on and in the ground and becomes vital *qi*. Vital *qi* travels on and in the ground and engenders the myriad things." Vital *qi* is further subject to the forces of wind and water: "The [*Burial*] *classic* says that *qi* rides the wind and disperses. When bounded by water, it halts" (*Zangshu*, cited in Bennett 1978: 9–10). With respect to a place characterized by multiply dividing streams, the *Shuilongjing* (Water dragon classic) says: "If the wind shakes the willow branches, or if the wind bends the grass whether passing over the position or not, it will mean trouble, and even meandering water will not justify the site. It will bring decay and sickness" (Feuchtwang 1974: 139).

Water molds the natural environs from the outside in obvious ways, primarily through watercourses' cutting into the earth, but also through precipitation's sculpting over time the shapes of mountains. Winds, too, move earth, if not mountains, over the long term – in ways less obvious than waters since the movement of air is itself invisible, becoming perceptible only through its effects on water, vegetation, and loose soil. But *fengshui* is concerned with winds and waters in a deeper sense too: with the invisible "breath of the earth" discussed above,

[2] The quote is cited from the article by H. Chatley in Samuel Couling's *Encyclopaedia Sinica* (1917).

[3] Cited from the *Shiji* (Records of the Historian), in the *Cambridge History of China* 1: 62.

and with the "flows" of *qi* beneath the earth that were thought to be responsible for the formation of minerals (Needham 1970: 3:637, 650).

The art of proper burial consists in choosing a site with favorable life-breath. Guo Pu puts it succinctly by saying: *cheng shengqi*, "burying [is a matter of catching] life-breath" (cited in March 1968: 256). The understanding of *qi* expressed in the *Zangshu* has been aptly characterized as:

> "the breath at the origin of things, forever circulating," which flows through the whole of space, endlessly engendering all existing things, "deploying itself continuously in the great process of the coming-to-be and transformation of the world" and "filling every individual species through and through" (Jullien 1995: 91–2).

The quality of a place, according to Guo Pu, depends on the local *shi*, meaning configurations of earth-energy (which François Jullien translates in this context as "lifelines"): "The vital breath circulates along the lifelines of the terrain and is concentrated at the points where they come to an end." John Hay draws a helpful distinction between *shi* as "dynamic configuration" and *xing* as "form" or "shape" of concreted objects: "It is the changefulness of *shi* that is lasting, whilst the fixedness of *xing* is transient" (Hay 1985: 53). On the *fengshui* understanding of a landscape, *shi* refers to both the "veins" of earth through which the *qi* flows and also the "skeletal structure" or "spinal column" of the terrain. In order to perceive the dynamic configurations of a landscape, it is necessary to gain some distance for a broader perspective: "The lifelines are visible from a thousand feet away, the particular configurations of the terrain from a distance of one hundred feet" (*Zangshu*, as cited in Jullien 1995: 93). Another way, as Jullien suggests, is to consult an appropriate masterpiece of Chinese landscape painting, the primary principle for which was to "achieve the *shi*" of the landscape (99).

Another important source of ideas behind *fengshui* is the *Huangdi zhaijing* (The Yellow Emperor's Siting Classic), attributed to the fifth-century thinker Wang Wei. As the title leads one to expect, a central idea in this text is that of *zhai*, meaning "site/siting" or "place/placing": "All human dwellings are at sites… sites are the foundation of human existence" (cited in Bennett 1978: 5). A *zhai* is therefore not merely some location in abstract space, but rather a place as defined both by a particular topography and by the kinds of human activities that take place in it.[4] Since an inhabited place is a dynamic locus of flowing energies, the *Siting Classic* addresses the temporal as well as the spatial aspects of *fengshui* practice: "Every year has twelve months, and each month has positions in time and space of vital and torpid *ch'i* [*shengqi* and *siqi*]" (Bennett 1978: 7). Human activities undertaken at times of vital *qi* are more likely to be successful than at times when the *qi* is torpid. The quality of *qi* also varies within smaller cycles, such as the diurnal: Manfred Porkert characterizes *shengqi* as "the quality of energy during the *yang* hours of the rising sun (midnight to noon)… [which has] a quickening and invigorating effect on active enterprises," and the opposite for the yin hours from noon to midnight (Porkert 1974: 172–73). The *Siting Classic* also asserts an isomorphism between a *zhai* and a human body, a correlation that is central to Daoist thinking about the relations of the human being to the landscape: "The forms and configurations are considered to be the body; water and underground springs are the blood and veins; the earth is the skin; foliage is the hair; dwellings are the clothes; door and gate are the hat and belt" (Bennett 1978: 13).

In spite of the prevalence of all these ideas, it was not until the Tang dynasty (618–906) that *fengshui* theories and practices began to be synthesized and formalized into a distinct school named as such.[5] Wang Wei's historical survey distinguishes two schools, one using the "Kiangsi [Jiangxi] method" and the other the "Ancestral Hall" or "Fukien [Fujian] method," both of which he claims are derived from Guo Pu (March 1968: 261). The latter (founded a century or two later) is also known as the "Compass School" and it emphasizes the importance of the Eight Trigrams of the *Yijing* and the Five Planets, as well as the indispensability of the geomantic compass. Since this school's methods are more abstract and less scientific, it seems to have been infected by more charlatanry than its counterpart.[6]

The school employing the Jiangxi method is also known as the "Form and Configuration" (*xing shi*) School, because of its concern with intuiting the configurations (*shi*) of *qi* from the shapes or forms (*xing*) of the landscape. It was apparently founded by an imperial *fengshui* master by the name of Yang Yunsong (c. 840–888). In its consideration of mountains and watercourses the Form and Configuration School lays particular emphasis on the motif of the dragon as a pattern to be found in "all topographical formations" (Feuchtwang 1974: 141), as indicated by the

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[4] Western philosophy has generally devoted far more thought to abstract space than to live place: for a judicious restoration of this imbalance, see Casey (1997).

[5] For example, the *Guanshi dili zhimeng* (Mr. Guan's Geographical Indicator) attributed to the third-century author Guan Lo, the *Zhangshu* (Book of Funerals) attributed to Guo Pu, and Wang Wei's *Huangdi zhaijing* (The Yellow Emperor's Siting Classic); see Needham (1956: 360).

[6] A comprehensive account of the practices of the Fujian School, with fascinating descriptions of the geomancer's compass, is to be found in Feuchtwang (1974: 18–95).

titles of such important treatises by the founder as the *Hanlongjing* (Classic on Arousing the Dragon) and the *Yilongjing* (Classic on Approximating the Dragon).

The dragon is best understood as an image for all vital topographical formations, since some places may simply be "dead" in terms of the flows of *qi*. As a later author, Shen Hao (seventeenth century), puts it:

> Surely nothing but the writings of the magic dragon is an adequate figure of the mountain-ridges' permutations. What does not resemble the permutations of the magic dragon does not realize the subtle geomantic essence. Therefore it is said: if it has permutations, call it dragon; if it has none, call it barren mountain. (cited in March 1968: 256–57).

This is not the Azure Dragon as an image for one of the four directions, which is culturally and geographically specific to China, but "a universal symbol of the powers of nature" and especially of "the power of [self-]transformation."[7] Since Chinese culture is based on the premise that all events in the world are continually transforming themselves, the dragon is its perfect emblem. It is also an archetypal image common to a wide range of cultures and mythologies, in some of which its meaning is negative by contrast with its generally auspicious quality in China.

General Meng Tian's concern for respecting the earth is often echoed in the Ming period, which also saw a special flourishing of the art of garden making in China. Fear of damaging the "earth's veins" fueled opposition to gypsum mining in Taihe county in the fourteenth century, and the government prohibited the digging of ponds in Nanjing "lest they damage the *qi* of the earth in the imperial capital" (Clunas 1996: 181). The sixteenth-century author of the *Nongshuo* (Talks on Farming) writes eloquently of "energy arteries running within the earth" and how "earth and bone are like the arterial system of the human body which carries the energy-blood" (cited in Hay 1985: 42). When the body is understood as an organism situated within the larger organism of the environment, its various energetic pulses (*mo*) correspond to the dynamic configurations referred to earlier as the earth's "lifelines" (*shi*).

To fully appreciate sciences based on becoming rather than being, on energy rather than matter, we need to reorient our ways of perceiving our environment. In introducing his discussion of the notion of *shi* as "lifelines" in the earth, François Jullien recommends that we stop regarding nature as "an object of science" in the Western sense: "Rather, we should here perceive nature intuitively, through the sensibility of our bodies and their activity, as the single common principle within and outside us that operates throughout reality and explains how the world is animated and functions. Let us imagine a new 'physics' and stop thinking of nature abstractly" (Jullien 1995: 91). If this idea seems too exotic – a physics associated with a transformation in our experience – we might recall that there exists something similar in the Western tradition, with the Hellenistic philosophies of the Stoics and Epicureans. As Pierre Hadot puts it: "Contemplation of the physical world and imagination of the infinite are important elements of Epicurean physics. Both can bring about a complete change in our way of looking at things. The closed universe is infinitely dilated, and we derive from this spectacle a unique spiritual pleasure" (Hadot 1995: 87–8).

Just as the breath that animates the human body through bringing oxygen to the blood is invisible (the misty exhalations in cold weather being water vapor rather than air), so the cosmic breath animating the body of the earth cannot be seen, though it can be felt or otherwise sensed. The science of acupuncture, which is closely related to *fengshui*, has been slow to gain acceptance by practitioners of Western medicine. The main reason is that its background assumptions are so different, and there is also that fact that the meridians (*jingluo*) through which the currents of *qi* flow through the human body are invisible, and Western researchers were looking for literal conduits such as veins or nerves.

Corresponding difficulties arise with the idea of energies flowing through the earth (in the broad sense, including watercourses, vegetation, and the other processes of metal and fire) along "lifelines" that are invisible to the eye but can be intuitively discerned by the well-trained practitioner. This notion should, however, be less mysterious to Western physicists since the discovery of the earth's magnetic field (the magnetosphere), whose energies flow along lines that are similarly invisible. Indeed the Chinese appear to have been the first to understand the phenomenon of magnetism, and texts referring to the "south-controlling spoon" – a piece of lodestone carved into the shape of the Northern Dipper (Ursa Major) – appear in China over a 1,000 years earlier than the first European references to the magnetic compass. These Chinese discoveries naturally took place within the context of *fengshui* (Needham 1969: 71ff; 1962: 4/1, 229–334).

In conclusion, a brief look at three Chinese arts will help further our understanding of *fengshui*, especially along the experiential dimension: landscape painting, garden making, and the martial arts and their derivatives.

We saw that Guo Pu understood the lifelines of the land as both its "skeletal structure" and its "veins," and when the Form and Configuration School of *fengshui* applied the image of the dragon to any important topographical formation, it was on the assumption that the dragon was animated by *qi* flowing through its

[7] Feuchtwang (1974: 149–150). See also the chapter entitled "The Dragon Motif" in Jullien (1995: 151–161).

bones as well as its veins. This idea is associated with the distinction between the "mountain" (*shan*) and "waters" (*shui*) *qi* animating a landscape (*shanshui*), with peaks and ridges as skeletal structure and watercourses as veins, and it is also exemplified in one of China's greatest contributions to the world's art, landscape painting (Feuchtwang 1974: 141–48). François Jullien quotes and comments upon the tenth-century aesthetician Jing Hao on this topic:

> Under the painter's brush, as in nature, "the aspects of mountains and waters are born from the interaction of vital breath and the given layout to which that force imparts dynamism." In China, the purpose of painting is to rediscover the elemental and continuous course of the cosmic pulsation through the figurative representation of a landscape. (Jullien 1995: 94).

Thus an excellent way of learning to discern the lifelines in a landscape is to study Chinese landscape paintings, which is in itself one of life's great pleasures.

Another great Chinese contribution to the world of the arts, again associated with *fengshui,* is the art of the garden. We saw earlier that *fengshui* allows for certain kinds of human intervention in order to improve, when necessary, the conditions of a particular site – though the tragic figure of Meng Tian stands as a constant reminder of the dangers of too deep an intervention. As an important adjunct to the dwellings of the living in China – of the well-to-do in particular – the garden provides an opportunity to put the principles of *fengshui* into practice from the ground up, as it were.

The classic garden manual, the seventeenth-century *Yuanye* (Craft of Gardens) by Ji Cheng, talks of the way a well constructed garden, where one has "visualized the balustrades as if they were in a painting", can "flood the heart with intoxication" and create "a pure atmosphere around our tables and seats [so that] the common dust of the world is far from our souls" (Ji 1988: 43–44). Chinese gardens would often be laid out in such a way as to "borrow" features of the neighboring landscape, by offering views from within the garden of a local mountain or lake. A basic premise of the Chinese garden is the microcosm/macrocosm correlation between the human body and the physical environment: the well designed garden sets up a pattern of energies that corresponds to the dynamic configurations of a larger landscape – and indeed energies just as powerful thanks to the amplifying effect of miniaturization.[8]

[8] The classic work on this topic is Stein (1990): see, especially, part one: "Trees, Stones, and Landscapes in Containers," and "Survey of Themes." For a brief history of the remarkable lithophilia (or petromania?) that has characterized the Chinese tradition, see Parkes (2005).

For those of us unable to afford the luxury of a garden, there are other ways of cultivating an appreciation for the relations between the body's energy configurations and those of the environment – through practices such as *qigong* (literally, "energy work") and *taiji quan* ("Great Ultimate bare-hands-combat-technique"), one of the "softer" martial arts to have been developed in China. Anyone who is skeptical about the existence of the *qi* that flows through and energizes the body need only try some *qigong* exercises (for example, the set known as the "eight sections of brocade," often used as a warm-up for *taiji* practice) in order to experience the flow of *qi* in his or her own person. As with yoga, the breath is central to *taiji* practice, insofar as breathing is a manifestation of the cosmic breath in the human body.

Taiji practice brings about precisely what *fengshui* encourages: a greater awareness of the relations between one's activities and the configurations of the surroundings, whether natural or built. Unless one has the luxury of choosing a place to live and building a dwelling there, there is no opportunity for engaging in the practice of *fengshui* as "siting" and participating in the architect's decisions concerning the orientation of the house in relation to prevailing sun, wind, rain, and terrain. But one can always change the ways one's living space is configured in a residence already built, by the simple expedient of becoming more aware of one's activities in relation to the surroundings. It is quite possible thereby to improve the positioning of one's furniture and personal effects without going to the expense of hiring an "expert" consultant. A little common sense combined with heightened sensitivity to one's environment goes a long way. Opportunities to set up one's workspace will generally be more limited than in the home, but improvement is usually possible nonetheless.

One might take encouragement from those writers on *fengshui* like Shen Hao who emphasize intuition. Coming upon a place that is right, he writes,

> One's eyes are opened; if one sits or lies, one's heart is joyful. Here the breath gathers, and the essence collects. Light shines in the middle, and the magic goes out on all sides. Above or below, to right or left, it is not like this… Try to understand! it is hard to describe (cited in March 1968: 259).

Among contemporary scholars, no one has put it better than François Jullien, who paraphrases Guo Pu as follows:

> Not only my own being, as I experience it intuitively, but the entire landscape that surrounds me as well, is continuously flooded by subterranean circulating energy… The most glorious sites will be those where it is most densely accumulated,

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where the circulation of the breath is most intense, its transformations most profound… By rooting one's dwelling here rather than elsewhere, one locks into the very vitality of the world, taps the energy of things more directly (Jullien 1995: 92).

If in response to such an expression of the more sensible tenets of *fengshui* we could become skeptical concerning the modern conceit that we can be at home anywhere, no matter where, and instead practice some environmental science at the personal level, we would surely witness a greater flourishing on the part of human beings and the natural environment on which we depend.

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Fishing in Ancient Egypt

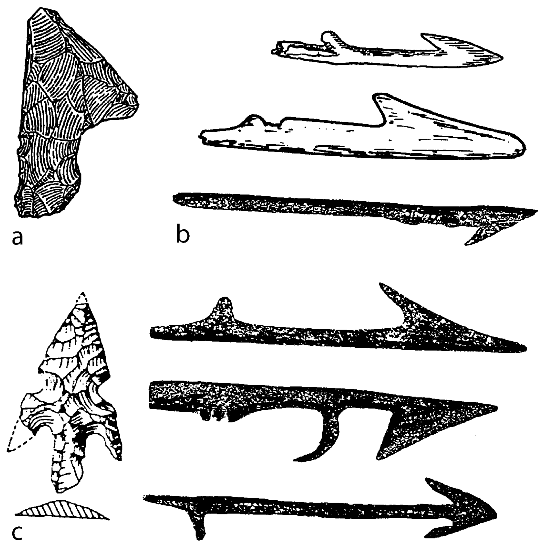
Dietrich Sahrhage

Early civilization in the Nile valley developed mainly because of heavy summer rains in the highlands of Ethiopia and around the East African lakes. Every year a huge flood reached Egypt around mid July, carrying to the lower parts of the Nile enormous quantities of fertile silt. This settled as soil especially suitable for agriculture and filled up the Delta, originally a bay of the Mediterranean Sea. The timing and intensity of the floods determined whether people would have wealth or famine, depending on the water supply and agricultural production.

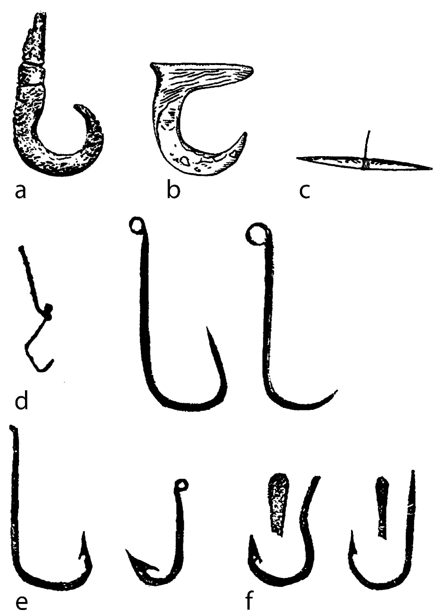
The waters of the Nile, the floodplains, and many pools that remained when water receded or evaporated in autumn, as well as the coastal lagoons of the Delta, contained rich resources of fishes and other aquatic animals which were utilized since prehistoric times. There is much evidence for this from archaeological finds, well preserved in the desert, engravings and wall paintings in tombs and temples, and from hieroglyphic inscriptions.

As indicated by bone and shell remains at Kom Ombo near Aswan, hunter-gatherers already fished during the Late Palaeolithic around 15000 BCE for Nile perch, catfishes and barbels, and they collected Nile oysters and African softshell turtles. Some flint tools have been interpreted as points of lances. After 10000 BCE, as North African savannas deteriorated to deserts due to climatic changes, game became rare, and hunters turned increasingly to fishing, employing gear like spears with stone or bone points, harpoons, and curved fishhooks and gorges made of bone or antlers (Figs. 1 and 2). Hippopotamuses and crocodiles were also harpooned or caught in traps (Fig. 3). The development intensified during the Neolithic (5500–4000 BCE), when Lake Quarun in the Faiyum Depression filled with water and became an important fishing area like the Delta. Around 3500 BCE the first fishhooks of copper appeared and increasingly replaced the stone and bone tools.

The unification of Upper and Lower Egypt around 3000 BCE led to the formation of the Old Kingdom (ca. 2600–2150 BCE) with powerful rulers and an efficient administration, promoting the construction of pyramids and hydraulic engineering for drainage and irrigation to improve agriculture, fishing and transport.

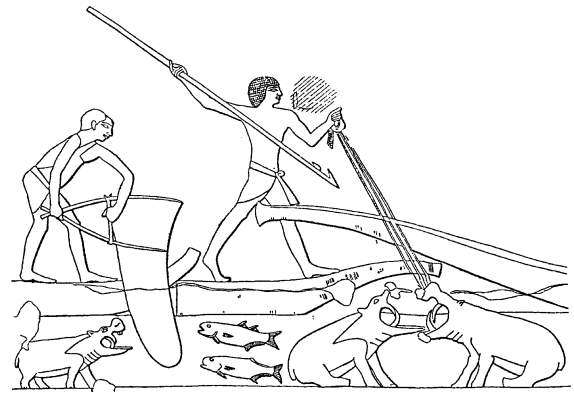


Fishing in Ancient Egypt. Fig. 1 Ancient gear: (a) points of lances and spears made of flint stone; (b) prehistoric harpoon points made of bone; (c) points of copper harpoons (after Petrie 1920; Brewer and Friedman 1989).



Fishing in Ancient Egypt. Fig. 2 Hooks for line fishing: (a) bone; (b) antler; (c) gorge; (d) copper hooks, Old Kingdom; (e) barbless copper hooks, Middle Kingdom; (f) barbed copper hooks with plate for fixing a line, New Kingdom (after Eiwanger 1992; Debono and Mortensen 1990; von Brandt 1975; Petrie 1917; Brewer and Friedman 1989).

During this epoch artists created very realistic images of fish species and fishing methods in reliefs and wall paintings on tombs, mainly at Saqqara, the necropolis of Memphis (*Mennofer*), the old capital

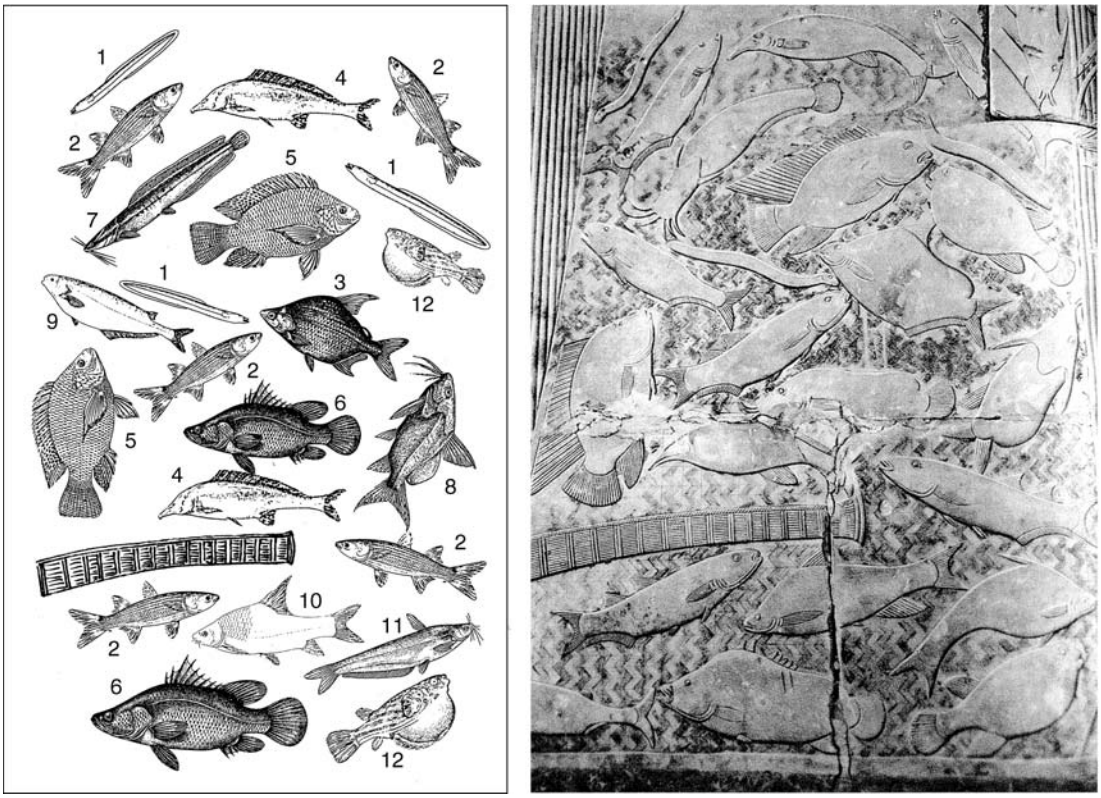


Fishing in Ancient Egypt. Fig. 3 Harpooning hippopotamus and fishing with hand net. Relief in tomb of Princess Idout at Saqqara, Old Kingdom. The harpoon head was attached to a retrieving line (Macramallah 1935).

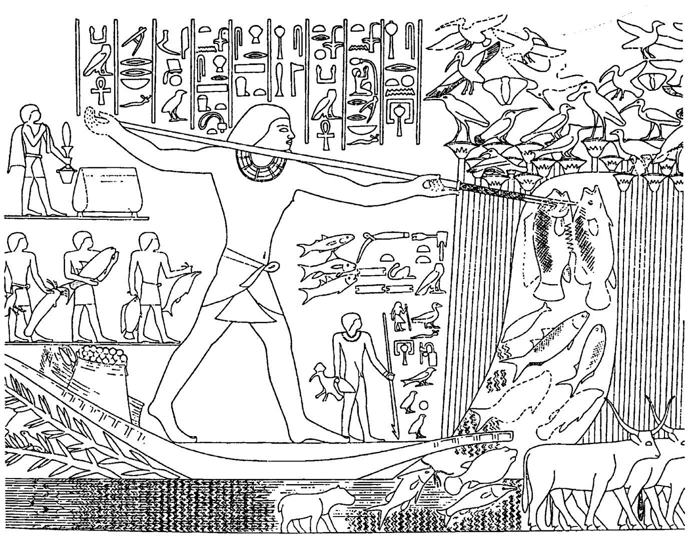
Fishing in Ancient Egypt. Fig. 4 Fishing with multiple hook and line and with hand net. Relief in tomb of Kagemni at Saqqara, ca. 2280 BCE (von Bissing 1905).

(Fig. 4). The fishes frequently depicted are Nile perch, Nile tilapia, various species of catfishes and elephant-fishes, barbels, mullets and eels (Fig. 5). Modern studies revealed about 65 fish species in the Nile waters; some 30 of them can be recognized in ancient images. Presentations of fish and fishing had revivals during the Middle and New Kingdoms (ca. 2000–1780 and 1550–1070 BCE), particularly at Thebes, west of Luxor, and elsewhere. A considerable number of marine species from the Red Sea/Indian Ocean are depicted under ships of the expedition to Punt in reliefs of the mortuary temple of Queen Hatshepsut at Deir el-Bahri.

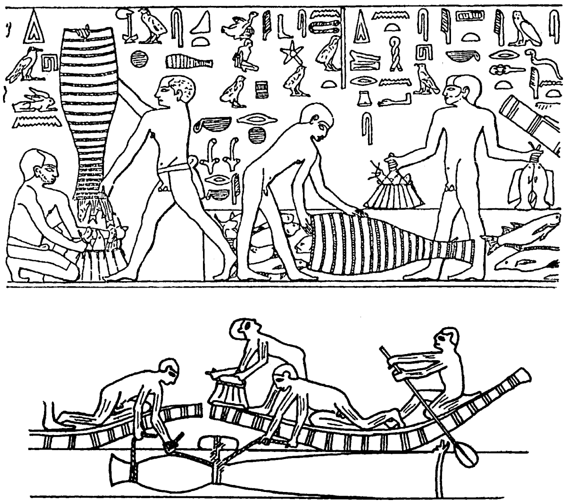
Famous pictures in tombs show the deceased spearing fish, usually Nile perch and tilapia, in the papyrus swamps (Fig. 6). Many images illustrate the use of weir baskets (Fig. 7) and of nets, mostly small hand nets and seines, operated both from the beach and from boats (Figs. 8 and 9). Fishermen made and repaired seine nets of flax or other natural fibres (Fig. 10) which were kept vertical in water by floats



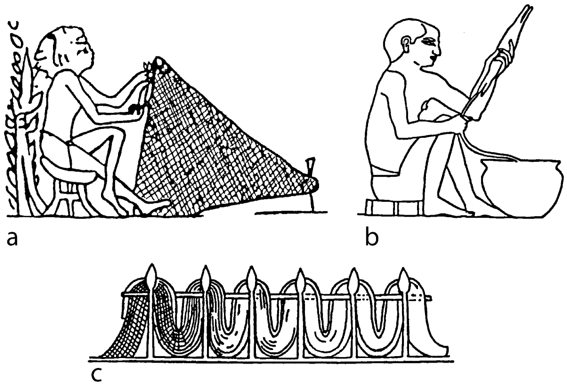
Fishing in Ancient Egypt. Fig. 5 Right: Wall picture in mastaba of Mereruka at Saqqara with various fish species (Duell 1938); Left: Same fish species in modern drawings: 1 eel (*Anguilla anguilla*); 2 mullet (*Liza spec.*); 3 moonfish (*Citharinus citharus*); 4 elephantfish (*Mormyrus caschive*); 5 Nile tilapia (*Oreochromis niloticus*); 6 Nile perch (*Lates niloticus*); 7 North African catfish (*Clarias gariepinus*); 8 upsidedown catfish (*Synodontis batensoda*); 9 elephantfish (*Hyperopisus bebe*); 10 barbel (*Barbus bynni*); 11 African butter fish (*Schilbe mystus*); 12 puffer fish (*Tetraodon lineatus*).



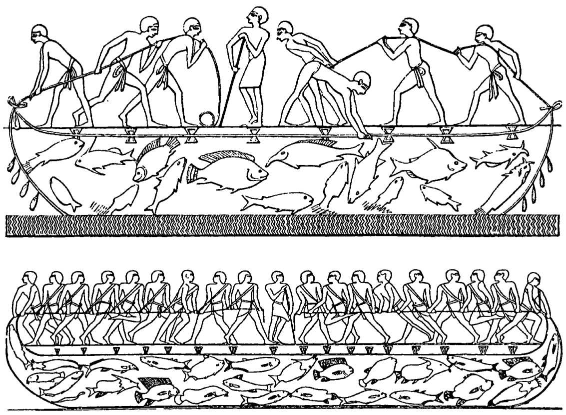
Fishing in Ancient Egypt. Fig. 6 Spearing of Nile tilapia and Nile perch in the papyrus swamps. Wall painting in the mastaba of Kaiemanch at Giza, Old Kingdom (Desroches-Noblecourt 1954).



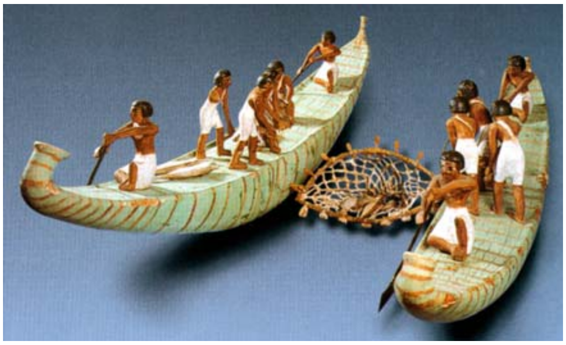
Fishing in Ancient Egypt. Fig. 7 Emptying catches from wicker baskets, depicted in the tomb of Ti at Saqqara (above), and setting a large basket (below) (Bates 1917; Loat 1907).



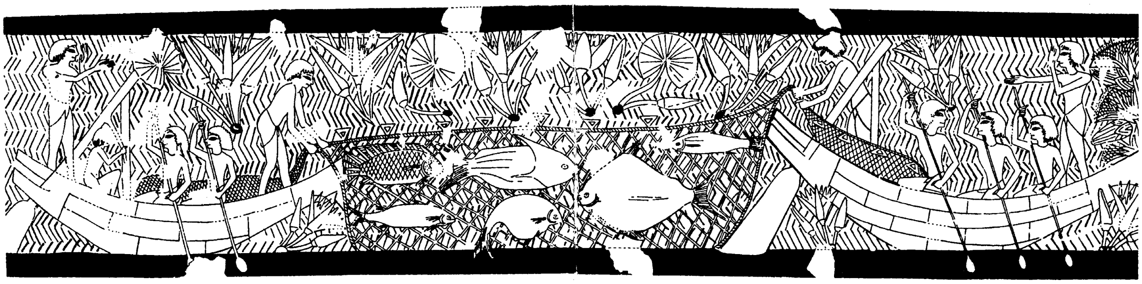
Fishing in Ancient Egypt. Fig. 10 Repairing and drying fishnets: (a) knitting of net in tomb of Ipuje at Deir el-Medina, Thebes; (b) reloading net needle with yarn in tomb of Ti at Saqqara; (c) stand for net drying in tomb of Kagemni at Saqqara (Wreszinski 1923–36, Bidoli 1976).



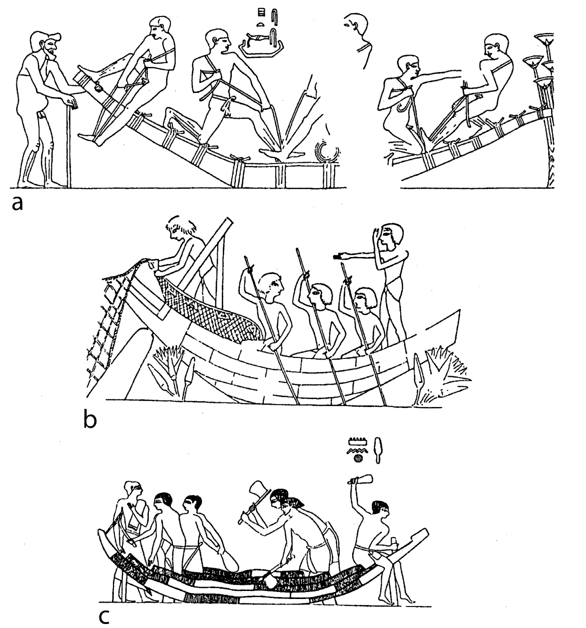
Fishing in Ancient Egypt. Fig. 8 Beach seine fishing. Shown are ropes, floats, sinkers and various fish species (Lepsius 1842–1845; Duell 1938).



Fishing in Ancient Egypt. Fig. 11 A small fishnet is pulled between two wooden boats which resemble the original form of papyrus rafts. Model, discovered in tomb of Meketrê at Deir el-Bahri, Thebes, ca. 2000 BCE, in Egyptian Museum, Cairo (photo: Sahrhage).



Fishing in Ancient Egypt. Fig. 9 Seine fishing between two vessels. Wall painting in tomb of Ipuje at Deir el-Medina, Thebes, ca 1290 BCE (Davies 1927).



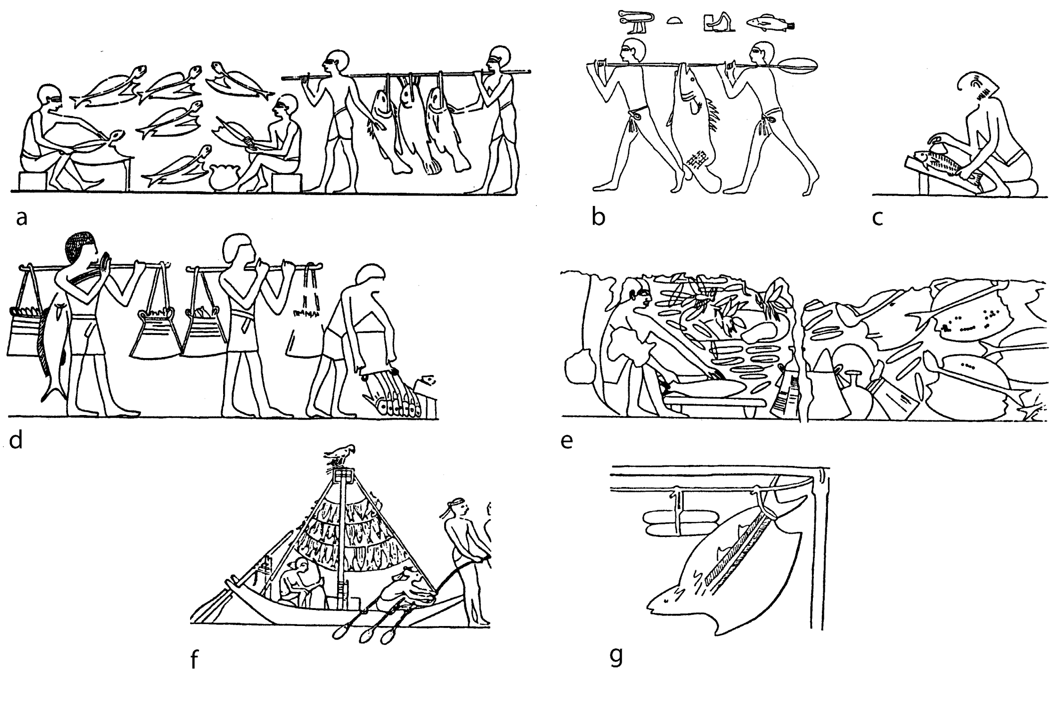
Fishing in Ancient Egypt. Fig. 12 Fishing vessels: (a) lacing of papyrus rafts. Relief in tomb near Meir, ca. 1950 BCE (Landström 1970); (b) wooden boat during seine fishing. Wall painting in tomb of Ipuje at Deir el-Medina, ca. 1290 BCE (Davies 1927); (c) construction of vessel from blocks of wood. Wall picture in tomb of Knumhotep at Beni Hassan, ca. 1950 BCE (Newberry 1892–1894).

and sinkers. Trawls pulled between two boats may even have been used (Fig. 11). Cast nets appear in the Late Period. Fishing vessels were papyrus rafts and boats constructed from blocks of wood, since large trunks were scarce (Fig. 12).

As shown in wall pictures, fishes, mainly Nile tilapia, were kept in basins, apparently mostly waters belonging to palaces or temples. A few presentations seem to indicate that fish were also kept in natural ponds, perhaps as storage of living food (Fig. 13).

Fish were gutted and eaten raw or grilled. Large quantities were clipped and dried in the sun, often hanging on lines. Salted fish also had a wide market both in Egypt and for export (Fig. 14). Some sort of

Fishing in Ancient Egypt. Fig. 13 Miniature from the neck of a silver can found at Bubastis, showing a fish pond (after Vandersleyen 1975).



Fishing in Ancient Egypt. Fig. 14 Fish processing: (a) transport and clipping; (b) carrying a large Nile perch; (c) removing the fish spine; (d) baskets full of fish for processing; (e) gutting (insects are shown infesting the meat); (f) fish hanging in ship's rigging for drying; (g) clipped mullet and its roe hanged for drying (Épron and Daumas 1939; Petrie 1892; Taylor and Griffith 1894; Moussa and Altenmüller 1977; Wreszinski 1914; Keimer 1939).

caviar was prepared from mullet roe. It seems that fish for food consisted almost exclusively of freshwater species.

The profession of fishermen was regarded socially as only of a low level. Various images show how they participated in coarse games, knocking each other from the boats with long poles.

Catches usually had to be delivered to palaces or lords of the manor, and fish were often used, jointly with other natural products, as payment in kind for labour. Catches were subject to taxation, and fees had to be paid for fishing rights.

Also well documented is the important role of fishes and other aquatic animals in religion, mythology and medicine. In many provinces different fish species were adored as representing gods, e.g. African butter catfish (*Schilbe mystus*) as a symbol of Hatmehit at Mendes in the Delta, Nile tilapia as a symbol of fertility and rebirth, elephantfish as a symbol of Hathor at Oxyrhynchus and other places, Lepidotos (*Barbus bynni*) at Lepidopolis near Abydos, Phagros (mullet?) and puffer fish at Aswan, and Latos (*Lates niloticus*) at Esna. Devotion to fish was often combined with a ban on the consumption of certain fish species at certain times in certain areas, especially by priests in temples. Mainly during the New Kingdom and Late Period thousands of fishes were mummified and buried in large animal cemeteries. Fishes were found as gifts to the deceased in graves, and fish offerings were portrayed on tomb walls, although infrequently.

As described in papyri, extracts from various parts of fish were used as drugs for medical purposes. For curing gout, live electric catfish (*Malapterurus electricus*) were placed under the feet of patients.

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Fishing in the Indus Valley

Dietrich Sahrhage

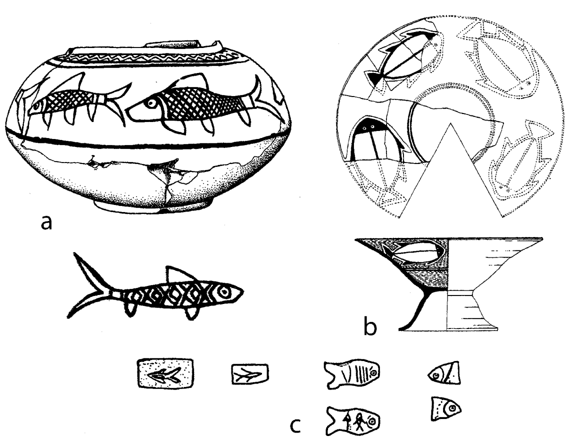
The ancient civilization in the region of the Indus valley reached its zenith around 2600–1900 BCE. It was characterized by cities like Harappa, Mohenjodaro, and many urban sites which have been excavated or identified by archaeologists in what is now Pakistan and Western India.

It was the regular supply of water that allowed the early development of agriculture and hence the growth of the human population. The main sources were the rainfalls and melting snow from the Hindukush and Karakoram Mountains in the north and monsoon rains from the west. This resulted annually in mighty, though very variable, floods in the River Indus and its effluents with a peak in July and August. The water carried enormous quantities of very fertile soil to the south, which filled the riverbeds and forced streams to change their channels frequently, inundating large areas.

The rivers, numberless lakes and pools, often arising and vanishing, and the waters of the Arabian Sea along the Makran coast were the home for large resources of fish, crustaceans and molluscs. These animals formed a significant element in the diet of people and of the trade in the region.

Since the Indus script and language have not yet been deciphered, and there seem to be no reliefs or wallpaintings in temples or palaces, we depend mainly on archaeological finds and on the observation of apparently old practices today for information on fishing and other activities in ancient times.

Fishing in the Indus Valley. Fig. 1 Steatite stamp seal from Mohenjodaro with pictogram of fish in the script line on top, 3.5 × 3.5 cm. National Museum Delhi (from Jansen 1986, drawing Bunse, Aachen). Used with their permission.



Fishing in the Indus Valley. Fig. 2 Fish images on pottery and in figurines: (a) red/black ceramic vessel from prehistoric cemetery at Nal (Baluchistan). Used with their permission, (b) painted dish on stand with fish from Lewan, ca. 3000 BCE (Allchin 1982/1993), (c) zoomorph figurines with fish design.

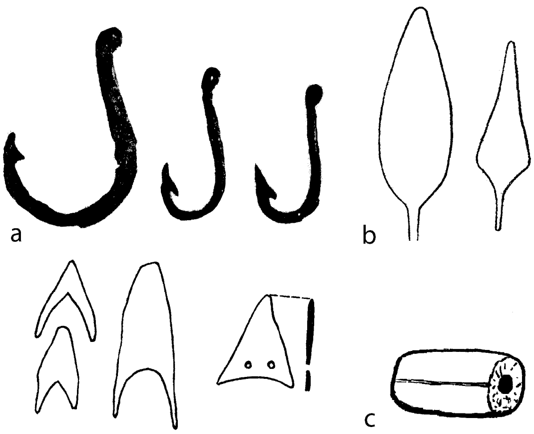
Fishing in the Indus Valley. Fig. 3 Potsherd from Harappa with painted men fishing with baskets, in front probably seine net (after Vats 1940 from Jansen 1986). Used with their permission.

Fishing in the Indus Valley. Fig. 4 Remains of a fishing net, discovered near Shahr-i-Sokhta in the swamps of the Seistan Depression, third millennium BCE. Netting knitted with reef knots, square mesh 4 cm on average, finely woven fibre, possibly wool (Istituto Italiano per l'Africa e l'Oriente, Rome. Photo: Bonardi). Used with their permission.

The importance of fishes in the Indus civilization is evident in many typical seals with a pictogram of fish (Fig. 1). Presentations of fish and fishing also appear on pottery and in the form of small zoomorph ceramic figurines (Fig. 2). Most interesting is a potsherd, discovered at Harappa, with the drawing of men obviously fishing with baskets (Fig. 3). In the foreground one sees netting which could be interpreted as part of a seine. The existence of such nets is revealed by a great number of typical sinkers, mostly of limestone. Pakistani fishermen still use the same type today. Direct evidence for net fishing is provided by remains of an almost 5,000 year old net discovered in 1972 by an Italian mission at Shahr-i-Sokhta in the Seistan Depression, today in Iran near the border with Afghanistan (Fig. 4) .

Finds of ancient fishing gear consisted mostly of spear points, arrowheads and a limited number of fishhooks (Fig. 5). Spears and arrows were certainly also used for hunting. With the development of metallurgy since the fifth millennium BCE, artefacts were made of copper. Fishhooks discovered at Mohenjodaro, Chanhudaro and Harappa were 1–10 cm long. The longest must have been employed in fishing for very large fishes. Hooks were mostly barbed, but barbless hooks were also found. From investigations it appears that copper was imported from Baluchistan, Rajasthan (Khetri) and overseas from Muscat and Oman (Magan).

In the absence of ancient fish images, skeletal remains are of utmost importance for identifying fish species caught in ancient times. From fish bones unearthed in Mohenjodaro, Harappa and elsewhere it is indicated that catches in freshwaters consisted mainly of carp-like fishes, particularly the large barbels *Catla catla*, Mahseer (*Tor tor*) and the Rohu (*Labeo rohita*), which grow to lengths of over 2 m, and also various species of small barbels which nevertheless are important due to their biomass. Also the large catfish *Wallago attu* was a major food fish.

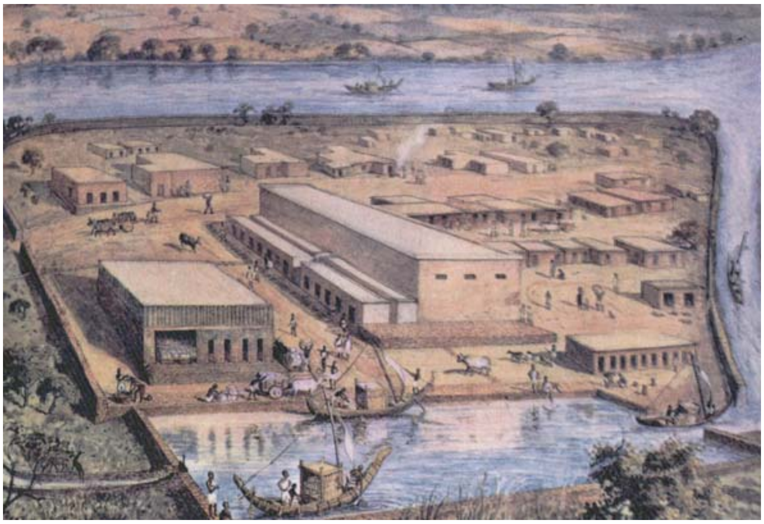


Fishing in the Indus Valley. Fig. 5 Fishing gear in the Indus civilization: (a) Copper fishhooks from Mohenjodaro (Sarkar 1953); (b) spearpoints and arrowheads (Agrawala/Kumar 1993); (c) net sinker of limestone discovered at Mohenjodaro (Marshall 1931/1973).

The coastal waters of the Arabian Sea provided good catches mostly of giant seacatfishes (*Arius thalassinus*), croakers, grunts, skates and small sharks. This was discovered when a French team with Desse and Desse-Berset in 1989 found thousands of fish bones, together with shells and Harappan potsherds, lying on the Prahag beach near Pasni. Finds of such bones at Miri Qalat, 120 km north of Prahag, and even at Harappa, some 900 km further north, prove that fish had been transported far inland.

In a region with a hot climate this would have been impossible without proper conservation of the catches near the coast. The bone remains on the beach of Prahag gave a hint: they were placed in a number of circles 5–8 m in diameter. It seems that the fishes had been put into round pitches in the sand for salting. In fact, this method is being used by present-day Baluchi fishermen, as Belcher observed at Balakot near Karachi. The fish, mostly silver grunt (*Pomadasys hasta*), are beheaded, clipped, the halves put into brine for 2–3 days and exposed to wind and sun for drying.

Rivers, lakes, and the Indian Ocean offered good opportunities to catch crustaceans and to collect mussels and gastropods. Whereas the crustaceans remains decayed, the mollusc shells lasted over thousands of years. Already during the Stone Age they were worked into ornaments, amulets and objects of daily life like vessels and spoons. Workshops existed in many Harappan cities, where craftsmen produced highly artistic objects with fairly uniform techniques and styles. Like precious stone products, mollusc shell products were also traded in the Indus region and far beyond (Kenoyer 1984).



Fishing in the Indus Valley. Fig. 6 Reconstruction of the city of Lothal with harbour basin, wharf and store. Large central building (“acropolis”) on platform of loam bricks. In the back living quarters and workshops for copper, marine shells, lapidary and semi-precious stone working industries (Rao 1973).

The central part (columella) of sacred conch (*Turbinella pyrum*) was used to produce hollow cylinders for seals which were exported to Oman and Mesopotamia. Finds of such cylinders, and of Indus stamp seals, in Mesopotamia prove trade connections between Meluhha (as the Indus region was named) and the cities on the rivers Euphrates and Tigris. Cuneiform scripts on clay tablets from Mesopotamia tell that King Sargon I, around 2300 BCE, ordered that ships from Meluhha sail upstream on the Euphrates beyond Ur to reach his capital Akkad for unloading their cargo. After the Akkad period direct connections were discontinued but indirect links via Dilmun on the Bahrain Islands and Oman lasted for many years.

One of the ports for trade overseas was Lothal on the Bay of Cambay, where a basin and likely harbour installations and workshops have been excavated (Fig. 6).

The Indus civilization perished around 1700 BCE for unknown reasons. Possible explanations include climatic changes, tectonic activities with earthquakes, and socio-economic influences like overgrazing, burning of grassland and forests, and the impossibility for rural people to feed the increasing urban population.

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Fishing in Mesopotamia

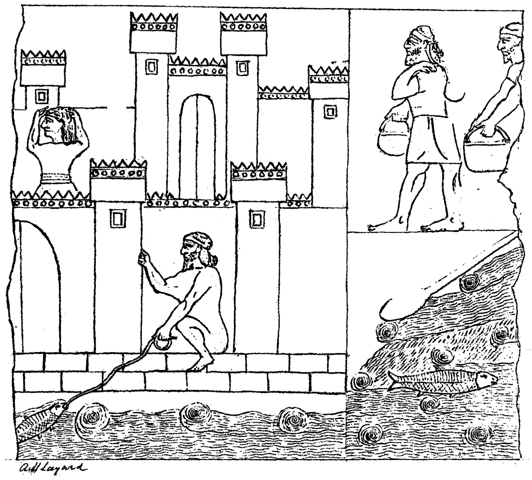
Dietrich Sahrhage

In Mesopotamia, the region of the rivers Euphrates and Tigris and their tributaries, the formation of old civilizations depended on water for drinking, agriculture, traffic and trade. Living aquatic resources like fish, crustacea, molluscs and turtles contributed substantially to feeding the growing human population.

Annual floods, originating from rainfall and meltwater in the highlands of Anatolia and the Zagros Mountains, transported large amounts of pebble and fertile silt downstream; rivers frequently changed their channels, often with catastrophic consequences. During highest water-levels (April–June) wide areas were flooded until water ran off or evaporated in the hot climate. Swamps with reed thickets and lakes (Hors) developed in the depressions. Floods became less dangerous when rivers were regulated with dams and canals, and when irrigation was implemented in the south, from at least 5000 BCE. The many waters were productive areas for fishing.

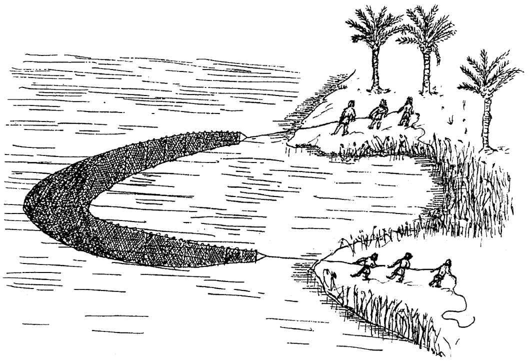
Investigations have shown that Neanderthals lived in northern Mesopotamia as nomads at least 100,000 years ago. During the Neolithic, after 10,000 BCE, the people formed settlements and developed farming and animal husbandry. The oldest evidence for fishing activities are points of spears and arrows of flint and obsidian, fish bones and shells of river mussels (*Unio tigridis*) from around 5500 BCE.

Reports on clay tablets seem to indicate that fish-hedges, traps and baskets were widely used; however any evidence we have has decayed long ago. Fishhooks of stone have only occasionally been discovered, but hooks became more numerous after the implementation of tools of copper around 4500 BCE and bronze (copper–tin alloy) around 3000 BCE. Hook and line fishing is represented in many reliefs (Figs. 1 and 2). According to texts in cuneiform characters, net fishing was frequently used. Stationary nets were set between stakes and seine nets used from the beach, probably also from reed rafts and boats, to encircle fish shoals



Fishing in Mesopotamia. Fig. 1 Fishing with hook and line on the river banks. Drawing after a relief in the Southwest Palace of King Ashurnasirpal II (883–859 BCE) at Nimrud (Layard 1853).

Fishing in Mesopotamia. Fig. 2 Fishing with rod and line. Quare stone of basalt from Tell Halaf, Syria. Height 47 cm (Staatliche Museen zu Berlin-Preussischer Kulturbesitz, Vorderasiatisches Museum). Used with their permission.



Fishing in Mesopotamia. Fig. 3 Hauling a seine net (after Salonen 1970).

Fishing in Mesopotamia. Fig. 4 Impressions from cylinder seals showing fishing activities. (e) and (f) may depict traps, (g) and (h) fishes in front of nets (after Amiet 1972/80; Legrain 1936; Lenzen 1960; Van Buren 1948/49).

(Fig. 3). Cast nets were also known. Impressions of cylinder seals often show fishing activities (Fig. 4).

Mesopotamian graves are much simpler than Egyptian tombs, where fish images, particularly from the Old Kingdom, are presented naturalistically. In contrast, Mesopotamian reliefs, sculptures and cylinder seals show such pictures, but they are fairly stylized. However, rich finds of ancient fish bones from food remains on many sites provide the possibility of identifying a great number of fish species by comparing them with skeletons of modern fishes. Such investigations revealed that various species of barbels, some of very large size (Fig. 5), catfishes and mullets formed the bulk of catches in freshwater areas, whereas sea breams, grunts, croakers, groupers, and many other marine fishes were caught along the coasts of the Arabian/Persian Gulf. Frequent finds of marine fish

Fishing in Mesopotamia. Fig. 5 Pride of the fisherman: A large barbel (Barbus esocinus), probably the prototype of the Apkallu (photo: H. Pfälzner). Used with his permission.

Fishing in Mesopotamia. Fig. 7 Investiture of King Zimri-Lim (1782–1759 BCE). Colored wallpainting from the palace at Mari, central panel. In the lower part streams of water and fishes can be seen (Parrot 1958).

Fishing in Mesopotamia. Fig. 6 Clay tablet from Lagash with text in cuneiform script listing the quantities of various fish species delivered by the fisherman Lugal-sala-tuku to the palace of King Urukagina, ca. 2350 BCE (Staatliche Museen zu Berlin-Preussischer Kulturbesitz, Vorderasiatisches Museum). Used with their permission.

Fishing in Mesopotamia. Fig. 8 Detail of impression from cylinder seal: God Enki (Ea) with running water and fishes. Akkadic period, ca. 2360–2180 BCE. Height 3.8 cm.

remains far inland prove that these animals were traded over long distances. The same holds true for marine mussels and gastropods, which were converted into ornaments, inlaid work and objects of daily life.

Texts on thousands of clay tablets with writing in cuneiform characters permit a deep insight into many aspects of Mesopotamian matters, especially in the fields of economics, legal affairs, medicine, religion and literature. From these scripts it can be seen what names in Sumerian and Akkadic languages people used

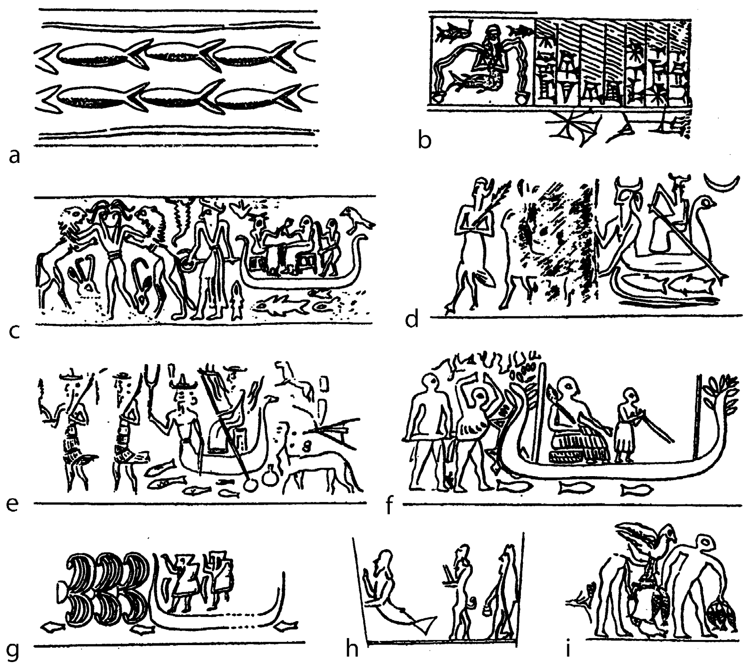
Fishing in Mesopotamia. Fig. 9 Mixed figures in Mesopotamian mythology: (a–c) goat-fish; (d) dragon and birdlike beings with fish tail; (e) fish-man and fish-woman; (f) and (g) Apkallu (after Legrain 1936; Potraz 1961; Scheil 1918; Thureau-Dangin/Durand 1936).

Fishing in Mesopotamia. Fig. 10 Fish-man on quare stone from Tell Halaf, Syria, ca. 900 BCE. Limestone, ca. 40 × 60 cm (Staatliche Museen zu Berlin-Preussischer Kulturbesitz, Vorderasiatisches Museum). Used with their permission.

for various species of fish. Most of the 324 names collected could not be attached to a certain fish species, but some could, like *kusu* for the dangerous Ganges shark (*Glyphis gangeticus*) which migrates upstream from the Gulf to the north of Baghdad.

The texts also provide information on the organization of fishing, commitments and wages of fishermen, as well as facilities for the delivery and distribution of catches. Regulations were most rigid around 2300–1600 BCE, when palaces and temples played a central role for the public production, storage and distribution of foodstuffs and commodities. Detailed statistics were collected regarding the deliveries of fish (Fig. 6). Sometimes temples let out fishing rights to independent fishermen who paid a fee in the form of fish and delivered the rest to trade agents who organized the barter on the basis of silver equivalents for natural goods.

In the vicinity of rivers, lakes and the Gulf, fish were mainly consumed fresh. Because of the hot climate and because fish are perishable, large parts of the catches had to be processed. The fish were gutted, and the marine fish were mostly clipped, dried in the sun, crushed and pressed to blocks suitable for

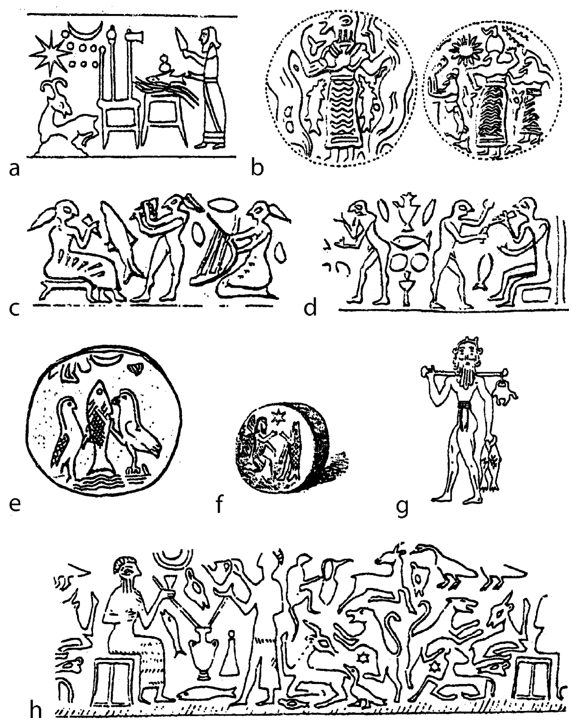


Fishing in Mesopotamia. Fig. 11 Impressions from cylinder seals with mythological scenes related to fishing (after Amiet 1972/80; Orthmann 1975; Weber 1920).

transport over long distances. Freshwater fishes were dried for longer times in the shade. Salting seems to have been less important, but many fish were put into brine prepared from fish guts and crustacea, possibly a forerunner of garum in Greek and Roman times.

Texts on clay tablets also describe medical prescriptions against various diseases in which substances from fish, turtles and seaweeds were considered helpful. Doctors and priests collaborated closely during magic exorcism.

Fish were an important element in Mesopotamian religion and mythology. From the many gods of the Mesopotamian pantheon it was particularly Enki (Ea in Akkadic), the creator of man and god of wisdom, who was adored as the donor of water and fertility. Usually he was depicted carrying a vase through which water from heaven flowed down to earth (Figs. 7 and 8), while fishes, as symbols of life and fertility, swam upwards in the running water. Enki's attributes were goat-fish and fish-man (Figs. 9 and 10). Frequent figures related to Enki are also men, dressed in the skin of a large fish, probably a barbel (*Barbus esocinus*) (Fig. 5). These figures (priests?) presented in cylinder seals, sculptures and many reliefs, are called Apkallu, which means sage. A great number of cylinder seals show scenes with fishing, boats, fish offering and libation ceremonies (Figs. 11 and 12).



Fishing in Mesopotamia. Fig. 12 Impressions from cylinder seals with scenes of fish offerings and libation ceremonies (after Amiet 1972/80; Buchanan 1966; Heuzey, Legrain 1936; Perrot/Chipiez 1884; Weber 1920).

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Fishing in the Stone Age

DIETRICH SAHRHAGE

Fishing is one of the oldest activities of man. The hunter-gatherers of the Stone Age not only fed on game and plants but also on fish and other aquatic animals. Living as nomads, they were bound to the neighbourhood of springs, rivers and lakes for drinking water, hunting game at the watering places and using the dense vegetation. No wonder that they soon discovered rich aquatic resources for their food. Also in coastal areas, preferred as migratory routes, they were able to collect and catch many fishes, crustacea and molluscs.

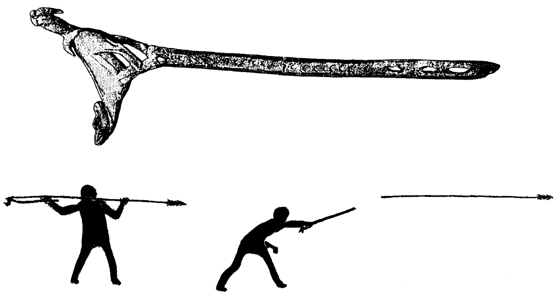
It is striking that fishing gear was developed in different regions of the world to rather similar, sometimes almost identical, forms, although the globe was still only thinly populated. Whether the various techniques were invented independently in different civilizations since human intelligence led to similar solutions (convergence), or whether the experience was distributed by migrations and cultural exchange (diffusion), is an open question.

The oldest indications of fishing, about 2 million years old, are bones of Tilapia and shells of molluscs together with simple pebble tools and human bones left by *Homo habilis* in the Olduvai Gorge in Tanzania, but no fishing gear was found.

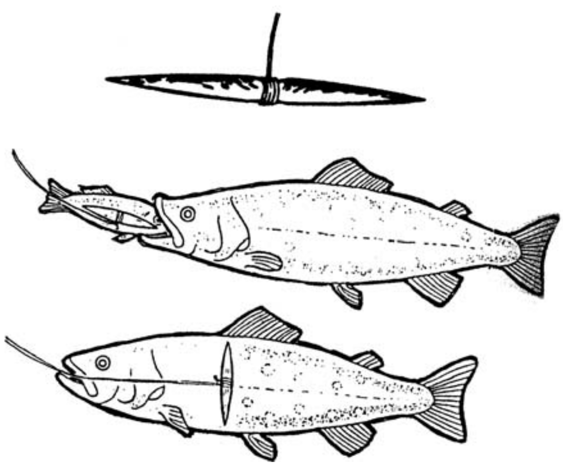
It may, however, be assumed that already during the Palaeolithic times humans were able to develop a palette of simple techniques to reach their goal. Men went hunting for fish with the same gear used for small game, particularly with wooden lances equipped with stone points (Fig. 1). Women and children collected crustacea and molluscs in shallow waters. People soon managed to catch fish with their bare hands and to build stone walls and wooden hedges to improve fishing

Fishing in the Stone Age. Fig. 1 Group of Bushmen hunting fish with lances. Drawing after prehistoric rock painting at the Tsielike River, South Africa (Battiss 1945).

Fishing in the Stone Age. Fig. 2 Harpoon of prehistoric fishermen on the coast of southern Peru used for hunting seals and possibly sharks. The harpoon consists of seal bone with a flint point and ligature of leather or sinew. Shaft is of wood, retrieving line of plant fibre (Lavallée, *Pour La Science* 2001). Used with the permission of *Pour La Science*.



Fishing in the Stone Age. Fig. 3 Atlatl, spear throwing sling from the cave of Mas-d'Azil, Ariège, southern France, about 20,000 years old (after Stodiek and Paulsen 1996). The 32 cm long stick is decorated at the end with a highly artistic sculpture of a fawn and a bird. The end of a spear is put against a spur of the sling, and – as with a catapult – the hunter can propel the spear with a force much greater than that of a hand-thrown spear.

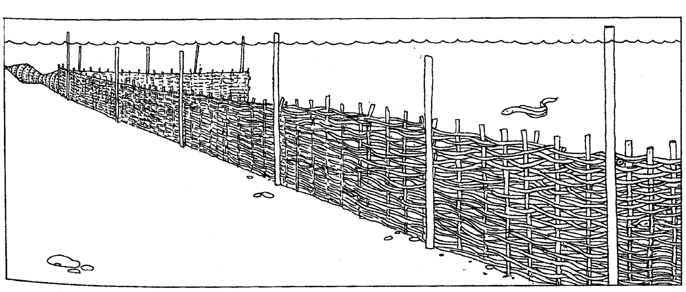


Fishing in the Stone Age. Fig. 4 The gorge, probably the oldest angling tackle. In Europe it has been used since the Magdalenian, about 16,000 years ago. The stick is put into the bait. When the prey snaps at the bait, the gorge turns transverse as the line gets tight (Evers, Franz Steiner Verlag Stuttgart 1988). Used with their kind permission.

possibilities. Branches of bushes were stuck into the ground in waters where fishes concentrated to shelter. The hunters also discovered that fish were attracted by light from fire. Most likely they built fish traps similar to those used for game, but any material evidence decayed long ago.

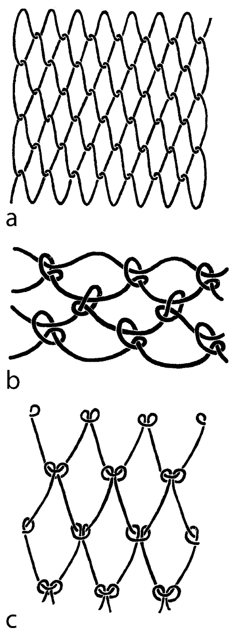
A great step was the invention of the javelin. This tackle was used by *Homo erectus* some 400,000 years ago, as proved by finds in Lower Saxonia, Germany.

Fishing in the Stone Age. Fig. 5 Above: Curved fishhooks from the Mesolithic period found at various sites in Denmark (The National Museum of Denmark, Copenhagen). Used with their permission; Below: Compound fishhook of seal bone with mussel shell barb from Quebrada de los Burros on the coast of southern Peru, about 8,000 years old (Lavallée, *Pour la Science* 2001, drawing by Bailly). Used with the permission of *Pour La Science*.



Fishing in the Stone Age. Fig. 6 Reconstruction of a fish hedge with trap from Oleslyst, Denmark, about 4,500 years old. Hazel stakes in the sea bottom held wickerwork panels over a length of about 45 m. Fish, mostly eels, swam along the hedge to deeper water and were caught in a weir at the end (Pedersen 1997; drawing Petersen, Kalundborg Regional Museum). Used with their permission.

Fishing in the Stone Age. Fig. 7 Hugh mounds of shell middens were left over from meals of Stone Age people in many places of the world, as here in Otuma on the coast of Peru (photo: Tulio Cusman, Lima).



Fishing in the Stone Age. Fig. 8 Fish nets with different kinds of knots to produce meshes: (a) knotless nets with simple hanging in; (b) nets knitted with "lake-dweller knots," (c) nets knitted with "Peru knots" (von Brandt 1984).

Fishing in the Stone Age. Fig. 9 Rock painting of a flatfish (flounder?) in the cave of La Pileta near Ronda in Andalusia, Spain, around 20,000 years old, length 1.5 m (photo: José Bullón Giménez ►http://www.cuevadelapileta.org). Used with permission.

Fishing in the Stone Age. Fig. 10 Barramundi fish (*Lates calcarifer*) painted by Australian aborigines about 2–3,000 years ago in "Roentgen" (X-ray) style in the Cockatoo National Park, western Arnhemland (photo: Tacon, The Australian Museum, Sydney. Used with their kind permission).

Neanderthals (*Homo sapiens neanderthalensis*), living in Europe and the Near East some 200–30,000 years ago, fed mainly on meat, as indicated by their petrified excrements, but fish also played an important role. This was shown by bone remains of trout and salmon on their resting places along rivers in France and Spain.

Much progress was achieved after modern man (*Homo sapiens sapiens*) originated. This began about 150,000 years ago somewhere in southeastern Africa and spread out over the globe, reaching Australia around 40,000 BCE and the American continents via the Bering Straits about 15,000 BCE, perhaps earlier. Now more delicate spear points, blades and scrapers of stone, were produced, and later tools of bone and antler.

Modern humans invented the harpoon, a sharp barbed piece of bone, detachable from the spear shaft, which kept the prey (game or fish) on a retrieving line when it stuck in the body of the animal (Fig. 2). Such gear was found on many locations in the world and has been used frequently up to the present. The oldest harpoon head, found in East Africa, is about 90,000 years old.

Another ingenious invention was a spear-throwing instrument, later called *atlatl* by the Aztec of Mexico, which was distributed widely over all continents (Fig. 3). The oldest known atlatl was used in northwestern Africa 25,000 years ago; Australian aborigines still hunt with similar tools today. The atlatl was increasingly replaced by bows and arrows, known in Europe since 25,000 BCE, and in America since about 2,500 years ago. Many native people even today fish with this technique.

Angling may have started during the latest glacial epoch with the gorge, a little wooden stick, pointed at both ends, with a ring furrow for fixing a line (Fig. 4). Curved fishhooks seem to appear only after the Ice Age in the subarctic hunter civilizations of northern Eurasia from where this method spread out to Europe and to the Far East and America (Fig. 5).

With major climatic changes around 12,000 BCE, large parts of the ice cover melted and the sea level rose in all the oceans. Wide coastal areas were flooded and many valleys and depressions filled with water. People changed their activities increasingly from hunting to fishing with subsequent improvements in catching techniques (Fig. 6). Temporary, and later permanent, settlements on rivers, lakes and the seaside developed where fishing possibilities proved favourable. Dense concentrations of prehistoric fish, seal and whale remains, and huge heaps of shell middens in many places of the world indicate the great importance of aquatic fauna as human food (Fig. 7).

Remains of fishnets lasted only under special conditions in swamps and arid deserts. Knowing how to knit netting marked a major form of progress (Fig. 8). The oldest nets, excavated in Finland and Peru, are 9–10,000 years old, but the history of nets may go back far earlier. In the Czech Republic 27,000 year-old impressions in clay were found which seem to originate from net meshes.

Fishing in the Stone Age. Fig. 11 Fishing with tamed cormorants. *Above*: An old method used in China (Dabry de Thiersant 1872); *Below*: Drawing from a ceramic receptacle from the Moche culture, 100 BCE–700 AD in Peru, exhibited in the Museo Amano, Lima (drawing Sahrhage).

Fishing in the Stone Age. Fig. 12 Prehistoric dugout canoe, about 8,000 years old, being excavated near Dufuna in northern Nigeria (photo: Breunig). Used with permission.

Many rock paintings and engravings certify the role of fish in the spiritual life of Stone Age people, possibly during magic rites in shamanism (Fig. 9). This is evident also from X-ray images found in Europe, northern Asia, America and Australia, showing the inner organs of the animals (Fig. 10).

A sophisticated technique of fishing developed in China, Japan and Peru, where cormorants were tamed to deliver their fish prey to the fisherman who took care of the birds (Fig. 11).

Probably rather early, people started to build vessels for crossing the waters and reaching aquatic resources in deeper areas. For this they used the materials locally available to produce, for example, reed rafts in swamps, dugout canoes in forest regions (Fig. 12), and boats with skin hulls stabilized by wooden sticks.

Various methods of fish preservation were also developed during the Stone Age: drying over the fire or in the wind and sun to produce stable food for the long winter periods passed mostly in caves, and for migrations, as well as salting and pickling.

Most of the basic types of fishing techniques originated in the Stone Age. They are still widely applied.

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Five Phases (*Wuxing*)

Ang Tian Se

Five phases, or *Wuxing*, is one of the basic concepts used by the ancient Chinese along with *Qi*, *Yin*, and *Yang*, to explain natural phenomena. The term *Wuxing*, formerly translated as "Five Elements" is now rendered as "Five Phases". The reason for such a rendering is simply that the term *Wuxing* in Chinese did not necessarily mean "Five Elements" as we understand them today but is a term which implies something dynamic, ever moving, and transforming in a regular pattern through the operation of *Qi* in nature.

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Before we trace the origins and development of the *Wuxing* concept, we should bear in mind that early Chinese thought was perennially involved with the relationship of humanity and nature. Humans were seen to hold an integral but not an assertive place in nature. They had to understand nature and live harmoniously with it. To provide a rationale for it, *Zou Zhuan* (Master Zou's Enlargement of the Spring and Autumn Annals) of the fifth century BCE says:

> There are Six *Qi* in nature. When they descend, they give rise to the Five Tastes; display themselves in the Five Colors, and are evidenced by the Five Sounds. When they are in excess, they generate the Six Diseases. The Six *Qi* are *yin* and *yang*, wind and rain, dark and light. They divide to form the Four Seasons, showing the Five Periods in sequence. When they are in excess, they bring about calamities. Excess in *yin* results in cold diseases; excess in *yang*, hot diseases; excess in wind, the diseases of the extremities; excess in rain, the diseases of the stomach; excess in dark, delusions; excess in light, diseases of the heart.

Realizing that nature is vicissitudinary, the early Chinese classified, through their observations and experiences, all the natural phenomena as well as mundane affairs in groups of fives. Classification as such was based on their perception of nature and the society in which they lived. Hence, in several pre-Qin (third century BCE) texts we come across such terms as *Wufang* (Five Directions), *Wushi* or *Wuchen* (Five Periods/Seasons), *Wude* (Five Powers), *Wucai* (Five Materials), and other fivefold categorizations. The oldest reference to the term *Wuxing* without the nomenclature for the set of five is found in the *Guo Yu* (Discussion on the Ancient Feudal States) of Western Zhou in the eighth century BCE.

The person purported to have systematized and stabilized these ideas of categorization was Zou Yan who flourished between 350 and 270 BCE. He referred to the set of Water, Fire, Metal, Wood, and Earth as "Five Powers". He cited the rise and fall of past dynasties to put forward a cosmological theory of monarchy. As a reflection of the order on Nature, the political order was subject to the Five Powers which conquer each other. This sequence later came to be known as the Mutual Conquest Order (*Xiang Ke* or *Xiang Sheng*), wherein Water conquers Fire by extinguishing it, Fire conquers Metal by melting it, Metal conquers Wood by cutting and carving it. Wood conquers Earth either by digging it up or growing out of it, and Earth conquers Water by damming it up and constraining it. Because the Five Powers dominate alternately, it is seen that the process of domination is itself "controlled" by the Power which conquers the conqueror. For example, Wood conquers Earth, but Metal controls the process. There is yet another sequence which is found in the *Chun Qiu Fan Lu* (String of Pearls on the Spring and Autumn Annals) by Dong Zhongshu of the second century BCE. The sequence gives rise to the Mutual Production Order (*Xiang Sheng*), in which the Five Powers generate each other. The sequence begins with Wood which produces Fire (being consumed as fuel). Fire produces Earth (by forming ash), Earth produces Metal (by fostering the formation of metallic ores), Metal produces Water (by liquefying itself when heated), and Water produces Wood (by nourishing the plants). If both the orders of Mutual Conquest and Mutual Production are taken together, it is seen that in the process of destruction of one Power by another, the process of change is somehow "masked" by some other process which produces more of the substrate, or produces it faster than it can be destroyed by the primary process.

Another *locus classicus* of the pre-Qin period which describes the Five Powers as Five Processes is found in the *Hong Fan* (Great Plan) chapter of the *Shu Jing* (Historical Classic). The text gives the names of *Wuxing* in numerical order, followed immediately by their respective descriptions. Thus, we have:

- Water: wetting, descending
- Fire: flaming, ascending
- Wood: (allowing to be) carved, straightened
- Metal: (allowing to be) molded
- Earth: sowing and harvesting

The description suggests five sorts of fundamental processes characterized by their respective quality in nature.

In their effort to understand the physical changes in Nature, the early Chinese tried to establish a viable system in terms of abstract ideas. In the *Wuxing* chapter of *Guan Zi* of the late fourth century BCE, the set of Wood, Fire, Earth, Metal, and Water is fitted to 72-day divisions to the 360-day year in order to show the change of seasons in an evolving manner. The set of five is associated with five types of *Qi* that bring about changes in nature. Then, in another *Wuxing* chapter in *Bai Hu Tong* (Comprehensive Discussion in the White Tiger Hall) of the first century, the word *Xing* is specially used to mean "the activity of *Qi* by the natural order." In the *Chun Qiu Fan Lu*, too, *Xing* means "activity". It is clear that *Wuxing* is no longer seen as a set of chemically or physically distinct substances, nor is it a force itself which is capable of performing actions. The *Wuxing*, then, are phases of change brought about by *Qi* in Nature.

See also: ►Yinyang

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Food Technology in Africa

RICHARD NNAMDI OKAGBUE

Food processing embodies all treatments applied to foodstuffs after harvest, capture, or slaughter to prepare them for consumption or preservation. Treatments may be single or suitably combined physical, mechanical, chemical, and biological procedures which modify foodstuffs aesthetically, nutritionally, texturally, and organoleptically.

In traditional Africa, food processing is a daily domestic or village-level activity. Women constitute the main workforce and appropriate skills are acquired informally during the process of acculturation. Male professional blacksmiths, stone-cutters and wood carvers, basket makers, and others produce the grindstones, earthenware pots, pans and plates, wooden pestles, mortars and spoons, baskets, knives, calabashes, and gourds used in the processing.

In addition to familiar food plants and animal resources some uncommon products have food uses in certain areas of Africa, depending on their availability and on the prevailing culture and religion. For example, toxic castor oilseeds (*Ricinus communis*) and leaves of the toxic legume *Cassia obtusifolia* are processed into food condiments in Nigeria and Sudan, respectively. *Spirulina*, a "vegetable" microbe, is consumed in Chad, and caterpillars called mopane worms constitute human food in Zimbabwe. Other items include dog meat, cow and goat blood in parts of Nigeria, Kenya, and Zimbabwe, and gall bladder juice, hides, and skins in Sudan and Nigeria, respectively.

First-stage processing is a preliminary treatment used to release valuable seeds and fruits from heavy pods, heads, or husks. Melon pods (*Citrullus vulgaris*), breadfruit heads (*Treculia africana*), and oil palm husks (*Elaeis guineense*) are examples, and they are generally allowed to ret or soften over a period of time. The process may occur in the farm or bush to circumvent transportation and pollution problems.

Retting occurs naturally, but it is aided traditionally by hitting the structure on a hard surface or with a machete in order to rupture it. After about a week, the rotten seed-containing pulp is scooped into a basket. Loose material leaches out, leaving the seeds which are washed and sun-dried.

Sundrying precedes other steps for treating cereal heads to release grains and for shelling legumes and other fruits like the castor seed. Dried millet, sorghum, and rice heads or husks are threshed on hard ground or pounded lightly in a mortar to detach the grains; rice is invariably pounded. Mixtures of grains or seeds are winnowed with flat winnowing baskets. Then manual screening separates the food material from the chaff.

On a large-scale sun-dried pods of legumes such as the cowpea (*Vigna* sp.) are packed in jute bags, and then shelled by being beaten by sticks or trampled upon. One method of separating mixtures of seeds and chaffs is to spread them on a mat across a distance of 4–5 m. The lighter chaffs fall-off during the throwing, and denser seeds are retained on the mat.

Overall, first-stage processing eliminates bulky wastes from harvests and prepares foodstuffs for markets and for further processing. The products mostly remain inedible or unpalatable.

In second-stage processing, foodstuffs undergo textural and organoleptic modification to yield palatable products or flours and oils. Two categories of second-stage processing will be treated—those not involving fermentation and those which are fermented.

Cooking with water, frying in oil, and roasting are commonly used methods. Individual cooked items or suitable mixtures may be pounded into sticky doughs and eaten with relishes. Pounded yam is popular in West Africa, and small amounts are also used for thickening soups or relishes. Ordinary cooking suffices for preparing some cocoyam (*Colocasia esculenta*) varieties but at least one toxic variety is detoxified by prolonged boiling.

Leguminous seeds are generally cooked and consumed with their skins (testas). However, groundnuts (*Arachis hypogaea*) and the bambara nuts (*Voandzeia subterranea*) are often cooked in the pod and later extracted manually.

Smoking is rarely used for preserving plant-based unfermented foods. In contrast, sundrying is widely practiced. Raw or lightly cooked thin slices of sweet potatoes may be so preserved in Zimbabwe, but thinly-sliced cassava is cooked and washed throughly before sundrying, to remove the cyanide and guarantee a safe product. In the Chad Republic, mats of *Spirulina*, a microscopic alga which grows in ponds around Lake Chad, are sun-dried for use as a vegetable in local sauces.

Roasting is traditionally carried out with a burning or glowing fire and is commonly applied to tubers and plantains. Among the legumes, only groundnut seeds are roasted. Cowpea seeds are dehulled, without roasting, by first soaking them in water overnight. Placing the container on the surface of water in a deep bucket or pan makes the testas float, and they are skimmed off. Wet dehulled cowpea seeds are pounded further and ground into a slurry which is seasoned and fried in hot palm oil to form palatable balls called *akara* in Nigeria.

Many kinds of dried foodstuffs are processed into flours. In Southern and Eastern Africa, flours from grains are called meals, as in maize meal, and production begins with pounding and winnowing to remove coarse chaffs. The grains or the mortar are then moistened to prevent scattering during a second pounding. The material is then sun-dried for a few hours and finally ground on a grindstone. The finished meal is sun-dried on a mat before storage or use.

Yam and sweet potato tubers are peeled, chipped, and blanched by soaking the chips overnight in hot water before sundrying, pounding, and grinding. In processing cassava flour, chips of peeled and sun-dried tubers are ground.

Many other types of foodstuffs are processed into flour. Shelled groundnuts are roasted and ground for meat seasoning in Nigeria and as a source of butter in

Zimbabwe. Various dried spices are also processed into powders.

Cooking oil is extracted from raw or cooked palm fruits and from roasted groundnut seeds. By pounding oil palm fruits in a deep mortar the oil-laden fibrous pericarps are abraded from the kernels which are sorted manually. Batches of the fibrous mass are subsequently warmed in a wide-mouthed earthenware pot to melt the oil. Then suitable portions are pressed between the palms of the hands and the oil flows into a bowl or other container.

Food processing by fermentation is widespread in Africa and various cultures have developed methods of fermenting selected food resources for different purposes. Virtually every kind of foodstuff can be fermented, and suitable processes produce heavy main course meals, condiments, and flavor enhancers, nonalcoholic and alcoholic beverages, meat substitutes, and foods for the elderly, infants, and the convalescent.

Cassava tuber is processed mainly by fermentation to detoxify it by eliminating the cyanogenic glucosides linamarin and lotaustralin and to impart desirable flavors. Important fermented products from grated material include *gari* (West Africa), *attieke* and *plakali* (Ivory Coast), and *oyoko* (Zaire).

Major products of fermenting cassava are *chikwange* (Central Africa), *ntuka* (Zaire), and *fufu* (Zaire and Nigeria). The fermentations are retting processes because they soften the tubers. For *chikwange* and one form of Nigerian *fufu* the fermented pulp is mashed and sieved through a basket into a cloth bag; the solids are concentrated by pressing the water out. Meals are prepared by steaming portions of the processed material, and then kneading, boiling, and pounding into a gel. In Zaire the fermented pulp is steamed (*ntuka*), or sun-dried, milled, and cooked (*fufu*).

African cereal-based fermentations result in diverse foods and beverages which satisfy different nutritional needs. Maize (*Zea mays*), sorghum (*sorghum bicolor*), and various millets – pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*) – are the fermentation substrates and products include acidic porridges, nonalcoholic beverages, and opaque beers.

The first step in preparation of acidic nonalcoholic beverages and porridges is soaking the cereals. Subsequent sieving, sedimentation of solids, and decantation of liquor leaves a product which can be molded into various sizes for sale. They are particularly useful for infant weaning and convalescent feeding.

Examples of acidic nonalcoholic drinks are Southern African *mahewu*, Nigerian *kununzaki*, and Sudanese *hulumur*. In *mahewu* preparation, a suspension of maize meal in boiled water (1:9) is cooked and cooled. Some wheat flour is added and the drink is ready after a day's fermentation. Nigerian *kununzaki* uses flour produced by grinding grains soaked in water for 1 or 2 days. Sudanese *hulumur* is prepared by flavoring cold water with flat sheets of fermented and baked sorghum dough prepared with equal amounts of flours from malted and unmalted sorghum.

African acidic alcoholic beverages are produced from malted grains. Malting involves germination of the appropriate grain followed by malt grinding and mashing in warm water to saccharify the malt. Unmalted grain or another carbohydrate source may be added to the mash before fermentation, which may proceed naturally or by induction with a starter from a previous brew.

Clear beers are relatively rare in Africa. Nigerian *otika*, Cameroonian *amgba*, and Sudanese *assaliya* are exceptions. *Talla* is an Ethiopian home-brewed beer which differs from the others in some respects. First, it is brewed with barley or wheat, hops, or spices. Secondly, it has a smokey flavor due to the addition of bread darkened by baking and use of a fermentation vessel which has been smoked by inversion over smoldering wood.

Sugary plant juices and saps and honey are the substrates for wine and spirit production. West African palm wines are produced by fermenting saps from oil palm trees (*E. guineense*) and from Raphia palm trees (*Raphia* spp.). In Zimbabwe sap from the ilala palm tree (*Hyphaene benguel-lensis*) is fermented into wine, while in Northwest Africa a wine called *lagmi* is produced from the sap of the date palm. Over-ripe bananas and plantains are also used for wine production in Southwestern Nigeria. For West African palm wines, the best known, fresh juice tapped into gourds contains up to 10% sugar and has a neutral pH. The fermentation occurs naturally and in 24 hours lowers the sugar content considerably, acidity develops, and alcohol builds up so that the wine becomes intoxicating.

Spirits are processed in Africa by distillation of fermented sugary substrates. Zimbabwean *uchema*, Nigerian *ogogoro*, and Ghanaian *ekpeteshi* are distilled from Zimbabwean ilala palm wine and from West African palm wines. Kenyan *chang'aa* and *Nigerian kai–kai* are distilled from fermented cane sugar juice. Generally the alcoholic content of African spirits ranges from 20 to 30%.

Food fermentations based on oilseed and leguminous seeds are sometimes called vegetable protein fermentations. West African *iru* or *dawadawa* (from locust bean), *ugba* (from oil bean), various *ogiris* (from melon, fluted pumpkin, *Telfaria occidentals*, castor bean and sesame), and Sudanese *sigda* (from sesame oilseed press cake) are fermented vegetable protein foods, and they are flavor enhancers.

Sudanese *kawal* produced by fermentations of leaves of a toxic legume *C. obtusifolia* and Nigerian *ule* are examples of African food products of leaf fermentation. *Kawal* and *ule* are flavoring materials for stews and other relishes.

Meat fermentation is uncommon in West Africa. However in Sudan virtually every part of a carcass including bones, hide, and gall bladder juice is fermented for food purposes. Fermented gall bladder juice is called *itaga*. It is prepared by adding some sorghum flour or grains to the juice which is then hung up to dry slowly. *Itaga* is pounded and used as a kind of spice for fatty meat dishes.

Fish is processed like meat, and fermentation is also uncommon. It appears to be a last resort for preserving a day's unsold catch. *Bonome* and *guedj* are fermented dried products of Ghana and Senegal, respectively. Fresh fish is allowed to undergo putrefactive fermentation in the open air for 20 hours. It is then eviscerated, soaked in salty sea water, and dried in the sun for 2–4 days with or without filleting. Sudan has a variety of fermented fish products including pastes and sauces prepared from fresh water Nile fish.

Many insects, especially gregarious and seasonal types, were traditionally acceptable as food in Africa. Examples are locusts, swarming winged reproductive termites, the large cricket (*Brachytrypes*), and caterpillars of the African silkworm (*Anaphe* spp.). Traditional processing of insects included cleaning and salting, then roasting or tying in parcels and boiling. Although the practice is now restricted to isolated areas of the continent it is noteworthy that in Zimbabwe the commercial product *madora*, also called mopane worms, consists of edible caterpillars. *Madora* is available in markets or in supermarkets. The caterpillars are generally squeezed after capture to press out the digestive fluid, then salted and preserved by sundrying.

The art of fermenting milk is widespread in Africa. Cattle and camels are important dairy animals, and milk fermentation products vary widely. For example, *jben* and *ayib* are Moroccan and Ethiopian cheeses, *nono* is a Nigerian yoghurt-like product, and Zimbabwe and Sudan also have fermented milk products. African milk fermentations occur naturally with attendant souring or coagulation, the milk having usually been collected into clay or earthenware pots or animal skin bags, gourds, or calabashes. They are often churned to produce butter. Moroccan *jben* is prepared by placing the coagulated milk (*raib*) in a cloth at room temperature and draining the whey. In Kenya various additives such as wood ash, animal blood, urine, and sometimes leafy vegetables may be added to preserve a fermented sour milk called *maziwa lala*.

Scientific Bases of Some Traditional Practices

African traditional food processing is a cultural activity which evolved independently from modern science and technology. Nevertheless valid scientific explanations can be offered for many food practices.

In many traditional fermentations, starters consisting of small amounts of previously fermented materials are introduced into new processes. Scientifically speaking, the starter contains a dense population of relevant microbes which accelerate the new process. Also, most fermentations are carried out in warm conditions, or fermentation time is prolonged in cold weather; these practices are consistent with scientific knowledge of beneficial and adverse effects of warmth and cold on the growth and activities of microbes.

Traditional food preservation with plant extracts is exemplified in the processing of Nigerian palm wine and *nono* with *nche* and *kuka*. Both preservatives inhibit spoilage microorganisms by means of chemicals: *nche* contains phenolics and alkaloids, and *kuka* contains tartarates. Again, the use of small amounts of urine, among other things, for improving the shelf life of Kenyan sour milk has been explained in the context of the lactoperoxidase system which inhibits Gram negative, catalase positive bacteria in milk. Traces of hydrogen peroxide and thiocyanate are known to be present in urine and these may exhibit antimicrobial effects together with lactoperoxidase which normally occurs in bovine milk.

Traditional food softening or flavoring with extracts from ashed monocot heads or husks is exemplified by the use of Sudanese *kambo* from sorghum, Nigerian *ngu* from palm oil husk, and Zimbabwean products from yellow nut grass (*Cyperus esculentus*) and maize cobs. Ashing concentrates inorganic elements, and high levels of potash in the leachates influence flavor and soften foods by hydrolysis.

African traditional food processing involves diverse food resources, equipment, practices, and products. Productivity is low, and final products often lack good hygienic quality, uniform composition, and predictable shelflives.

Research efforts to modernize food-processing systems have been intensified in African institutions. Production of Southern African opaque beers and *mahewu*, Nigerian *gari*, *dawadawa*, and *poundo* yam have become industrialized, and microbiologically safe processes have been developed for production of Moroccan and Ethiopian dairy products. These developments are encouraging and continuing research efforts will probably assist future generations in preserving Africa's rich traditional food heritage.

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Food Technology in China

H. T. Huang

Agriculture started in China with the domestication of rice in the middle reaches of the Yangtze Valley at about 8000 BCE. Rice was followed by millet (at about 5000 BCE), wheat and barley (1500 BCE) and soybean (1000 BCE). In the classical period (1000–200 BCE), the principal grains of the realm were millet (both panicum and setaria), rice, wheat, barley, and soybean. Much ingenuity was expended by the Chinese to develop methods for processing these crops into attractive and nutritious articles of food and drink.

The kernels of both rice and millet are relatively soft. They were steamed to produce tender, palatable granules called *fan*. Pottery steamers of great antiquity (4000–5000 BCE) have been found in the neolithic sites in Banpo near Xian in the north, and at Hemudu near Hangzhou in the Yangzi delta. It was probably the use of steaming that fortuitously led to the discovery of a distinctive technology for the conversion of cereal grains into alcoholic drinks.

The Discovery of *Qu* (Chinese Ferment)

The fragrant, fluffy *fan* granules obtained by steaming rice grains were not only appetizing to humans, but also highly attractive as a medium for the growth of airborne fungi, such as those of the genus *Aspergillus*, *Rhizopus*, or *Mucor*. As these fungi proliferate they produce enzymes which hydrolyze the starch in the granules into fermentable sugars. Yeasts then multiply on the hydrolyzed granules and convert the sugars to alcohol. This mixed culture of fungi could be used to inoculate larger amounts of *fan* to produce an alcoholic drink, or dried and stored as a stable solid product known as *qu* (translated as *ferment*) for use in future fermentations. As we shall see, in addition to its role in alcoholic fermentations, *qu* ferment was the foundation upon which a rich array of fermented foods were later developed.

Alcoholic Drinks

The use of *qu* to make an alcoholic drink or wine called *jiu* was probably practiced in China as early as 2000 BCE. The technology for *qu* and *jiu* reached a mature level by the Han Dynasty (206 BCE–AD 220). Extensive recipes for preparing varieties of *qu* and *jiu* (as well as vinegar from it) are given in the *Qimin yaoshu* (Important Arts for the Peoples' Welfare), of AD 544. In making wine, *fan* (steamed millet or rice) was mixed with *qu* and the semisolid medium allowed to ferment until the substrate was depleted. The semisolid mash was then pressed and clarified to give the finished wine. One interesting innovation was the cumulative addition of fresh *fan* to the medium before the substrate was spent. This technique made it possible for skilled brewers in the sixth century to produce wines with alcoholic contents that were comparable or even superior to those of grape wines in the West.

During the Song Dynasty (AD 960–1280) the art of heating the wine before storage, later called pasteurization, was introduced; a red *qu* based on strains of *Monascus* sp. was developed, leading to the production of the so-called yellow or red wine. Although bronze stills were known as early as the Han, distilled spirit did not become commercial until after the Song dynasty. The fermented mash was placed directly on a grid in a boiler and the alcohol carried over by steam distillation. The result was a spirit with a strikingly rich flavor and an alcohol content of greater than 50%.

Malt Sugar

Sprouted rice or millet, *nie*, was of equal antiquity as *qu* in China and it has been suggested that some of the earliest wines might have been made with *nie* as the saccharifying agent. But soon *qu* displaced *nie*, and the *nie*-based fermentation died out. *Nie* from wheat or barley, however, lived on as the agent for converting steamed millet or rice into malt sugar, the most important sweetener in ancient China. Although its importance declined somewhat when the refining of sugar from sugar canes was introduced from India in the Tang Dynasty (AD 618–905) malt sugar continued to be a popular treat in the Chinese diet until the present day.

Products from Wheat Flour

Since the kernels of wheat are hard, they cannot readily be made palatable by boiling and steaming. Thus, wheat was less popular than millet or rice in ancient China. However, the situation changed during the Han when mills for grinding wheat into flour or *mian* became widely available. The dough made from *mian* could be processed into a dazzling variety of delicious pastas, cakes and breads (including leavened breads). Most of these products were cooked by steaming or boiling. As a result, wheat flour soon became the staple food in the North while rice remained the staple food in the South.

Probably the best known Chinese food processed from wheat flour is the filamentous noodle, *mian tiao*, which was first made in the second century AD. There is, however, no evidence that Marco Polo ever brought filamentous noodles from China to Italy. Filamentous pasta was already known in Italy before Marco Polo was born. It appears likely that the concept of filamentous noodles had traveled from China to Italy by transfusion along the Silk Road in the tenth to twelfth centuries.

Another important product processed from flour is wheat gluten *mian jin*, an valuable source of protein for vegetarians. It is obtained by the continuous washing of wheat dough with water. The phenomenon was first described in the *Qimin yaoshu* (AD 544), but gluten did not become a popular component of Chinese foods until the Song.

Soybean Processing

Although soybean is an excellent source of protein, it is hard to cook and difficult to digest. Three methods have been developed to process soybeans into wholesome, attractive, and nutritious products. The first is simply to allow the beans to sprout in the dark. Soybean sprouts were known before the Han as a medicament; they did not become popular as food until the Song. Since then sprouts from both soybean and mung bean have remained standard fare in the Chinese diet.

The second method is to process the beans into *doufu* (bean curd). The steps involved are: (1) soaking the beans in water overnight, (2) grinding the beans to a puree, (3) filtering the puree through cloth, (4) heating the milk to near boiling, (5) adding a coagulant, such as bittern, to the cooled milk, and (6) pressing the soft curd in a wooden frame. The procedure is depicted in a mural in a late Han tomb (second century AD), although the product did not become commercialized until the late Tang. Since then *doufu* has been the most important vegetarian source of protein in the Chinese food system. Soymilk, however, was not accepted as a food until the eighteenth century.

The third method is to ferment the cooked beans with *qu* in a high salt medium to give a triad of relishes and condiments; they are *shi*, fermented bean relish, *jiang*, fermented bean paste, and *jiang you*, soy sauce, probably the best known processed soybean product in the West. When cooked soybeans were incubated with *qu* and salt, the product was *shi*. When they were incubated with *qu*, wheat flour and salt, the product was *jiang*. Both *shi* and *jiang* were already made on a large scale in early Han. Recipes for their preparation can be found in the *Qimin Yaoshu*. Soy sauce was simply the liquid drained from *shi* or *jiang*. It was known during the late Han, but the name *jiang you* did not come into common usage until the Song.

Much of this distinctive food technology was transmitted to Japan during the Tang and later dynasties. Thus, *qu* and *jiu* are known as *koji* and saké in Japan; *shi*, *jiang* and *jiang you* evolve into *natto*, *miso* and *shoyu*; while *doufu* remains as *tofu*. All these products have become integral parts of the food system in Japan, Korea, and Vietnam. They are now gaining acceptance in the West.

However, the best known dietary product from China is actually a drink. Tea was first prepared by steaming, crushing, and drying the leaves of *Camellia sinensis* during the Han. It became widely popular during the Tang, and was disseminated to the West in the seventeenth century. Tea and coffee are now the two major beverages consumed throughout the world.

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Food Technology in Latin America

Judith Vidal

About 5000 years BCE, native populations in the Caribbean and Latin America developed food technologies which enabled them to exploit their natural biota and become settled. By the time of the Columbian encounter, Indians had evolved unique agricultural techniques suitable for efficient food production in various terrains and climates. Their indigenous staples were cassava (*Manihot esculenta*), maize (*Zea mays*), potatoes (*Solanum tuberosum*), and yams (*Ipomea batatas*), beans, and squash supplemented by fruits and vegetables, fish, turkey, deer, dogmeat, and guinea-pigs, as well as assorted beverages and flavorants.

Food technology began with soil preparation and with the selection of seeds, roots, tubers, or cuttings. The ground was cleared through slash-and-burn and girdling, which is removing a ring of tree bark. Farmers then worked the earth into numerous knee-high mounds several feet in diameter (*montones*), collectively called *conucos*, among the stumps in irregularly shaped fields, or *milpas*, fertilized by ashes and decaying vegetation. These mounds produced less water runoff, and hence less erosion, than traditional European fields plowed in rows.

In the Caribbean, Middle America, and South America, *conucos* were planted with bitter cassava, with a vegetable triad such as maize–beans–squash, or with potatoes in the Andean highlands. In the lake regions of Mexico, floating garden islets (*chinampas*) formed of dense intertwining roots covered with soil and plants could be paddled over the water. In the Andes, irrigated stone-walled terraces (*andenes*) allowed farming steep grades in narrow strips at higher altitudes dominated by llamas, quinoa, and potatoes, descending in ever broadening tiers to cacao, cacti, and tropical fruits at lower levels, each with its own biota, creating a diverse diet in a small vertical space. Where the parched soil of valleys was unyielding, natives removed the earth's surface in expanses as large as an acre to form *hoyas* (pits) which reached natural moisture and permitted cultivation.

Indians learned to cultivate strains of indigenous flora by taking cuttings, by planting tubers, or by carefully selecting seeds which they planted individually in small holes poked by a planting stick called a *macana* in the Caribbean and a *taclla* in the Andes. These methods produced more uniform quality than European broadcast seeding and resulted in higher caloric production per acre than Old World counterparts of wheat, rice, millet, and barley.

The bitter cassava (also known as *yuca brava*, manioc, mandioca, tapioca, and *farinha*) roots from 2 to 6 in. in diameter were dug up, peeled, and grated. The wet pulp was then stuffed into long mesh baskets and hung from a beam which allowed for twisting to express the poisonous prussic acid. When the toxic juice was removed, the pulp was forced through basket sieves or pounded, and the resulting flour was spread in flat three-foot cakes on hot stone grills or dried and stored for later use. The poisonous liquid was safe to drink after boiling. From Colombia southward down the Pacific coast of South America, a nontoxic sweet cassava was similarly processed and often made into preserves.

The true staff of life for most of Latin America was maize. This Indian corn occurred in hundreds of varieties and colors. Indigenous cultures hybridized the silky tassels by hand to breed the most desired traits. Some kernels were so hard they had to be soaked or chewed before boiling gruels. Women pounded grilled kernels with stones to produce a flour meal for tortillas or other dishes. Dried grain was also stored indefinitely in elevated, aerated storage silos.

Indians of the upper Andes invented freeze-dried potatoes by alternately exposing the tubers to night frost and sunshine. Within a few days all the water was removed, leaving a potato preserve called *chuñu* which could be further whitened or reconstituted by steeping in water. Lightweight and easily transported, the *chuñu* could be preserved indefinitely like cassava or maize. There were over 3,000 types of potatoes, sweet potatoes, ocas, and other tubers. Bean and seed pulses were also important foods throughout Latin America. They too were dried for preservation if not cooked immediately.

In addition to drying, there were several other technologies for preserving foods. These included salting, pickling, fermenting, toasting, and ensiling. Fish was salted as was meat cut into strips. Brine solutions and lime mixtures were also used. Vegetables and fruits were pickled in a variety of herbal vinaigrettes. Fruit and vegetable juices were fermented and distilled into alcoholic beverages which were also used as preserving agents.

Among native beverages, cacao (*Theobroma cacaoyer*) was the most lucrative exchange commodity in New Spain and parts of Peru. Cacao trees were grown by Indians in orchards shaded by large "mother" trees. When the large red pods ripened, they were picked, and hundreds of bitter-tasting seeds were removed by chewing the luscious fruit. The sun-dried seeds were used as money or ground and roasted for a bitter brew restricted to nobles and ceremonial rites. Under Spanish colonization, the chocolate beverage gained widespread popularity in Mesoamerica.

In the Pampas, another stimulating beverage came from a native tea known as *maté*, steeped in boiling water like East Indian varieties. When coffee was introduced to tropical Latin America, it was prepared much like cacao and was widely consumed. All three of these nonalcoholic beverages grew in popularity with the increasing availability of sugar and vanilla which replaced pepper as the preferred seasoning.

In addition to flavor enhancement, many herbs and spices were used to preserve foods and to add medicinal benefits. Seaweed supplemented natural salt sources in Andean diets to protect natives from goiter. Tropical fruits added vitamin C. Cinnamon, cloves, and capsicum peppers preserved as well as flavored foods. Sarsaparilla was a refreshing beverage which soothed gastrointestinal ailments. Another vegetable product, *guayacán* treated syphyllis while *cuasi*, a valuable insecticide, also eased fever symptoms. The most important treatment for malaria came from quinine or *chinchona* which remains a viable cure as well as a popular tonic water.

Alcoholic beverages were consumed in moderation before conquest. In Mexico, the agave or maguey was fermented and distilled into pulque, mezeal, and tequila. Maize was fermented into a beer-like beverage called *chicha* which was popular throughout Middle America and the Andes. *Chicha* could also be fermented from a variety of fruits. Other alcoholic beverages came from fermentation of potatoes, cassava, and tropical fruits such as pineapples and bananas. These were sometimes mixed into brandy called *aguardiente*. None of these beverages became popular in Europe, but rum – fermented from cane sugar – became commercially successful throughout North America and Europe.

Prior to European contact, indigenous populations had few meat sources and no beasts of burden other than the llama and the dog. With the introduction of horses, cattle, oxen, sheep, swine, goats, mules, and donkeys, they gained transportation, meat, and power to plow, haul, and operate mills. They also received protein-rich meat and dairy supplements to their diets. By-products from domesticated and feral herds included fibers, leather, tallow, bones, and horns.

Among the food cultigens brought to the New World, the grape–grain–olive culture remained heavily European. Sugarcane and coffee, however, dominated enormous regions where native labor consumed the stimulants while working plantations. Both commodities were labor-intensive requiring hand planting and harvesting. Sugar works (*trapiches* or *engenhos*) used human, animal, or water power for the crushing mills which released the sugary syrup. Slaves operated a train of boiling vats to purify and clarify the liquid for evaporation. The resulting muscovado sugar was 96% pure and was packaged in cones or loaves for shipment to European refineries. Hand-picked coffee beans were spread on patios to dry before roasting and shipping.

Many of the technologies used by indigenous populations are practiced today throughout rural areas of Latin America. Scientists are studying their techniques and lore for insights into environmental protection, expanded food production, and medicinal applications. Global dietary diversity has been accompanied by language enrichment as a result of food exchange. As a result of Latin American food technology, words such as barbecue, olla, mezquite, cassava, tapioca, quinine, banana, palm, tomato, etc. have joined the alimentary menu.

The Indians practiced ecological efficiency and perspicacity unrivaled by the colonial powers who imposed a wheat–wine–oil–meat agriculture in lands more suited to manioc, maize, and potatoes. None the less, dietary diversity has been enhanced throughout the world as a result of native Latin American technologies which first unlocked the secrets of preparing and preserving exotic New World foods which have become staples for subsistence.

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See also: ►Potato, ►Ethnobotany, ►Sugar, ►Crops in pre-Columbian Agriculture, ►Agriculture

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Food Technology in the Pacific Islands

Richard Beyer

The range, variety and sophistication of food preserving and commercialisation activities throughout the Pacific Island Nations (PINs) are as varied as the climate, agricultural framework and culture. The techniques so necessary for basic survival have been the foundation of food preservation but the practises have been refined and expanded since European arrival. Countries such as Fiji and the Marshall Islands are now home to highly sophisticated food processing operations sponsored by multinational companies that have been attracted by tax incentives and relatively low wage rates. The ethos of food processing and food exploitation has infiltrated wider communities as the international food standards defined by Codex Alimentarius have been adopted by *inter alia* Vanuatu, Samoa, Tonga, the Cook Islands and Fiji. Countries such as Kiribati and the Federated States of Micronesia remain at the other end of the spectrum but the importance of maintaining food quality has been strengthened by the mandatory conformance to the hazard analysis and critical control points (HACCP) system of quality maintenance for economically important fish exports to the US and EU markets (Beyer 2000, 2003a,b,c). The welfare of the people of the Pacific nations is nevertheless highly dependent on subsistence farming and traditional preserving techniques (Laban and Swain 1999) particularly of fish and starchy staples – cassava, taro, plantain, yam, breadfruit and sweet potato (Bradbury 1987).

Traditional Preserving Techniques

Historically, processing has been confined to practises that will preserve foods to reduce waste and to extend availability, particularly for foods with very short seasons (Greenwell 1947; Parker 1967; Root Crops Development Newsletter 1982; Kwatia 1986a,b, 1988; Atkinson 1990; Kordylas 1991; Root Crops Processing 1993; Beyer 2001). Traditionally, foods have been preserved using techniques that exploit environmental factors (Atchley and Cox 1985; Atkinson 1990). Sun drying has been used extensively as a means of extending shelf life because of the high ambient temperatures prevalent in the tropics. The process is benign – fish, occasionally pork, vegetables and fruits are merely sliced and laid on racks to dry. If prevailing conditions permit, the foods reach a final moisture content that will inhibit mould growth and the products are edible although not always appetising. In many cases vegetables turn brown, mould may grow before the drying process is completed – or occasionally later if the dried food reabsorbs water as a result of increases in relative humidity during storage. Other products may bleach and become tough.

A number of readily available chemicals have been used to stabilise foods. Salt obtained by sun-evaporation of seawater has been smeared onto root crops to prevent bacterial and mould growth. In other cases, the vegetables are dipped in seawater prior to drying and the salt concentrates during the drying process. Sun-dried lime segments and evaporated lime juice have been used to increase the shelf lives of some root crops and bananas – the vitamin C and the low pH (citric acid) both act as preservatives. Dusting with wood fire ash has been used to prolong the shelf life of breadfruit and yams. In this case, the high pH is hostile to moulds and other bacteria.

Many of these traditional preserving techniques continue to be appropriate for the preservation of root crops in the rural areas. Political upheaval in countries throughout the region has retarded economic progress, and economic empowerment has proceeded at rates below aspirations. Traditional food preservation techniques remain relevant but the end products enjoy declining popularity – particularly among the young. Some of these traditional products continue to appeal to older members of the community and to older expatriates now living in Australia, New Zealand, Canada and the USA. As a natural evolution, there are isolated instances where those products have formed the basis of export industries. Where markets have persisted for traditionally preserved foods, processes have been standardised with conformity in manufacturing techniques.

Nutritional surveys around the region however indicate that the consumption of traditional foods is decreasing. Such industries as the garment industry and tourism have provided increasing employment for women. As their time for food preparation has become eroded, they have become less tolerant of traditional foods such as yams, cassava and taro in favour of more convenient (often cheaper and lighter) alternatives such as rice and flavoured noodles (FNFC 1997; Hodge et al. 1997; Food Security: The New Millennium 1999; Paterson and Crossland 1999; FNFC 2000).

Travel, tourism urban drift television and other lifestyle changes have transformed food choices in the PINs. Although much of the food is imported, local entrepreneurs have copied and modified a number of these imports and form the basis of a wide range of small scale processing operations (Beyer 2001).

Conventional Preserving Techniques

Dehydrated Products

The cost of removing moisture from foods rises exponentially as the moisture content drops (Brennan 1994). Thus it is in the processors' interest to remove only that proportion of water that impinges on the keeping quality of the finished product. Not only are processing costs reduced to a minimum but also the product retains some water, which adds to the weight. Unfortunately, intermediate moisture foods (a_w values between 0.35 and 0.6) deteriorate unless they are protected with preservatives, humectants or antioxidants. Only at very low moisture contents (a_w values < 0.3) is deterioration kept to a minimum. The exceptions are non-hydrolytic reactions, which usually take place in fats and oils. Rancidity will continue in low moisture foods and may occur even faster than in moist foods because thereactants are very concentrated by the lack of moisture. It is important therefore that low moisture foods are protected with antioxidants. Antioxidants such as butylated-hydroxy-toluene (BHT) and butylated-hydroxy-anisole (BHA) and even ascorbic acid can be used.

Recent innovations in dehydration and drying are directed towards reducing the relative humidity of the air used for drying by removing the water vapour rather increasing its temperature. So-called heat pump dryers pass heated air, which has previously been used for drying, over cooling coils. The water vapour in the drying air condenses on the cooling coils and thus the relative humidity is reduced. The same air is used repeatedly on this drying cycle. The low temperatures used in this technique cause less oxidative damage and food dried by this means is usually much higher quality. The heat pump dryers are used in some PINs for products where ultimate retail price advantage justifies the capital expenditure and the running costs, which in turn depends on the cost of electricity.

Throughout the PINs some success has been achieved in early trials using secondary air dryers. Secondary air dryers rely on drying an intermediary component – commonly coconut husk using wood-fired drying kilns. Ambient air is then circulated around the pre-dried coconut husk, which removes the water vapour. This reduces relative humidity of the air that is then passed over the food. The food – particularly in the latter stages of drying – is not subjected to high temperatures and therefore suffers less deterioration.

Modern processing techniques have been applied to a number of products including dried cassava dalo, fruit slices and some thinly sliced fish. The sliced product is immersed in a solution containing 150 ppm of sodium metabisulphite (or 200 ppm ascorbic acid). For vegetables they use 1–3% w/v of sodium chloride (soy sauce is used sometimes especially with fish). The slices are then dried on racks in a heat pump drier. The maximum outlet temperature of the drying air is 55°C, which is sufficiently low to prevent browning due to caramellisation of the simple sugars. The relative humidity of the outlet air is 55%, which gives a value for water activity of a_w of 0.55. Some sulphite is lost during the later stages of drying as sulphur dioxide.

These products are then shelf stable and do not brown on storage. Residual polyphenolase activity is inhibited by sulphite or ascorbic acid.

Dried granules from the starchy staples have also been developed as the raw material for extrusion. Extrusion technology has been applied to corn and rice starch and combinations of them. During extrusion, granules are forced at high pressure through a heated die. At the very high temperatures and pressures, the starch molecules align in the direction of shear and superheated water boils off rapidly as the pressure on the mass is released. This opens out the matrix to give the familiar honeycomb texture, which is a characteristic of puffed snack foods. Cassava granules in particular perform very well using this technology and preliminary trials have indicated that cassava is a likely candidate for future research and development (R&D) programmes.

Canning

Dalo, cassava, breadfruit and some local vegetables (e.g. *duruka*) and fruits have been canned and exported for some 12 years. The very high temperatures used in canning are responsible for significant damage to the texture and flavour of fruits and vegetables. The products have very soft textures and the heating regimen results in warmed over flavours characteristics of Amadori compounds. These quality characteristics are thus significantly different from fresh items. The market is somewhat resistant to such quality features and sales are consistent but small. Similar products canned in coconut milk are marginally better and sales figures are higher but coconut milk supplies are inconsistent.

Fruit and vegetables processed in retortable pouches (polypropylene/aluminium/foil/nylon/polyethylene laminate) have better quality characteristics because the heat penetrates to the centre of the pouch faster, but the technology is not readily available in the Pacific region (overpressure retort).

Conventionally canned fish (tuna) is the largest single item of canned food produced and exported from the Pacific region with very large factories in Fiji, American Samoa and the Marshall Islands and smaller factories located in Tonga and Manu Samoa.

An alternative technique (Beyer 1998) is a multiple pasteurisation technique. Foods are packed in polyethylene/nylon bags and vacuum-sealed in such a layout that the products are not touching and that heat can reach every food surface. They are then immersed in boiling water for sufficient time for the heat to penetrate through the bags so that the surfaces of the foods reach at least 80°C for 15 s. The pouches are then cooled using cold water to prevent over cooking.

In low acid foods, this is sufficient to destroy the vegetative cells of bacteria but not the spores of thermophilic organisms. However the heat shock is sufficient to encourage germination of the spores. These are then destroyed by pasteurising again 24 h later by immersion in the boiling water bath for enough time for the temperature at the surface of the vegetable to reach 80°C for 15 s. As an extra insurance measure, the package is heated in the same way on a third day. This is sufficient to destroy surface bacteria. With carefully handled vegetables, the deep tissue will be sterile. Thus this technique should result in pack sterility. In the event that the packs are still not sterile – which would be manifest by blowing – the product can be reheated for a fourth time since the heat penetrates to the same depth each time and damage to the product is still confined to the outer surface. The technique means that relatively little heat is applied to the surface of the vegetable and the damaging effects of the heat penetrate only a short distance into the tissue. The vegetable has the appearance texture and taste of fresh vegetables.

Freezing

In the short period of 30 months preceding May 2000, an export industry in free-flow frozen root crops was established, which peaked in February of 2000. At its maximum volume, 66 tonnes/month of frozen cassava were being exported to Australia (Beyer 2000). Much smaller volumes were destined for New Zealand. Trial shipments were also sent to Japan, but large-scale exports were not possible because of cyanide levels that exceed Japanese standards. An unexpected demand has arisen for frozen root crops however, and production level is well below market demand.

Fry Drying

There is now a plethora of small fried snack root crop and plantain producers throughout the PINs. Products are becoming commonplace and some are emerging as export products. Entrepreneurs are encouraged to use these products as a basis for increasing market depth and width through product development programmes described as more appropriate technology and products. By mixing into dough there are many opportunities to:

- Extend using other ingredients
- Improve acceptability by adding flavours
- Improve nutritional value by adding other ingredients such as carrot and tomato (vitamin A)
- Add improvers to extend shelf life
- Produce more consistent products

The cooking medium can have a significant bearing on the acceptability of the final product. Commonly soya bean oil is used, since it is the cheapest of the frying oils. The viscosity of oils is temperature-dependent. Oil temperature should be high as the product is removed. At high temperature, the oil is mobile and drains from the product easily. At low temperature, the oil adheres to the product, thereby increasing costs (oil is commonly very expensive in the PINs). Fried snack foods with high oil contents are more prone to rancidity during storage, they are nutritionally less desirable and the mouth-feel is poor.

Oils used for cooking should therefore be heated to temperatures a little below the smoke point and relatively small quantities of product added to it, to prevent excessive cooling. Used oil should never be topped up with fresh oil since rancidity is autocatalytic – the products of rancidity catalyse the onset of rancidity. Thus used oil should be stored and allowed to settle. It may be washed with water and the (more dense) water layer drained. It can then be shaken with dried calcium chloride that can be subsequently removed from the oil by filtering (and re-dried for repeated use). The used oil pooled in such a way can be used for several processes after it would normally have been discarded.

Rancidity is accelerated by ultraviolet light, some divalent metals such copper, (cast) iron and zinc and oxygen. Product keeping quality can thus be enhanced by high quality processing equipment fabricated from stainless steel and by using packaging material (usually incorporating foil) which is opaque to ultraviolet light and which prevents the transmission of oxygen. Vacuum packing improves keeping quality even further.

An antioxidant – an agent that captures free radicals – will also protect the product. Oils are frequently sold with antioxidant added. The antioxidants of choice are BHA or BHT. Unfortunately, these antioxidants are volatile and are lost after only two or three frying cycles so that they do not carry over into the final product. This assists the oil manufacturer because oil must be replaced more frequently, but the snack food is not protected to the same degree. A preferred antioxidant is tertiary butyl-hydoxy-quinone (TBHQ), which is not volatile and which carries over to the product for longer period. This affords antioxidant protection after the product is packaged and will assist in prolonging shelf life.

Current Food Activity

Commercial factors have been responsible for shaping the current status of food technology in the Pacific region. Unlike more developed regions of the world however, the strong cultural foundations have enriched the industry with the modernisation of traditional food preserving methods. Liberalisation of migration policies has resulted in alarming population movements from the island nations to Australia, New Zealand and the USA, however these immigrants have become nuclei markets for exported traditional foods. More than that, they have become ambassadors in the role of introducing new foods to their newfound fellow consumers.

Hence the region has a spectrum of food-related activity not only in the degree of sophistication of the technology but also in the demands of the markets.

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Forestry in India

Deepa Pande

One of the earliest civilizations of the Indian subcontinent was that of the Indus Valley (third or fourth millennium BCE). It was here that cedar (*Cedrus deodara*) and rosewood (*Dalbergia latifolia*) used for coffins was found. A wooden mortar of ber (*Zizyphus mauritiana*) for pounding grain and charred timber of *Acacia* spp., *Albizzia* spp., teak (*Tectona grandis*), haldu (*Adina cardifolia*), and *Soyamida febrifuge* were also found. This shows that Neolithic people not only made extensive use of wood, but also understood its particular characteristics for different purposes. This concept today is known as forest utilization.

Evidence of tree worship during the Indus Valley civilization is exhibited by various seals of the Harappan culture which depict the pipal (*Ficus*) and weeping willow (*Salix*) trees. Trees were an essential and integral part of the life support system and considered existing agencies of the creator of God.

Just as forests played an important part in Vedic India, tree worship was also practiced by the Aryans. Because of the human dependence on trees, they were venerated and protected by religious injunctions; their planting was encouraged by a promise of eternal bliss in future life. *Ṛgv̄eḍa* and *Aṭharv̄aveḍa*, basic texts of the Vedic period, contain several hymns praising and endowing trees, plants, and vegetation with various divine qualities, highlighting their medicinal significance, and enunciating the policy of conservation or sustainable management. Various *Upaniṣads*, a later group of philosophical treatises that explain the theology of Hinduism, like *Bṛhaḍāruṇyaka*, *Chāndogya*, *Chulikā*, and *Muṇḍakopniṣaḍa*, conclude that trees had life akin to human life. *Maṭsyapurāṇa* and *Varāhapurāṇa* describe the benevolence of trees along with the rituals of tree planting. *Skanḍapurāṇa* contains a long list of trees which should not be cut except for the purpose of *yajnas* (holy rituals). Whereas planting of trees led to heavenly comforts (*Agnipurāṇa*) indiscreet felling of trees meant torture in hell.

Vedas also contain valuable information about various species of birds. In *Ṛgv̄eḍa* for instance there is a mention of *Garuda* (eagle), *Mayūra* (pea fowl) along with various Himalayan pheasants, partridges, and other species of birds. Surprisingly *Ṛgv̄eḍa* also mentions not only anatomical details of some common birds, but also details about their staple food. For example *Vartika* (partridges) are said to have well-developed bills, legs, and rounded wings; their food consisted of grain, grass, weed, seed, tender shoots, insects, and even white ants. These kindled the sparks of wildlife management during the later period of civilization.

Great saints and sages who understood these texts, passed on their knowledge and wisdom to their disciples. Such education was given in the *Gurukuls* (schools) which were located in the forests. The students lived in the forests and continued their studies. Thus a sense of tolerance and coexistence with various forms of plant and animal life was infused in early childhood. This *Aranya* (forest) culture provided early exposure to nature study and ecology, as well as the policy of development without destruction in current parlance. Forest and environment consciousness was thus ingrained into the educational system from the very onset.

Even epics and religious texts written later on describe the protective role of trees and their unlimited usefulness. *Rāmāyaṇa* and *Mahābhārața* describe the rich biodiversity and multiplicity of flora and fauna. In *Bhagwaṭgīṭa* Lord Krishna compared himself to the *Aśvaṭha* (ficus) tree in order to emphasize the importance of trees.

Other religions of that time also mentioned the importance of forests and forestry. According to Lord Buddha it was the obligation of every good Buddhist to plant and nurture at least one tree every 5 years.

Moving along chronologically we find that forest management practices were well documented during the reign of Chandra Gupta Maurya (321–296 BCE). Reliable historical documents, such as the *Indika* of the Greek ambassador Magasthenese, the *Arṭhaśāsṭra* of Kautilya and the *Mudrārākśasa* of Viśākhadaṭṭa vividly depict various aspects of forestry and wildlife. Kautilya's *Arṭhaśāsṭra*, recognized as the pioneer work in economics in India, indicates the existence of a regular Forest Department headed by *Kūpyādhakśa* with definite duties and responsibilities for various officers of the department. Some of the important duties of *Kūpyādhakśa* were to increase the productivity of forests, classification, price fixation, and disposal of various types of forest produce, raising block plantations of important species (e.g., sandalwood), pasture development in saline–alkaline waste lands, and joint management of forests with people dependent on forests.

Forests were legally classified into three main classes: reserved forests, forests donated to eminent Brahmans, and forests for public use. They were classified into six categories on the basis of crown density, luxuriance, growth, and origin. Planted forests were called *Upvana*.

Forest and game laws were stringent and draconian, containing corporal punishment. The death sentence was envisaged for poaching of elephants. Awards were provided to a person who collected elephant tusks from dead elephants and deposited them with government officials. Kautilya's treatise also dealt at great length not only with the use of various trees and shrubs, but also with the specific use of various parts. For example it indicated that flowers of *Palāś*, *Kusuma*, and saffron are used as dyes, *Munja* and *Love* grass are used for making ropes, and fruits of *Aonla*, *Harara*, and *Bahera* are used as medicines.

Emperor Aśoka adopted and improved these practices. Plantation of fruit-bearing shade trees for the benefit of travelers and common people was started on an ambitious scale. Aśoka was the founder of *Abhyāranya*, the *sanctum sanctorum* of wildlife, now known as National Parks and sanctuaries. Aśoka's edicts at Sarnath Varanasi bear ample testimony to the above.

Forestry flourished during the Gupta period (320–800). *Ṣukranīti*, a well-known work of that time, throws light on the improvements in forest management practices. Seeds of "Social Forestry" were sown during this era. *Ṣukranīti* dwells on the concept of village forests, choice of species, afforestation and maintenance techniques, fertilization procedures, irrigation schedules, and measures to increase flowering and fruiting in trees. Names of various multipurpose trees such as *Kadamba*, *Sīśama*, *Peepal*, *Mango*, *Nīm*, *Coconut*, and *Imlī* are listed in this policy document for planting near villages. Incidentally many of these are also listed in the latest ICRAF (International Council for Research in Agroforestry, in Kenya) booklets. This shows the worth of these ancient publications.

It is thus clear that in ancient India trees were the best friend of people in a hostile environment. They were held sacred, worshipped, and studied in great detail for service to humanity. Forestry practices evolved gradually, in a scientific and rational manner, and are important even today, although in the modern parlance new names have been coined for them.

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Forestry in Japan

Conrad Totman

Forestry may be defined as "the science and art of forming, caring for, or cultivating forests." Another definition is "the science, the art and practice of managing and using for human benefit the natural resources that occur on and in association with forest lands."[1] The former, dictionary definition, leaves unidentified the interests to be served by this "science or art." The latter, autecological definition, with its explicitly human beneficiary, was propounded by the Society of American Foresters around 1970. It fitted nicely the Japanese approach to woodland for centuries down to about 1980. Since then, however, socioeconomic changes have undermined the established rationale of forest policy, permitting advocates of environmental protection to call for a richer synecological understanding of forestry's proper purpose.

Factors Shaping Japanese Forestry

In Japan, as elsewhere, forestry has been profoundly shaped by its geographical and social contexts.

By global standards the Japanese archipelago is extraordinarily youthful and mountainous. Mostly formed in the past 15 million years, it is characterized by elaborate dendritic systems of acutely upthrust ridges that are covered with thin, immature soils and incised by narrow valleys down which course fast-running streams that eventually debouch onto slender alluvial plains, most of which front the surrounding seas.

Because of the way continental and oceanic weather patterns interact in the northwestern Pacific region, Japan experiences pronounced seasonal differences and a relatively moist climate during most of the year. And its length from north to south assures it substantial variation in mean temperatures, which range from subtropical in the far south to subarctic in the far north. In consequence woodland vegetation is lush everywhere. But it varies from a thin strip of evergreen broadleaf forest along the southern littoral through woodlands of mixed deciduous broadleaf and evergreen firs (which cover most of the realm) to coniferous boreal forest in far northern regions and at high elevations.

Before the introduction of fully fledged horticultural practices some 2,500 years ago, these richly forested islands supported a very modest population of foragers. Once agriculture was introduced, however, the population grew rapidly, and over the course of two millennia cultivators opened much of the archipelago's lowland to cultivation or other human use. In the process, forest was eliminated from most lowlands and lower slopes of hilly terrain, an outcome reflected in the language. Forest of any substantial dimension is called *sanrin*, literally "mountain-forest," while the more basic terms for "woods," *mori* and *hayashi*, which lack reference to mountains, are ordinarily used when talking about small residual groves of trees or parcels of brushwood that have chanced to survive on or near lowland.

Nevertheless, because Japan is so extensively and acutely mountainous, even today about 70% of it still sustains woodland. Part of this is plantation stands and part mixed, natural growth, some subject to management, some not.

Within this physical context, forestry in Japan has moved, as it has elsewhere, through two major phases, from a long era of exploitation forestry to a shorter era of regenerative forestry. The latter runs from the seventeenth century to the present but can be examined in terms of preindustrial and industrial-age segments.

Exploitation Forestry

For millennia residents of the islands utilized their woodland primarily for fuel and food. With the development of agriculture, however, food came more and more from arable land, and the receding forest provided, instead, water and fertilizer materials to grow the food, fodder for beasts of burden, construction timber for buildings and gadgetry, and fuel for cooking and various industrial tasks, notably metallurgy and kiln work.

During the seventh and eighth centuries CE, political consolidation gave Japan grand capital cities that housed a ruling elite of unprecedented power and cultural pretension. They adopted new architectural styles and construction techniques that led to a major increase in the consumption of both timber and fuel wood (see Timber-Handling Technology in Japan). These developments led in central Japan to overcutting that created serious problems – flooding and drought, forest fire, wood and fuel shortages, and intensified competition for control of surviving woodland. On the other hand, because the Japanese did not maintain herds of goats and sheep for milk, meat, or wool, Japan's landscape was spared the devastation they have wrought elsewhere.

In the outcome, although the problems caused by overcutting did gradually become more widespread as Japan's population grew and towns proliferated, it was not until the seventeenth century that broadly effective patterns of remediation began to be devised and

[1] The former definition appears in *Webster's New Collegiate Dictionary* (Springfield, Massachusetts: G. & C. Merriam Co., 1956); the latter in Grant W. Sharpe, et al. *Introduction to Forestry.* 4th ed. New York: McGraw Hill, 1976. 187, quoting the Society of American Foresters.

applied. They emerged then because a sharp increase in wood cutting and another surge in land clearance were having severe downstream consequences during an era when society was well enough organized so that purposeful woodland regulation and management could not only be needed or advocated, but in fact be devised and implemented in a sustained manner.

Regenerative Forestry

Regenerative forestry can be examined in diverse ways. One approach discusses "negative" policies designed to prevent or contain unauthorized exploitation and "positive" policies designed to foster more, better, or different types of forest performance. An overlapping formulation speaks of "protection forestry," which is designed to protect the woodland itself and other areas and affairs vulnerable to damage caused by unwise forest use, and "production forestry," designed to enhance the quality or quantity of woodland yield.

In terms of the former approach, local instances of negative forest policy date from the eighth century, when rulers tried to restrict cutting in select locations. Negative policy became visible again during the 1300s–1400s, when some villages in central Japan began regulating the use of their communal woodland, and during the 1500s, when some regional barons (*daimyō*) tried to protect valued groves and stands from unauthorized harvest.

It was from the 1660s onward, however, that the hegemonial Tokugawa shogunal regime (ruled 1600–1868), the 250-odd daimyo, and villages all across the realm began drafting and enforcing, in woodland within their jurisdiction, regulations to control who might do what, where, when, how, with what tools, and how much yield. Those initiatives developed into a wondrously variegated system of multiple-use rights that allowed diverse people to extract diverse goods from designated parcels of woodland throughout Japan.

Regarding timber specifically – which was of particular concern to the rulers – shogun and daimyo not only regulated the harvest in forests they administered as domanial land, but also began stipulating that no good-quality tree of desirable species was to be injured or felled, save with official permission. And that prohibition applied to all formal categories of land, whether of village, fane, or household, even to include trees standing on a villager's house lot.

To enforce their proliferating rules, shogun, daimyo, and village headmen deployed forest wardens, guards, and patrols to catch rule-breakers. They established fines and other punishments, and they developed and applied adjudication procedures for handling those charged with violation of forest law.

These negative policies, together with vigorous programs of riparian management and repair, did gradually achieve major goals of protection forestry, reducing appreciably the extent of erosion and downstream silting, flooding, and damage. But in terms of production forestry, the rate of harvesting on accessible hillsides was so great that negative policies alone failed to sustain fuel, fodder, fertilizer, and timber supplies at the level of demand. And on numerous lower hillsides, especially those facing the agricultural lowlands of central Japan, overuse gradually destroyed vegetation, creating more and more barren hills and ridges known as *hageyama* or "bald mountains."

Under these circumstances positive policies designed to promote plantation stands, nurture mixed forests, and revitalize *hageyama* began to be advocated by government officials, village leaders, and Confucian scholars of the "practical learning" (*jitsugaku*) orientation. During the eighteenth century, moreover, land-use arrangements were gradually modified, creating forms of rental forestry that assured users long-term control of select parcels and their yield. These modifications encouraged landlords, entrepreneurial lumbermen, villages, and daimyo to invest time and wealth in programs of woodland planting and nurturing, confident that in due time they or their successors would recoup the investment.

As interest in reforestation spread, the body of silvicultural writings grew apace, enriched by the testimony of practicing tree farmers. It provided detail – mostly practical and biologically sound – on the selection, collection, and preservation of seeds and cuttings, on the preparation and use of seedbeds, on the transport and transplantation of seedlings and rooted cuttings, on the suppression of competing vegetation, on pest control, on restocking failed shoots, and on nurturing the growing stand to produce wood (or other) products with the desired qualities. Writers also offered advice on the use of rotation-cutting schemes, on techniques of stand valuation and harvest, and on wood processing and storage.

By the decades around 1800, and on into the nineteenth century, both plantation stands and managed forests of mixed, multiaged new growth were becoming valued sources of timber throughout Japan. They eased the overall timber shortage that had spawned regenerative forestry in the first place. And while *hageyama* were still common and much woodland was still poorly stocked, the humanly fostered forest did, by enhancing Japan's volume of standing timber, help equip the realm to handle the traumatic decades that lay just ahead.

Industrial-Age Forestry

During the 1850s–1860s the global wave of early industrial European imperialism finally reached Japan, where it overwhelmed the decentralized Tokugawa regime in 1868. The new Meiji government saw its primary task as mobilizing sufficient power not only to stay in office, but also to stop further foreign inroads and to repudiate the concessions previously made. Within this new and radically changed context, there were some strong continuities in forestry thought and practice, but the changes seem more noteworthy.

Both protection and production agendas continued to be clearly visible, the balance between them shifting with the ebb and flow of woodland condition and global context. And much of the existing silvicultural knowhow and procedure continued to be applied in planting, nurturing, and harvesting projects.

Even in terms of silvicultural content, however, change gradually occurred. One factor spurring it was new technology, particularly that of the harvest, which placed great new demands on woodland and its handlers (see Timber-Handling Technology in Japan). More strikingly, the practice of forestry became far more systematized. Whereas Tokugawa-era forestry had utilized precedents from China, Meiji leaders took their cues from current practice in industrial societies, Germany most notably. Starting in the 1870s, a number of Japanese studied forestry there and upon their return helped forestry officials develop new policies and launch new programs. By 1883 that government effort had created a school of forestry, a forestry experiment station, a professional association of foresters, and a research bulletin.

In following decades those trends continued: regional forestry associations proliferated, more and more professional meetings were held, technical matters were debated, and new techniques were tried. Students and officials continued going to Germany to study forestry, and German works on the subject were translated into Japanese. New journals appeared; more experiment stations and forestry training programs were established, and the body of trained foresters and published research findings grew apace.

From the outset Meiji leaders had claimed domanial woodland as government forest, and by the 1890s they had created a Forest Agency and subordinate bureaucracy to manage their newly unified system of national forests, which encompassed more than half of all wooded acreage. Later, authorities also developed programs of guidance and assistance for owners, mostly small-scale, of the remaining woodland.

On government woodland foresters developed both overall management plans and local operational plans. Revealing ever more sophistication as decades passed, the overall plans spelled out policies for afforestation, aftercare, harvesting, and the handling of road construction and other forest-engineering projects. They dealt with the technical tasks of mensuration and the fiscal, spatial, and material requirements of projects. They detailed personnel needs, particulars of organizational structure and of research and operations facilities, and estimates of income and expenditures.

Nor was the planning merely a bureaucratic exercise. Research and training in scientific methods did improve. Forest mensuration, one of the world's more arcane arts, made striking advances. The relatively simple task of measuring acreage gained accuracy as more surveyors were trained and deployed and as surveyor's levels and the techniques of triangulation were introduced and mastered. The much more difficult tasks of estimating stumpage volume and predicting timber yield advanced more slowly as "eyeballing" gave way to increasingly refined techniques of estimation, including the use of sample plots. And foresters began developing yield tables for particular species in select localities.

In their research work, professional foresters also undertook studies of specimen growth, soil acidity and its effects, factors affecting seed-germination rates, and other projects designed to improve forest productivity. They also imported and experimented with seed and seedlings of valued foreign species. By the 1920s they were becoming familiar with the concepts of forest succession and continuous forest, and they were beginning to look more skeptically at such recently touted practices as rotation clearcutting, fixed yield rates, and even-aged monocultures.

Behind – and clearly influencing – this story of forestry's development was a less tidy tale of ups and downs in the actual woodland condition. During the decades from about 1870 to 1900, Japan's forests were ravaged by a combination of pushes and pulls that spurred villagers, entrepreneurs, and government loggers to hack down stands, clear land for cultivation, and otherwise misuse it in ways that produced flooding, erosion, and downstream damage. Decades of later-Tokugawa forest recovery were undone. But from about 1900 into the 1930s governments at all levels and private landholders responded by pursuing remedial policies to control flooding, restock forests, and maximize their rate of sustainable production. By the 1930s, these efforts were yielding results all across the realm: reforestation was being pursued widely, flooding problems had abated, *hageyama* were being revitalized, and the volume of standing timber was gradually increasing.

Then, however, during 1937–1950, industrial-age warfare and its consequences undid the gains, stripping the realm of much woodland cover and again producing widespread and destructive erosion, flooding, and damage. That situation precipitated yet another effort at forest rehabilitation, by far the greatest in Japanese history. During the 1950s–1960s countrywide planting restabilized the hillsides, adding thousands of hectares to the country's hand-planted woodland. By 1980 Japan was again a green archipelago, lushly forested from far north to far south. And today about 40% of its forest acreage is in plantation stands, most of it trees 30–50 years old.

That outcome has not, however, proven an unqualified triumph. By 1960 the Japanese lumber industry was becoming enmeshed in the global timber trade, and imported logs and other wood products undersold nearly all the domestic competition. In consequence, by 1970 logging had lost most of its profitability, and reforestation and aftercare had become uneconomic, an investment that carried no promise of eventual return. By then, too, shifts to chemical fertilizers, fossil fuel, and motorized machinery had destroyed the markets for green fertilizer, fuel wood, and fodder for draft animals. Woodland had become useless. It was merely pretty scenery.

Since the early 1970s, therefore, tree planting, stand maintenance, and logging work have all been in sharp and sustained decline. Indeed, logging activity today yields only about a quarter of the peak output of ca. 1940–1960. Instead, intermontane regions depopulate as young people in particular leave to find employment elsewhere. And both plantations and mixed forests simply stand and age, increasingly subject to windthrow and snow breakage and gradually losing their potential economic value (Fig. 1).

Because of these developments, Japanese forestry has recently been facing a crisis of purpose. Government committees and other groups have continually, and especially during the 1990s, drafted and redrafted rules and guidelines, categorizing and recategorizing woodland, giving more emphasis to protection forestry, and formulating purpose one way and another. But at present the basic problem of an uneconomic resource persists, and no coherent and effective policy for addressing it has emerged either within the Forest Agency itself or within government or society more broadly.

So, from a human-centered autecological perspective, Japan's forest affairs currently seem to be in utter disarray. From a broader synecological perspective, of course, it would seem a golden opportunity to encourage the final evacuation of depopulated intermontane regions and their revitalization as more richly diverse biomes. Perhaps even wolves could be reintroduced to manage the population of wild ungulates – deer, wild boar, and serow – that now constitute a widespread nuisance to people. And at the same time, one could pursue at little social cost the gradual, managed restoration of many plantation stands to wildlife-friendly mixed forest.

However, in Japan, as elsewhere, the former perspective – the human-centered autecological assumption that forests exist to serve human purposes and that they do so best when subject to enlightened human management – continues to prevail despite the small voices that fret about biodiversity, species endangerment, and extinctions. And it seems likely that as the twenty-first century advances, global wood scarcities will revive Japan's plantation-based timber industry and revalidate the production-forest priority before a synecological perspective gains effective voice.

Forestry in Japan. Fig. 1 Near Ueda City in Central Japan, March, 1963. By 1950 many of Japan's forests had been stripped of timber, but in following years the hillsides were replanted. By 1980 most of these hillsides again sported rich young timber stands. In foreground terraced rice fields give way to dry fields which ascend the hillsides as far as gradient allows (photograph by the author).

See also: ►Agriculture in Japan, ►Timber-Handling Technology in Japan

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Gaitian

Christopher Cullen

Gaitian is the Chinese name for a scheme of cosmography, i.e., a description of the overall layout of heaven and earth. The term may be interpreted as "umbrella [-like] heaven."

The classical description of the *gaitian* view is found in the *Zhoubi suanjing* (Mathematical Manual of Zhoubi), dating from around the beginning of the Christian era. It seems likely however that it is a systematization of what was the common view of the shape of the heavens at least as early as 250 BCE. Heaven and earth are more or less flat and parallel planes, although they may sometimes be described as gently curved like the cross section of an umbrella. Earth is stationary, while heaven rotates once daily about an imaginary vertical axis through the north celestial pole, carrying the heavenly bodies with it. Day and night occur because this rotation carries the sun beyond the range of the observer's sight and back again. The rising and setting heavenly bodies are an optical illusion. In winter the sun is further away from the celestial pole than in summer, and is hence more distant from the observer and lower in his sky. The *Zhoubi suanjing* gives the height of heaven above earth as 80,000 li. The Chinese observer is said to be 103,000 li from the subpolar point, while the greatest and least radii of the sun's daily orbit round the pole are 119,000 li (summer solstice) and 238,000 li (winter solstice). The scheme gives a fairly good qualitative explanation of obvious phenomena, including the six-month alternation of day and night at the earth's north pole. By the second century AD it becomes clear that mathematical astronomers preferred not to think in *gaitian* terms, but were using the so-called *huntian* (continuous heaven) scheme.

See also: ►Zhoubi Suanjing, ►Huntian

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Gan De

Huang Yi-Long

As one of the earliest astronomers in China, Gan De, in the fourth century BCE, made many observations of the heavenly bodies, especially Jupiter, which was then called *Suixing* (the year-star). He wrote two books: *Suixing Jing* (Treatise on Jupiter) and *Tianwen Xingzhan* (Astrological Prognostications). Unfortunately these books were lost long ago, and only some quotations from them are extant in the *Kaiyuan Zhanjing* (The Kaiyuan Treatise on Astrology), compiled between AD 718 and 726.

In the *Kaiyuan Zhanjing*, Gan De is quoted as saying: "Jupiter was very large and bright. Apparently, there was a small reddish star appended to its side. This is called 'an alliance'." Included in the quotation were a date and rough coordinates, both in the ancient Chinese system.

Zezong, of the Institute for the History of Natural Sciences in the Academia Sinica, Beijing, claims that this record is evidence of the earliest discovery of the brightest moon of Jupiter, Ganymede, in the summer of 365 BCE.

Although Ganymede's magnitude of 4.6 is somewhat brighter than that of the naked eye's limit, Jupiter is 760 times brighter and located less than 5.9 arcmin away from this moon. Only people possessing eyes of extraordinary power would be able to see the satellite. Could Gan De have been one of these extraordinary people? We will never know.

Some people claim, on the basis of experiments, that under good observational conditions, the normal naked eye can determine Jupiter and its brighter satellites, especially Ganymede. However, Gan De's reference to the reddish color continues to be mystifying, because Ganymede is too faint for its color to be perceived with the naked eye.

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Gardens in Japan

WYBE KUITERT

The Early Centuries

Before a clearly defined native garden art appears in Japan's history somewhere in the eighth century, evidence is found of activities in the field of landscape design. It is mainly through archeology that these early centuries speak to us. At Jo-no-koshi (Mie prefecture) a rather naturalistic arrangement of rocks was unearthed; it was put up along a narrow stream at a point where it divides in two. The arrangement has been dated ca. 500 AD; it resembles a manner of handling rocks seen in a few gardens of the seventh and eighth centuries. Skill in engineering in this early history can be seen in bold burial mounds of advanced design, surrounded by moats. Some square ponds lined with rocks were found, as were quite a few artistic works in carved stone made to have some liquid flow. These were probably used for rituals involving rice wine or water for purification; similar artifacts are known from the continent. A well-known record, dated 612, speaks of a man who came from Paekche, a Korean kingdom; he built a garden arrangement and made a Chinese style bridge in the garden of the emperor. His name was Michi-no-ko Takumi in the Japanese reading of the Chinese characters of his name. It underlines how the early history of landscape design in Japan followed the models of the continent. At the mid-seventh century palace site of Fujiwara-kyo, remains of a winding garden pond have been found. At a slightly later site, parts of an extensive pond garden were unearthed. The pond had rather heavy embankments in piled-up rock, an island and a fountain-like feature. Most likely it had been part of the seventh century imperial Asuka palace of the emperor Tenmu (r. 673–686). Though only partly excavated, and much smaller, this garden arrangement resembles very much, in all its details, the seventh century pond garden Anap-ji in Korea.

The Nara Period (710–784)

Nara was founded as an imperial city in 710 AD; it was planned after Chinese geometrical schemes with streets running in a grid pattern. The imperial palace held a central position in the northern part of the city. It is known from scarce records that there were several gardens. None of these remain, but two extensive gardens were discovered and redone after detailed excavation and research.

Southeast of the main palace compound, a detached palace, To-in, was constructed in the early eighth century. The garden of To-in, or the East Palace Garden, is one of the gardens mentioned in contemporary records. Extensive archeological surveying gave a wealth of added information. The original pond bottom was paved with large flat stones. Like the Asuka pond, the heavy embankment of the East Palace Garden follows a design of simple curves, again similar to the Korean example. Interestingly, the garden had been rebuilt later in the same century, after a covering of the earlier design with soil. The second, younger pond was paved with much smaller pebbles, and the embankment runs in softer, more expressive curves. Rather than embankments, this second pond was contained with shores or beaches covered with smaller stones, the shingles found on Japan's seashore. Here and there at small peninsulas, rock groups suggested weather-beaten sea cliffs in miniature. A group of rather big and craggy stones is set as a decoration in the shore opposite the remains of a hall, traced from remains of foundation pillars. It is this second phase of the East Palace Garden that shows a clear departure from the continental style and the introduction of clearly native landscape motifs; the typical shingle beaches and rocky promontories of Japan's natural sea coast would continue to inspire garden designers for centuries to come. The East Palace Garden has been reconstructed on top of the archeological remains. Buildings, a bridge and planting were remade in a hypothetical reconstruction of what could be guessed from what was found in the soil.

A second garden recovered from eighth century Nara is known as the Imperial Villa Garden, or after its address in the old city of Nara, *Sakyo sanjo nibo rokutsubo kyuseki teien*. The site is not known from records; probably it was a private retreat of some courtly family or the emperor himself. It is in walking distance from the To-in garden. The most distinctive feature of this garden is a double S-curved winding pond, or wide stream bed. The pond was paved with fist-sized stones in the old continental manner, but decorative rock groups at protruding curves and beaches covered with pebbles are completely in the native naturalistic manner. Drawing from a natural river the winding pond has its water running from north to south. It is generally accepted that this pond was used for the so-called winding-stream banquet: guests were sitting along the stream, writing poetry. A poem had to be finished before a cup of wine set on a float would reach the poet. This festivity became famous after the Chinese calligrapher Wang Xizhi (303–379) had invited 41 men for a winding stream banquet on the third day of the third month in 353. Poetry written on the occasion was compiled in the *Records of the Orchid Pavilion*, a Chinese literary classic, well known in eighth century Japan. The garden at Nara's Imperial Villa Garden will also have been used for winding stream banquets. The rockwork excavated was in such perfect condition that it was decided to reconstruct the garden with most of the original stones. Remains of two sets of wooden boxes were found, set among the stones of the pond bottom; these were probably planting boxes for irises. A banquet hall was reconstructed departing from the remains of pillar foundations found. As plant material in these garden reconstructions the Chinese plum (*Prunus mume*) and Japanese pine (*Pinus thunbergii*) are used among other plants.

The Heian Period (794–1185)

In 794 the city of Heiankyo, now Kyoto, was founded as a new capital in a plain surrounded on three sides by hills. The city would remain the most prosperous cultural center for many centuries to come. The site for the new city was well chosen and blessed with a lot of pure water and natural springs, giving great advantage for the household and for garden building. Indeed, natural ponds and streams were used in large palatial gardens. In some cases dams were built to contain more spacious garden ponds. At the back and in between the palace buildings sand was spread out in small court gardens and a little stream ran among flowers, shrubs and bamboo planted as decoration. The old glory is perceived in garden remains in Kyoto such as the one at Shinsen-en or at Saga-in, a place now known as the temple Daikaku-ji. At other places, excavations again revealed garden details. Rocks arranged to make a waterfall were found in some sites. These are never high, as gardens were made in the plain.

Within the city a peculiar architectural style in which the nobility built their palaces became defined. After the main hall, the *Shinden*, it is called the "shinden style," or *shindenzukuri*. In combination with the architecture, the garden also developed into a typical *shindenzukuri* garden style. Of course, each garden was different, but some features appear characteristic. Seen from the main hall, white sand was spread in the front part of the garden; more at the back one found a large pond that could have one or more islands. An arched and a level bridge connected islands and shores. Along the edge of the pond one could find pebble beaches, or standing rocks arranged to suggest a weather-beaten sea cliff. The typical garden stream mostly ran from the northeastern corner through the garden, then among some low garden mounds before emptying into the pond, usually in the southern half of the garden. Hills at the back of the garden provided a background.

But times were changing and the twelfth century brought the nobility an unstable political situation. To counter the increasingly pessimistic worldview that prevailed, they built themselves large temples, with gardens referred to as paradise style gardens. Yorimichi Fujiwara in Uji, for instance, reconstructed his palace and modeled it as a temple named Byodo-in, in a setting of a large pond garden. The still extant Phoenix Hall is shown on the Japanese 10 yen coin. After an archaeologic survey, medieval repairs were removed and the original pebbled beach was repaired. The Paradise style meant to express the ultimate Paradise of Amida Buddhism in this world. Other still extant gardens of the same style are in Hiraizumi, Iwate Prefecture, or the Shiramizu-Amidado in Fukushima Prefecture, and Enjo-ji and Joruri-ji close to Nara. Many elements of the palace style remained to be used in these temple gardens as well; ponds and islands are typical. The garden stream of Motsu-ji in Hiraizumi is extensive and resembles garden streams as represented in paintings of the period. Around this time a nobleman wrote a well-developed manual on garden theory – the eleventh century *Sakuteiki*. It set the tradition for centuries to come. Nameless workers, supervised by noblemen, built gardens in this period; a class of gardening priests soon followed.

The Kamakura Period (1185–1334)

Although a shogun's government of military men was set up in Kamakura, the center of culture remained Heiankyo (modern Kyoto), and all through the Kamakura Period garden art remained under strong influence from the earlier style. Temple gardens built by order of military men followed the pattern of the Paradise style. For instance, Yorimasa Minamoto, after suppressing Hiraizumi in 1189 where he had seen its Paradise temples, was greatly impressed by their magnificence. He started building Eifuku-ji in Kamakura in the same year and in 1192 the ceremonial services for inaugurating the new buildings were performed. At present on the designated historic site the remnants of this garden can be seen.

The gardens at residences of the military class had the same influence, but their scale and their function as a space for ceremony were smaller, leading to more attention being paid to practical use. Also, with a garden space becoming smaller, it became rather a place to look at and enjoy by admiring than a place to enter. Starting from the thirteenth century, garden culture came to receive Chinese influence again, this time, through visiting Zen priests. High-ranking priests of the Chinese Song dynasty, like Rankei Doryu (1213–1278) or Issan Ichinei (1244–1317), given the Japanese pronunciation of their names, were influential cultural leaders of Japan. Many landscape paintings of the Song and Yuan dynasties were imported as gifts and brought a new vision of an imaginary landscape. The Chinese vision of landscape is still profoundly felt in the artistic composition of rocks arranged for garden waterfalls. For example at Tenryu-ji and the Golden Pavilion they probably date to this early period when Chinese priests were around.

The Muromachi Period (1334–1573)

A new ruling class of military men finally replaced the courtly culture of noblemen.

The influence of Chinese culture on garden art was now backed up with a growing trade with China on an unprecedented scale, making a taste for Chinese goods the great fashion. Shogun Yoshimitsu and his palace – of which at present only the Golden Pavilion remains – naturally formed the center of this Chinese fashion. His court was affected by the Chinese mood as can be recognized in the architecture of the Pavilion. The Chinese influence in the fifteenth century shows in the adding of a great variety of pavilions, bridges, and two- or three-storied buildings to the spacious pond gardens of the earlier shindenzukuri-style. The temple Eiho-ji in Tajimi (Gifu-prefecture) is a typical example. Gardens from these days are adorned with Chinese literary phrases. Later, in the days of shogun Yoshimasa around 1500, the fashionable and gorgeous Chinese taste came to an end. Growing power and influence of townspeople mingling with the military rulers led to a less superficial urban culture. A shift toward a more subdued and intellectual expression is seen in a new garden style that came into formation. At present referred to as the "dry landscape style" (*karesansui*), it was called *kazan*, or *kasenzui*, meaning "imaginary landscape" in its time. It strives for an abstraction of landscape by careful placing of rocks. In miniature these can be realistic and suggestive of mountains and waterfalls, employing white sand as an expression of water. Also a quite abstracted placing of just a few rocks was called an imaginary landscape. The textbook examples of the style are now Daisen-in of the Daitoku-ji monastery and the garden in front of the main hall of the temple Ryoan-ji, although this garden was rebuilt in the late eighteenth century. Among the so-called "riverside people" (*kawaramono*) living at the very bottom of the social ladder, skilled gardeners called "landscaping riverside people" (*senzui-kawaramono*) became a group of professional gardeners. They become persons known by name in the records at the end of the Muromachi period. Gardeners living in and around the temple Ninna-ji have left us a detailed hand-written manual on gardening technique (*Sansui narabini yakeizu*) dating from the 1460s.

The Momoyama Period (1573–1603)

The Momoyama period is a period of transition and sudden wealth after the country's unification. On the one hand we see gardens expressed in gorgeous splendor beside the expansive mansions of the powerful military leaders, gardens often employing the ostentatious sago palm tree that was the great fashion of the day. One may visit the garden at the large Reading Hall of the Nishi-Hongan-ji temple in Kyoto, a garden said to have been moved from shogun Hideyoshi's castle at Fushimi to its present site. Another example is the sumptuous garden at Sambo-in of the monastery Daigo-ji, commissioned by the same shogun; it is in fact a lavish display of expensive garden rocks.

On the other hand the subdued taste of the townspeople developed in opposition to the ostentatious manner. Gardens with a romantic vision of landscape were developed around simple grass-thatched huts. These were used for socializing, and in time became associated with the etiquette of drinking tea. These small gardens employed simple stepping-stones, a basin to wash the hands and some rustic stone lanterns. In later history these were classified as tea gardens. Professional gardeners known by name appear as modern tradesmen.

Gardens of the Edo Period (1603–1867)

Two and a half centuries of nationwide peace and stability characterize the Edo period. Garden culture was polished and evolved to an extreme level of contrivance and perfection. In the early Edo Period some fine examples of garden art came about among wealthy members of the imperial court, like the gardens at the detached imperial villas in Kyoto. In contrast with the pond gardens of classical days, garden routes were now intentionally laid out along the shores for the purpose of strolling, as seen in the Katsura Detached Villa, showing scenic techniques taken straight from the tea gardens of earlier days. A garden path of stepping-stones and designed pavements is aligned with tea pavilions and tea huts, or other kinds of garden architecture. Garden mounds, pebble beaches, bridges, stone lanterns, and washing basins were installed to produce scenery that changed with almost every step. This tendency to decorate the garden with numerous details became typical of the later Edo Period garden developed by the *daimyo*, or governors of the provinces.

These daimyo were obliged to live in Edo, currently Tokyo, for six months every year. They had their official residences in the city; some were many hectares large. The other half of the year they lived in their own home province where they constructed their gardens in the same manner. With daimyo challenging each other all over the country, and above all in Edo, the cultural hegemony of Kyoto gardening came to an end. Daimyo gardens first of all served for holding banquets or other garden pleasures, but also signified the birth of a new garden aesthetic. The scale was large and evoked a concern for scenery, thus a more bucolic sense is seen in miniature landscapes reproduced. Some gardens have mini Mount Fujis; others have small tea plantations or rice fields. All over the country daimyo left us with many good examples. In Tokyo, there are Korakuen, Rikugi-en, Shiba-*Rikyu*, and Hama-*Rikyu*. In Okayama one may visit Korakuen, Takamatsu has its Ritsurin-en, Hiroshima Shukkei-en, Mito Kairaku-en, or in Hikone the Genkyu-en garden.

In the course of time well-to-do citizens also came to possess a garden, and gardening became more popular. Popular garden books spread a stylized mannerism, dividing "the" garden in two styles each in three levels of elaboration. The thing to have was for instance an "elaborate hillock-style garden," or an "abbreviated flat garden" as these were shown in the picture books. Gardeners became professional specialists, organizing themselves in houses that would pass on the trade for generations. Propagating and breeding of novel garden plants reached a level matching the modern garden center.

Gardens of the Later Nineteenth and Twentieth Centuries

After the 1860s "the West" was brought to many facets and aspects of Japan's society, but this did not readily reach the garden. Several western-style gardens were built in Tokyo, often with lawns, winding paths, and a look-out on a hill; an extant and successful example is Shinjuku Gyoen. But in face of Japan's century-old tradition these were isolated experiments.

Little by little though, new ideas began to inspire the top end of the garden trade. Among some captains of industry the cramped world of the picture book garden was considered obsolete, and a new taste was required, giving room for a more liberal naturalism. In the course of the 1890s great progress was made again in Kyoto at Murin-an, a garden ordered by a powerful politician Aritomo Yamagata and built by gardener Jihei Ogawa (1860–1933). The garden had meadows of wild flowers set among a pastoral landscape of meandering streams, set before a background of natural hills outside the garden. The meadows and a design of trees and shrubs reflected Japan's agricultural landscape around Tokyo with its coppice woods. Murin-an had many deciduous trees, rather than the eternal pine trees. The experience gained by gardener Ogawa at this job was put into wide practice in many other and larger gardens in the region around the temple Nanzen-ji in Kyoto. These gardens quickly became famous; most are still extant. The garden he designed at the Heian Shrine is open to the public; it is typical of his work and shows us how he interpreted tradition in a contemporary way. Besides Ogawa, we find many other able landscape gardeners. Perhaps Jukki Iida (1890–1977) should be mentioned here, as one of the men important in carrying the traditions over the Second World War, working with a similar feeling for the naturalistic landscape of deciduous trees.

A garden artist negating this style was Mirei Shigemori (1898–1978). He was like a producer, working with gardeners rather than being a gardener himself. Therefore, as he was freer from tradition, he found an appealing new definition of the dry-landscape style, employing coarse white gravel and thick, dark green moss. All over Japan he left us many of his at the time avant-garde gardens, some of them with strong lines and forms expressed in concrete.

The enormous economic expansion of the later decades of the twentieth century brought many commissions and big budgets. Landscaping became a large-scale operation of companies with nameless designers. Experiments with expensive materials such as worked natural stone, often set in concrete, mark this period. Although design was influenced by American plaza design, the tradition remained meaningful. Ogawa's discovery of the deciduous tree and the coppice wood became common in parks, as well as in the private garden. Rock design remained strong, in some cases adding the strong line of the cutter, as can be seen in the Japanese Garden at the Expo site in Osaka.

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For serious research on the history of Japanese gardens Japanese language sources are required. Sources in Western languages have already made a shift to another mind-set, crossing centuries and cultural borderlines when translating information found in ancient, primary sources. This bibliography has used such sources only if they rely (more or less) on primary, Japanese sources. Western sources on Japanese garden art have, throughout history, always showed interpretations that should be understood in view of the Western context. Some of these are included, as these are of historic interest, having in turn influenced views on Japan's garden art by the Japanese themselves. Some Western sources, as Condor 1893–1912, contain interesting photos illustrating gardens and garden styles that have now disappeared.

Any serious researcher should refer to the volumes of *Zōen zasshi*, continued as *Randosuke-pu kenkyū*, edited by the Nihon Zōen Gakkai (Tokyo) to find updated research results. This journal has a catalogue (searchable with keywords) for the years 1977–1994: *Nihon zōen gakkaishi sōmokuroku*, April 1995. One may also check my bibliography in *Themes in the History of Japanese Garden Art*, University of Hawai'i Press, 2002.

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Gas: Exploitation and Use of Natural Gas in Premodern China

Hans Ulrich Vogel

Ancient Chinese sources give many references to strange fiery phenomena burning on water or rising out of the earth. For instance, the *Hanshu* says that in 61 BCE the emperor sacrificed at the “fire well” (*huojing*) of Hongmen (Shaanxi). We do not know the cause of this fiery discharge, but it is clear that this fire well was an object of religious worship, because a fire well temple had been erected there. No mention was made of any use for industrial purposes (Fig. 1).

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The first reports on the industrial use of a fire well come from the middle and late third century AD. One of these reports state that there is a fire well in Linqiong, Sichuan province. Once Zhuge Liang (181–234), counselor-in-chief of Liu Bei (162–223), came to see it, whereafter the fire turned stronger. People put pans on the well to boil salt. When brands of common hearths were entered into the well, it at once extinguished and did not burn again. Thus, it is clear that the prosperity and decline of the well was seen as corresponding to political developments. Another source, for instance, interpreted the extinction of the well as an omen for the annexation of Shu by Wei.

We cannot ascertain whether the Linqiong fire well was really a natural gas well, because later texts appear to suggest that petroleum was involved. Whatever the case, there is no doubt that it was productive for only a short period. That later authors referred to this well time and again is because it constituted a strange and interesting historical phenomenon. It is therefore hardly justified to speak of the “systematic use” of natural gas for evaporating brine “on an industrial scale” starting in the second or even fourth century BCE, as Joseph Needham claimed. Moreover, Needham also assumed that deep drilling, which was one of the preconditions for a systematic exploitation and use of natural gas, had already been invented during the first century BCE or AD. Recent research showed, however, that deep drilling originated in the middle of the eleventh century.

After the Linqiong fire well had become extinguished, probably in the late third century, Chinese sources do not mention the use of fire wells for industrial purposes until the sixteenth century. Although they still report on the outflow of mist (*yanqi*) and hidden vapors (*yinqi*) from wells, it is clear that these discharges were conceived as threats to well salt production. For instance, in the tenth century explosive “hidden gas” was reported from the Ling well, a shaft well in the Lingjing industrial prefecture. Moreover, it is said that

Gas: Exploitation and Use of Natural Gas in Premodern China. Fig. 1 Fire wells of different quality, as shown on a mid-eighteenth century scroll. The scroll was photographed by Rewy Alley in Beijing in 1954. The location of the original is unknown. Photograph used with the permission of the Needham Research Institute, University of Cambridge.

in the eleventh century, when workers had been let down into the well for repair work, they were killed. Only by the installation of a so-called "rain basin" (*yupan*) over the top of the well could these difficulties be overcome. From the rain basin water sprinkled down like rain, which carried the gas down into the well. This device was derived from the observation that gas discharge was restrained during rainy days.

Systematic use of natural gas began in the sixteenth century. In the beginning, the number and output of industrially used fire wells appear to have been still limited. Until the end of the eighteenth century a fire well usually could supply fuel for only one to four pans, though exceptionally productive wells like the Yongtong well existed, which is said to have fed sixteen pans. A scroll of the mid-eighteenth century shows interesting details of fire wells of differing productivity probably in northern Sichuan.

The standard situation appears to have been that one well was feeding one pan which was placed directly over the well. A bamboo tube inserted into the well served as burner. It was covered by a stone, in case the fire was to be extinguished. The scroll also shows a very productive fire well supplying two pans. The gas distribution device consisted of a large bamboo tube on which a porcelain vessel filled with water was put. The gas was distributed to the pans by two small pipes connecting the burners with the large bamboo tube. Finally, less productive fire wells not only could not feed more than one pan, but had also to be supported with firewood.

The situation changed dramatically with the development of deep drilling techniques in the nineteenth century, when the high pressure gas deposits in the deeper strata of the Ziliujing gas field were tapped. For instance, the French missionary Imbert reported in September of 1827 that a single fire well of Ziliujing could feed more than 300 pans and that the wells were so productive that a part of the gas could not be used and thus had to be burnt off. A new generation of productive fire wells supplying 400–700 pans is mentioned by Li Rong in his famous account of Ziliujing from the end of the nineteenth century. The use of the resources of such highly productive wells necessitated the invention of a number of devices for the control and distribution of the gas flow and for coping with variations in the well's pressure. The utilization of gas was a highly dangerous undertaking which could lead to explosions. That was also the reason why at least in Ziliujing gas was only rarely used for household purposes.

Natural gas was an amazing phenomenon which required explanation. Song Yingxing, in 1637, said that the fire wells contained simply cold water, but not the slightest evidence of the *qi* of fire. One can only see the notion (*yi*) of fire which is bursting forth from the burner's pipe, so that the brine will boil violently. Yet if the bamboo pipelines for conducting the gas are opened and examined, no sign of charring or burning can be seen. "To use the spirit (*shen*) of fire without seeing the solid form (*xing*) of fire – this is indeed one of the strangest things in the world" (Sun and Sun 1966). Later Chinese authors had less strange ideas of the phenomenon of fire wells. For instance, in 1791, Xu Deqing came to the conclusion that the existence of fire and wind in the earth of high-lying terrains should be regarded as something quite normal, similar to the existence of fresh water sources in marshy and low-lying regions.

See also: ▶Salt in China

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Ge Hong

Ho Peng Yoke

Ge Hong (ca. 283–ca. 343), alchemist, physician, astronomer, and government officer, was the greatest alchemist and physician in fourth-century China. We also know him under several other names, such as Ge Zhiquan, Zhiquan Zhenren, Baopuzi, and Xiao Ge Xianweng. His exact dates are not known with certainty. Some say that he was born between 280 and 286. Other dates given for his birth are ca. 253, 280, 281, 283, and 284. The year of his death has been variously given as ca. 333, 340, 343, 361, and 364. Chen Guofu's elaborate study suggests the period 283–343 for him. Ge Hong's autobiography is contained in his *Baopuzi waipian* (Exoteric Chapters of the Preservation-of-Solidarity Master), but it says precious little about the author's scientific achievements. His biography is given in the *Jinshu* (Official History of the Jin Dynasty). Since he is regarded by the Daoists as having attained physical immortality, his hagiography is found in abundance in Daoist literature.

When he was young Ge Hong studied alchemy under Zheng Yin and Bao Jing, whose daughter he later married. He also learned much about medicine. He joined the government as an army officer in a military campaign to suppress an uprising in the year 303. After peace was restored he left without seeking reward and traveled widely in search of books. In the year 306 he accepted an invitation from his friend Qi Han to become his military adviser when the latter was appointed Governor of Guangzhou. Qi Han, the author of the *Nanfang caomuzhuang* (Records of Plants and Trees in the Southern Region) was one of the greatest botanists in traditional China, but unfortunately he was soon assassinated. Ge Hong remained for some time in the South and then returned to his place of birth, Nanyang, in Jiangsu province. A belated award came for his past service in the army. He was given the title Marquis of Guannei, and was recommended to the emperor for appointment as a member of the bureau of historiography. He declined the offer, but requested that the emperor make him magistrate of Goulou in South China, which was a rich source of cinnabar that he needed to prepare the elixir of life. Eventually the emperor granted him his wish. Ge Hong then went to live in the Luofoushan Mountain where he carried out his alchemical and protochemical experiments. It was probably there that he completed his famous alchemical work, the *Baopuzi*. Some say that the year was 317.

The *Baopuzi* consists of a *Neipian* (Esoteric Chapters) in 20 chapters and a *Waipian* (Exoteric Chapters) in 32 chapters. Among those in the *Neipian*, chapters 4, 11, and 16 are of special interest to the alchemists, while the other chapters also contain bits of information on alchemy scattered here and there. Chapter 16 specifically describes the transmutation of base metal into gold or silver. Chapter 1 of the *Waipian* contains Ge Hong's autobiography. The rest of the *Waipian* says nothing about science or alchemy. The relevant sections in the *Neipian* contain names of more than 50 elixirs supposed to have various efficacies – some could only prolong the human lifespan, while others could transform the aspirant to a holy immortal varying from 3 days to 3 years depending on the elixir itself. Ge Hong seemed to be successful in aurifiction, the process of imparting an appearance of gold to base metals by artificial means. It is interesting that the attributes of the elixir of being a panacea, of being able to translate base metals into gold or silver by means of projection, and of being able to impart longevity and perpetual youth were already mentioned by Ge Hong in the case of some of the elixirs in his *Baopuzi*. Sulfur and mercury were used in many of his elixir recipes.

Ge Hong was an eminent physician in his own right. His *Baopuzi neipian* describes the medicinal values of many plants and minerals. During his stay at the Luofoushan Mountain he also wrote the *Jingui yaofang* (Prescriptions in the Treasury of Medicine), in 100 chapters. Later he added an abridged version, entitled *Zhouhou jiuzufang* (Handbook of Medicine for Emergencies) in three chapters. Ge Hong's writings contain prescriptions for various types of diseases, including eye trouble, ailments of women and children, and infectious diseases such as smallpox and tuberculosis. They prescribed soya beans, cow's milk and goat's milk for the treatment of beriberi, and for treating bites from mad dogs the recommendation was to apply the brain of the culprit over the wound.

Ge Hong also showed considerable interest in astronomy. The *Jinshu* (Official History of the Jin Dynasty) quotes from a piece of his lost writings on the construction of astronomical instruments by Zhang Heng in the second century. It also narrates Ge Hong's participation in the great cosmological debate of his time. There were then two rival schools, the *Gaitian* (Canopy Heaven) and the *Huntian* (Spherical Heaven). The former was more ancient and pictured a canopy heaven covering a square earth like a tilted umbrella. The latter visualized the earth as the yolk of an egg floating on water at the center of a spherical heaven that was itself supported by water. The argument used against it was that the sun rising from and setting into water would be quenched of its fire and heat. In supporting the *Huntian* theory, Ge Hong skillfully quoted the hexagrams and passages from the *Yijing* (I Ching, Book of Changes) to silence its critics. Ge Hong also observed the effect of the moon on the water in the sea and on the tides. In his *Baopuzi* he referred to the waves of the sea heaving up and down with the waxing and waning of the moon and the increase in magnitude of the tide when the moon was full.

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Geodesy

Raymond Mercier

Geodesy, the measurement of the earth, is an essential component of both astronomy and geography. The spherical shape of the earth was a concept developed in the early stages of Greek science, and one finds this concept wherever the legacy of Greek science was taken seriously. Figures for the radius of the earth were reported by Aristotle and a number of other Greek scientists, although a judgment of their accuracy is hindered by our ignorance of an exact measure in modern terms of the units in which the radius was expressed. The coordinates in Ptolemy's geography were fixed by him from various distances measured in terms of *stadia*, converted on the assumption that one degree equaled 500 *stadia*; for Eratosthenes, the degree equaled about 700 *stadia*. On the other hand sources in Latin and Syriac rather later than Ptolemy worked on the assumption that one degree equaled 75 Roman miles, which we can evaluate because the length of the Roman mile is well established, so we know that it is very precise. The radius and circumference of the earth follow immediately from the length of one degree.

In the early stages of Arabic science, especially the work heavily patronized in the early ninth century by the Caliph al-Maʾmūn, various Greek and Syriac sources were consulted with a view to fixing the earth's dimensions. Here the intention was to evaluate the degree in terms of the Arabic mile, which we know to be 4/3 Roman miles, 1,972 m. The Arab scientists of the time, however, were uncertain as to the interpretation of the various figures given in their sources, and they were certainly confused about the true length of the Roman mile. While they were aware that the Roman and Arabic miles were, respectively, 3,000 and 4,000 cubits, they were ready to assume that it was the cubits and not the miles which differed.

Against this background they set about to measure the length of the degree by direct observation of the latitude variations along a north–south traverse in the desert of Iraq. They chose a region south of Sinjār, which is about 100 km west of Mosul. According to extant reports two expeditions were made, one led by al-Marwarrūdhī, the other by ʿAlī ibn ʿIsā al-Asṭurlābī. In one account it is said that they agreed on the ratio 56 miles per degree, but other accounts of the expeditions report 562/3, or 561/4 miles. There is probably a blending here of observation together with a conversion of the late Roman figure of 75, since 3/4 × 75 = 561/4. The accounts are somewhat lacking in circumstantial detail, and probably the methods employed, which must have involved a sufficiently portable quadrant for the measurements of latitude along the route, would not have sufficed to provide more than a rough verification of the received figures, sufficient at least to distinguish between the two different interpretations of the mile.

The great scientist al-Bīrūnī (fl. AD 1030) carried out some work of great value in his determination of a series of longitude differences for stages leading from Baghdad to Ghazna. These were reported in both his treatise on geodesy *Taḥdid nihāyāt al-amākan li-tasḥīḥ masāfāt al-masākin* (The Determination of the Co-ordinates of cities), and in his astronomical treatise the *Qānūn al-Masᶜūdī*. He also reported his own attempt at a determination of the length of the degree. The latter took place in the Punjab, where the plain to the south may be seen from a peak (479 m) in the Salt Range, some 50 km South West of Jhelum. Al-Bīrūnī says that he measured the dip of the distant horizon as 34 min of arc, from which according to his calculation, he finds slightly more than 56 miles to the degree. He considers however that this should be regarded not as a new result but as a confirmation of the earlier result fixed at the time of al-Mamᶜūn. In fact his procedure was flawed in various ways, for his measurement of the height of the mountain was considerably in error, and a correct interpretation would have required that refraction be taken into account. Moreover we may calculate, taking refraction into account, that he would have obtained a dip nearer to 29 min, so that his whole account is quite suspect. The method has been suggested independently by a number of scientists, but even when carried out with the greatest care, it is doomed to failure because the degree of refraction is unpredictable for a ray grazing the earth's surface.

Al-Bīrūnī's determination of the longitude differences was much more successful. The tables of mean motion in his astronomical treatise were referred to the meridian through Ghazna (near Kabul), and he was naturally obliged to determine the time/longitude difference between that place and Baghdad. The primary information available to him, as to Ptolemy before him, was provided by travelers who would have converted a traveler's time to a distance. The region between Baghdad and Ghazna is divided up by al-Bīrūnī into shorter stages along two different routes, one passing North through Rayy and Jurjaniyya, and the other South through Shiraz. For each short stage, he calculated the difference of longitude, given the latitudes at each stage, and the distance from one stage to the next. In every case the travelers' distance is discounted to allow for the fact that the real path deviates from a perfect great circle. The problem of fixing the longitude difference is posed and solved correctly in terms of spherical trigonometry, and he gives all the numerical details, so that one can judge the accuracy of his work. In spite of occasional lapses in the calculation the results represent a very considerable improvement over that available in Ptolemy or al-Khwārizmī; the final longitude difference between Baghdad and Ghazna is only some 15 min of arc short of the true value. People would not be able to improve on that until entirely new methods were discovered in the late seventeenth century, such as the use of Jupiter's satellites.

See also: ►al-Bīrūnī

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Geographical Knowledge in Ancient Sri Lanka

P. Wickramagamage

Our knowledge about the early inhabitants who lived prior to the sixth century BCE in Sri Lanka is very limited, but more historical data is available for the period thereafter. Sri Lanka gained a place in the East–West trade and became an important centre in the sea route connecting the Far East and the West. It was known to people outside by several names (Lanka, Serendib, Sihaladeepa, Taprobane, Seylon, Zeylon, Ceylon, etc). Its proximity to the Indian subcontinent meant that people moved back and forth freely in ancient times. The Island has a long history of human habitation from about 130,000 years or more (Deraniyagala 1998).

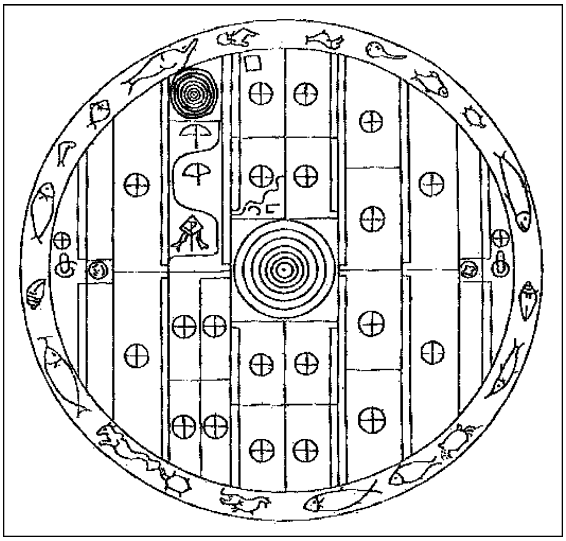
The island is divided into two major climatic zones, dry and wet, with a narrow belt in between with transitional characteristics. The Sinhalese civilization flourished in the Dry Zone, despite a severe water shortage during the long dry season. The highly seasonal rainfall meant rain-fed cultivation was possible only during the wet season. Despite this constraint, the main livelihood of the people was rice cultivation, which required considerably more water than any other crop. The need for artificial irrigation to overcome water deficit was understood from a very early stage, and the technology to develop a complex system of reservoirs and canals seems to have evolved out of this necessity. Development of irrigation demanded a high level of knowledge of the terrain as well as the principles of hydraulic engineering.

Sinhalese Cosmology

The ancient Sinhalese are thought to have known a great deal about the earth, its spherical nature, its position among other planets and the universe at large (Gunawardana 1979). Sinhalese did have close contacts with various parts of India and the Greco-Roman empire, particularly from the first century AD. Both ancient Hindus and Greeks had certain concepts of the earth, solar system, and the stellar constellations. Astrology played an important role in the ancient Sri Lankan and Indian cultures at a very practical level, and knowledge of astronomy was essential to make astrological calculations. It is possible that there was a considerable exchange of astronomical ideas between the east and the west. Verse 29 in *Sūryasiddhāntha* says "This Brahma-egg is hollow; within it is the universe, consisting of earth, sky, etc.; it has the form of a sphere, like a receptacle made of a pair of cauldrons" (Burgess 2000: 285).

Sūryasiddhāntha also places the zero meridian (*madyama-rekha*) over Sri Lanka (Burgess 2000: 362).

There is evidence that *Sūriyasiddāntha* was one of the astronomical/astrological texts taught in the educational institutions of ancient Sri Lanka. *Girasandesaya,* a message poem, composed in the fifteenth century "describes how students at the Vijayaba Pirivena studied the *Sūryasiddhāntha*, plotting the location of various planets by placing sea-shells as markers on a blue board and then moving them in accordance with their calculations" (Gunawardana 1979). The *Vijayaba Pirivena* was one of the foremost educational institutions of Sri Lanka at that time. It is probable that the Indian astronomical texts were in use in Sri Lanka long before that. Further evidence of this can be found in *Sūryasiddhāntha* itself, which speaks about exchange of ideas between students of astronomy in Sri Lanka and elsewhere in South Asia (Gunawardana 1979). At the same time, their links with the Greco-Roman empire means they would have known the ideas of Greco-Roman philosophers. The Sri Lankan ambassadors who visited Rome during the reign of Emperor Claudius are known to have discussed the stellar constellations they observed in Rome and compared them with those observations back in Sri Lanka (Gunawardana 1979).

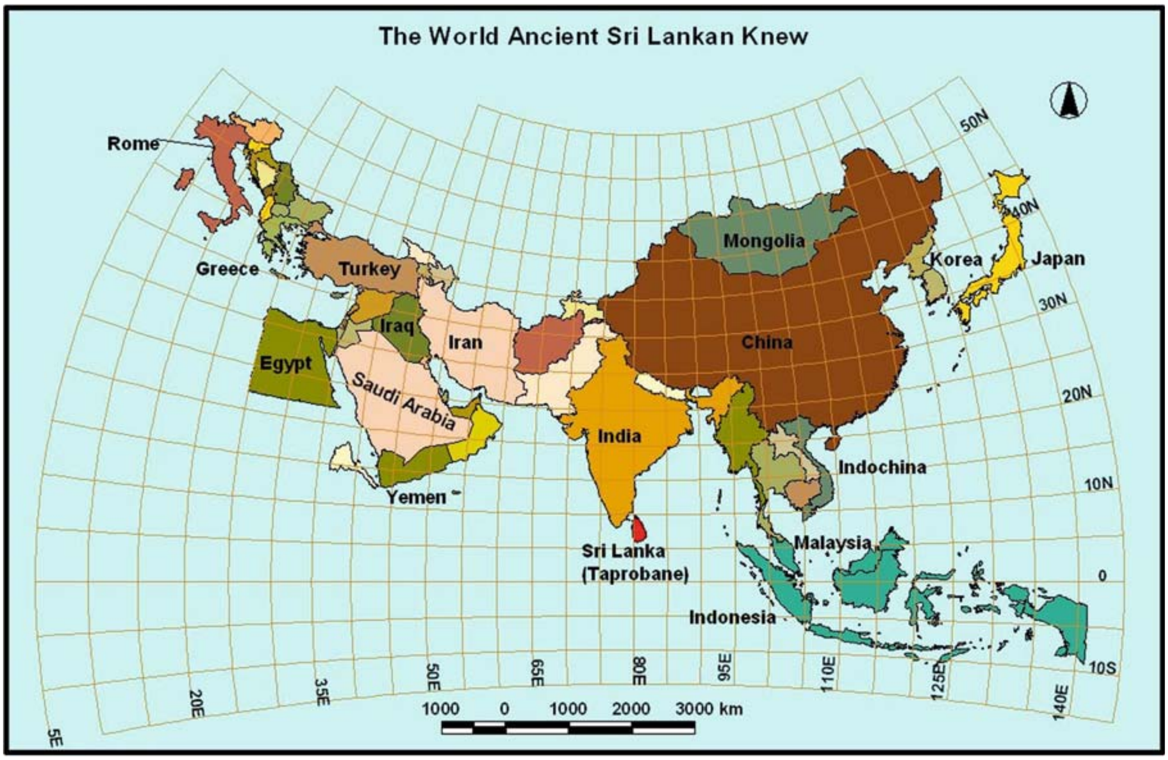


Geographical Knowledge in Ancient Sri Lanka.

Another piece of evidence of the Sinhalese cosmology and the shape of the earth is a carving in a cave in Anuradhapura (Fig. 1), which was discovered by archaeologists at the turn of the twentieth century (Bell 1901), and was named *Sakwala* (earth or universe). It is a circular figure within which numerous symbols are carved and the outermost ring contains aquatic life forms. At the centre of the figure is a carving with seven concentric circles with a dot marking the centre. At this time, there was a belief that this was Mount Meru located at the centre of the world surrounded by seven oceans and four continents. It is possible that the figure with seven concentric circles represent the earth and seven oceans. The same concentric circles occur at the top of the figure as well. The other figures in the interior of the circle have not been identified. Wickramagamage (1995: 54) is of the view that this is a *yanthra* which may have been used for meditation purposes. There is a seat made of stone right in front of this figure.

Ancient World Geography

The ancient Sinhalese maintained relations with countries in South Asia as well as the countries up to Rome in the west, and up to China and beyond in the east. This was facilitated by its strategic position in the east–west sea route. Seafarers from the west and east came to Sri Lanka which acted as a trading post in the ancient world, (Tampoe 1995). Two other ports that participated in this trade are Gokannapatuna (Trincomalee) in the northeast and Magama in the south. Manthai (Near Mannar) functioned as the main harbour and as a great emporium in the ancient South Asia region. Sri Lanka sent its own ships to China (Tampoe 1995).



Geographical Knowledge in Ancient Sri Lanka. Fig. 2 The World Ancient Sri Lankan Knew.

Sri Lankan kings had established links with Greece and Rome as far back as the first century AD. The king of Sri Lanka (Bhatikabaya) explored the possibility of developing direct trade links with Rome. In the year 361 AD, an embassy from Serendivi was received by the Emperor Julian. Similarly, commerce between Sri Lanka and China goes very far back into history. Manthai was involved in transhipment of Chinese goods to the West. China–Sri Lanka trade relations were also reported by the Sinhalese ambassadors to the court of Claudius in the first century AD. Embassies carrying gifts from the Sinhalese king visited China in the first century AD. The relations with China were not confined to trade. There were cultural exchanges between the two countries. The countries with which Sri Lanka maintained relations include Greece, Rome, Egypt, Arabia, Afghanistan, and Persia on the west and China, Korea, Japan, Malay-Indonesian Kingdom in the east (Bandaranayaka 1998). At the same time relations with India remained at a high level. As Weerakkody (1997: 139) has pointed out Sri Lankans themselves had gone to foreign countries on business, and owned ships of considerable size. The Chinese writer, Kien Chang found people from Sri Lanka in Canton. Also a Javanese inscription belonging to the eleventh century mentions Sinhala merchants putting in at ports there (Weerakkody 1997: 139). This evidence indicates that ancient Sinhalese knew a large part of the civilized world. The continents of Americas, Africa, and Australia were not known to them. The world they knew in ancient times is depicted in Fig. 2.

Knowledge of the Island

The dry lowlands of Sri Lanka received early waves of immigrants from India and continued to be the main areas of population concentration up to about twelfth century. Although available evidence shows that the Wet Zone was inhabited since the Stone Age, evidence of major population centres is found only in the western lowlands, where the Kelani Kingdom existed. There are however some references to villages and places of religious importance in the Wet Zone. The Wet Zone highlands were a part of the *Tri Sinhale*, the three provinces the country was divided into. Distribution of stone inscriptions is often taken to indicate the distribution of the ancient settlements in Sri Lanka (Perera 1978). The high concentration of inscriptions in the Dry Zone lowlands can be interpreted as evidence of ancient settlements in that area, and absence or low density of ancient inscriptions in the Wet Zone (both lowlands and highlands) may indicate that these areas were not densely populated at that time.

A number of villages were involved in various crafts and functions, such as industrial, agricultural, King's service, etc. According to Perera (1978) there were four types of settlements in ancient Sri Lanka:

1. *Gama*: Consisting of paddy fields, gardens, and chena. The people belonged to the same caste.
2. *Nigama*: Larger than *Gama* and a market town where traders met.
3. *Patun Gama*: More urbanized than *Nigama*. Both local and foreign merchants traded. These settlements were situated by the shore and usually had a harbour.
4. *Pura* or *Nagara*: Urban settlements, usually seats of government, with streets. Both local and foreign merchants met.

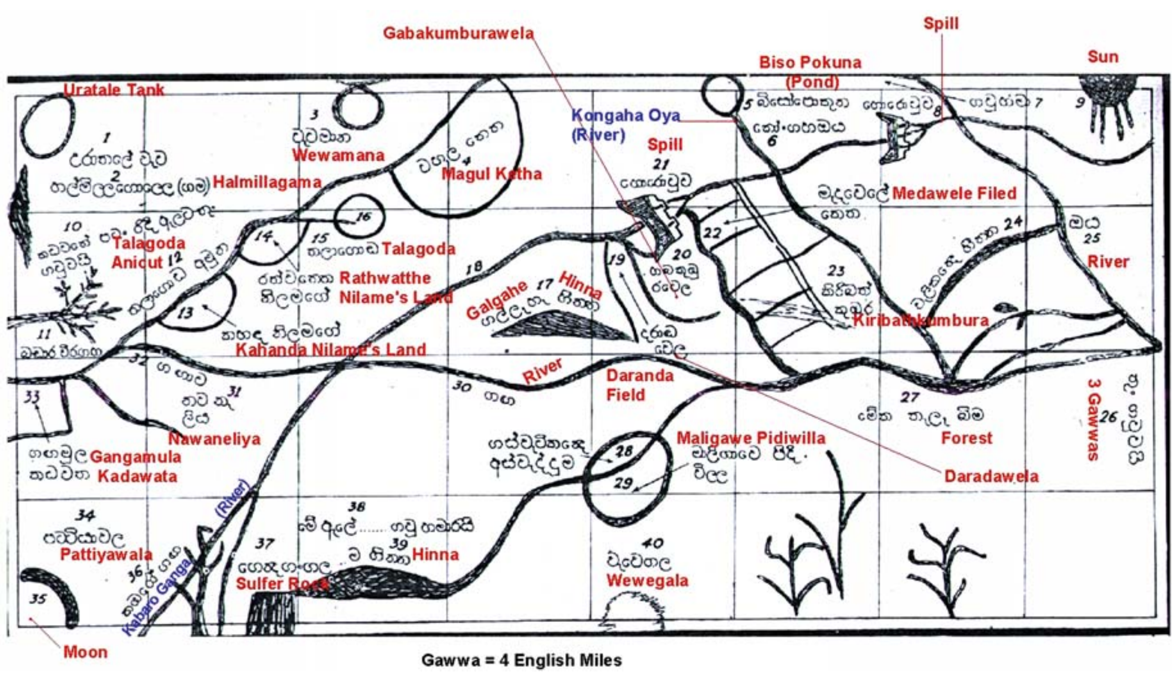
These villages were given names based on a salient characteristic of the village, and it is often its geographic character. There are many village names indicative of land forms, habitats, minerals, or man-made structures such as village tanks. The frequency of a certain name of a landform as a prefix or suffix to the village name indicates the dominance of that landform in the area. For example in the midcountry areas, there are many village names with '*deniya*' which means a valley. This area is characterized by the presence of a ridge and valley topography, and the people have shown a preference to settle in such areas for the reason that they are suitable for paddy cultivation. Some villages are named after a dominant plant or animal species present in the area.

The island has been under one monarch from time to time or split into several kingdoms when there was no strong ruler to unify the country. Unification of the country led to wars which made it essential that the warring armies were acquainted with the terrain. From a very early stage, the different parts of the island were well interconnected by major routes. The chronicles and commentaries speak about five main highways. King Nissankamalla (1187–1196), according to an inscription, fixed *guavas* (2.25 English miles) on the main highways and laid inscribed stone pillars (Nicholas 1959). Buddhist pilgrims from all parts of the island used to visit Adam's Peak (*Sri Pada*) mountain on top of which the foot print of the Buddha is supposed to have been placed. Long distances were covered to reach the *Sri Pada*.

The *Sandesa Kavya* (Message Poems), composed in the Kotte period (fifteenth to sixteenth century), were written to dispatch a bird as a messenger with a message to kings and deities. The route to be taken by the messenger is described in detail in poetry, which contains a geographic description of the landmarks the messenger would encounter in its journey.

Cartography

The oldest known map that has survived goes back to the seventeenth century based on a claim by the person in whose custody it was kept (Fig. 3). This map shows "certain lands and the topography including the



irrigation system in the valley of the Amban-Ganga, near Elehera, in the District of Matale" (Brohier 1951: 192). It has been drawn on a closely woven fabric (40 in. × 80 in.). A reproduction of this map has been published by Brohier (1951) together with the corresponding portion of the one-inch map of the area. The two maps show a remarkable resemblance. The scale of the map appears to be about one inch to a 1/4 mile, but this is not consistent throughout the map. The distances on the map are given in the Sinhala mile of *gauwa* which is about 4 English miles. The relative position of geographic features is accurate. There is no information about authorship of the map, or for what purpose it was produced. The directions are indicated in the map using the rising sun (east) and the waning moon (west). Brohier (1951) is of the opinion that the cartographer of this map was not familiar with the compass. If the author of this map learn the art of mapmaking from the Portuguese who were in the maritime provinces of Sri Lanka since 1505 and the Dutch later, he would have known to determine compass direction. Without more of such evidence, no firm conclusion can be drawn about the history of mapmaking in Sri Lanka. Given the need of such a practice in order to design irrigation canals, paddy lands, and reservoirs, it is conceivable that some form of mapmaking tradition existed in Sri Lanka. Maps may have been drawn on perishable material and therefore no evidence was left for the present generation.

Land Surveying and Design of Irrigation Systems

Without a clear understanding of the characteristics of the topography, construction of large reservoirs, tank cascades, and laying out of canals in an almost flat terrain would not have been possible. These irrigation works and their design can be used as indirect evidence of this knowledge. The early settlers of Sri Lanka chose the dry lowland plains for their settlements despite the severe water shortage during much of the year. This natural constraint was overcome by constructing first what is known as village tanks throughout the settled areas for irrigation as well as domestic use. Later, with an increasing population to be fed, it was discovered that these works were insufficient to last the dry season. This led to the development of large scale irrigation systems such as large reservoirs to store water by damming streams originating in the Wet Zone highlands. To convey water to paddy fields a system of main and distributary canals were constructed. They made decisions on the way canals are constructed, placing of sluices, and constructing dams in an undulating plain taking advantage of the topography. This point can be illustrated using the example of the trans-basin canal, *Yoda Ela* (Giant's Canal), running from *Kala Wewa* reservoir in the *Kala Oya* river basin to the *Tissa Wewa* of *Anuradhapura* (the ancient capital of Sri Lanka) located in the *Malawathu Oya* basin. This canal has a gradient "for the first 17 miles (27 km) of 6 inches" (Brohier 1979: 8). This shows the extent to which the ancient irrigation engineer understood the hydraulic principles and was able to convey water for long distances efficiently in a gently undulating terrain. Further evidence of the knowledge of the ancient Sinhalese engineer can be illustrated by a case where a branch canal from the Yoda Ela constructed by modern engineers some years back was later discovered to have run along the trace of an ancient canal which was used to irrigate the same lands using the water from *Yoda Ela*.

Another example for the extent to which the ancient Sinhalese understood the topography is the construction of village tank cascades in the Dry Zone of Sri Lanka (Fig. 4). "A cascade is a connected series of tanks organized within a micro-catchment of the Dry Zone landscape, storing, conveying and utilizing water from an ephemeral rivulet" (Madduma Bandara 1985). They are constructed taking advantage of the topography along the tributaries of Dry Zone streams. There are 127 tank cascades in an area of 1,225 km^2 covered by the Anuradhapura and Medawachchiya one inch topographic maps alone. This amounts to one cascade per square km. Over 85% of the operational tanks are located in cascades. The tank cascades allowed the optimal utilization of meagre water resources of an area. Each tank is associated with a paddy field, and the excess water from the paddy field returns to the tributary to be input to the tank downstream. The size of the tanks in a cascade tends to increase towards the lower end. The cascade system is reckoned to be one of the most efficient systems of water storage, conveyance and irrigation.

The ancient Sinhalese had a remarkable knowledge of the island as well as the South Asian region, and the countries in the west and the east. Their knowledge was not confined to the knowledge of places, but included such areas as the characteristics of the earth as a planet.

An area that should receive a great deal of attention and in-depth research is the knowledge the ancient Sinhalese had on harnessing water resources of the country. Construction of artificial irrigation systems of colossal magnitude and conveyance systems is a remarkable technological achievement. The most surprising of all is the ability to design these systems with such precision with minimal equipment. They seem to have had an intimate knowledge of the terrain which they utilized to the maximum extent in designing and constructing irrigation systems.

After abandoning these systems for largely unknown reasons, the population moved into the lower parts of the hill country and again used the topography of the terrain to their advantage to protect themselves from enemy attacks. The new settlements were established in the hill country which was completely protected by natural barriers, and entry was possible only through narrow mountain passes which were well guarded.

Although mapmaking would have been an immense help to the designers of irrigation system, no evidence is found on a cartographic tradition in Sri Lanka, except for a Sinhalese map attributed to the seventeenth century. This is surprising given the fact that locating of reservoirs and construction of canals would have to be carefully designed and planed.

A substantial amount of original material is available for careful examination and study. It would be a rewarding exercise which could reveal depth of geographical knowledge of the people who lived in this island for over 3,000 years.

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Geographical Knowledge in Non-Western Cultures

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Cultures differ in their assumptions about the nature of life, the place of their existence, and the place of humanity within their environment. Places, like space and time, are constructed socially and culturally and as such can provide ways to understand the literal and metaphorical geographies of humans. The specificity of place derives from the fact that each place is the focus of unique mixtures of wider and more local relations between social groups, and it is this mixture which accumulates continually to create the distinct place. While distinguishing labels, for people involved in these social relations, such as woman, Canadian, Maori, can be starting points, no one person or one group is exclusively one complete identity, Western, or non-Western, in the end of the twentieth century.

Human cultures are neither essentially coherent nor wholly homogeneous. The borders between nations, classes and cultures have become more fluid. The very notion that the majority of the world's population is defined by not being something (in this case non-Western) infers the continuing power of the past legacy of European and more recently American colonialism or imperialism. The majority of the world's population are non-Western. They did not originate from Europe's colonial expansion into the Americas, Australia and New Zealand.

This geographical inquiry into the historical experience of non-Western cultures is made from the perspective of a Western woman, a cultural/historical geographer, born in Canada, now residing in Australia. A renewed concept of culture refers not to any unified entity. In a post-colonial world, the idea of an authentic culture as an internally coherent world is no longer tenable. Increasing global interdependence has made it clear that neither "we" nor "they", Western nor non-Western cultures, are neatly separated and mutually exclusive. All of us inhabit an interconnected, late twentieth century world, marked by porous national and cultural boundaries that are enmeshed with power, domination and inequality.

It is however, impossible to deny persisting continuities of long standing traditions, literate or oral, sustained habitation and cultural geographies of non-Western traditions. Human history is rooted in the earth. To understand this history, it is necessary to consider human dwelling and also to realize that European expansion meant the taking of land which was already owned by indigenous residents. With the beginning of European expansion in 1500, most indigenous peoples lived on their lands practicing agriculture, hunting and gathering. While all of these people have expanded geographically into adjacent territories, or into lands near where they once lived, there is no comparison with the great spread of people from European nations. It has been this modern colonialism which forced many indigenous peoples off their own land: Aborigines of Australia, Maoris of New Zealand, the indigenous peoples of North and South America. This compulsion of the Western world to explore, conquer, occupy and own other lands has involved such a long continuous process that it has been called the distinctive Western characteristic.

In contrast, a deep sense of belonging to the land, is central to the identity of indigenous peoples throughout the world, as exemplified by this Maori statement, that while "people disappear, land remains; land doesn't belong to the people, people belong to the land" (Yoon, 1986). The names many of these First Peoples call themselves, such as Inuit, Maori, Saami, mean "people" and the names of their places mean "land". They literally know themselves as people of the land. "We have opted to become part of the environment", explains Burnum Burnum of Australia. Although differing widely in their customs, culture, economic status, physical surroundings, and impact on the land, many indigenous societies often share a set of values that are in marked contrast to Western priorities. The Cree of Quebec, San of Kalahari and Tukano of Brazil are all connected through a profound relationship and spiritual attachment with the land.

Human beings have created various cultural space and time systems in order to maintain their unique spiritual relationship with the universe. Before the dominance of Western ideas and colonial empires throughout the world, literate societies of Japan, China and India were eloquent in describing their human relationship with non-human species and their place within the greater environment. Oral traditional societies had highly developed constructions of their environments which were transmitted through stories, dance and by paintings to successive generations. For non-Western peoples, although widely different in customs, culture and impact on the land, there was a shared belief in a deep bond with nature, an awareness that all life, rivers, skies, people, ants and rocks were inseparably interconnected. Physical and spiritual worlds were woven together in one web. Humans were not separate from nature but were a part of the nature of the world. Geographical knowledge concerning human and environmental nature is always socially and culturally construed. Through specific examples from non-Western cultures of both literate and oral traditions, an understanding of the diversity of specific geographical knowledges can be explored.

The Mythic Creation of the World

Each culture possesses creation myths which speak of the creative beginnings, an energetic phase prior to the appearance of physical matter and life. Marriage between the Ancestral couple is common to creation myths of India, Egypt, Mesopotamia, China, Central America and New Zealand. In all these myths, creation is sparked by a cosmic copulation. The intercourse of Geb and Nut in Egyptian mythology and that of Shiva and Paravati in the Indian myth, and Ranginui and Papatuanuku, the primeval pair in Maori myth, reflect creation themes. The vision of the sacred earth as a ledger of cosmology is unique to Australian Aborigines with their creation story written like a book in the earth's topography.

There is evidence of great length and complexity in Australian Aboriginal culture, the oldest continuing society in the world, reaching back to the Pleistocene Age which is based on the remembrance of the origin of life. Aborigines speak of the forces and powers which created their world as Creative Ancestors. During this epoch of world creation called the Dreaming, the Ancestors travelled across a barren flat terrain. Their hunting, loving and fighting shaped the land, deeply marking the surface of the earth and leaving their imprints forming the topographical landscape, making riverbeds and forming rocks and deserts. Before their travels, the Ancestors would sleep and dream the adventures of the following day. In this way, moving from dreaming to action, they had the ability to alternate between pure spiritual powers and an apparition of other forms. In Western scientific language, the earth evolved through a phase of powerful geological and climatic forces which shaped the earth's crust, creating mountains, oceans and rock formations. The main difference between these two myths is that Western scientific description acknowledges only physical forces, while Aboriginal explanation attributes consciousness to the creative forces and to everything created.

The Dreamtime epoch concluded with three fundamental conditions making possible the embodiment of conscious life: the earth's distinct topography, all variety of species of life, and patterns for social relationships. With the completion of this task, the Ancestors grew weary as the world was shaped and filled with species and varieties of ancestral transformations and they retired into the earth, the sky, the clouds and the creatures to exist like a potency within all that they had created. Their journeys were preserved in stories, paintings, ceremonies and patterns of living and extended a universal psychic consciousness to every living being as well as to the earth and the primary forces and elements.

The Western tendency to view land as material object, existing separately from humanity, allowed for it to be bought, sold and exploited. In contrast, Aboriginal culture shared the identity of the forms, principles and activities by which the natural world was created and saw life and sustenance embedded in the landscape which must be cared for as a friend and provider in continuing reciprocity. "With the birds, the fish, the animals, the plants and all of nature we are still Yorro Yorro, standing up in accordance with the blueprint of Creation", explains Mowaljarlai, concerning the role of men in maintaining the connection between cosmic regions and earthly community life in the Kimberley, Western Australia.

Understanding Nature and Humanity

Generally, the Japanese philosophical and religious traditions represent a holistic ecocentric view characterized by an aesthetic and material oneness with all things. In pre-industrial Japan, the intimate relationship between people and their surroundings can be grasped by the Japanese word *fudo*, which translates into the natural environment. While nature and humanity have been viewed as separate but connected in Western thought, fudo refers to the idea that nature and society are inseparable. *Shi-zen* or *Ji-nen* is the Japanese word which most closely corresponds to the European term nature. The connotations of this term signify a concept of nature in which nature is not objectified. Rather, *Shi-zen/Ji-nen* represents the manner of being and becoming of nature, human and environment. *Shi-zen*, originally a Chinese word, was adopted by the Japanese about 1,500 years ago. In ancient Chinese culture, the term had fundamental significance. Lao-Ze wrote: man is based on earth, earth is based on heaven, heaven is based on the Way (*Dao*) and the Way is based on nature (*Zu-ran*, or *Shi-zen* in Japanese).

The contrast between European and Japanese garden design illustrates the difference in perspectives of nature. In the English garden, a person seeks escape from humanity into a natural space free of artificiality. In the Japanese garden, one tries to express, within a defined space, the totality of mountains and rivers. This is an artistic, human act representing the highest meaning of *Shi-zen*. The English garden is a public place, open to all. The Japanese garden is of a private nature created solely for the few who are artistically gifted. Nature relates equally towards all in the English garden. The *Shi-zen* of the Japanese garden requires those who are able to experience *Shi-zen*. This implies that *Shi-zen* can never be separate, but within the person.

It is the same for Ikebana art and the *Shi-zen* of the tea-ceremony. In the Japanese tea-ceremony, the everyday routine becomes an art form. Sitting in a quiet, small room allows for the mind and body to become alert to the slightest sound, movement of the wind, perfume of flowers, changes in the intensity of light. This time passed within a small room heightens the sense of place by creating a moment of spiritual connection with the environment.

Sense of Place

The sense of place exists in the area where nature and humanity interact and shape each other. Within cultures, information concerning the geographical environment is expressed in certain ways, such as the making of maps, conceptualizing landscapes, and giving places names. In the Pintupi language of Central Australia, a place, or a country, or a camp is called *ngurra. Ngurra* signifies both the physical place where people share food, sleep, and dance, and also the metaphysical act of dreaming the country into existence. In this way, the question of Aboriginal identity is obtained by knowing the place. As Kuningga, the ancestral cat, travelled north he crossed plains, identified water sources and, after reaching a ceremonial site, continued north through a gap in the range. Kuningga's dreaming track weaves north, describing the particular geography of the land and of the natural resources contained within through a song cycle. Thus Kuningga's song can be understood as an oral map of the country. Places where significant events happened, where power was stored, or where the Ancestors had retired into the ground and still remain today are known as *Yarta Yarta* or special sites because of their concentrated ancestral potency.

Certain landscapes create a sense of awe by their presence. In Japan, Mt. Fuji, rising 13,000 ft above sea level, has been depicted in poems, paintings and stories from ancient times. The sheer physical presence of mountains which appeared to connect the earth with the sky allowed for them to be considered Japanese shrines. The word *oyama* sometimes means shrine and is derived from *yama* (mountain). Tadahiko Higuchi in his book *The Visual and the Spatial Structure of Landscape*, described seven protoype shapes for shrine and temple complexes which were translated by Kazuo Matsubayashi. They are:

1. Water-distributing: where water flowed out of the mountain creating a perfect rice irrigation place
2. Bowl: a small, peaceful, plain surrounded on all sides by green mountains
3. Lotus Flower Calyx: the site of a mountain temple surrounded by eight other mountains, which resembled the calyx of a lotus
4. Wind and Water (*fusui*): usually having mountains to the north, hills to the east and west, and a sea or river to the south, which was the ideal place to build a city, house or tomb
5. Valley: enclosed by mountains on both sides, which was thought to be the home of the spirits of the dead
6. Thickly forested: a small mountain covered in thick foliage in sharp contrast to its situation near a flat plain, which was believed to be the sacred dwelling of a god
7. Country-viewing: a low hill or mountain standing in the middle of a plain, commanding a view of the surrounding land

The close relationship between the people and their mountainous environment, with each of the types serving a unique purpose, demonstrates the vital reciprocity between humanity and nature.

In Maori tradition, the special relationship between people and their land is revealed, first by the myths explaining the origin of the universe, in which the material world proceeds from the spiritual and the spiritual world interpenetrates the material, physical world of Te Ao Marama, and secondly by the use of dominant landmarks, mountains, or water sources, as symbols of tribal identity. While many indigenous peoples live intimately with nature, the Maori appear to be unique in their formulation of their *pepeha* or popular sayings of tribal identity. Every established Maori community may apply their standard *pepeha* or introduction by naming their mountains, river and tribe at intertribal meetings, now as in the past, actively maintaining the oral tradition and identity of place.

Makeo is the mountain – Ko Makeo te manunga
Waiaua is the river – Ko Waiauna te awa
Tutamure is the Ancestor – Ko Tutamure te tangata

Hong-Key Yoon has described the pattern of structure of these sayings which includes the first two phrases for natural identity in terms of landscape and the third for cultural identity in terms of people. The first phrase mentions the most significant landform, almost always a *Maunga* or mountain followed by the second phrase giving the name of a prominent body of water or *te wai, te awa* or river, *te awauni* or big river, and *te moana* or sea. The third phrase names the tribe, giving social and cultural identity. Maoris associated intense feelings with the mountains, considering them to be the place of buried ancestral bones, while the valleys and rivers, often serving as tribal boundaries, did not assume as intense a sanctity.

These *pepeha* revealed the symbolic relationship of the people within their place and were combined with the functional territorial boundary delineating home territory, while also perpetuating cultural heritage. Today, the Maori traditions of respect for place are represented by the Maori Secretary in the Ministry of the Environment. The name of their movement, *Maruwhenua* comes from the understanding of the human responsibility for protecting the land. Mmaruwhenua reflects the saying, "People perish, but the land endures".

Sustaining Natural and Human Place

Indigenous knowledge of nature has ensured the survival of many peoples living in fragile habitats. For example, the Tuareg of West Africa practice nomadic pastoralism in a land so arid that it cannot sustain continual habitation, and the Inuit of the frigid Arctic regions have traditionally depended on hunting and fishing. Modern hunting and gathering depends on cooperation between group members and the formation and maintenance of economic relations with other groups. In Ituri, the tropical rainforest of northeastern Zaire, a mutually supportive, economic relationship has been created between the Efe, who practice a semi-nomadic lifestyle, and the Lese, who live as shifting cultivators. The Efe trade forest products, nuts, construction materials, meat and fish for produce grown by the Lese, and for their pottery, tools and arrows.

In many areas of the world, indigenous societies have classified soils, climate and animal species. Many of these words and descriptions for insects and plants are yet to be known by botanists or entomologists. The Hanunoo people of the Philippines distinguish 400 more plant species in their forests than the 1,200 ones identified by the scientists working in the same location. The Kayapo of Brazil gather about 250 types of wild fruit, hundreds of tubers, leaves, and nuts, and at least 650 plants which are used for medicinal purposes. This vast, complex, indigenous knowledge is now viewed as being important not only to the sustenance of the traditional owners, but to the very survival of the world.

The human relationship to the natural environment has been conceptualized differently over time and through space. At the end of the twentieth century, understanding of the human experience of nature, from both a Western and non-Western cultural tradition, has become an urgent imperative. The challenge now is to regard humanity and earth in global terms while also seeking an understanding of the social and ecological implications of the whole of humanity planetized. There has been much discussion concerning the damaging perspectives of the Western, anthropocentric approach to nature which has led to actions based on a premise of the separation between mind/body, human/nature and individual/society. This view has been blamed for much of the environmental destruction and exploitation of the world's human and natural resources. At the same time, there have been appeals to consider alternative modes of conceptualizing humanity and nature, such as developing a reverential attitude towards nature and acting in a socially cooperative manner, based on a non-Western, ecocentric perspective.

Cultural expressions, Western or non-Western however, show a universality only at the broad structural level. To go beyond this, it is necessary to explore the specific historical contexts of human habitation in place and through time. Non-Western and Western cultures are historically dynamic. It is important therefore to emphasize the particular and convey the diversity of traditions within and between groups, in order to create mutual understanding.

See also: ►Knowledge Systems, ►Ethnobotany

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Geography in China

Mei-Ling Hsu

The term geography (*di li*) which first appeared in Chinese documents during the Spring–Autumn period (770–476 BCE) literally meant the study of the order and morphology of the land. In the beginning the purpose of such a study was for survival; later it was used to facilitate the production of food and gathering materials for shelter. Agriculture was central to the economy, hence information was collected on climate, land, and water supply, and for crop cultivation and water control, e.g., to construct dikes. Because of these needs, studies in "geography of production" increased. Thus the Chinese have accumulated much geographic knowledge since ancient times.

The two frequently cited geographic classics are *Yu Gong* and *Di Li Zhi*. They demonstrate the importance of geography in delineating major regions in the country and in collecting locational information; these geographical applications facilitated the governing of the ancient Chinese empire. Mapping of large regions and local areas followed.

Yu Gong (The Tribute of Yu, who was a semi-legendary emperor) is a short but brilliant work, written in the Warring States period (475–221 BCE). It presents chapters on mountains and rivers, and on two methods of organizing geographical space: delineating nine physical regions, and allocating five political regions in China. Thus this work presents the earliest examples of regional and systematic geographies.

The term geography was first used as a title of a work in *Di Li Zhi* (Treatise of Geography), a chapter in the *Han Shu* (History of Han Dynasty), by Ban Gu (AD 32–92). It includes three sections, of which the first and third were reprints of earlier works, including *Yu Gong*.

The second section is devoted to the geography of 103 prefectures (*jun*/*guo*) and their subunits, the 1,587 counties. Within each administrative unit, some physical, cultural, economic, and demographic features are described. Cities are mentioned. Interestingly, it also describes petroleum as some kind of liquid that can be burnt. However, the major focus of this work is on the history and changes of boundaries of administrative divisions and settlements; such information was important to the governing of a large empire. Unfortunately, too often this particular focus was emphasized at the expense of a more thorough treatment of the physical characteristics of an area, and their effects on the inhabitants and the economy.

The publication of *Di Li Zhi* marked the beginning of a chapter on geography to be included in a dynastic history; this chapter appeared in the second of the 24 such histories. Thus the content and the methodology presented therein became a model that was followed in the later dynastic histories.

Ban Gu's work also planted the seeds of a later development: the publication of local gazetteers (*di fang zhi*) with maps included in these volumes. Beginning in the fifth century, the production of these gazetteers increased in number and gradually became the most prevalent form of geographic writing and compilation in pre-modern China. During the Tang Dynasty (AD 618–907), the scope of some gazetteers began to expand to cover a province and even the whole country; some of these compilations were multi-volume and were really geographical encyclopaedias. Today they constitute a voluminous geographical and historical literature.

Beginning in the Tang Dynasty, field studies became more important. Perhaps, by this time, long distance travel in China had become more manageable. Noted scholars spent many years away from home travelling and studying the country. They left with us their vivid descriptions and insightful interpretations of the geography of China. Among these books, the best known is the *Xu Xiage Yuji* (Dairy of The Travels of Hsu), written in the seventeenth century. Thanks to the efforts of these scholars, accurate geographical knowledge was accumulated, e.g. of the source of the Huang River, the process of erosion, and the retreat of the sea in the area of today's eastern lowlands. The last of these was studied by Shen Gua in the eleventh century; similar observations to that of Shen's were made in Europe by J. Hutton in the nineteenth century.

Despite the richness of the pre-modern literature, geography was not formally included in the civil examination in imperial China. Only during the late nineteenth century, as the modern school system was developed was geography incorporated as an instructional subject in schools. Today, in Taiwan and on the Chinese mainland, geography courses, which vary in area coverage and degree of difficulty, are taught in every grade in the secondary schools. The two major purposes of this instruction are to provide students with basic knowledge of China and of other countries in the world and to foster the spirit of patriotism.

In historical China, geography and cartography played important roles in scientific inquiry and applications. In this century, the subject geography is taught in schools and colleges, and mapping activities are routinely carried out by government agencies and educational institutions.

See also: ►Maps and Mapmaking in China

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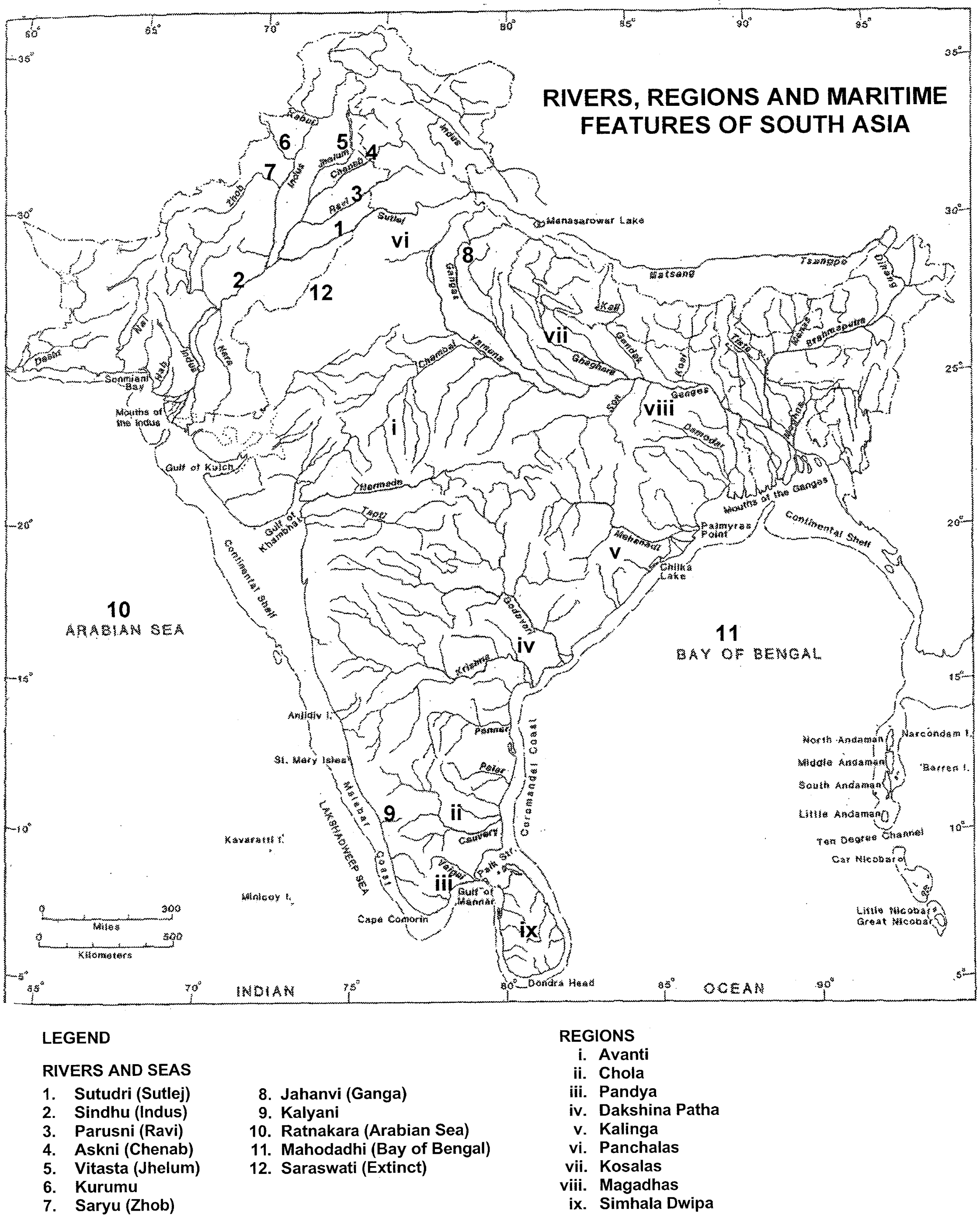
Geography in India

Ashok Dutt, Meera Chatterjee

The study of geography as a systematic science was a significant gap in Indian knowledge during ancient times. However, geographical facts were presented in a nonsystematic manner in the whole range of Sanskrit, Pali, and Prakrit literature. Compositions of a geographical character are often found embedded in the religious, legendary and astrological literature of ancient India. Both religious and secular literature contain numerous isolated references to cities, mountains, rivers, regions, and society, which collectively amount to a considerable addition to geographical knowledge. India is the home of an ancient civilization that originated over 5,000 years ago and attracted many travelers, scholars, ambassadors, and missionaries. Many conveyed impressions back to their compatriots through lively tales, anecdotes, and travel journals. These writings also became important sources of geographical knowledge. The writings of the Chinese, Greek, and Arab geographers are rich sources of information relating to various aspects of geographical science. Various names such as *Bhuvankosa* (Terrestrial Treasure), *Trilokya Darpaṇa* (World's Mirror) and *Kṣetrasamāsa* (Combination of Countries) were used to denote geographic phenomena. Hence, the principal sources of information about the status of geography in ancient India are sketchy because they are obtained from references extracted from nongeographical works, foreign accounts, and inscriptions. The ancient literature developed over the centuries could easily be arranged in a chronological sequence. *Ṛg Veda* (about 1500 BCE) was the first, which was followed by three other Vedas, *Sama, Yajur,* and *Atharva*. The *Upaniṣads, Purāṇas, Jātaka* tales and great epics – *Rāmāyana* and *Mahābhārata* were composed between 1000 and 500 BCE. Kautilaya's *Arthaśāstra* was composed around 300 BCE. Other than these, there are writings of different poets and foreign people that also help us to infer the geography of ancient India.

The *Ṛg Veda* is the earliest Indian literature that has been discovered. It mentions many geographical facts such as tribes, rivers, and mountains. According to Al-Bīrūnī (Alberuni), an Arab traveler in India, "Veda is knowledge of that which was unknown" (Kazmi 1995: 41). These and associated books contain knowledge about philosophy, mathematics, medicines, navigation, music, and dance. The *Upaniṣads* are works on religious meditation (Tamaskar 1985). It is difficult to find any direct description of the earth or the world, but, as in the *Ṛg Veda*, geographical phenomena or features are embodied in them. Like the *Vedas*, the *Purāṇas* also did not deal with geography in a systematic manner; however, they have a lot of geographical facts in them. The scientific material covers a wide range of topics from astronomy, cosmography, and cosmogony to the classical concept of region and regional classification. As defined by Alberuni, *Purāṇa* means "first eternal" and the *Purāṇas* are associated with the names of animal, human or angelic beings. *Purāṇas* not only contain mythical and legendary materials, but also contain scientific information, which is sometimes accurate. Information about astronomical geography can be easily extracted out of the *Purāṇas*. *Jātaka tales* are a huge source of unsystematic geographical information. The legendary stories contained in the *Jātakas* relate the previous lives of Gautama Buddha, the founder of Buddhism. He lived and preached in northeast India between 563 and 483 BCE. As there was no written common language, the stories were memorized and handed down from generation to generation by word of mouth. Several hundred years later they were written down in the Pali language; in the process many facts were exaggerated or lost. The *Jātaka* tales were set in some contemporary kingdoms. Kautilaya's *Arthaśāstra* mentions the names of a few mountains, regions, and tribes. It also provides us with a lot of information about territorial sovereignty and geopolitical principles. The great epics *Rāmāyana* and *Mahābhārata* contain extensive geographical descriptions of north and south India, military geography, family structure and the presence of non–Aryan tribes. (*Mahābhārata* depicts the war that occurred about 900 BCE).

The Aryans, who brought the *Ṛg Veda* from outside the borders of India (possibly from Persia), first settled in northwestern India (Punjab and the Indus plain). They mentioned regional rivers and their branches, such as the Saraswati (extinct), Sutudri (Sutlej), and Sindhu (Indus) (Fig. 1). The rivers, seas and regions had different names in ancient India. A few of them are mentioned in Fig. 1.



Geography in India. Fig. 1 Rivers, regions, and maritime features of South Asia. Base map from Dutt and Geib 1998. Permission obtained from the copyright holders. The authors gathered the information on the names of the ancient rivers from various sources.

According to *Ṛg Veda,* Saraswati was the greatest and most powerful river that flowed from the mountains to the sea. The greatest and the holiest river mentioned was not the Ganges, but the dry Saraswati. The latest studies have shown that the Ṛg Vedic Saraswati was a perennial river. The confluence of the Ganges (Gaṅgā) and its tributary Yamuna are mentioned as the eastern boundary of the Aryan settlement. However the Ganges was mentioned only once, whereas the Saraswati was mentioned many times.

By the beginning of the Christian era, three other Vedas, epics and *Purāṇas* were written, and a more extensive description of Indian geography evolved. The Aryan settlements advanced eastward all the way to Bengal and toward southern India. The latter, though Dravidian in terms of linguistic and physiognomic characteristics, became Hinduized.

Ṛg Veda set the layout of an important aspect of social geography by stratifying Indian society into four different castes. (1) *Brahmins*, who were the interpreters of religious texts and handled all the scholarly literature, (2) *Khasatriyas*, the warriors and the rulers, (3) *Vaiśyas*, the merchants and farmers and (4) *Śūdras,* slaves who did all the hard work including cutting jungles to make land arable. Some of them were designated as untouchables. The following extract is based on *Ṛg Veda* explains the function-based, social hierarchy (four castes).

> The *brahmans* form the highest social order, the literate intelligentsia which gave India its priests, thinkers, law-givers, judges, and ministers of state. The *rajanyas*, later called *khsatriyas* or rulers, were the second social order. The Indian counterpart of feudal nobility: from this class was recruited kings, vassals and warriors. The *vaishyas* formed the class of landowners, merchants, money-lenders, while the *śūdras* originally those people conquered by Aryans, were workers, artisans, or serfs. (*Ṛg Veda*, 10.90, as cited in De Bary 1967: 13–14.)

The caste system still persists among the Hindus. As most of the Muslims and Christians in India are converted from Hinduism, many of them have retained their caste distinction.

Ancient Indians also knew about the land and water ratio on the earth's surface. Though they did not have accurate knowledge of the ratio, they believed that oceans occupied twice as much area as the land surface on the Earth. In the second *Anuwaka* of third *Brāhmana* of III *Adhyaya* of the *Bṛihadāranyaka-Upaniṣad* it is said, "The oceans surround this earth on every side twice as large" (Tamaskar 1985: 7).

The Himalayas were mentioned in *Upaniṣads* as the "White Mountains" because their upper reaches are snow clad year-round. The rivers flow out of this mountain chain in an east and west direction. They have also been referred to as a powerful barrier for invaders, thus acting as natural borders.

The river Ganges is mentioned in the *Vayu-Purāṇa* as a purifier of sinners, passing through thousands of mountains and irrigating hundreds of valleys thus establishing the importance of rivers in the environment. *Matsya-Purāṇa* also mentions the rivers of Jambū-dvīpa (consisting of most of Asia) and Bharatvarsha or India (the southernmost country of Jambū-dvīpa) rising in the ranges of Himavanta (Himalayas). It was in *Kausītaki* that the southern mountain – Vindhyas – was first mentioned, while both *Vasishṭa Dharmasūtra* and the C*ode of Manu* referred to the Vindhyas by name. *Rāmāyana* and *Mahābhārata* give extensive descriptions of geographic features of both north and south India. When King Dasaratha (in *Rāmāyana*), father of Rama, performed an *Aśvamedhayajaña* (Horse Sacrifice) to establish his supremacy over the world, both north and south Indian kings were referred to. In the *Bhīṣmaparva* section of the *Mahābhārata*, Sañjaya, the chariot driver of the blind king Dhṛitarāstra, identified the nations, mountains, and rivers of India. Epics also describe Hastināpur (situated by the side of Ganges), capital of the Kauravas, Indraprastha (situated by the side of Yamuna), capital of Pāṇḍavas, Ayodhyā (in Uttar Pradesh), capital of Rāmā and the city of Mithilā (in Nepal terai). In the *Rāmāyana*, the city of Mithilā, possibly Janakpura in Nepal terai, is referred to as a "city of color and pleasure with people enjoying the business of living." It had "golden turrets and domes, and lofty towers." The book also says that, on the eve of Sītā's *Swayambara* (a ceremony in which the princess selects her groom from among the invited guests), there was a "moat" surrounding (King) Janaka's palace (Narayan 1972).

The *Jātaka* tales were set in some contemporaneous kingdoms. The topographic features are embedded in the tales. The Himalayas were mentioned many times. References to small water bodies (ponds) can also be found. Mostly the stories were woven around animals; this referred to the conservation of wildlife. The tales mentioned the coexistence of carnivores and herbivores, a condition required in nature for a balanced ecology. They frequently refer to thick forests which indicates that the Himalayan and sub-Himalayan zones and parts of the Deccan plateaus were once covered by dense and luxuriant forests. Numerous species of plants and trees were also mentioned. Cultivation and rearing of animals were the principal occupations of the population, although there is a mention of nonprimary activities, such as mining, textiles and trading. The *Ṛg Vedic* literature talks about the abundance of water in North India brought about by melting of ice caps. Present arid regions like Thar and Rajasthan deserts and the deserts of Sind were once fertile and supported agriculture.

Permanent settlements and agriculture led to trade and other occupational differentiation. Aryans after settling in Pañchāla (Punjab and Haryana) started colonizing the central and eastern Ganges plains and advanced to the Ganges delta in Bengal. From east to west there is a progressive diminution of Aryan traits among the population. As the Aryans advanced eastward, more slaves and śūdras (tribals, vanquished people and Dravidians) were used to clear forests in order to make the Ganges and other plains cultivable. The eastward terrain was inhospitable, wet and disease laden and had limited attraction to the Aryans. They employed slaves and śūdras in vast numbers, who performed the most difficult task of land reclamation. As lands along the Ganga (or Ganges) were cleared, the river became a trade route; the numerous settlements on its banks became markets and trading centers. The cities of Varanasi and Pāṭaliputra (Patna) are two important examples. As the majority of the settlements grew up along the river the probability of their being linear was very high. Trade was restricted initially to local areas, and barter was an essential component of trade, cattle being the unit of value in large-scale transactions, which further limited the geographical reach of the trader. Consequently, markets and the trading process were concentrated in some regions. Custom was law, and kings and chief priests were the arbiters, perhaps advised by certain elders of the community. An Aryan *rājā*, (king) was primarily a military leader, who took a share from the booty after successful cattle raids or battles. Although the *rājās* had managed to assert their authority, they scrupulously avoided conflicts with *Brahmin* priests as a group, whose knowledge and austere religious life surpassed others in the community. The priests were the educated group of the society and considered superior to other castes, and they also interpreted religious books.

Kautilaya's *Arthaśāstra* prescribed a state planned colonization policy for undeveloped (primarily natural vegetation covered) areas with people from foreign lands and kingdoms' surplus labor. Each village was to have 500 families, mostly śūdra cultivators or laborers; villages were to be grouped in a hierarchy of settlements of 800, 400, 200, and 10 units with a large town (*sthaniya*), small town (*dronamukha*) smaller town (*karvatika*), and large village (*samgrahara*) to serve each group, respectively.

Beginning with the *Ṛg Veda* through the *Purāṇas*, cosmological and cosmogonic interpretations of the causes of wind, precipitation, day and night, seasons, and the planetary movements were made. A four-way explanation of the origin of the universe was also given: artistic, mechanical, instrumental, and philosophical. First, the artistic origin refers to god as an artist who skillfully constructed the universe. Second, the mechanical origin is conceived as a sacrifice of the *Ādipuruṣa* (primeval body) who not only had the soul and the nucleus of the universe, but also embodied the Supreme spirit, resulting in the formation of the earth, sky, wind, moon, sun, and other terrestrial elements.

> The origin of universe from a primeval sacrifice, in which a cosmic being offers himself as an oblation, is not known in primitive mythological traditions. However, the sacrifice of the male Purusha here is not so much the primordial sacrifice of a world giant or the type *Ur-mensch* found in Norse or Germanic mythology, as it is a cosmogonic idea based on ritual sacrifice itself as the origin of universe. (Based on *Ṛg Veda* 10.90, as cited in De Bary 1967: 13.)

Third, the philosophical concept considered the beginning as an empty space with no atmosphere or sky. The universe was born out of its own nature, possibly by its own inherent heat. The *Ṛg Veda* also attempted to provide a scientific explanation of the mystery of the origin of the universe. Accordingly, the "creation of universe has started with the origin of water and the cosmic golden egg [embryo, *Hiraṇyagarbh*] which very well fits in the geological and biological evolution of the earth with the water age, origin of Zoophytes, primeval fishes, reptiles, invertebrates, vertebrates, and mammals"(Tripathi 1969: 3). It also said that water pervaded the whole universe which held fire in its womb. This indicates that during the Vedic age, the civilization was aware of the fact that the interior of the earth was very hot. The fire probably refers to the rising temperature beneath the surface. The importance and dominance of the water were also realized. The *Māhāpurāṇa* further crystallizes the idea that the world endures under its own nature and is divided into hell, earth and heaven.

Fourth, the instrumental origin idea is reflected in the union of heaven and earth caused by the action of different gods, such as fire (*Agni*), sun (*Sūrya*), and *Indra*. "The central idea of various cosmogonic theories of the vedic and postvedic period appears to be (1) existence of the water in the beginning, and (2) creation of the cosmic nucleus – *Prajāpati*" (Ali 1966). *Prajāpati* is an embodiment of propagation and hence maker of universe. In this concept, they also recognize the supportless movement of the heavenly bodies as iron pieces around a magnet in the sky. Puranic literature mentions solar and lunar eclipses several times although their true mathematical theory was not known. Therefore mystical explanations were advanced.

> The demon will obscure the moon and the sun at the end of the dark fortnight and the full moon. Entering the shadow of earth and moon, the swarthy-figured concealed demon will bring adversity to the moon and sun respectively (Tripathi 1969: 39).

The *Upaniṣads* spoke indirectly about the spheroidicity of the earth. The description of the rising and setting sun is mentioned in *Prapathaka III, Khanda* 6–10 to the *Chandogya-Upaniṣad*: "So long as the Sun rises in the east and sets in the west" (sixth *Khanda*) (Maxmuller 1900). The concept of the rising and setting of the sun was directly related to the shape of the earth. It has been

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suggested that the sun's rays did not spread over the earth at the same time, but that they fell by slow degrees, suggesting that the earth was a sphere.

Jātaka tales also mention the rising and setting sun. The whole society seemed to try to have a proper balance with the environment. They frequently referred to the laws of nature which were important for their survival.

> The sun gets up each morning
> (And the sun is free)
> It goes to bed each night,
> Why not we?
> The clouds, the rain, the earth,
> This very Banyan tree,
> Obey the laws of nature.
> So do we!"
> ("The Oldest of the Three" DeRoin 1975)

There were six seasons: *Vasanta* (spring), *Grishma* (summer), *Varsha* (rains), *Hemanta* (early fall), *Sisira* (late fall) and *Seet* (winter) are recognized in Vedic literature. Seasons are also discussed in the *Upaniṣads,* but they identified only five, as *Hemanta* and *Sisira* were merged. In the region where the *Upaniṣads* were composed (Punjab Plains) it was difficult to differentiate between the two. The year began with *Grishma* (summer) and concluded with *Vasanta* (spring). Wherever it rained sufficiently, crops were produced; this implied regional variation in rainfall. Punjab, where Aryans settled first, is drier than the east (Bihar and Bengal). With the spread of Aryan colonies from west to east, it was possible to draw a comparative picture of rainfall. The correlation between availability of rain water and food production has also been established in the ancient documents, pointing to the absence of irrigation.

The ancient literature also described the racial composition of the population and their geographical distribution. The *Ṛg Veda* also mentions non-Aryan tribes. It talks about *Dasyus* (Dravidians) not tamed by Aryans, who were considered civilized and supported a matriarchal family system as opposed to the Aryan patriarchal family. The *Ṛg Veda* also mentions *Rakshasas* (demons), who were short, dark, thick lipped, fierce in appearance, curly haired and possibly of Negroid origin. They were considered hostile to Aryans. They did not worship fire. *Rakshasas* were engaged in guerilla warfare, attacking Aryans at night and stealing their cattle. Another tribe mentioned in the *Ṛg Veda* is *Paishachas*, who were ruddy in appearance.

The ancient literature discussed a cyclical human development on the earth. The Hindu view expressed in the *Laws of Manu*, speaks of four ages – *Kṛita, Tritā, Dvāpara,* and *Kali* with a sharp break at the end of each age. Physical and spiritual deterioration occurs at the completion of the four-age period with the universe coming to an end and then beginning a new cycle. The *Laws of Manu* also stated that the age of Gods starts with the *Kṛita* (Winning Age).

> In the Winning Age [*Kṛita*], religion is entire, standing on all four feet, and so is truth; and men do not acquire any gain through irreligion. But in the other [ages], through [such wrong] gains, religion is brought down foot by foot; and because of theft, lying and deceit, religion goes away foot by foot. In the Winning Age people are free from sickness, achieve all their goals, and [have] a lifespan of four hundred years; but in the ages that begin with the age of Treta, their lifespan grows smaller foot by foot" (*Laws of Manu* 1991).

Jainism adheres to the teachings of Mahāvīra who died in 468 BCE. He was a contemporary of Buddha. The Jains also believed in the cosmic cycles, but unlike Hindus they did not foresee any sharp end at the end of the periods (ages). The Jains divided a full cycle into six periods, each with ascending and descending halves. At the end of the sixth period, designated as "very wretched," human deterioration reaches its peak with a fierce storm wiping out almost all inhabitants. After this a new six-cycle period starts.

As discussed by Tripathi, *Vrhannardiya Purāṇa* provides valuable information on mathematical geography. It gives the radius of the earth as 800 *Yojanas* or 4,000 miles (1 *Yojan* = 5 miles). The diameter was calculated as 1,600 *Yojanas* and circumference as 1,600/10 or 1,600 × 3.162 *Yojanas.* It provided a formula for calculating the circumference of any latitude parallel to the equator. These facts show that ancient Indian society was indirectly aware of geographical facts and they also made an effort to work on it scientifically (Tripathi 1969: 40).

A section of *Atharva Veda* and the *Aitareya Brāhmana* refers to five geographical divisions of India, which remains valid today. Further details of the divisions are given in the two great epics *(Rāmāyana and Mahabharta)* and the *Purāṇas.* They contain some chapters giving a fairly good account of not only the different territorial divisions of India, but also rivers, mountains, lakes, forests, deserts, towns, countries, and people (Gupta 1973). India, as mentioned in the *Purāṇa,* is bordered by Himavat or the Himalayas in the north and by the seas in the south, but Puranic *Bhāratvarsha* stretched from the Himalayas in the north to the Southeast Asian archipelago.

The authors of the *Purāṇa* seem to have been acquainted directly or indirectly with the major portion of India. The concept of Hell as described in the Puranic literature covers a geographical region, which is inhospitable and uninhabitable. The road leading to Hell had extreme weather conditions (arid and devoid of water), marshy and swampy land, and very dense forest infested by dangerous animals. They knew that the planet earth had regions which were not conducive for human habitation. So the importance of a favorable environment to survive was known to the people. Living in unfavorable and dull conditions was equivalent to living in "hell." The *Purāṇa* also mentioned favorable sites for human settlements. Availability of water was the decisive factor. According to Tamaskar, sites of settlements during the Puranic age were associated with escarpments, summits of mountains or hills, riverbanks, situation near lakes or tanks, islands, seacoast and forests. Riverbanks were the most important of all the sites. In addition to providing water, they also served as a means of transportation for goods and humans. Modern settlement geography also finds the wet-point-sites as the most favorable for human settlement.

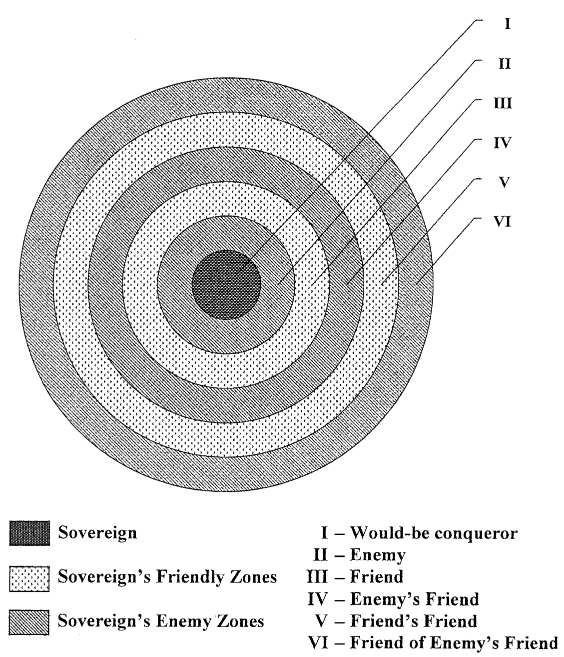
Different geomorphologic features were discussed in the *Rāmāyana*, such as mountains, plateaus, disintegrated rocks, cascades and falls, caves, etc. The mighty Himalayas were divided into three regions – the outer, the lesser, and the interior conforming to the present day classification. The *Rāmāyana* indirectly deals with economic and commercial geography. It mentions the trading relations between different regions, trading items such as horses of Kāmboja (Cambodia), silk goods and silver in the neighboring islands of Java, gold mines in the west and so on. The epic also provides information regarding prevailing weather conditions.

> Mist and its disappearance through diurnal rise of temperature, mist and severe cold, cold western wind, water vapor hanging on the surface of the river, dew formation on the sandy margin of the bank and snowfall give a very good description of winter season with some of its geographic paraphernalia. Mountain winds or wind of mountain valleys are also spoken of" (Tripathi 1969: 103–104).

The *Rāmāyana* indirectly explains the hydrological cycle in its simplest form. It relates solar heating of the ocean, evaporation and cloud formation. It narrates the physical movement of people in different directions. This implies that the transportation and communication system were in a developed stage. There is mention of five types of roads – lanes (*Vithi*), streets (*Rathya*), by-roads (*Uprathya*), roads (*Mahapath*), and National Highways (*Rajmarg*) (Tripathi 1969: 166).

The *Mahābhārata* gives a good account of topography, crops, people's occupations and their political and legal institutions. During that period, India had flourishing international trade with central Asia. This points to the fact that ancient Indians had enough knowledge about sea and land routes and even knew about the air circulation system and the tides. By the time of the composition of the *Mahābhārata* the idea of seven continents, each surrounded by oceans, was firmly established. Four areas are Jaṃbū (all of Asia minus the east), Kuśa (Middle East), Śālamali (Eastern Africa), and Puskara (Eastern Asia). The southern part of Jaṃbūdwīpa was inhabited by Hindus in the land called Bharata or Bharatvarsha. At the center of the Jaṃbūdwīpa was the Meru, identified with Pamir knots, and at the northern extremity adjoining the Arctic Ocean was the Uttarakaru. Jaṃbūdwīpa was surrounded by an ocean, meaning a physical barrier.

Kautilaya's *Arthaśāstra* discusses the principles of territorial sovereignty and geopolitical principles. According to Kautilaya, the seven elements of the state were the king (*Swāmi*), the minister (*Amātya*), the country (*Janapada*), the fort (*Durga*), the treasury (*Kosa*), the army (*Danda*), and the ally (*Mitra*) (Kangle 1965). *Janapada* meant both the land and the people. The organization of space also extended into the coastal regions and territorial waters. Kautilaya believed that success of any state depended on peace which could be affected by the internal and external forces reflecting centripetal and centrifugal forces of modern political geography, discouraging disintegration and encouraging integration of the state. Kautilaya's sixfold policy dealt with the internal and external problems of the state directly, and the policy revolved around peace, war, preparation for war, neutrality, seeking shelter and dual political policies. On the basis of political attitudes the neighboring states at the periphery or beyond were conceived as geopolitical zones of enemy, friend, enemy's friend, friend's friend, or friend of enemy's friend with increasing distance (Fig. 2).



Geography in India. Fig. 2 Geo-political zones of Kautiliya (Modified from Tamaskar 1985).

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According to Kautilaya, "place means earth. In that the region of the sovereign ruler extends northwards between Himavat and the sea, 1,000 yojanas in extent" (Tamaskar 1985: 96). This implies that the natural boundaries for the states were considered important. The right location of the capital within the boundary manifested geographical consideration. Kautilaya emphasized the importance of the strategic location of the capital.

> …The king may have his fortified capital, as the seat of his sovereignty (*Somudayasthanam*) in the center of his kingdom in a locality naturally best fitted for the purpose, such as the bank of the confluence of the rivers, a deep pool perennial water, or of a lake or a tank, a fort, a circular, rectangular or square in form, surrounded with an artificial canal of water, and connected with both land and water paths (Kangle 1965).

The *Arthaśāstra* also mentioned the importance of developing means of transportation and communication in order to have political unity within the state. Developed transportation would serve as channels for the army to reach at a time of crisis. In addition to defense it would also help to promote trade and commerce, serving as a lifeline for the state.

The great verse writer, Kalidasa, (designated the "Shakespeare of India"), created *Meghadūtam* and *Raghuvaṁśa.* They showed a detailed knowledge of hills, rivers, plains, and cities. In *Meghadūtam*, Kalidasa's description of the path from Ramagiri to the Himalayan gate in the poetry is no less than a geographer's account. While sending clouds as messengers, the routes, rivers, hills, and cities lying on the way were described. Again, in *Raghuvaṁśa*, the poet showed in-depth knowledge of Indian geography. The kingdoms as described by Kalidasa show that he had some knowledge of the southern countries of Pandya and Kerala.

Greeks and Persians are the earliest foreign people to leave accounts of India. Greek writings indicate that ancient Indians had knowledge of the shape and size of their country. In 320 BCE, Eratosthenes gave India the shape of a rhomboid or unequal quadrilateral which had Indus on the west, the mountains on the north and the sea on the east and south. In 300 BCE, Megasthenes, a Greek ambassador of Seleucus Nicator, visited the court of a north Indian King, Chandragupta, and left an account of India on his return. In the *Mahābhārata*, India is described as an equilateral triangle divided into four smaller equal triangles. The apex of the triangle was Cape Comorin and the base was the Himalayas. Cunningham drew a small equilateral triangle by drawing a line between Dwarka (Gujurat) and Ganjam (Orissa) and repeated the exercise on each of the three sides to obtain four divisions of India in one large equilateral triangle. Varāhamihira identified eight divisions. The central division of Pañchāla (Punjab/Haryana) was surrounded by Maghada (east), Kalinga (southeast), Avanta (south), Sindhu-Sauvīra (west), Anarta (southwest), Madra (further south) and Kauṇḍa (northeast).

In the world map of Ptolemy (second century AD), a Greco-Egyptian geographer–astronomer, the true shape of India was distorted. He ignored the southern peninsula and drew an almost straight line from the Gangetic delta to the Makran coast in Baluchistan.

> The cause of this mistake is partly due to the erroneous value of 500, instead of 600, Olympic stadia, which Ptolemy assigned to an equatorial degree, partly to an overestimate in converting the road distance into map measurement, but chiefly to the excess which he allowed for the distances of land journeys over those of sea voyages" (Cunningham 1979).

Though only the southern part of Jaṃbūdwīpa was considered Bhāratavarsha, the Indians referred to the latter as the whole earth because the landmass of South Asia surrounded by mountains in the north and seas in the south was not only a physical cul-de-sac, secluded from other people, but was so productive and large that to the people of India it constituted the world. Puranic legend claims that King Bhārata, whose name was identified with the country (Bhāratavarsha), ruled the entire earth, meaning all of India. Such was the case with the emperor Aśoka as inscribed in his Fifth Rock Edict declaring that he was ruler of the world.

During the ancient Indian historical period when the country was shedding its narrow tribal characteristics, turning into a consolidated tribal conglomerate of Aryavārta (land of the Aryans), converging into organized states, no systematic study of geography evolved. On the contrary, during the same period, the Greeks and the Romans explored the geographical features of their known and unknown worlds and provided the basis for modern geography.

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Geography in the Islamic World

Amriah Buang

Geography is the study of the earth's surface as the space within which the human population lives. The internal logic of this study has tended to split modern geography into two parts: physical and human. Such a division was inapplicable in the geography of the Middle Ages, the golden age of scientific inquiry in Islamic civilization. Nevertheless, if we confine the meaning of science and technology to the natural and exact sciences, then a survey of geography in Islam may be divided into three categories: exploration and navigation, physical geography, and cartography and mathematical geography.

Prompted by the sense of Islamic brotherhood, and the quest for knowledge and piety, Muslim scholars engaged in many exploration and navigational activities between the ninth and twelfth centuries. The journeys were not confined to the political boundaries of the Islamic empire but extended to distant regions such as China, Southeast Asia, Southern Africa, and Russia. In Northern Europe, the extent of the Muslims' travels may be gauged from the fact that some ten million pieces of the Islamic state's coins have been found around the Baltic. In Sweden alone 12,000 such coins were discovered at 169 sites.

From extant documents, it may be deduced that no less than 20 geographers were involved in navigation and exploration, resulting in a massive store of information and descriptions of the terra-cognita. Out of these, five may be regarded as outstanding. These geographers are al-Muqaddasī (b. tenth century), Ibn Jubayr (b. AD 1145), Yāqūt (b. AD 1179), Ibn Baṭṭūṭa (b. AD 1304), and Ibn Mājid (b. AD 1400). The contributions of Ibn Faḍlān (tenth century), Ibn Ḥawqal (tenth century), Masʿūdi (d. AD 456), al-Bīrūnī (b. AD 972), al-Idrīsī (b. AD 1099), Ibn Rushd (AD 1300), Jawainī (ca. AD 1000), Abdur Razzāq (AD 1000), Yaʿqūbī (d. AD 897), al-Marwazī (d. AD 887), Nāṣir-i-Khusraw (b. AD 1003), al-Māzinī (b. AD 1080), al-Maghribī (d. AD 1274), and Ibn Khurdādhbih (ca. AD 900) are also noteworthy.

Al-Muqaddasī or al-Maqdisī spent 20 years travelling the length and breadth of the Islamic empire. He perceived that it was important to be able to substitute hearsay with personal observations, and set out on a series of field trips to gather information and knowledge about places. One of his major works was *Kitāb aḥsan al-taqāsim fī maʿrifat al-aqālīm* (The Best Climatic Divisions), which was regarded as accurately informative of areal differences in climate in the Islamic world. Ibn Jubayr was meticulous in his description of places such as Mecca and Medina in his The Travels of Ibn Jubayr, which became a basis for historical comparison with later writings. Yāqūt 's *Muʿjam al-buldān* (Dictionary of Geography) was another major contribution, and his extensive travelling within the Islamic empire resulted in a vivid account of the Islamic world before its fall to the Mongols. Ibn Baṭṭūṭa certainly stands out as the most seasoned traveller. In 20 years he journeyed as far as 120,675 km (75,000 mile) covering countries like China, Southern Ukraine, Sumatra, the Malay Peninsula, Kampuchea, Maldive and the Volga. His detailed accounts of life in these places contributed further to the geographical preoccupation with different areas. However, Ibn Mājid and Sulaymān al-Mahrī were better informed about the Southeast regions of the world. The former's *Kitāb al-fawāʾid fī uṣūl ʿilm al-baḥr waʾl-qawāʿid* (Principles of Navigation) and the latter's *ʿUmda and Minhāj* became important references for those who wanted first-hand information on the Malay Archipelago.

The fact that collectively the Muslim travellers and navigators covered more than two-thirds of the earth's surface illustrates the Muslim scholars' disdain for armchair scholarship. That distant places were visited for collecting information at a time when vehicles, vessels, and instruments were underdeveloped, and when both land and sea routes were more unsafe than otherwise, serves to prove the inquiring spirit of the Muslim geographers.

In physical geography the contributions made by Muslim geographers in the Middle Ages pertain to their theoretical speculations about the lithosphere, atmosphere, hydrosphere, and biosphere. In cosmology, they came out with new notions regarding the relationship between cosmological cycles and geographic changes. For instance, the Sincere Brotherhood or Brethren of Purity (*Ikhwān al-ṣafā*), an association of scholars whose treatises were considered the standard for scientific knowledge of their day, conceived of the influence of the angle of declination on insolation, the influence of relief on precipitation, and the relationship of precipitation with the origin of streams and springs.

With regard to the lithosphere, the solid part of the earth, Muslim geographers thought of landforms as being the results of erosion, deposition, and tectonic activities. Soils were considered the results of organic decomposition, and winds (gases in modern usage) trapped underground and seeking outlets were held responsible for earthquakes.

Their theories on atmosphere embraced both local atmospheric phenomena and the distribution of macroclimatic elements. Thus, by envisaging atmospheric processes, such as insolation, convection, and evaporation, they were able to account for the formation of clouds, rainfall, snow, fog, and dew as different forms of evaporation due to differences in temperatures. They also divided the world into three climatic zones: hot, cold, and temperate, based on their understanding of the changing positioning of the sun.

In terms of the hydrosphere, most of the Muslim geographers' works were focused on understanding the causes of tides, and the origin of oceans and reasons for their salinity. In accounting for tides, the geographers were divided. Some pointed to the influence of heat generated by the sun and moon; others attributed the tides to the influence of wind on the movement of sea water. Muslim geographers, in general, concurred with their Greek counterparts in thinking the oceans had originated from the remnants of primitive precipitation which did not get dried when matter was formed in the universe. They, however, differed again with respect to marine salinity. Some ascribed it to the transformation of calm water to salty hard water after prolonged gestation.

Regarding the biosphere, geography in the Islamic Middle Ages saw the categorization of flora and fauna according to the grade of their creation. Thus, al-Jāḥiẓ wrote of four classes of animals based on their locomotion: those that creep, walk, swim, and fly.

By contrast, Ibn Maskwaih's division was based on the creatures' stage of evolution, with the lowest stage being occupied by vegetation which did not require seeds to grow, and humans occupying the highest stage of evolution. The categorization by the Ikhwān al-ṣafā was based on senses, whereby creatures with one sense occupied the lowest level and those with five senses the highest. In spite of these differences, the Muslim biogeographers agreed that the spatial distribution of organisms was governed by climate, topography, and soils.

Yaqᶜūbī was noted for his *Kitāb al-buldān* (The Book of Countries) written in AD 891, in which he described in detail the physical characteristics of Baghdad, Samarra, Iran, Turan, and the present Afghanistan. Ibn Rustah discussed the importance of locational and physical environmental factors on the development of cities, such as Medina and Mecca, in the seventh volume of his *al-Aᶜlāq al-nafīsah* (The Book of Precious Things), an encyclopaedia completed in AD 903. Al-Maqdisī described an imperfect spherical earth, the northern hemisphere of which contained more land than water. He also gave a detailed account of the world climate in terms of zones. Yet the most daring speculation may be ascribed to al-Bīrūnī, who theorized that, based on empirical evidence of its physical environment, the Indian subcontinent might have been a continental shelf before depositions raised it into a landmass. Lastly, al-Qazwīnī (b. AD 1203) produced two books: *ᶜAjāʾīb al-buldān* (The Wonders of the Lands, or Geography) and *ᶜAjāʾīb al-makhlūqāt* (The Wonders of Creation, or Cosmology), which were notable for their reference to more than 50 authors. The significance of this fact is that the large number of practicing geographers that were cited indicates how active and prolific physical geography was in the medieval Islamic civilization.

The achievement of Muslim geographers in mathematical geography may be described in various phases of development. An important phase was the establishment of the school of mathematical geography in Shiraz, Persia after AD 950. This school produced important scholars such as ᶜAbd al Raḥmān al-Ṣūfī and Ibn al-Aᶜlam. ᶜAbd al Raḥmān reviewed Ptolemy's *Star Catalogue*, while Ibn al-Aᶜlam compiled an astronomical table which became a main source of reference for centuries. Important developments took place in the school in Cairo towards the end of the tenth century and the early eleventh century. Important scholars from this school included Ibn Yūnus, who prepared astronomical tables and corrected several errors committed by the Greeks Ptolemy and Hipparchus. For instance, according to Ptolemy, the precession of equinoxes occurs at 1° in 100 years, but the correct measure was 1° in 70 years, as calculated by Ibn Yūnus. His book entitled *Al-zīj al-ḥakimī* (Tables of Wisdom) explained, among other mathematical ideas, the method of calculating longitudes and latitudes.

Among the notable works written in Central Asia of this school was al-Bīrūnī's book entitled *Taḥdīd nihāyāt alamākin* (The Determination of the Coordinates of

Cities). Other scholars of high reputation were al-Zarqāllu, Naṣal-Dīn al-Ṭūsī, and Ulugh Beg. Al-Zarqāllu produced several books on astronomy including the *Toledan Tables*. His other work, entitled *Qānūn* (Canon), was used by European scholars during the Renaissance. Al-Ṭūsī is remembered for his book *Zij-i-īlkhānī*, which recorded all the notes and observations he made from the observatory of Maragha. His other important writing was on the astrolabe and the problems related to the measurement of time, celestial altitudes, meridians and the like. Ulugh Beg was a Tartar prince (AD 1393–1449) who was also noted for the observations he conducted from the observatory in Samarkand. He managed to point out several errors committed by Ptolemy in the latter's tables and made new tables of latitudes and longitudes.

With respect to cartography, Muslim scholars followed two schools: one was based on the cartographical method of Ptolemy and the other on that pioneered by al-Balkhī. Ptolemy's teachings were followed by al-Idrīsī, and al-Balkhī's were continued by al-Istakhrī, Ibn Ḥawqal, and al-Maqdisī. The Muslims' maps were drawn and utilized in conjunction with countries and regions. Idrīsī became famous in the West because of his maps and cartographical work. His maps were valued not so much because of their accuracy but because of the symbols he used to distinguish various physical and cultural forms.

A prominent feature of the achievement of Muslim scholars in mathematical geography and cartography was the invention of scientific instruments of measurement. Among these were the *astrolab* (astrolabe), the *ruba* (quadrant), the gnomon, the celestial sphere, the sundial, and the compass. The portable astrolabe was used by navigators for measuring altitudes up to the seventeenth century. The ruba was used for measuring the value of angles. The gnomon was also used for measuring altitudes of the sun and other planets. The use of celestial sphere was to explain celestial movements, the sundial for calculating daily time and the azimuth (compass bearing) of Mecca, and the compass for finding direction during navigation. In human geography the achievement of Muslim geographers during the Middle Ages may be summarised into two main categories (1) works which attempt to explain factors deemed responsible for influencing, or even determining the traits, characteristics or qualitative nature of a population or community; and (2) works which describe basic facts (social, economic, political, and cultural aspects) about a society's or a community's life. Viewed from the perspective of contemporary modern human geography, some of these works coincide with discourses on environmental determinism (the doctrine that human activities are controlled by the environment) and environmental possibilism (the view that the physical environment provides the opportunity for a range of possible responses and that people have considerable discretion to choose between them). Others may be aligned more with traditional regional geography which was heavy in chorography (the study of the areal differentiation of the Earth's surface; i.e. the areal variation of human and physical phenomena as they relate to other spatially proximate and causally linked phenomena) or idiography (a concern with the unique and the particular). Some of the names identifiable with this episode of Islamic human geography were Al-Masudi – for his explication as to how climates differentiate between people of northern and southern hemispheres – and Al-Maqdisi – for his characterisation of settlements based on the temperament of their inhabitants.

Modern human geography has since been dominated by thoughts and works of Western human geographers. So much has happened to the secular epistemological thinking of this sub-discipline of geography, and an Islamic preliminary review of it has been written by Buang (1992) (link to attachment on Buang's article).

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Geography in Mesoamerica

Vincent H. Malmström

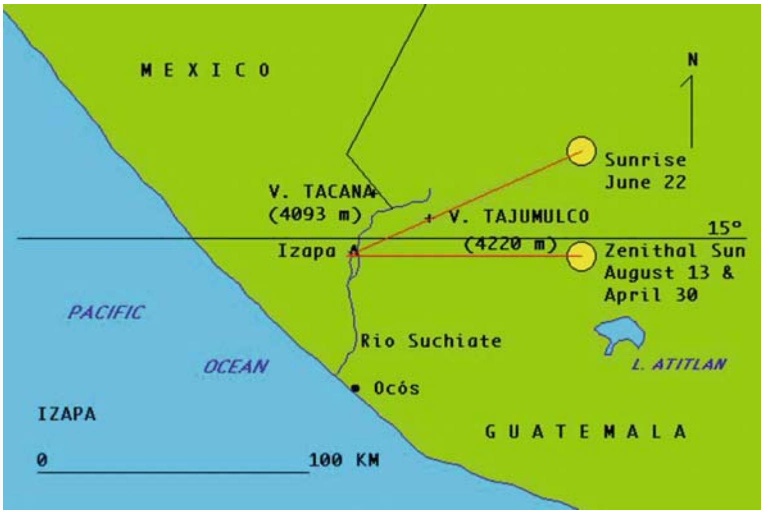
Unlike the ancient Greeks, for whom all knowledge could be categorized according to a tripartite classification – the phenomenon itself, its place in time (history), and its place in space (geography) – the civilizations of pre-Columbian Mesoamerica viewed all knowledge as religion, some aspects of which found their reflection both in time and space. The most original intellectual creation to emanate from Mesoamerica was the 260-day sacred almanac, known variously as the *tzolkin* among the Maya and as the *tonalpohualli* among the Aztecs. Predating the 365-day secular calendar, which these people also developed, it ran concurrently with the latter to produce a never-ending series of 52-year cycles (365 × 52 = 260 × 73 = 18,980 days), giving rise to the Mesoamerican belief that history repeated itself every 52 years.

Though the origin of the 260-day calendar has long been debated, the most convincing explanation for its astronomic underpinnings was first given by Zelia Nuttall in 1928, who argued that it represented the interval between zenithal sun positions at Copán, the major Maya astronomical center located in the mountains of western Honduras. At the latitude of Copán (14.8°N.), the sun passes overhead at noon on August 13 on its apparent southward journey to the Tropic of Capricorn and again on April 30 on its apparent northward journey to the Tropic of Cancer. In 1945, Merrill called attention to the "coincidence" of the August 13 date with the start of the so-called Maya Long Count, which in the Goodman–Martínez–Thompson correlation between the Maya and Christian calendars fixes the beginning of the present cycle of the world as August 13, 3114 BCE. (The Long Count represented a meshing of the 260-day sacred almanac and the 365-day secular calendar in such a way that each day was as uniquely and precisely identified as they are in the Julian Day system employed by modern astronomers.) In 1948 a Guatemalan scholar, Girard, contended that the calendar's birthplace lay along the same parallel of latitude but in the mountains of his country instead. While concurring in the astronomical importance of the 14.8° parallel of latitude, the present writer was forced to reject both Copán and the highlands of Guatemala as the calendar's cradle, for reasons both of history and of geography. No pre-Columbian site situated along that parallel in the highlands of Central America predates the fifth century AD, whereas the sacred calendar is known to have been in use for several centuries BCE. Furthermore, many of the day–names used in the sacred almanac commemorate lowland tropical animals. The only place where the requisite astronomy, history, and geography come together is at Izapa, on the Pacific coastal plain of Mexico, where a large ceremonial center of Formative age (1500 BCE–300 AD) is found amidst a tropical rainforest ecological niche (Fig. 1).

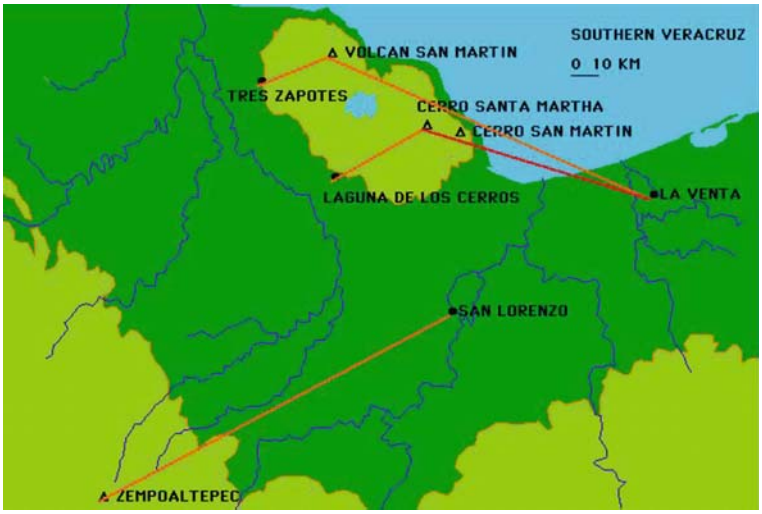
Field work at Izapa in 1974 not only revealed that the entire ceremonial center is oriented to Tacaná, a commanding volcano of 13,428 ft elevation on the northern horizon but also that the highest volcano in Central America, Tajumulco (13,845′) marks the azimuth of the rising sun on the summer solstice (June 22) as seen from Izapa (Fig. 2).

This use of prominent topographic features to serve as calendrical markers was subsequently traced to the oldest so-called Olmec ceremonial centers of San Lorenzo (1200 BCE, oriented to Zempoaltepec (11,138′) at the winter solstice sunset), La Venta (1000 BCE, oriented to Cerro Santa Martha (4,600′) at the summer solstice sunset), and Tres Zapotes (800 BCE, oriented to Cerro San Martín (4,600′) at the summer solstice sunrise), but also to the earliest ceremonial centers of the Mexican plateau, including Cholula, Cuicuilco, Tlatilco, and Tlapacoya (Fig. 3).

Geography in Mesoamerica. Fig. 1 Both Izapa and Copán are situated just south of the 15th parallel of North latitude, the former immediately adjacent to the boundary between Mexico and Guatemala and the latter in the mountains of western Honduras (map by the author).



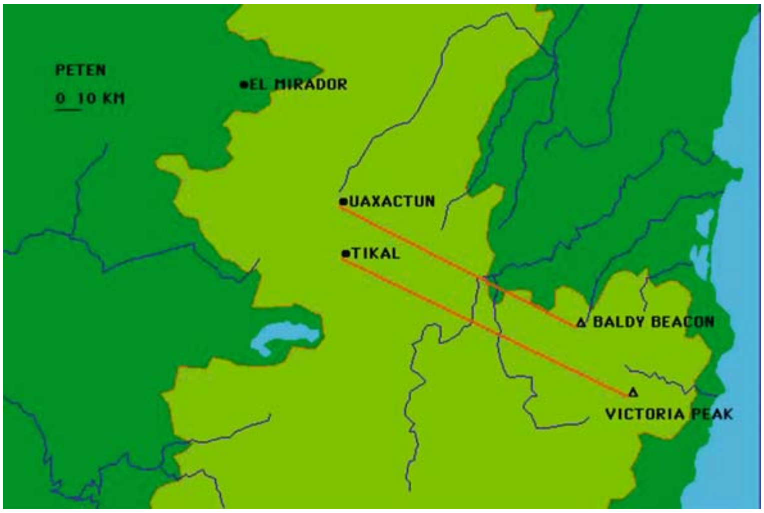
Geography in Mesoamerica. Fig. 2 The unique geographic position of Izapa permitted its priests to calibrate precisely both the length of the 260-day sacred almanac and the 365-day secular calendar – the first by zenithal passages of the sun and the second by measuring the interval between summer solstice sunrises over Central America's loftiest volcano. The sacred almanac had its beginnings about 1320 BCE and the secular calendar was initiated some 34 years later (map by the author).



Geography in Mesoamerica. Fig. 3 Throughout the areas they occupied in present-day Guatemala, El Salvador, and Mexico, the Olmecs continued the precedent of orienting a ceremonial center to a solsticial sunrise or sunset, begun at Izapa. On this and subsequent figures, lines in orange indicate solsticial orientations while those in red mark orientations to the August 13 sunset. Here we see the orientations found at the oldest Olmec sites in southern Veracruz state (map by the author).

Significantly, only two of the earliest Maya sites, Uaxactun and Tikal, have mountains within view, but both of them are likewise oriented to the winter solstice sunrise over the highest peak within sight – the first to Baldy Beacon (3,346′) and the second to Victoria Peak (3,680′). In each instance, the local site-factor which pinpointed the ceremonial center's location was the availability of water, both for domestic uses and, in the early Olmec centers, for transport, but only when the situational factor of the proper solsticial orientation coincided with it (Fig. 4).

Interestingly, where prominent mountains are not visible on the horizon, the early Mesoamericans substituted architectural alignments for solsticial orientations. The greatest of pre-Columbian cities, Teotihuacán, about 30 miles northeast of present-day

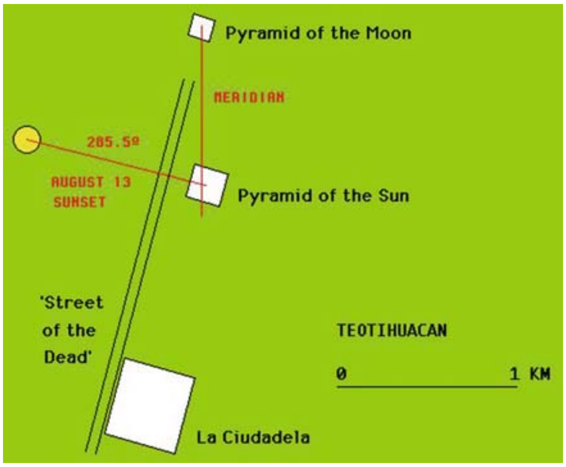


Geography in Mesoamerica. Fig. 4 The flat and relatively featureless peninsula of Yucatán provided the lowland Maya with no mountains with which they could locally calibrate the calendars they had inherited from the Olmecs. However, once within sight of the Maya Mountains of present-day Belize, the practice was revived at two of their most ancient and important sites in the Petén region of Guatemala, Uaxactun, and Tikal (map by the author).

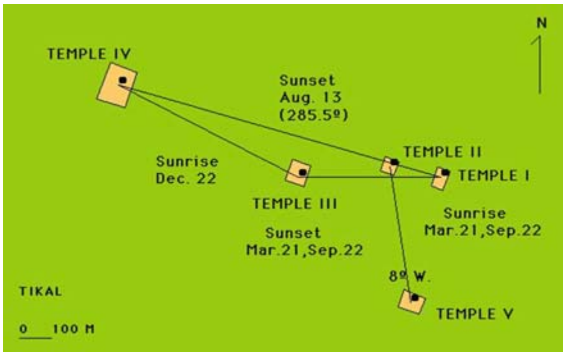
Geography in Mesoamerica. Fig. 5 As the Olmecs carried their calendrical systems onto the plateau of Mexico, they found a plethora of great volcanoes to which they could orient their incipient ceremonial centers. Following the destruction of Cuicuilco about 150 BCE, they founded what was to become the largest urban center in the New World at Teotihuacán and ensured that it was solsticially oriented to Orizaba, the highest mountain in Mexico (map by the author).

Mexico City, combines an intriguing blend of both principles: it is located precisely in line with the winter solstice sunrise over the highest mountain in Mexico – Citlaltépetl, or Orizaba, 18,700′ – but the peak itself is obscured by a low ridge of hills on the southeastern horizon. It would appear that a "relay station" was built there to allow the priests of Teotihuacán to calibrate their calendar with the southernmost position of the sun, whereas the entire city itself was meticulously gridded to the sunset position on August 13 – the day the present cycle of the world was believed to have begun (Figs. 5 and 6).

The commemoration of the August 13 sunset is also found in the layout of other ceremonial centers on the Mexican plateau of later, Toltec vintage, but its most widespread use in city planning was amongst the Maya. The location of the earliest Maya ceremonial center at Edzná (dating to 150 BCE) was primarily dictated by the presence of the largest Aguada, or temporary lake, in all of the Yucatán, but its internal layout clearly



Geography in Mesoamerica. Fig. 6 At least three key astronomical concepts are built into the layout of Teotihuacán, Mesoamerica's greatest pre-Columbian metropolis. Not only it is oriented to the winter solstice sunrise over the highest mountain in Mexico, but its entire internal structure is also aligned to the sunset position on August 13. Furthermore, the location of the Pyramid of the Moon and the Pyramid of the Sun, its two most imposing architectural features, precisely defines the meridian, enabling both noon and midnight to be calibrated as well (photo by author).



Geography in Mesoamerica. Fig. 7 At Tikal, sometimes called "the capital of the Maya," the planning and construction of five "skyscraper" pyramids, all carried out within about a 50 year period in the late eighth century, pointedly demonstrates how the Maya combined the spatial arrangement of their architectural structures with key temporal "landmarks" in their religious year (map by the author).

reflects their religious preoccupation with the August 13 sunset. Similarly, numerous structures throughout the Maya regions of Yucatán and Petén reflect the August 13 alignment, among them the Codz Pop at Kabah, the Pyramid of the Magician at Uxmal, and El Caracol at Chichén Itzá, to name but a few. The crowning blend of celestial mechanics, time, and space is to be found in the Maya capital of Tikal, where five sky-scraper pyramids, all about 200 ft in height and all constructed in the eighth century, mark the alignments of the August 13 sunset (Temple I to Temple IV), the equinoxes (sunrise Temple III to Temple I; sunset Temple I to Temple III), and the winter solstice sunrise (Temple IV to Temple III) in a sophisticated astronomical matrix. Further, an alignment from Temple V to Temple I not only marks a perfect right angle to the August 13 alignment but one from Temple V to Temple II likewise pinpoints the westernmost point in the rotation of Polaris, which at that time was the closest thing to a polestar which existed, even though it was a full 8° away from its present position (Fig. 7). (Clearly, the repeated use in Mesoamerican ceremonial centers of the August 13 sunset orientation not only forcefully argues for the sacred almanac's astronomical origin but it also makes any alternative explanation, such as the length of the human gestation period or the simple permutation of the numbers 13 and 20, untenable.)

In the fifth century, the Mesoamericans appear to have carried out two remarkable geographic expeditions. Although they both had ultimate religious goals in mind, these endeavors probably reflected the closest approach the pre-Columbian civilizations ever made to what we regard as scientific inquiry. The priests of Teotihuacán dispatched an expedition into the northern desert to determine where the "sun stopped" in its annual migration, and in consequence of this, the astronomical center of Chalchihuites was founded on the Tropic of Cancer. Lacking a better means of recording key alignments, they dug trenches through the earth and plastered them with adobe to mark the summer solstice sunrise. (In the tenth century the Toltecs added a trench to mark the beginning of their New Year, February 12.) Perhaps under Teotihuacán's sponsorship, the Maya carried out a similar expedition at about the same time to locate the place where the 260-day sacred almanac could be calibrated. The result of this venture was the founding of Copán, in the western mountains of Honduras, whose oldest recorded Long Count date is 435 AD. Thanks to its key geographic location, Copán was ultimately to become the Mayas' principal center for astronomic studies – the late and distant heir of Izapa where the first intellectual stirrings had begun nearly two millennia earlier.

See also: ►Long Count

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Geography of the Native North Americans

Martha L. Henderson

Native North Americans sustain sophisticated and complex cultures. What native peoples say about themselves with their own constructs of space and place is essential to understanding native North American populations. This essay attempts to describe geographical data including native spatial organization, relationships with the natural environment, and the location and significance of places. These data and their analysis can shed light on native identity, problems of intercultural relations from a geographic perspective, and the contemporary context of native geography within the pluralistic federal states of Canada and the United States.

North American natives, those living north of the Mexican–United States border, were divided regionally by specific cultural patterns and practices such as language, religion, and relationships with the natural world. Oral traditions and material artifacts about past events provide clues to a native North America. Similar culture groups established territorial boundaries that served to strengthen group identity. Porous boundaries allowed for fluid contact between groups when conditions required. Territories generally conformed to major ecosystems of the continent.

North American ecosystems are roughly divided by landform and vegetation that include a direct reference to climatic conditions of the modern period. The subtropical Southeast extends from the center of the continent at approximately 100° West to the Atlantic coast to its northern limit at approximate 35° North. Corresponding to the west is the Southern Great Plains, Southern Rocky Mountains, and the desert Southwest. Between 35° and approximately 50° North is the temperate zone. In the west, this zone includes the rainy coastal mountain ranges of the Pacific, the cold Rocky Mountains, the dry Central and Northern Great Plains, and the humid Northeast Atlantic region. North of the temperate zone climatic conditions are generally cooler. The northern region was drastically affected by continental glaciations. Except for the Northern Rocky Mountains that extend into Alaska, the northern region has been heavily eroded and generally flattened. Very large lakes and river drainages cut across the rocky surface. Soil development is slowed due to cold temperatures. Trees rarely grow above 55° North. These basic environmental conditions set the framework for native population habitation of the land mass (World Atlas).

Today, the international boundary between Canada and the United States divides federally recognized tribes but not self-identified culture groups. Historic treaty-making and reservation assignments create a federal geography while native populations recognize a cultural geography that reaffirms a traditional past, present, and future in Indian Country.

Traditional Native Geography

Native geography can be described on the basis of creation stories, location, territoriality and boundary making, resource adaptation and interaction with the physical environment, and place-making. Native–land relations are primarily structured around a set of beliefs that recognize Earth as the spiritual and material center of life. Generally, Natives do not divide their world between the real and the spiritual. The world includes every existing entity and those spirits who occupy them. All aspects of nature are sacred; there is no separation between the universal and human actions. For example, the Ojibway of the Upper Great Lakes region view Earth as "spirit garden." Resource adaptation and cultural patterns are closely linked, one sustaining the other. Spiritual, cultural, and physical collaboration established a balance that supported native populations in sustainable, traditional patterns.

Places usually recognize the spiritual integrity of natural objects or events that magnify the wishes of a creator. The Hopi of the American Southwest named each of their mesa homelands with respect to physical features and conditions of Hopi creation beliefs. Hopi place names not only imply the physical, but also the spiritual conditions of existence. Prior to contact with non-Hopi groups, especially non-Indian groups, each mesa was a world unto itself, anchored in a spiritual and material existence. Recent events within Hopi mesas, such as surface coal mining by western industrialists, have wounded this sacred ground.

The White Mountain Apache maintained an oral history by telling each other about specific places. Specific places in traditional territory evoked significant events, lessons of survival, life passages, and mystical events. Without these places, the traditional history of the Apache did not occur. The power associated with each place captures the power of place within many native culture groups (Basso 1996).

Creation Stories

The native populations of the Western Hemisphere constituted a major portion of Earth's human populations prior to European contact during a period of time generally recognized by scholars during the fifteenth century. It is estimated that populations in Central and North America could have been as high as ten million with the same amount in South America. The extent of nonnative knowledge about human habitation in other parts of the world is speculative. It is apparent in some oral traditions that natives knew of white visitors to the Americas prior to the temporal divide of the 1400s.

Northern American natives believe, and continue to believe in, creation stories that do not include a Beringia migration during periods of colder climatic conditions. Recent discoveries in North America of pre-Paleolithic skeletal remains and artifacts stimulate a growing awareness that native occupation is part of a much longer legacy of continental occupation. Native American artifacts have been found across the North American continent in such quantities as to suggest that all parts of the land mass were occupied at the close of the last major glacial period. The post-Pleistocene period is a convenient but tentative temporal divide. Contemporary native peoples are reasserting their own stories of origin, culture, language, and environmental ethics that reset the balance of authority between native peoples, federal governments, and academic researchers.

Location, Territoriality, and Cultural Boundaries

Within each major group were specific groups who established their location around specific physical features at a density that allowed a sustainable population to exist within the entire ecosystem. Local shifts in location, resource acquisition, sacred sites, and interaction zones between groups were not uncommon. These shifts were sanctioned by mutual consent although peaceful readjustments were not always the case. Major stresses such as prolonged drought or loss of a major resource caused location changes and readaptation across ecosystem boundaries.

Natives generally view area based on concepts of territoriality. Territoriality is a common recognition of a physical landscape that supports loosely allied group needs. Acute observation skills, familiarity with local and regional physical characteristics, and recognition of other social groups within the area are consistent attributes of native geography. For example, the Apache utilized an area of the American Southwest generally between the Rio Grande River and the Great Plains. Primarily a mountain people dependent on species found at various elevations during changing seasons, the Mescalero Apache also developed hunting skills that allowed them to take advantage of grasslands species such as buffalo. They shared buffalo hunting with distant Apache relatives. These other Apache groups were permitted to hunt and gather resources in the Mescalero mountain territory when grasslands resources were scarce. The Mescalero Apache held all resources as a common good to be shared when other Apache required assistance.

An important aspect of territoriality is the ability to communicate conditions of space and place. The Inuit are superb cartographers, able to produce maps of territory with accurate scale, a system of symbols, and direction. The maps also convey a sense of space and place where value is placed on animal trails, natural features, and settlement locations. An Inuit map of the north therefore demonstrates Inuit reality as opposed to another culture's maps of northern places.

The continental context of native occupation was well known to native peoples. Means of transportation and navigation technologies existed that allowed for transcontinental exchange as well as regional interaction between groups. Regionally, large game hunting and other resource-sharing opportunities allowed for contact and exchange between groups. Finally, small groups who occupied specific areas achieved a balance between resources and population needs. Expertise in the maximum utilization of all resources supported native populations within a context of spiritual, cultural, and physical balance.

Resource Adaptation

The map of traditional native North America includes recognized areas of group occupation, fluid and sometimes shifting boundaries between groups, and cultural indicators that promoted group identity and survival. Groups of similar culture and subsistence patterns are recognized within each of the major ecosystems of North America. Each major group had unique linguistic, religious, and subsistence patterns. Within each ecosystem were specific groups who maintained their own identity while recognizing their commonalities with similar groups within the ecosystem. Native populations are generally divided into the following large groups: Mississippi temple-mound builders; eastern woodlands hunter-gatherers and cultivators; plains bison hunters; southwest Anasazi; desert hunter-gatherers; west coast foragers, hunters, and fishers; plateau fishers and hunter-gatherers; sub-Arctic forest hunter-gatherers; Arctic marine mammal hunters; and island fishers (Carnegie Museum).

The use of natural resources for survival is generally framed within the context of small Indian populations, exploitation to meet needs, and returning something to nature for the use of an item. Native Americans developed a resource use paradigm that focused on the unity of all beings and their systemic value rather than individual worth. For example, individual animals within a forest ecosystem were recognized in relationship to other plants, soil, water, and air. The use of a specific animal was always observed with respect to other elements of the ecosystem with an attitude of thankfulness and recognition of the animal as a gift. Reliance upon specific species developed over centuries of adaptation. As native groups entered new areas of North America and as North American physical environments were transformed by primarily climatic events, groups had to adjust, migrate, or face decline.

This is not to suggest that specific species were not singularly important to American Indian groups. The buffalo provided nearly all of the needs of plains bison hunters while west coast fishers relied heavily but not exclusively upon salmon. Given the low population numbers of natives, neither species were threatened with extinction due to overkill. It is reasonable to believe that resource demands and human populations would have remained static if European explorers with different technologies and valued resources had not impacted native culture groups (Native North America).

Perhaps the most striking of examples of native cohabitation is found in the cold deserts of the plateau fishers and hunters and gatherers, and the Arctic marine mammal hunters. Using simple technological devices, native peoples occupied and survived in both areas. The Piute established their primary homes along pluvial spring-fed lakes that survived continental warming. These people developed fishing and hunting technologies that allowed them to utilize birds, animals, and fish that inhabited the lakes and marshes of the Great Basin. While large game animals are scarce in the region, small animals such as antelope and rabbits were easily trapped. Plants, whose life cycles were well known to local Piute groups, were readily available. These food resources were abundant to the point that it is estimated that the Piute had more time available for leisure and social activities than any other native group.

Similarly, Eskimo experienced a high amount of time available for artist expression and social activities because they developed sufficient technologies and skills to maintain caloric intake and clothing needs. The Arctic is one of the richest animal and fish ecosystems on Earth. Native fishing, watercraft, celestial navigation, and clothing technologies allowed the Inuit and Eskimo to thrive in the high latitudes.

Oral traditions and present practices indicate that management techniques were utilized to create and sustain certain types of ecosystems. Native use of fire to maintain open fields is apparent across the continent. Native burning may also be the primary force that created the grassland ecosystems of the mid-continent. The eastern woodland natives such as the Iroquois practiced burning of areas, known by European setters as “old fields,” to maintain open areas for large game hunting.

Native cultural ecology places a high degree of respect for living with environmental conditions. The mental constructs of discovery and contact by Europeans overlooked the brilliance of native populations who had, through experimentation and accident, come to live in a state of balance with the physical environment. This balance was radically changed with the permanent migration of Europeans to North America.

Historic Geographies: Cultural Conflict and Emergent Identities

European influences in native North America are generally recognized as beginning in the fifteenth century with earlier contact periods a probability based on archaeological data. Contact between natives and Europeans resulted in major shifts in native geography. European tools, technologies, diseases, and interruption of traditional patterns of resource acquisition and spatial organization altered those natives who experienced direct contact. More importantly, the changes spread within the native population to affect large groups of natives who did not experience direct contact. The presence of English, French, and Scandinavian explorers and their patterns of living spread quickly from the eastern coastal areas inland. Similarly, natives living in the southwest were affected by the presence of Spanish explorers in Central America. The diffusion of European goods, ideas, technologies, and diseases spread quickly across the entire continent.

Once European settlements were established, their demand for resources had an immediate effect on the location and territoriality of native groups. For example, as French fur traders moved into the Great Lakes region, northern Algonquian peoples moved westward into Ojibwa territory. The Ojibwa peoples moved westward into Sioux territory west of Lake Superior. This migration resulted in conflict and warfare between the two native peoples. Eventually the Sioux moved further west and established themselves on the northern Great Plains. When American ethnographers described the Sioux, they called them Plains people who had adapted to living off buffalo, yet this was a very recent location and adaptation for the Sioux.

Spanish *entradas* into the southwest also created a chain reaction of relocation and territorial disputes within native peoples. Coronado's 1540 brutal search for the Seven Cities of Cibola caused Pueblo and Hopi groups to make alliances in order to protect their holdings in the upper Rio Grande valley. In 1598 the Onate and a group of Spanish settlers entered the central Rio Grande valley. Their presence forced Pueblo groups to reestablish themselves in a new configuration of alliance and mutual support.

Some native groups were able to maintain control of their territory and command a more powerful position with colonial and, later, American federal interests. The first treaties between native groups and the Euro-Americans were based on the strengths of two powers entering into treaties as equals. Native peoples agreed to allow Euro-Americans to inhabit certain spaces for mutual protection. In some cases, native treaty-makers did not perceive that what they were agreeing to was conceptualized in a very different way by the Euro-Americans. These natives could not conceive that what the Euro-Americans were doing was acquiring full rights to the land base because the natives did not believe that land was owned or tenured to any one specific group.

Once established, however, Euro-Americans continued to acquire and use land beyond treaty boundaries. This form of disrespect for the treaties caused continue disruption of native use of resources, attempts to live with the new population, and peaceful relations with other native groups. Native peoples also faced disequilibrium as Euro-American settlement spread westward across the continent. Debilitating diseases, alcohol, and physical attacks rapidly reduced native populations.

Native groups in the west, especially the Nez Perce, quickly adapted to the use of horses. The introduction of horses added speed and the ability to cover large distances to these native cultures. By the time the American and Canadian governments made contact with these culture groups, their strength in hunting and raiding proved them to be powerful forces that stood in the way of the federal governments.

By 1830, native groups across the continent were significantly reduced and very strongly affected by the presence of the American and Canadian governments. Population numbers were greatly reduced and in some cases entire culture groups were wiped out. Both governments carried out major campaigns to exterminate native peoples. Those remaining were required to sign treaties that established reservations for native groups. Groups of differing traditional backgrounds were often placed on the same reservations. For example, the Cherokee of the southeast mound-building culture were forced to walk nearly a thousand miles in the winter of 1839 to a reservation established for them in the southern Great Plains. The walk, known as the *Trail of Tears*, resulted in the loss of hundreds of Cherokee lives. Those who survived the walk found themselves in a completely new physical environment for which they were not prepared. They were settled with other native groups with whom they shared little in common. Such conditions continued to undermine natives' ability to maintain cultural identity until the late 1870s. Populations were required to stay on reservations that were inadequate and unable to supply the needs of traditional peoples. Population numbers continued to decline.

Both American and Canadian governments, with the assistance of well-meaning missionary groups, assumed that native peoples would fit into a Euro-American North America if they became farmers. Both governments instituted assistance programs and land tenure policies intended to assist natives into assimilating in the agricultural economies of the United States and Canada. These programs ultimately failed although some natives became farmers. The overall process continued to reduce native populations and open native lands for white settlement.

In a reversal of policy, the federal governments instituted new programs in the mid-twentieth century with the goals of creating tribal governance and business programs for native revenues and protection of native cultures. These new programs assisted native groups in developing tribal resources on tribal lands. Some tribes such as the Mescalero Apache, the Confederated Tribes of the Warm Springs, and the Red Lake Band of the Chippewa developed timber and cattle enterprises. The revenues from these enterprises helped to support native educational, health, and social services needs. However, the revenues were never large enough to fully empower the tribes. Tribes continued to be dependent upon federal programs for basic needs. These programs were unequally and generally poorly funded and administered. The distribution and quality of services on reservations was far from adequate.

The federal governments choose to eliminate many of the native programs at the end of World War II. The American government terminated reservations and treaties in many areas of the United States. All tribes, even those who had created profitable enterprises, were disrupted by these termination policies. At the same time, natives were encouraged to move to urban areas and learn skills that would allow them to find jobs and reside away from rural reservations. As a result of these policies, today the highest population concentrations of native populations in both Canada and the United States are in urban areas.

Contemporary Geographies of Native Peoples

The last decades of the twentieth century saw another policy reversal by both federal governments. Working with native leaders, both governments are now committed to a process of native self-determination. Native groups have recovered some of their powers as established in treaties and have also been able to secure religious, burial, and cultural freedoms through national laws. As natural resources have become scarce in North America, it is increasingly evident that negotiations with native groups are essential in protecting habitats and threatened species, watersheds, major landforms, and critical wetlands. Native peoples continue to develop resources such as fishing and timber to meet their own needs. Native groups have quickly adopted technologies such as geographic information systems to maintain and plan resource management on native lands. Propagation and protection of flora for medicinal purposes have become major foci of native peoples. The Bella Coola and bands of Puget Sound natives have, for example, reclaimed land and protected specific species that play a significant role in cultural identity and health.

Native groups in the United States have exercised the right to develop casinos on native lands. The popularity of gambling and a desire to meet that need with additional casinos has required extensive mapping to identify the exact location of native lands. Revenue from gambling has been invested in resource development and cultural identity programs that support native populations. In some cases, casino revenue has made it possible for native groups to extend financial assistance to other cultural groups including the dominant white culture in local areas. Mutual resource management goals are also being identified and shared by more than one racial and ethnic group.

First Peoples in Canada have recovered major portions of the Northern Territories as part of the new native province of Nunavut (Atlas of Canada). Native peoples who are implementing traditional ideals and ways of knowing administer this province. Place names, the location of sacred places, resource gathering techniques, and social affairs are practices in Inuit traditions. Native groups throughout North America are experiencing a resurgence of cultural identity as the landscape of North American reflects growing acceptance of a plurality of cultures.

Today, the largest growing populations in North America are native. More that half of all native peoples is below the age of 15. This growth rate requires planning and development of tribal resources. This expanding native population is able to access both the traditional knowledge of their cultural past and the freedom to express their native identity. The new emphasis on native knowledge is ultimately changing the power relationship between federal and tribal governments, the rights of native peoples, and the cultural and geographical record of the native populations of North America. With full recognition of native power and self-identification, this short essay is offered as only an introduction to the multidimensional and cultural diversity found among native North Americans.

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Geomancy in China

Hong-Key Yoon

The Chinese word for geomancy is *feng-shui*, which means “wind and water” or *ti-li*, which means “the principles (patterns) of the land.” The term *ti-li* is also the Chinese word for geography, which suggests an intimate relationship between Chinese geomancy and geography.

In Chinese geomancy, a place having certain landforms and orientations is believed to be more auspicious than others. An auspicious place is where vital energy (*sheng-ji*) is accumulated and available to humans who occupy the site. The function of vital energy is to give birth to and support all living things, and it is stored in certain places meeting geomantic requirements, blessing the people who use the site in harmony with the surrounding landscape.

The flow of vital energy underground (often through mountain ranges) is analogous to that of blood through the veins of the human body. Therefore, a geomancer’s job is to find a spot where vital energy is accumulated, in a similar way that an acupuncturist finds a critical spot of the body where a needle can be planted.

An auspicious site (geomancy cave) is sometimes compared with a melon on a vine. The nutrients from the soil are taken through the roots, and transported through vines to be stored in the melon before being consumed by humans. In a comparable manner, the vital energy flows underground through the veins and is deposited in the geomancy cave to be available for humans who use the place appropriately by building, for example, a house or a grave.

The most important geomantic condition of an auspicious site is that it be sheltered by a surrounding range of hills on three sides, with one side open. The range on the left (normally East) side is called "azure dragon"; the right (normally West) range, "white tiger"; the hill behind an auspicious site is called the main mountain or "black warrior." A horseshoe shaped basin is an auspicious site. The most desired orientation of the site should face south. The land also needs to have access to a watercourse; the most desirable ones flow slowly with many bends.

In geomancy, the people who occupy auspicious sites are believed to benefit from the land by enjoying longevity, accumulating wealth, or achieving fame in the world. Traditionally, geomancers were normally consulted when cities, temples, graves, and other human settlements were built. Professional geomancers are supposed to know how to choose an auspicious site by applying geomantic principles, and can be seen as the traditional Chinese version of modern geomorphologists, location analysts or landscape, and architectural planning consultants.

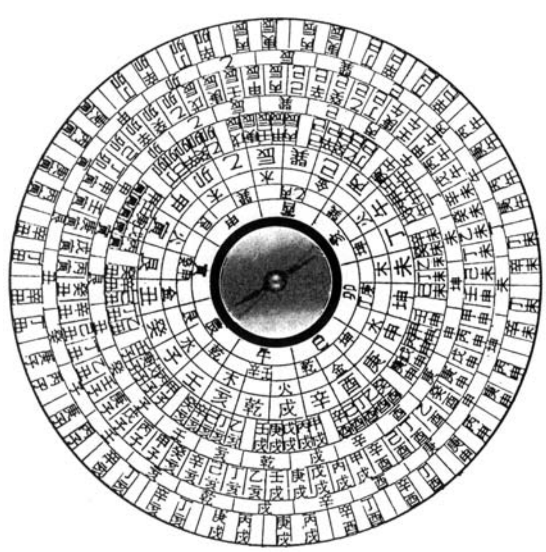
It is virtually impossible to understand the East Asian cultural landscape without having knowledge of geomancy. For instance, important cities like Beijing and Nanjing in China, Seoul and Kaesong in Korea, and Kyoto and Nara in Japan all were chosen and planned geomantically. Thus, Chinese geomancy is defined as "a unique and comprehensive system of conceptualising the physical environment, which regulates human ecology by influencing man to select auspicious environments and to build harmonious structures (i.e., graves, houses, and sites) on them" (Yoon 1976).

In the evaluation of the quality of the landscape (the environment, place) in geomancy, the following three images are important. First, the landscape is perceived as a magical being which can influence people mysteriously, either auspiciously or inauspiciously. An auspicious site can bless people with a happy life, whereas an inauspicious site can cause people to suffer misfortunes, including disease, bankruptcy, death, and infertility.

Secondly, the landscape is personified and regarded as a system of either a living organism or an inanimate object. Either an element of a local landscape such as a hill or stream, or the entire landscape itself may be treated as a functioning system of an object such as a cow, boat, or a flower. Personification of a landscape as a beautiful, balanced, and peaceful object normally indicates an auspicious site, whereas personification as an ugly, dangerous, and unbalanced object suggests an inauspicious site. Depending on how a geomancer perceives a local landscape, it may be compared to (personified as) any object in the world.

Thirdly, the landscape is seen as a vulnerable being, which can easily be hurt or remedied by human interference, because the vital energy that flows beneath the surface is extremely vulnerable. Vital energy is only one particular phase of the *Yinyang* energy according to a geomantic classic called *Zang-shu*. When *Yinyang* energy belches out, it becomes the wind. When the wind ascends, it becomes a cloud. When it descends, it becomes rain. When it flows under the ground, it becomes vital energy, but when it emerges out of the ground, it is no longer vital energy (*Guo Bu*). That is why the vital energy of an auspicious site should be utilized without disturbing it, by building a house or a grave in harmony with the surrounding landscape.

In the history of China, geomancy was often more popular for choosing an auspicious site for a grave rather than for a house, although the same geomantic principles were applied for both cases. All the important principles concerning an auspicious place are in fact about ideal conditions relating to a living person's dwelling site. The analysis of geomantic principles concerning auspicious locations suggests that Chinese geomancy began as an art of selecting a comfortable place to live, and then came to be applied to selecting grave sites as well (Fig. 1).



Geomancy in China. Fig. 1 A geomantic compass currently in use by professional geomancers.

By the sixth and seventh centuries, geomantic principles as we know them today were probably well established in China. Ever since then, geomancy in China has been a powerful part of the art of environmental planning, landscape design, and determining various types of settlement location.

This art was probably diffused to Korea with an early wave of Chinese cultural diffusion. Koreans in turn introduced this art to Japan. Judging from ancient capital sites in Korea and Japan, this art was introduced and practiced in those countries by the seventh century. Geomancy is still practiced in China, Taiwan, Hong Kong, Singapore, Korea, and Japan. In fact, in Hong Kong, Singapore, and Korea, a number of geomantic institutes were established, and professional geomancers practice their art in planning building structures and in the selection of residential and gravesites.

Geomancy has been adapted to the modern urban environment, and even many Chinese living in cities like America apply geomantic principles in selecting their house sites and designing house structures. In city situations the main points of geomantic considerations are in place of the land-form conditions, street patterns, roof lines of neighbors, the shape and situation of a house section, and the floor plan of a house. In some cases, the furniture arrangement inside a house is decided by applying Chinese geomancy to present day city dwellings.

There have been numerous geomantic textbooks and manuals throughout the history of China, and even now there are more than a dozen printed editions of geomantic books are available for purchase in the Chinese language alone.

See also: ►Geography in China – Maps, ►Geomantic – Divination

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Geomancy in the Islamic World

Emilie Savage-Smith

The term geomancy comes from the Latin *geomantia*, first used in Spain in the twelfth century as a translation of the Arabic *ʿilm al-raml* (the science of sand), the most common name for this type of divination. The practice is to be distinguished from a totally unrelated Chinese form of prognostication based on land forms, unfortunately also called geomancy in English. The origin of this distinctly Islamic art is a matter of speculation, but it appears to have been a well established practice in North Africa, Egypt, and Syria by the twelfth century.

The divination is accomplished by forming and then interpreting a design, called a geomantic tableau, consisting of 16 positions, each of which is occupied by a geomantic figure. The figures occupying the first four positions are determined by marking 16 horizontal lines of dots on a piece of paper or a dust board. Each row of dots is examined to determine if it is odd or even and is then represented by one or two dots accordingly. Each figure is then formed of a vertical column of four marks, each of which is either one or two dots. The first four figures, generated by lines made while the questioner concentrates upon the question, are placed side by side in a row from right to left. From these four figures the remaining 12 positions in the tableau are produced according to set procedures. Various interpretative methods are advocated by geomancers for reading the tableau, often depending upon the nature of the question asked. The course and seriousness of an illness, the outcome of pregnancy, the location of lost or buried objects, and the fate of a distant relative are among the most popular questions addressed to a geomancer.

The acknowledged master of geomancy was Abū ʿAbdallāh Muḥammad ibn ʿUthmān al-Zanātī, who lived before AD 1230. Virtually nothing is known of his life, though his name suggests that he was from the North African Berber tribe of Zanāta that was known for practicing other forms of fortune telling, particularly scapulomancy (divination by inspection of shoulder blades). One of the great codifiers of geomancy was ʿAbdallāh ibn Maḥfūf who lived, probably in Syria or Egypt, before AD 1265 and whose treatise is preserved today in several Arabic manuscript copies. Brief discussions of geomancy are included in a Persian encyclopedia composed at the end of the twelfth century by the celebrated theologian Fakr al-Dīn al-Rāzī and in short Persian tracts by the mathematician, philosopher, and founder of the observatory at Maragha in northwest Iran, Naṣīr al-Dīn al-Ṭūsī (d. AD 1275).

The majority of existing treatises on the subject are from the fourteenth century and later, with numerous ones still being written in the nineteenth and twentieth centuries. In view of the relatively few written sources on the topic before the fourteenth century, an intricate metal geomantic tablet, now in the collections of the British Museum, is of considerable importance. It was made in AD 1241–1242 (H. 639) by the metalworker Muḥammad ibn Khutlukh al-Mawṣilī, who also made an incense burner in Damascus about AD 1230–1240. This unique device is of a brass alloy inlaid with gold and silver, with a front plate carrying 20 dials and four sliding ares and a back plate engraved with inscriptions, both plates held in a rectangular frame which has a triangular suspensory device on top similar to that commonly found on astrolabes. No writings before or after its construction mention such a mechanical contrivance for establishing a geomantic reading, and there is no other known geomantic device from any culture remotely similar to it. It is evident that the designer of this elaborate device was well-versed in the geomantic literature of his day.

In Iran the term *raml* is applied to two types of divination. One type, frequently described by travelers, employed the throwing of brass dice that were strung together in groups of four. Although these dice are commonly referred to as geomantic dice, they are not marked so as to produce a geomantic figure, and thus the divination using such dice is a form of lot casting or sortilege different from true geomancy. *Raml* is also used in Iran for the traditional form of geomancy, and in modern Persian writings the art often attains an astounding degree of complexity, with successive tableaux generated from previous ones. A large number of lithographed Persian texts were published in India in the nineteenth century.

From the twelfth century until the seventeenth century, geomancy, in a slightly altered form, was very popular in Europe, where only astrology seems to have outranked it in popularity. The Spanish translator Hugh of Santalla working at Tarazona in Aragon appears to have been the first to prepare a Latin paraphrase of an Arabic treatise on the subject, with his slightly younger contemporary working in Toledo, Gerard of Cremona (d. AD 1187), translating another Arabic tract. After the seventeenth century, interest in geomancy faded abruptly in the West, and today it remains relatively unknown there.

There are many non-Western areas where geomancy and derivative methods of divination are still practiced. Geomancy in sub-Saharan Africa and Madagascar, which employs simplified but clearly derivative versions of classical Islamic geomancy, has been the subject of several anthropological studies. The mathematical structure of the practice has also received some scholarly attention. In nearly all Islamic lands geomancy and related methods of divination are still practiced, in forms varying from the simple casting of a favorable or unfavorable geomantic figure to the complex interpretation of tableaux employing a large number of procedures.

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Geometry

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Geometry is the branch of mathematics that deals with the partitioning of a physical or abstract space and the relationships induced by that partitioning. Historically, as a human activity, it is said by the Roman historian Herodotus (d. 425 BCE) to have begun in Egypt where the annual inundation of the Nile River obliterated field boundaries. In order to preserve the royal system of land distribution and taxation, official priest-surveyors measured the land and reestablished boundary markers. Their land-measuring techniques were imported to Greece and given the collective name "geometry" (*geo*, "earth"; *metrein*, "to measure"). Thus the practices of land measurement became the science of geometry. However, all peoples and societies possess and use some geometrical knowledge. For example, decorative pottery motifs and textile or basket weaving patterns demonstrate a geometric knowledge and facility on the part of their creators. Certainly the blanket patterns of the Ibans of Borneo and the rafter carvings of New Zealand's Maori people reflect an appreciation of symmetry; a complexity of line relationships is evident in the *sona* tracings of the Tshokwe culture in southern Africa, and a mastery of geometrical figures is illustrated in the sand drawings of North America's Navajos. All these non-Western cultures possess "a geometry" but to survey these traditional geometries would present a monumental task and be beyond the scope of this present survey. Therefore the discussion below will view geometry in a narrower sense, i.e., as an exact science and as a subject of acknowledged societal concern either documented by existing historical records or the evidence of archeological excavations.

Egypt and Babylonia

Egyptian geometry was practical in its conception and tied to measurement and the bureaucratic needs of the state. A small collection of surviving papyrus problems provided a limited glimpse into the workings of Egyptian geometry. The ancient Egyptians possessed correct computation formulas for determining the areas and volumes for a variety of plane and solid figures. Apparently they deduced such formulas by techniques of "dissection and rearrangement." Correct formulas for the areas of rectangles, triangles, and isosceles trapezia were employed. Problem 50 of the Ahmes Papyrus (1650 BCE) gives the area of a circle with known diameter d as $A = (8/9d)^2$ from which it is found that the Egyptians of this time used a value $\pi \approx 3.1605$. Problem 48 of the same sequence provides an illustration that has been interpreted as a polygonal approximation for the area of a circle and from which the formula was derived. In total, the Ahmes Papyrus contains 19 problems of a geometrical nature. The Moscow Papyrus (1850 BCE), in its 14th problem, offers a correct computational procedure for determining the volume of a truncated square pyramid of given height h and with bases whose sides measure a and b in length; $V = h/3(a^2 + ab + b^2)$. Problem 10 of the Moscow Papyrus requires the surface area of a "basket" with known diameter and has resulted in a yet unresolved controversy as to whether the Egyptians were considering the basket as a hemisphere or as a semicylinder. If the former interpretation is accepted this would indicate that the Egyptians possessed rather sophisticated geometrical insights at a very early date. Egyptian geometry remained utilitarian in nature and was never advanced to the status of an abstract science.

In a similar manner, Babylonian geometry was also of a computational nature and devoted to solving practical problems. In our context, the term "Babylonian" designates the civilization that occupied the Tigris–Euphrates region in the period 3500–539 BCE and includes the Sumerian, Akkadian, Chaldean, and Assyrian peoples. Knowledge of Babylonian geometry has been obtained from a limited examination of cuneiform texts and mathematical tables. This examination reveals that their authors possessed computation procedures for obtaining the areas of rectangles, right-angled triangles, isosceles triangles, and trapezia with one side perpendicular to the parallel sides. They knew several numerical properties of a circle and approximated the area of a given circle radius r by $A = 3r^2$. A clay tablet from the Old Babylonian Period (1900–1650 BCE) supplies a more accurate value of π as 3.125. The Babylonians could determine the length of a chord l, given the diameter of a circle d and the length of the sagitta in question a: $l = \sqrt{d^2 - (d - 2a)^2}$. Tablet no. 322 in the Plimpton Collection at Columbia University, whose origin is traced to 1800–1650 BCE, provides a list of Pythagorean triples indicating that the Babylonians of this period were familiar with the "Pythagorean Theorem." A clay tablet excavated at Tell Harmal in Iraq and dated to about 2000 BCE indicates that its users knew some properties of similar triangles and could employ these properties in solving numerical problems involving triangles. Babylonian scribes also could compute the volumes for simple solids and possessed an approximate formula for the volume of a truncated square pyramid of height h and bases of length a and b, i.e., $V = h/2(a^2 + b^2)$. Although several excavated clay tablets bear geometric diagrams, these diagrams serve as illustrations for relevant concrete problem situations and are not theoretical constructions. Apparently for the Babylonians, geometry remained an adjunct to numerical problem solving and did not evolve into a separate discipline.

Ancient India

Geometric activity on the Indian subcontinent can be traced back to the Indus Valley Civilization (ca. 3000 BCE). Excavations at this civilization's urban centers of Harappa, Lothal, and Mohenjo-Daro reveal the existence of a baked-brick technology allowing for the erection of numerous structures: houses, baths, and market places. This construction entailed large-scale city planning and the use of geometry. Archeological evidence indicates that the Indus peoples were familiar with the basic properties of rectangles, triangles, and circles, and could employ right-triangle principles for planning and structural purposes.

With the arrival and dominance of the Aryan culture in the region (1500–800 BCE), there developed a sacred Vedic literature of rituals and customs. Part of this literature concerned the construction of sacrificial fire altars of specific shapes and dimensions. Cord stretching techniques were described to obtain the required results. This collection of construction procedures and techniques became known as the *Śulbasūtras* (800 BCE) or "the rules of the cord." Using cords and pegs, squares, circles, rectangles, and trapezia of specified dimensions and areas could be laid out and constructed by the Vedic priests. Although outwardly religious texts, the *Śulbasūtras* presented a codified system of geometry. Besides obvious geometric constructions, the texts supplied a technical vocabulary for geometrical principles and concepts including a theory of similar triangles. Techniques for transforming shapes while preserving areas considered the quadrature of rectangles and circles, and procedures were also given for doubling the area of a circle and transforming a square into a circle. The principle of constructing a square on the diagonal of a rectangle ("Pythagorean Theorem") was also known to the writers of *Śulbasūtras*. No formal "proofs" were given but some results were justified by arguments.

The subsequent influence of the *Śulbasūtras* on the latter development of Indian geometry is controversial: early researchers such as G. R. Kaye could discern no influence, whereas more modern writers such as T. A. Sarasvati Amma believe that the *Śulbasūtras* established the foundation for all Indian geometry. Whatever the influence of these Veda texts on geometrical thinking, later developments in this field were spotty and isolated. Geometry became closely associated with astronomy and cosmography. It was dominated by numerical problem solving based primarily on the use of right-triangle principles and was mainly concerned with finding the length of circular chords. The post-Vedic period saw the rise of the Jaina school of philosophical and scientific thought. The Jainas, in their cosmological considerations, held two geometric figures – the circle and trapezium – in high regard. Much of their geometry focused on mensuration problems involving these figures. In general, they considered geometry important denoting it as "the lotus of mathematics." The Jainas employed the approximation $\pi = \sqrt{10}$.

The next Indian mathematical text of note to appear was the *Āryabhaṭīya* (ca. 499) of Āryabhaṭa I (476–550). While many of its problems concern the applications of geometry to astronomy, its author also considered the computation of area for triangles, trapezia, and circles, and the volumes of spheres and triangular pyramids. Āryabhaṭa's formula for the area of a circle is correct; his approximation for π is 62832/20000 or 3.1416. However, his results for the volume of a sphere are $V = \pi^{3/2} r^3$. Subsequent mathematical authors would refine and extend Āryabhaṭa's work. Brahmagupta (ca. AD 628) in his *Brahmasphutasiddhānta* (Correct Astronomical System of Brahma) provided sections on *Ksetra* (plane figures), *Khāta* (cubic figures), *Citi* (solids composed of piles of bricks), *Krakaca* (truncated solids), and *Chāyā* (plane figures resulting from shadows). Much of Brahmagupta's results are limited to triangles and quadrilaterals inscribable in a circle. His most notable findings include:

- The correct determination of the area of a cyclic quadrilateral of sides a, b, c, d, with s as its semiperimeter, i.e.,

$$A = \sqrt{(s-a)(s-b)(s-c)(s-d)}.$$

- The length of the quadrilateral's diagonals d_1 and d_2:

$$d_1 = \sqrt{\frac{(ac+bd)(ad+bc)}{(ab+cd)}},$$

$$d_2 = \sqrt{\frac{(ac+bd)(ab+cd)}{(ad+bc)}}.$$

- The volume of a cone as 1/3 the product of its base area and its height.

Mahāvīra (ca. 850), a Jaina mathematician, improved upon Brahmagupta's theories in his *Ganitasārasamgraha* (Summary Compendium of Mathematical Astronomy), greatly extending geometric terminology and classification systems. For example, he divided quadrilaterals into five different subcategories: equal sides, opposite sides equal, etc., and triangles into three categories: equilateral, isosceles, and scalene. Bhāskara II (b. 1114), author of one of the most illustrious of Indian mathematical classics, *Līlāvatī* (The Beautiful), obtained accurate formulas for the volume and surface area of a sphere and obtained close approximations for the length of a circular arc in terms of its known chord. Mādhava of Sangamagrāmma (ca. 1340–1425), a Kerala astronomer, is noted for his work on the circle as well as spherical geometry.

Euclid's *Elements* were known and studied in India in the fourteenth century, but the first complete Sanskrit translation of this work appeared in 1718. The translation was performed by Jagannātha Samrāt at the request of his patron king astronomer Jayasimka of Jaipur.

The Islamic World

The founding of Islam in AD 622 was marked by the flight of Muḥammad from Mecca to Medina. Initially experiencing a period of rapid expansion, it was not until the founding of the Abbasid Caliphate, with the establishment of Baghdad as an intellectual and political center (AD 726) that Islamic civilization could begin to express its own intellectual and scientific traditions. The early Abbasid caliphs were patrons of the collection and translation of foreign scientific texts into Arabic, thus establishing a basis for Islamic science. Although Muslim scholars became the heirs of existing western (and eastern) scientific theories and traditions, they did not remain mere translators and passive communicators of this knowledge. In many fields they became true innovators and amplifiers of their mathematical and scientific inheritance. Geometry was one such field that was enriched by Islamic contributions.

The Greek sources that most influence Islamic geometric thinking were Euclid's *Elements*, Archimedes' *On the Sphere and Cylinder*, and Apollonious of Perga's *Conics*, all of which found their way into Arabic during the eighth to the ninth centuries. Muslim geometers pursued the theoretical problems poised in these texts and used their principles in a wide variety of new applications, particularly the study of optics and the design of mathematical instruments. The earliest documented Islamic geometry appears as a separate section of al-Khwārizmī's *Kitāb al-mukhtaṣar fī ḥisāb al-jabr wa 'l-muqābala* (Compendious Book on Calculation by Completion and Balancing), where rules for mensuration and geometric computations involving areas and volumes are stated. The value of π is given as $31/7$. Within 50 years of al-Khwārizmī's work, his successors were involved with far more complex geometric theories.

Thābit ibn Qurra (830–890) discussed the geometric verification of algebraic results in his *Qawl fī taṣḥīḥ masā' il al-jabr bi'l-barāhīn al-handasīya* (On the Verification of Problems of Algebra by Geometrical Proofs). In a private correspondence with a colleague, he expressed dissatisfaction with the existing Socratic proof of the "Pythagorean Theorem" and went on to derive three new proofs, one of which provides a generalization of the theorem to all triangles. Thābit also wrote on the trisection of an angle problem. His grandson, Ibrāhīm ibn Sinan (d. 946), continued researching this problem and provided for "ruler and compass" constructions of the conic sections in his *Rasm al-quṭūʿ al-talātha* (Outline of Three Sections). In approximately AD 950, Abū'l Wafāʾ wrote a book on applied geometry for craftsman, *Kitāb fī mā yaḥtāj ilayh al-ṣāniʿ min al-aʿmāl al-handasiyya* (Book on Necessary Geometric Construction for the Artisan), in which he presented several original constructions for conic sections. Around the year 1000 Abū ʿAbdullāh al-Ḥasan ibn al-Baghdādī published a comprehensive treatment of incommensurables improving on the theory given in the *Elements*.

One of the recurrent themes in Islamic geometry is the concept of parallel lines and the provability of Euclid's fifth postulate. Ibn al-Haytham (ca. 965–1039), known in the West as Alhazen, attempted to reformulate Euclid's theory of parallel lines by assuming the constructibility of the lines. He presented his theory in a work entitled *Maqāla fī sharḥ muṣādarāt kitāb Uqlīdis* (Commentary on the Premises of Euclid's *Elements*). ʿUmar ibn Ibrāhīm al-Khayyāmī, or ʿUmar al-Khayyām (ca. 1048–1126), in investigating the concept of parallelism, developed a series of eight propositions eventually leading to the establishment of Euclid's fifth postulate. ʿUmar al-Khayyām's work was based on the possible relationships of the angles of a quadrilateral. In turn, this work was expanded by Naṣīr al-Dīn al-Ṭūsī (1201–1274). He also explored parallelism with the aid of a quadrilateral, but allowed for the existence of acute and obtuse angles within the quadrilateral seeking to obtain a contradiction to his premises concurring the nature of parallel lines. He published his work on the fifth postulate in 1250; it was entitled *Al-risāla al-shāfiya 'an al-shakk fī al-khuṭūṭ al-mutawāziya* (Discussions which Remove Doubts about Parallel Lines).

Eventually the theories of Islamic scholars such as Ibn al-Haytham and al-Ṭūsī reached Europe; there they profoundly affected the nature of geometric thinking.

China and the Far East

Most geometrical considerations in early China were empirically based. However, during the Mohist school of activity (ca. 300 BCE) a deductive approach to understanding geometry was undertaken. Mohist philosophy and scientific theory were based on the use of logic. The Mohist Canon (*Mozi*) (ca. 330 BCE) develops a formalist approach to plane geometry building upon a concept of points and lines. Mohist theories did not become popular, and the development of a theoretical geometry progressed no further.

The earliest extant references specifically on Chinese mathematics are the *Zhoubi suanjing* (Arithmetical Classic of the Gnomon and the Circular Paths of Heaven) and *Jiuzhang suanshu* (Nine Chapters on the Mathematical Art, ca. 100 BCE). A discussion of right-triangle relationships is given in *Zhoubi*, along with a dissection proof demonstrating that the sum of the squares of the sides adjacent to the right angle in a right triangle is equal to the square of the hypotenuse. Four chapters of the nine chapters of *Jiuzhang* are specifically devoted to geometrical computations involving areas, volumes, and work with right triangles. Correct procedures for finding a variety of areas and volumes are given; the area of a circle of radii r is noted as $A = \pi r^2$ with $\pi = 3$; but the volume of a sphere with diameter d is incorrectly found, $V = 9/16d^3$. An approximation for the area of a circular segment with chord C and sagitta S is given as $A = S/2(S + C)$. Similarity among right triangles is employed in several problem situations.

In the third century, the scholar Liu Hui wrote a commentary on the *Jiuzhang* in which he provided dissection proofs for many of its geometrical formulas. Liu also employed a circle dissection technique involving a 192-sided polygon to estimate π as 3.141024. He extended the right-triangle theory of the *Juizhang* to include more complex problem situations involving pairs of similar right triangles. Using a technique called *chong-cha*, Liu provided proofs for solution procedures and published his findings in an appendix to *Juizhang*. Eventually, this appendix became a separate geometrical classic called *Haidao suanjing* (Sea Island Mathematical Manual). Zu Chongzhi (429–500) refined Liu's approximation for π obtaining a value of 355/113 or 3.1415929. Further, using a geometric slicing technique, Zu found the volume of a sphere, radii r, correctly as $V = 4/3\pi r^3$.

In 656, the geometric theory contained in *Zhoubi suanjing*, *Juizhang suanshu*, and *Haidao suanjing* was sanctioned by the Tang dynasty as a formal curriculum for its scholar officials. This curriculum was also eventually adopted in Japan and Korea, establishing a limited geometrical outlook based on empirical problem solving. This outlook would remain unaltered until the sixteenth century when a translation of Euclid's *Elements* appeared in the Chinese language. This translation of the first six books of Euclid was made by the Jesuit missionary Matteo Ricci and the Chinese scholar Xu Guanggi.

Pre-Columbian America

Although no written records exist to document the geometric knowledge of the early Native American civilizations, archeological sites testify to their use and understanding of geometry. In particular, the city planning and construction techniques employed by the Olmec, Maya, Teotihuacan, Toltec, and Aztec peoples of South and Central America and the Anasazi of the North American Southwest indicate that these peoples utilized the properties of circles, squares, and rectangles and employed right-triangle theory.

See also: ►Liu Hui, ►*Śulbasūtras*, ►Āryabhaṭa, ►Brahmagupta, ►Mahāvīra, ►*Elements*, ►Bhāskara, ►Mādhava, ►al-Khwārizmī, ►Thābit ibn Qurra, ►Ibrāhīm ibn Sinān, ►Abū'l Wafā', ►Ibn al-Haytham, ►Naṣīr al-Dīn al-Ṭūsī, ►ʿUmar al-Khayyām, ►Liu Hui and the *Jiuzhang suanshu*, ►*Zhoubi suanjing*

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Geometry in Africa

Paulus Gerdes

The *sona* tradition is a part of the heritage of the Tchokwe, Lunda, Lwena, Xinge and Minungo peoples that inhabit the northeastern part of Angola, and of the Ngangela and Luchazi peoples of southeastern Angola and Western Zambia. When the Tchokwe met at their central village places or at their hunting camps, they usually sat around a fire or in the shadow of leafy trees spending their time in conversation, illustrated by drawings in the sand. These drawings are called *lusona* (singular) or *sona* (plural).

Most of these drawings belonged to an old tradition. They referred to proverbs, fables, riddles, animals, etc., and played an important role in the transmission of knowledge and wisdom from one generation to the next.

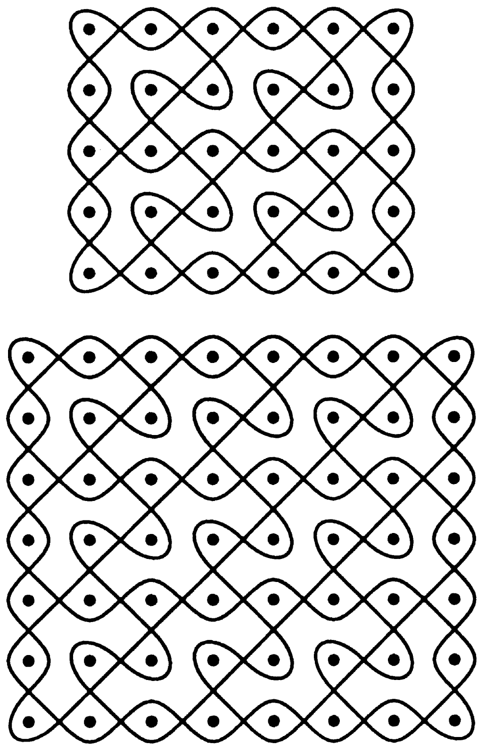
Every boy learned the meaning and execution of the easier *sona* during the intensive schooling phase of the circumcision and initiation rites. The significance and creation of more difficult *sona* were known only by specialists, the *akwa kuta sona* (those who know how to draw), who transmitted their knowledge to their sons.

The designs have to be executed smoothly and continuously. In order to facilitate the memorization of their standardized 'sona', the drawing experts used the following mnemonic device. After cleaning and smoothing the ground, they first set out with their fingertips an orthogonal net of equidistant points. Then one or more lines were drawn that 'embraced' the points of the reference frame. By applying their method, the drawing experts reduced the memorization of a whole drawing to that of mostly two numbers (the dimensions of the reference frame) and a geometric algorithm (the rule of how to draw the embracing line(s)).

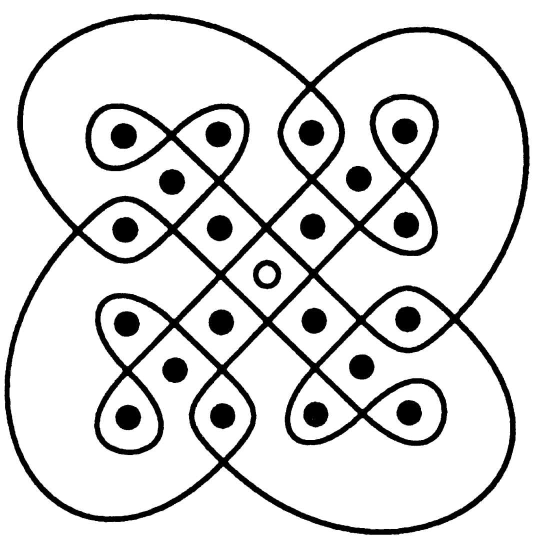
The *sona* tradition vanished almost completely. Tentative designs have been made to try to reconstruct the mathematical knowledge of the drawing experts.

They considered symmetry and monolinearity (i.e. a whole figure made up of only one line) important. Note the example of a *lusona* that is monolinear and that displays a rotational symmetry of order 4 (Fig. 1).

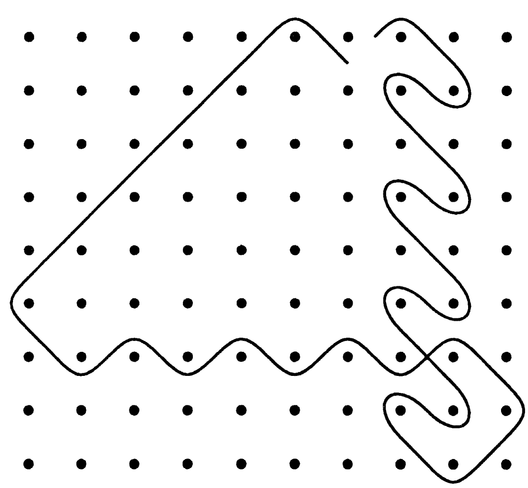
They invented geometrical algorithms for the construction of classes of 'sona'. Fig. 2 displays two monolinear drawings belonging to the same class and constructed in agreement with the same algorithm



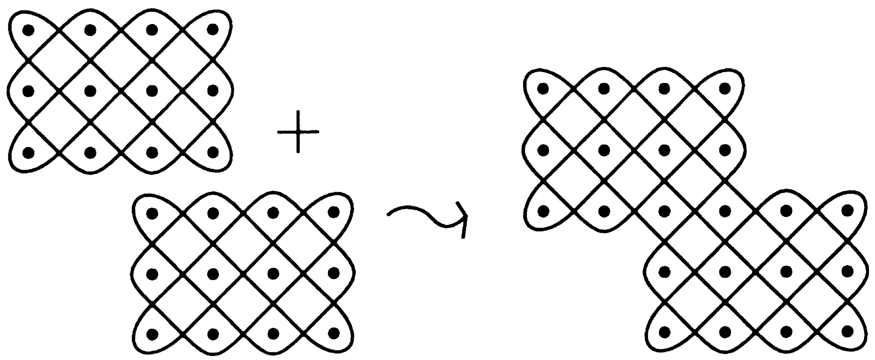
Geometry in Africa. Fig. 2 Two instances of "chased chicken" sona.



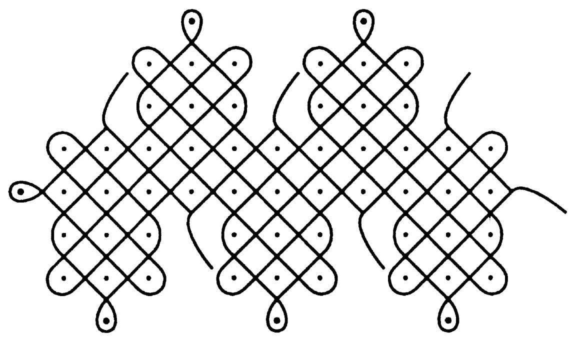
Geometry in Africa. Fig. 1 Monolinear *lusona* with rotational symmetry.



Geometry in Africa. Fig. 3 Geometrical algorithm for "chased chicken" patterns.



Geometry in Africa. Fig. 4 Example of a composition rule.



Geometry in Africa. Fig. 5 Representation of a leopard with five cubs.

(Fig. 3). Both drawings represent the marks left on the ground by a chicken when it is chased.

The drawing experts also invented a series of rules for the systematic construction of monolinear *sona*. They probably knew why the rules were valid: they could prove in one way or another the truth of the theorems that these rules expressed.

Fig. 4 illustrates one such a rule. This rule serves for chaining monolinear patterns and has been applied four times in the Tchokwe representation of a leopard with five cubs (see Fig. 5).

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Geometry in Chinese Mathematics

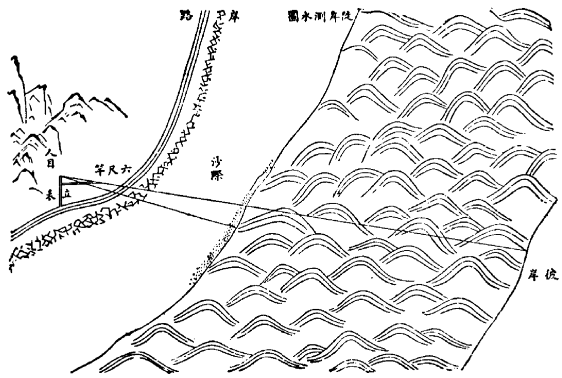
JEAN-CLAUDE MARTZLOFF

The earliest evidence of a systematic organization of regular shapes reproduced on material objects found in China dates from the third millennium BCE or even earlier. Painted motifs displaying geometrical patterns such as symmetrical arrangements of triangles, lozenges, or circles have been found on pottery pieces unearthed at Banpo[1] (near present-day Xi'an) and other archaeological sites. These designs demonstrate an early interest in spatial ordering and are perhaps at the origin of subsequent developments even though we are now unable to establish any continuity between prehistoric and historic Chinese mathematics. Nonetheless, several Chinese myths and legends attest that the plumb line, the compass, the carpenter square, and the gnomon (a post of standard height) were commonly used in Zhou China (1121–256 BCE). This last instrument, in particular, was considered so important

[1] Banpo (Pan-p'o) Neolithic dwelling site, one of the most important of its kind, located in the vicinity of Xi'an, south Shenxi, to the north of the present village of Banpo, on a hillock. It was discovered in 1953 while men were constructing the foundations of a plant. It belongs to the Yangshao culture (ca. 6000 BCE). It comprises the remains of the foundations of 45 huts, 200 silos, painted potteries, animal bones, farming and fishing tools, and a necropolis (more than 200 tombs and 37 funerary urns).

that the Chinese began founding their astronomical and calendrical conceptions on the determination of the length of gnomon shadows.

Chinese mathematical computations based on the gnomon have been preserved in several important sources from Chinese antiquity such as the *Huai Nan Zi* (The Book of the Prince of Huai Nan)[2] and the *Zhoubi suanjing* (The Canon of Gnomon Computations from the Zhou Dynasty) (Cullen 1996). In these sources, gnomons and their shadows are considered as sides of similar right-angled triangles and properties of similarity are applied to the determination of the height of the sun, at noon, above the flat earth. Later on, the same technique was generalized and used for the determination of earthly distances not directly measurable such as the depth of a well, the height of a mountain, or the distance of an island from the shore. Toward the end of the third century AD, these techniques were edited in algorithmic form in a book entitled *Haidao suanjing* (The Sea Island Computational Canon)[3] (Fig. 1).



Geometry in Chinese Mathematics. Fig. 1 A variant of the *Haidao* technique, taken from Problem IV-3 of the *Shushu juzhang* by Qin Jiushao (1248). The drawing explains the process of "measuring the width of stream from a steeply slanting bank" in order to construct a pontoon bridge in view of military operations (Libbrecht 1973).

In a quite different spirit, the Mohists – a sect of preaching friars from the fourth and third centuries BCE – approached geometry from a logical point of view and attempted to define the point, the circle, the square, space, and even parallelism (this last point is controversial). Certain of these definitions bear a striking resemblance to those found in Greek mathematics, particularly in Euclid's *Elements*. Still, there are important differences between both approaches: the Mohist definitions do not concern a single science, geometry, but include optics, mechanics, and economics. Moreover, the Mohists allow their definitions to incorporate familiar objects from the immediate human environment such as the sun, the bolt of a door, and other very concrete notions. More importantly, the grammatical structure of the Chinese language is

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[2] The prince of Huainan, Liu An, lived under the first half of the Former Han (~206–8), his grand father was Liu Bang (r. ~206 to ~196), the founder of the Han dynasty. The whole text of the *Huai Nan Zi* has been recently translated into French (Le Blanc and Mathieu 2003).

[3] *Haidao suanjing*, one of the Ten Mathematical Manuals (*Suanjing shishu*) of the Tang dynasty (618–907), was composed much earlier by the famous Liu Hui (late third century AD) and commented upon by Li Chunfeng (640–670). From the beginning, it was considered a sequel to the *Jiuzhang suanshu*. Under the Tang dynasty (618–907), it was incorporated in the famous *Suanjing shi shu* mathematical collection composed of ten treatises, just after the *Jiuzhang suanshu*. It was also first officially printed under the Northern Song. None of these antique manuscripts and prints have been handed down to us and the present edition of the text is mainly the result of a late eighteenth-century compilation of incomplete Southern Song dynasty editions, together with excerpts of the text incorporated into the famous encyclopedia, *Yongle dadian* published under the reign of the emperor Yongle (1403–1407).
The *Haidao suanjing* is a very short treatise, composed of only nine problems, all concerned with the determination of inaccessible lengths. Word for word, its title means "Sea *hai* Island *dao* computational *suan* classic *jing*"; it should not be taken literally since only the first problem of the collection has really something to do with a sea island, while some others concern mountain distances, the depth of a well, the width of a river estuary. In a word, its real topic is topometry seen under the angle of various special examples, not maritime surveying. In fact, the title is only here to give an idea of what the book contains by alluding to the specific content of its first problem. It is a kind of mnemotechnic device, a reminder.
As for the problems, their textual structure is uniform, composed as they are in the tripartite form of, first, the statement of a little enigma, second the solving technique and last, the commentary. While the problems are rather realistic, the solving technique is announced in a general way and states the succession of arithmetical operations to be performed in order to obtain the answer from the known data of the text, irrespective of the special numerical values various elements are given in the statement of the problem. In sharp contrast with the commentaries of the *Jiuzhang suanshu*, the present one is not devoted to the rational justification of the sequences of calculations. Rather, they only give some specific details concerning the underlying arithmetic.
The statement and solution of the first problem are as follows: Let a Sea Island be observed. Erect 1,000 *bu* (paces) apart two poles of the same height, three *zhang*, in such a way that both are aligned on an equal level. When moving back 123 *bu* from the front pole and looking from the ground up to the top of the island, the top end of the front pole lies in the alignment. When moving back 127 *bu* from the rear pole and looking from the ground up to the top of the island, the top end of the back pole lies again in the alignment. Question: find the height of the island and its distance from the front pole?
Answer: height of the island 4 *li* 55 *bu*; distance from the front pole 102 *li* 150 *bu*.

such that objects and their properties are not distinguished in any way in the Mohist definitions cf. A. C. Graham, 1978.

Mohist logic did not arouse much interest and was never again studied in China; Chinese geometry developed without concern for geometrical definitions, let alone axiomatic–deductive constructions. But during the Han dynasty (206 BCE–AD 220) Chinese mathematical knowledge was for the first time separated from other domains and recorded in the *Jiuzhang suanshu* (Computational Prescriptions in Nine Chapters, also translated as Nine Chapters on the Mathematical Art[4]). Composed of 243 problems and almost as many prescriptive solutions (*shu* = method, device, prescription, algorithm), this very influential manual was eventually revered as a kind of mathematical Bible, so that as late as the seventeenth century certain respected Chinese mathematicians considered that all imaginable problems and computational methods would necessarily be interpretable in terms of the traditional nine chapters of the *Jiuzhang suanshu*.

In fact, the geometry of the *Jiuzhang suanshu* is not precisely an autonomous body of knowledge and consists essentially in a threefold compilation of problems pertaining to planimetry, stereometry, and right-angled triangles. Planimetry is included in the first chapter of the *Jiuzhang suanshu* and comprises a collection of formulae needed to compute the area of fields in the form of squares, rectangles, triangles, trapezia, circles, rings, and segments of circles. Stereometry is found in the fourth and fifth chapters and concerns the computation of volumes or capacities of cubes, parallelepipeds, pyramids, spheres, as well as that of various prisms, dikes, moat walls, ditches, excavations, and cylindrical or prismatic grain silos. Problems on right-angled triangles are found in the last chapter of the *Jiuzhang suanshu* and bear upon Pythagoras' theorem, where some dimension of a right-angled triangle is sought, given simple algebraic combinations of other dimensions (such as the sum of its base and hypotenuse, its area, and so on). Lastly, the determination of the side and diameter of a square and a circle, respectively, inscribed in the same right-angled triangle are also considered. Nongeometrical subjects are also dealt with in the same chapters (for example, fractions in the first chapter, square and cube roots in the fourth). In addition, various concerns (units of measurement, for example) frequently interfere with the geometrical aspect of problems, so that they seem highly realistic at first sight. In reality, most of them are artificial, since the situations they describe are often the inverse of what would naturally occur in real life: one is often asked to determine the dimensions of a figure given its area or its volume. On the whole, these problems are strikingly similar with those found in the *Suanshu shu (Book of arithmetic)* an arithmetical manual written on bamboo strips from ca. 186 B. C, found in 1983–1984 in a tomb of a Chinese nobleman from the Western Han Dynasty in a site neat Zhangjiashan, Jiangling country, Hubei province.

Given that problems on planimetry, stereometry, and right-angled triangles quite similar to the above ones are also well represented in the known corpus of Babylonian mathematics, it would seem that there is no essential difference between Chinese and Babylonian geometry. That is not the case, however, for on the one hand, the solutions of Chinese problems are practically never stated using particular numbers but rather general formulations, and on the other hand, certain Chinese mathematicians have felt the need to justify geometrical results. Remarkably, these justifications would appear quite correct and even accessible to informal proofs in the eyes of modern mathematicians not at all acquainted with Chinese mathematics.

Chinese proofs of geometrical results have been preserved in various commentaries on the *Jiuzhang Suanshu* composed between the third and the seventh century AD by Liu Hui (fl. ca. end of the third century), the author of most of them, Zu Chongzhi (429–500), a famous astronomer and mathematician known for his approximation $\pi = 355/113$, and Li Shunfeng (602–670), an astronomer and compiler of the *Suanjing shi shu* (Ten Computational Canons), a collection of mathematical manuals representative of Chinese mathematical knowledge from the origins to the seventh century. As may be expected, the commentaries do not focus on mathematics alone, but concentrate also on many other aspects of problems needed to understand their original context and pertaining to history, geography, philology, pedagogy, and philosophy. The commentaries are thus intrinsically nonhomogeneous.

[4] Generally speaking, *shu* means "technique" or "art." For example, in terms like *labanshu*, cerography (lit. the art of cerography), *yaoceshu* (lit. the art of measuring from afar) telemetry, *qieduanshu*, amputation (the art of cutting limbs), *fashu* magic arts, *guoshu* (lit. national arts), i.e., Chinese traditional martial arts and gymnastics, *jianshu*, swordsmanship, *jishu*, technology, *mimashu* (lit. the arts of secret codes) cryptography, *meishishu* (lit. the art of fine eating) gastronomy, *suanshu* (lit. the arts of calculation) arithmetic and sometimes mathematics too, *yinshuashu*, printing, *zhanxingshu*, astrology, *zhiwenshu*, dactylography, and so on. From this, the title *Jiuzhang suanshu* could be said to be "the arts of the nine chapters." However, it is also a fact that the text of the *Jiuzhang suanshu* consists of a list of problems with their *shu*, i.e., their prescriptions - or receipts or "instructions" - which is precisely the special meaning of *shu*, in this context; these *shu*, receipts, are sometimes also called "procedures" in a rather anachronistic way, as if computer listings and algorithms were at stake here. The title *Jiuzhang suanshu* means exactly "the *shu* of the nine chapters," i.e., "the receipts of the nine chapters" or the "computational prescriptions in nine chapters."

In their turn, the proofs themselves are often interspersed with numerous digressions and are no more homogeneous that the rest of the commentaries they are imbedded in. Moreover, they frequently rely on all sorts of results (Pythagoras' theorem, for example) not yet proved when they were first used. Reasoning is thus neither constrained by formal modes of presentation nor by restrictions on what is admissible and what is not. In particular, numerical computations are liberally used, even when strictly speaking they would not necessarily be needed. More surprisingly however, but probably for mnemotechnical reasons, most proofs are formulated in a terse language; deductions are only suggested and based on a limited number of heuristic principles whose formulation is also extremely concise and which are used over and again.

One of these heuristic principles can be described as a generalized form of the so-called "Cavalieri's principle" (named by analogy with a famous proposition found in Bonaventura Cavalieri's *Geometria Indivisibilibus*; Bologna 1635).[5]

In its Chinese version, this principle is limited to solids and states that when the areas of the plane sections of two solids always have the same proportion between them, their volumes also have the same proportion. According to another heuristic principle, when a figure is dissected into several pieces as if it were a puzzle, and when the pieces are adequately reassembled, the area (or the volume) of the initial and final figures is equal. This principle is used with standard colored pieces (*qi*) but these are not necessarily the equivalent of concrete pieces of some puzzle since their number is sometimes infinite and involves the idea of carrying the process to the limit. This is the case, for example, in the derivation of the volume of the pyramid, in a way which reminds us of Euclid's proof of the volume of the pyramid (*Elements*, book 12, prop. 5), as the mathematician and historian of mathematics B. L. van der Waerden has suggested.[6] This dissection technique is so productive that its usage extends beyond the bounds of geometry. Very often, properties that we would call "algebraic" (especially when the equivalent of equations comes into play) are manipulated figuratively by means of dissections, so that algebraic relations are directly visualized without any recourse to discursive reasoning or even to particular computations.

As numerous quotations from classical texts (such as Confucius's *Analects*, the *Yijing* (*I Ching*, Book of Changes) or Zhuangzi's[7] works) found in the commentaries on the *Jiuzhang suanshu* suggest, this approach largely depends on Confucian and Daoist ideas. According to the Confucian conception, when presenting new knowledge, all the details should not immediately be revealed to students in order to oblige them to make efforts which would result in a deeper understanding. Similarly Zhuangzi favored conciseness of expression, but for a very different reason: he believed that, as sophisms show, discursive reasoning is intrinsically limited and therefore any efficient access to knowledge should necessarily include all imaginable modes of apprehension of reality and not only discursive reasoning. On the whole, these conceptions induced defiance toward modes of reasoning based on language alone; hence the recourse to nonlinguistic modes of communication such as those based on computations or figurative techniques. Still it remains possible that the *Jiuzhang suanshu* and its commentaries are also the result of various other influences which did not necessarily originate in the Chinese world. In this respect it should be noted, for example, that Archimedes and other Greek mathematicians already used equivalents of Cavalieri's principle many centuries before the advent of the *Jiuzhang suanshu* and its commentaries. Dissections are also attested in antiquity, particularly in Archimedes' *Stomachion*[8] and even more strikingly, the Chinese proof relating to the volume of the sphere relies, among other things, on the knowledge of the fact that the volume of a solid defined by the intersection of two orthogonal cylinders inscribed in the same cube is equal to two-thirds of the volume of the cube, a result explicitly stated in Archimedes's *Method of Mechanical Theorems for Eratosthenes* and in Heron of Alexandria's *Metrica*.

[5] The original text of Cavalieri's *Geometria Indivisibilibus* is wholly accessible from the Biblioteca Digitale IMSS (Istituto e Museo di Storia della Scienza, Firenze) (▶http://www.brunelleschi.imss.fi.it/bd/).

[6] "Liu [Hui]'s proof is very similar to that of Euclid, and it is based on just the same division of a tetrahedron into two prisms and two smaller tetrahedra" (van der Waerden 1983: 204, 202ff).

[7] Also know as *Zhuangzhou* (ca. 370–300 BCE), this Daoïst philosopher from the Warring States period is the author of the *Zhuangzi* and can be considered as the master of irrationalism.

[8] Cf. E. J. Diksterhuis (1987). The Stomachion: "This is a kind of game, played with ivory pieces in the form of simple planimetrical figures, the object being to fit these various bit together in such a way that various shapes of human beings, animals or different objects were imitated." Note that this conclusion is solidly based on quotations taken from several classical authors. In other words, the Stomachion is a kind of puzzle in use in classical antiquity, more than 2,000 years before the first mention of the tangrams in China, first in the seventeenth century, and above all at the beginning of the nineteenth century.

[9] On this the indispensable reference always remains U. Libbrecht's outstanding masterpiece, *Chinese Mathematics in the Thirteenth Century, the Shu-shu chiu-chang of Ch'in Chiu-shao*. Cambridge, Massachusetts: MIT Press, 1973.

After the seventh century, the Chinese repertory of planimetrical and stereometrical formulae was continuously enriched. Among the most interesting results from this period, one must cite Hero's formula for the computation of the area of a triangle given its sides, which was published in Qin Jiushao's *Shushu juzhang* (Mathematical Works in Nine Chapters, 1247).[9] Despite its title, this work is very different from the *Jiuzhang suanshu* and is better known for its study of the "Chinese remainder problem" (simultaneous congruences) and its algebraic developments. After the seventh century however, and until the seventeenth, geometrical proofs were never again recorded in Chinese mathematical books. This fact perhaps has something to do with the remarkable development of Chinese algebra which took place during the Song and Yuan dynasties, for algebraic computations have the capacity to generate new results by means of mere computations. Nevertheless, we must admit that we absolutely do not know why some eminent Chinese like Liu Hui or Zu Chongzhi became interested in mathematical proofs endowed with a rather strong Greek flavor, from the triple point of view of its methods, contents, and results, during a short interval of time, limited to a few centuries, and in a context where Chinese geometry was previously limited to trivial or semitrivial results (such as $\pi = 3$ in the *Jiuzhang suanshu*).[10]

At the beginning of the seventeenth century, the Chinese became aware of axiomatic–deductive modes of reasoning when, in 1607, the first six books of Christopher Clavius's commentary on Euclid's *Elements* were translated into Chinese by the Jesuit missionary Matteo Ricci (1552–1610) and Xu Guanggi (1562–1633) under the title *Jihe yuanben* (*jihe* = geometry or quantity and *yuanben* = elements, so that *Jihe yuanben* means either "*Elements* of Geometry" or "*Elements* of the Measure of Quantities") – here, the reader will perhaps deem this story unbelievable. Why, from the very beginning, were Jesuits in China more interested in translating Euclid into Chinese rather than the Bible, papal bulls, catechisms, and other religious texts much more in keeping with a missionary activity? In fact, the answer has to do with the Jesuit educational policy in the context of the Catholic counter-reform. In their *Ratio studiorum* the Jesuits stress the importance of deductive mathematics because of its strong connection with theology: mathematics are extremely important because the kind of knowledge they provide depends both on dogmatic assertions – axioms and postulates – and deductive reasoning leading to truth and certainty. In other words, teaching mathematics to the Chinese was felt like the first and necessary step toward the propagation of religious truths.[11] Xu Guangqi was a Christian convert and influential high official responsible for the reform of Chinese astronomy undertaken from 1630 onward on the basis of imported European knowledge. It has often been noted that some Persian or Arabic version of Euclid's *Elements* had already reached the Chinese imperial library three centuries earlier, during the Mongol domination of China, but there exists no evidence of any Chinese translation made during that period, and no trace of influence on subsequent Chinese mathematics has ever been detected.

At first, the new geometry was not much studied save by a few converts and Chinese students of Western astronomy who served the Jesuits at the imperial bureau of astronomy. However, as time went on, many Chinese scholars impressed by the successes of European sciences (especially mathematical predictions of celestial phenomena such as eclipses of the sun and calendrical computations) began to study the *Elements* seriously. The majority of these scholars considered that Euclid stood at the very basis of the new Western knowledge. At the same time they also believed that once properly reinterpreted, the results of the *Elements* were the same as those of their nine mathematical chapters; they also thought it desirable to dissociate the content of the *Elements* from its form. Far from representing the very model of logical clarity and the universal basis of all true knowledge, the formal structure of argumentation was judged inappropriate and even noxious. A textual recasting (of the *Elements*) not only affected demonstrations but also geometrical figures, and mathematicians of the first order such as Mei Wending (1633–1721) did their best to dissociate geometrical figures from the demonstrations to which they were attached. Thus, they sometimes redrew figures so as to make the corresponding theorems directly visible. Taking as it were the appearance of "monstrations," demonstrations changed of nature through the intermediary of tangible figurative representations. At the same time, this major transformation of Euclidean space was accompanied by an extensive "numerization" of geometry. Whereas, in their underlying logic, Euclid's *Elements* dealt with intrinsic properties of numbers in general, without ever quoting any precise number, even when questions of area and volume were at stake, Chinese geometers made

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10 Clavius, C. *Euclidis Elementorum libri XV, Accessit XVI de Solidorum Regularium cuiuslibet intra quodlibet comparatione*. Coloniae (Köln), 1591. Cf. P. M. Engelfriet. *Euclid in China. The Genesis of the First Translation of Euclid's Elements Books I-VI (Jihe yuanben: Peking 1607), and Its Reception up to 1723*. Leiden: Brill, 1998. Review: J. -C. Martzloff. Euclid in China. *Monumenta Serica* 47 (1999): 479–88.

11 Cf. Romano Antonella. *La Contre-Réforme Mathématique: Constitution et Diffusion d'une Culture Mathématique Jésuite à la Renaissance (1540–1640)*. Paris: École Française de Rome, 1999.

massive use of explicitly mentioned particular numbers, computed if need be with a high degree of precision (Martzloff 1993–1994: 71–72).

Such reactions against the *Elements* were also fairly common in Europe during the seventeenth century, but, in sharp contrast with what happened in China, these European reactions (which often went hand in hand with the rejection of Aristotelianism and scholasticism) were never powerful enough to dominate the mathematical scene, except perhaps in elementary education. In fact, during the seventeenth and eighteenth centuries, China was dominated by a strong reaction against all sorts of speculative reasoning prevalent during the preceding centuries which was designated as the source of Chinese decline. Consequently, numerous scholars advocated the development of concrete sciences (*shixue*), i.e., of applied sciences whose usefulness could be tangibly demonstrated by an increased social welfare. Thus, if mathematics were to be used at all, computational results had to be expressed in the form of easily understandable instructions. In this respect, syllogisms like those of the *Elements* were particularly difficult to use, inasmuch as they also involved numerous repetitions, a characteristic which was also contrary to the canons of Chinese literary composition. In addition, certain critics also wrote that Euclid's *Elements* were written in a cryptic language devised purposefully to obscure simple mathematical results. Many scholars found still another reason to defy geometry; they believed – not without basis – that they had detected an essential similarity between formal discourses typical of the rhetoric of geometrical demonstrations and the scholasticism of the theological speculations widely diffused by the European missionaries. Hence there was a rejection of forms of expression which tended to speculative form.

These ideas remained unchallenged in China until the end of the nineteenth century, but if axiomatic–deductive reasoning was never studied as such during that period, geometrical results were nevertheless taken seriously as early as the second half of the seventeenth century. In particular, a famous mathematician Mei Wending developed at length the computational aspect of the stereometry of regular and semiregular polyhedrons on the basis of a very incomplete description of these that he had found in the *Celiang quanyi* (Complete Treatise on Measurements), a manual based on Clavius's *Geometria practica* and translated into Chinese ca. 1635. Others tried to recast to content of the *Elements* into the mold of the nine chapters of the *Jiuzhang suanshu*. From the end of the seventeenth century, new Chinese and Manchu translations of the *Elements* were realized under the patronage of the Kangxi emperor. These were all given the same title as the former translation of the *Elements* published a century earlier. However, they were very different from

Geometry in Chinese Mathematics. Fig. 2 Alexander Wylie.

Clavius's commentary since they were all essentially based on Father Gaston-Ignace Pardies (1636–1673) (Ziggelaar 1971). *Elements de géometrie*, a French manual very different from Euclid's initial text and intended for the teaching of geometry in Jesuit colleges (Ziggelaar 1971). Pardies' manual (first published in 1671) was so popular that it remained in use in Europe during a whole century and was translated into several European languages. The new translations of the *Elements* all remained in manuscript form, but these eventually gave birth to a final text which was eventually incorporated into a famous mathematical encyclopedia published by imperial order at the end of Kangxi's reign, the *Shuli jingyun* (Collected Essential Principles of Mathematics, 1723). Whereas this encyclopedia remained in use in China for two centuries, the not yet translated part of the first translation of the *Elements* was carried out between 1852 and 1856 by Alexander Wylie (1815–1887) (Fig. 2), a British Protestant missionary, and Li Shanlan (1811–1882), a renowned translator of Western manuals on astronomy, mathematics, botany, and other scientific subjects. This time, the translation was not based on Clavius' commentary but on Heury Billingsley's English translation of Euclid's *Elean eats* released in 1570[12] in seventeen books. After 1760, other elementary Western textbooks on geometry, which have been forgotten since, were again translated into Chinese.

[12] cf. Xu Yibao, "The First Chinese translation of the last nine books of Euclid's *Elements* and its source" *Historia Mathematica*, 2005, vol 32, no.1, pp 4–32.

After the 1911 revolution, Chinese mathematics was never again studied for scientific purposes (except by historians) and China gradually made its way into the international mathematical community. Nowadays, there is of course no distinction between geometry developed in China and in other countries.

See also: ▶Liu Hui and the *Jiuzhang suanshu*-*Elements*: Reception in the Islamic World, ▶Pi in Chinese Mathematics, ▶Liu Hui, ▶Zu Chongzhi, ▶Li Shunfeng, ▶Qin Jiushao, ▶Algebra

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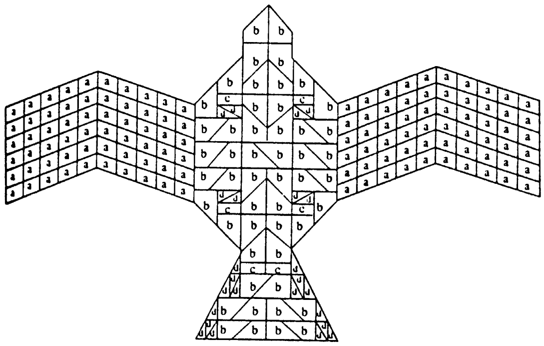
Geometry in India

George Gheverghese Joseph

An examination of the earliest known geometry in India, Vedic geometry, involves a study of the *Śulbasūtras*, conservatively dated as recorded between 800 and 500 BCE, though they contain knowledge from earlier times. Before what is conventionally known as the Vedic period (ca. 1500–500 BCE), there was the Harappan civilization dating back to the beginning of the third millennium BCE. Even a superficial study of the Harappan cities show its builders as extremely capable town planners and engineers requiring fairly sophisticated knowledge of practical geometry. An interesting conjecture has been suggested by a drawing on a seal found from Harappa (ca. 2500 BCE): was there an awareness then that the area of a polygon inscribed in a circle approaches the area of the circle as the number of sides of the polygon keeps increasing? This is the basic idea behind techniques that were developed for the mensuration of the circle in a number of mathematical traditions including Indian.

The *Śulbasūtras* are instructions for the construction of sacrificial altars (*vedi*) and the location of sacred fires (*agni*) which had to conform to clearly laid down instructions about their shapes and areas if they were to be effective instruments of sacrifice. There were two main types of ritual, one for worship at home and the other for communal worship. Square and circular



Geometry in India. Fig. 1 The first layer of a Vakrapaksa-syena altar. The wings are made from 60 bricks of type "a," and the body, head and tail from 50 type "b," 6 of type "c" and 24 type "d" bricks. Each subsequent layer was laid out using different patterns of bricks with the total number of bricks equaling 200.

altars were sufficient for household rituals, while more elaborate altars whose shapes were combinations of rectangles, triangles, and trapezia were required for public worship. One of the most elaborate of the public altars was shaped like a giant falcon just about to take flight (*Vakrapraksa-śyena*). It was believed that offering a sacrifice on such an altar would enable the soul of the supplicant to be conveyed by a falcon straight to heaven (Fig. 1).

It is clear that if in the construction of larger altars they had to conform to certain basic shapes and prescribed areas or perimeters, two geometrical problems would soon arise. One is the problem of finding a square equal in area to two or more given squares; the other is the problem of converting other shapes (for example, a circle or a trapezium or a rectangle) into a square of equal area or vice versa. The constructions were achieved through a judicious combination of concrete geometry (in particular what would be known today as the principle of dissection and reassembly), ingenious algorithms, and the application of the so-called Pythagorean theorem. The essence of the dissection and reassembly method involves two commonsense assumptions. The first is that both the area of a plane figure and the volume of a solid remain the same under rigid translation to another place. The second says that if a plane figure or solid is cut into several sections, the sum of the areas or volumes of the sections is equal to the area or volume of the original figure or solid. The reasoning behind this approach was very different from that behind Euclidean geometry, but the method was often just as effective, as shown in the Indian (and Chinese) "proofs" of the Pythagorean theorem.

In the *Kātyāyana Śulbasūtra* (named after one of the authors) the following proposition appears: "The rope (stretched along the length) of the diagonal of a rectangle makes an (area) which the vertical and horizontal sides make together." (2.11). Using this version of the Pythagorean theorem, the *Śulbasūtras* show how to construct both a square equal to the sum of two given squares and a square equal to the difference of two given squares. Further constructions include the transformation of a rectangle (square) to a square (rectangle) of equal area and of square (circle) to a circle (square) of approximately equal area. The constructions "doubling the square" and "squaring the circle" lead naturally to devising algorithms for the square root of 2 and other numbers, for implicit estimates of π, and for constructing similar figures in required proportions of a given figure.

The composers of the *Śulbasūtras* made it clear that their work was not original but could be traced to earlier texts, notably the *Saṃhitās* and the *Brāhmaṇas* of which the most relevant text, *Śatapatha Brāhmaṇa*, is at least 3,000 years old. In spite of its obscurities and archaic character the text is valuable for an early discussion of the technical aspects of altar construction. The instructions given in *Śatapatha Brāhmaṇa* (X.2.3.11–14) for constructing a falcon-shaped altar consisting of 95 layers of bricks are as follows:

$$\text{Area of the body (Atman)} = 56 + \frac{12}{7}\sqrt{56};$$

$$\text{Area of two wings} = 2(14) + \frac{3}{7}\sqrt{14} + \left(\frac{1}{5}\right)\left(\frac{1}{7}\right)(3)(\sqrt{14});$$

$$\text{Area of tail} = 14 + \frac{3}{7}\sqrt{14} + \left(\frac{1}{10}\right)\left(\frac{1}{7}\right)(3)(\sqrt{14}).$$

The total area is about 116 square *purushas*, which is an over-estimate of the required 101.5 square *purushas*, arising in part from a rounding off error involved in taking 14 rather than 13 + 8/15.

A major strand running through the history of Indian geometry and also providing the main motivation for the development of the subject was a recognition of the impossibility of arriving at an exact value for the circumference of a circle given the diameter (i.e., the incommensurability of π). A passage in Āryabhaṭa's *Āryabhaṭīya* (AD 499) – Verse 10 of the section on *Gaṇita* – reads:

> Add 4 to 100, multiply by 8, and add 62,000. The result is *approximately* the circumference of a circle whose diameter is 20,000. (Giving an implicit value of 3.1416 for π. This was the most accurate estimate for π known at that time. About six hundred years earlier (ca. 150 BCE), there was

an implicit estimate of π as the square root of 10 in a Jaina text called *Anuyoga Dwāra Sūtra*.)

It was the word "approximately" that gave food for thought to commentators of Āryabhata's work from Bhāskara I (ca. AD 600) to Nīlakanṭha (b. AD 1445). The first formal proof of the transcendental nature of π was given by the Swiss mathematician Lambert in a paper to the Berlin Academy in 1671. However, about 150 years earlier. Nīlakanṭha's commentary on *Āryabhaṭīya* contained the following statement:

> Why is only the approximate value (of circumference) given here? Let me explain. Because the real value cannot be obtained. If the diameter can be measured without a remainder, the circumference measured by the same unit (of measurement) will leave a remainder. Similarly the unit which measures the circumference without a remainder will leave a remainder when used for measuring the diameter. Hence the two measured by the same unit will never be without a remainder. Though we try very hard we can reduce the remainder to a small quantity but never achieve the state of 'remainderlessness'. This is the problem. (Adapted from Sarasvati Amma 1979)

Once the incommensurability of π was accepted, the approach of the Indian mathematician was to obtain as accurate a value of this quantity as possible, and the strategy to be followed was expressed thus by Śaṅkara Variyār and Nārāyana Kriyākramakarī (ca. 1550)]:

> Thus even by computing the results progressively, it is impossible theoretically to come to a final value. So, one has to stop computation at that stage of accuracy that one wants and take the final result arrived at ignoring the previous results. (Adapted from Sarma 1975)

The major breakthrough came from the revolutionary idea, most probably that of Mādhava (ca. 1340–1425), that it was possible to obtain an infinite series whose sum would be exactly equal to π and that an increasingly close rational approximation of the quantity could be obtained by taking partial sums successively of higher order. While the question of the slow convergence of this series was not explicitly discussed, the need for increasing rapidity of convergence was recognized and some remarkable corrections to be applied to truncated series were deduced. The work on infinite series for circular functions provided an impetus to derivation of other infinite series for trigonometric functions, namely arctangent, sine, and cosine series. Often inductive reasoning (and intuition) built upon geometrical representation helped them to discover these results, but the proof of these results can withstand any rigorous criterion applied to it today. An implicit estimate for π based on infinite-series expansion given by Mādhava around 1,400 is correct to eleven decimal places.

Another area of geometry in which the Indian contribution was significant was in the study of the properties of a cyclic quadrilateral. In the *Brāhma Spuṭa Siddhānta*, Brahmagupta (b. AD 598) gives these results:

1. The area of a cyclic quadrilateral is given by the product of half the sums of the opposite sides, or by the square root of the product of four sets of half the sum of the sides (respectively), diminished by the sides.
2. The sums of the products of the sides about the diagonal should be divided by each other and multiplied by the sum of the opposite sides. The square roots of the quotients give the diagonals of a cyclical quadrilateral.

The derivations of these results are first referred to in a tenth-century commentary on Brahmagupta's work, but find their full expression in the sixteenth century Kerala text *Yuktibhāṣā* by Jyeśṭhadeva. This makes use of Ptolemy's theorem that in a cyclic quadrilateral the product of the diagonals is equal to the sum of the products of two pairs of opposite sides.

Notable extensions in this area are contained in Nārāyana Pandita's *Gaṇita Kaumudī* in the fourteenth century and Parameśvara's *Lilāvati Bhāsya*, a detailed commentary on Bhāskaracharya's *Lilāvati*. In the latter is found a new rule for obtaining the radius of the circle in which a cyclic quadrilateral is inscribed. The great interest in the cyclic quadrilateral in Indian mathematics arose from the fact that it was an important device for deriving a number of important trigonometric results which were in almost all cases used in astronomy.

In India geometry never became idealized in the way it did in Greece. Geometry was largely concrete and empirical in character. It did, however, have an algebraic character which is best seen in the genesis of trigonometry there. Because of their geometric emphasis, the Greeks used chords in their astronomical calculations, whereas the Indians developed the notion of sines and versines (i.e., 1 – cosine of an angle) as early as AD 500. Āryabhata was perhaps the first Indian astronomer to give a special name to these functions and draw up a table of sines for each degree. Approximation formulae were developed for these functions, culminating in the construction of sine tables in Kerala during the fifteenth century where the values in almost all cases are correct to the eight or ninth decimal place, a remarkable degree of accuracy.

See also: ►Śulbasūtras, ►Geometry, ►Nīlakantha, ►Āryabhaṭa, ►Nārāyana, ►Mādhava, ►Bhāskara, ►Parameśvara

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Geometry in Islamic Mathematics

Boris Rosenfeld

Many original Muslim geometric works are "books" or chapters of great mathematical, astronomical, and encyclopedic works. Geometrical parts are contained in the algebraic treatise of al-Khwārizmī (ca. 780–850), in the *Miftāḥ al-ḥisāb* (Key of Arithmetic) of Jamshīd al-Kāshī (d. ca. 1430), in the astronomical *al-Qānūn al-Masʿūdī* (Masudic Canon) of Abū'l Rayḥān al-Bīrūnī (973–1048) and in his treatises on astrolabes, as well as in the encyclopedic *Kitāb al-shifā* (Book of Healing) of Abū ʿAlī ibn Sīnā (Avicenna 980–1037). There are also special geometric treatises, commentaries on Euclid, and treatises on geometrical theorems, calculations, constructions, and the foundations of geometry.

Calculations of areas of plane figures and of volumes of solids were considered in the chapter "On mensuration" of the algebraic treatise of al-Khwārizmī. Many rules in this chapter coincide with the rules of Hero's *Metrics* (first century AD) and of Indian mathematicians of the fifth and sixth centuries. For the area S of a circle with radius r, he supplies the rule $S = \pi r^2$, where $\pi = 3\,1/7, \sqrt{10}, 62832/20000$.

The contents of this chapter are similar to the Hebrew *Mishnat ha-middot* (Treatise on Measuring) which was believed to be part of the *Talmud* written in the second century AD. Recently Zarfatti (1968) showed that this book was written after al-Khwārizmī's treatise and under its influence.

Many treatises on geometric calculation were written by Thābit ibn Qurra. In his *Kitāb fī misāḥa al-ashkāl al-musaṭṭaḥa wa 'l-mujassama* (Book on Mensuration of Plane and Solid Figures), he provides many rules for measuring area and volume. For example, there is his general rule for the calculation of the volume V of a right round cylinder, cone, and truncated cone expressed by one formula: $V = 1/3h(S_1 + S_2 + \sqrt{S_1S_2})$.

In his *Kitāb fī misāḥa qaṭ ʿal-makhrūṭ alladhī yusammā al-mukāfī* (Book on Mensuration of a Conic Section Named Parabola) and other works, Thābit tackles many geometric problems. Among these are the problems of calculating the area of a segment of a parabola, the volume of segments of solids obtained by the revolution of segments of a parabola, and of the area of a surface of an oblique round cylinder. Thābit calculated the area of segments of an ellipse by means of an equi-affine transformation of the ellipse onto a circle with equal area. His grandson Ibrāhim ibn Sinān (908–946) in his *Kitāb fī misāḥa al-qaṭ ʿal-mukāfī* (Book on Mensuration of a Parabola) calculated the area of a segment of a parabola by means of a general affine transformation. Wayjan al-Qūhī (tenth to eleventh centuries) and Ibn al-Haytham (965–ca. 1040) calculated the volumes of segments of solids obtained by the revolution of segments of parabolas that Thābit had not considered.

Al-Bīrūnī, in the mathematical part of his *Masudic Canon*, calculated the sides of a regular triangle, square, pentagon, hexagon, octagon, and decagon inscribed in a given circle. Also, he provided the length $C = 2\pi r$ as the circumference of a circle where $\pi = 3.7305910$ in sexagesimal fractions and 1628631471/518400000 in decimal. Al-Kāshī in his *al-Risāla al-muḥīṭiyya* (Treatise on Circumference) calculated the length $C = 2\pi r$ by means of the calculation of the perimeter of regular inscribed and circumscribed polygons with 3.2^{28} sides. The number of sides was chosen on the condition that the difference between these perimeters for the great circle of the sphere of fixed stars must be less than the "width of a horse hair." The result was expressed in sexagesimal and decimal fractions as 3.829440472553725 and 3.14159265358979325. In the last case the calculation is correct up to 17 digits.

The teachers of Thābit ibn Qurra, the brothers Muḥammad (d. 872), Aḥmad, and al-Ḥasan Banū Mūsā ibn Shākir, in their *Kitāb al-shakl al-mudawwar al-mustaṭīl* (Book on an Oblong Round Figure), proposed the construction of an ellipse by means of a string attached to its foci (the so-called "Gardiner's construction"). Thābit himself solved two classical problems of antiquity: the construction of two mean proportional magnitudes between two given ones ($a : x : y : b$), which is the Delic problem of the duplication of a cube (if $b = 2a$), and the trisection of an angle. He also proposed the spatial construction of a semiregular polyhedron with 14 faces, which some now say was discovered by Archimedes.

The great philosopher Abū Naṣr al-Fārābī (ca. 870–950) proposed many geometric constructions of parabolas, regular polygons, squares equal to three given equal squares, constructions with one opening of the compass, and constructions on the sphere. These were also studied by Thābit's pupil's pupil Abū'l-Wafā al-Būzjāni (940–998) in the *Kitāb fī mā yakhtāju ilayhi al-ṣāni ͨmin a ͨmāl al-handasiyya* (Book on What is Necessary from Geometric Construction for the Artisan).

Ibrāhīm ibn Sinān ibn Thābit proposed many ways to construct a parabola (including al-Fārābī's one), ellipse, and hyperbola. One of the constructions of an ellipse is based on the compression of a circle; one of a hyperbola is based on a projective transformation of a circle.

Al-Qūhī described the instrument for the construction of conics, which he invented. It is a compass in which one leg varies in length and the second leg can change the angle of its slope to the plane. Many methods for the construction of conics were described by al-Bīrūnī in *Isti ͨāb al-wujūh mumkina fī ṣan ͨa al-aṣturlāb* (The Exhaustion of Possible Ways of Constructing an Astrolabe). In particular he mentions the "Gardiner's construction" of Banū Mūsā, the perfect compass of al-Qūhī, and constructions of all three kinds of conics based on projective transformations.

Al-Fārābī revised the order of the first definitions of Euclid. The first definition of Book 1 of the *Elements* was that of a point as "that which has no parts." Later Euclid defined a line as "a breadthless length" and a surface as "that which has length and breadth only." In Book 11 he defined a solid as "that which has length, breadth, and depth." Al-Fārābī, following Aristotle, defined a solid as the first abstraction from a physical body, a surface as the abstraction from a thin solid, a line as the abstraction from a narrow surface, and a point as the abstraction from a short line. The same order of geometric definitions was used by al-Bīrūnī in the geometric part of his *Kitāb al-tafhīm li-awā'il ṣināͨa al-tanjīm* (Book of Instruction in the Elements of the Art of Astrology).

In his *Taḥrīr Uqlīdis* (Exposition of Euclid) Naṣīr al-Dīn al-Ṭūsī added to Euclid's axioms that of the existence of points, lines, and surfaces, and the axiom of possibility of choice of a point on an arbitrary line and surface and of a line on an arbitrary surface and through an arbitrary point. There are also analogous axioms ascribed to al-Ṭūsī's version of the exposition of Euclid's *Elements* and in the geometric part of the encyclopedic work of his pupil Quṭb al-Dīn al-Shīrāzī (1236–1311). In both these works there are also attempts to prove Euclid's first three postulates about the ideal ruler and compass.

In al-Shīrāzī's commentaries to al-Ṭūsī, the rules of the theory of syllogisms from Aristotle's *Analytics* are systematically used.

In many Islamic treatises the problem of mathematical atomism was discussed. Aristotle's ideas, on which Euclid's *Elements* is based, ousted the mathematical atomism of Pythagoras and Democritus. According to them, finite solids, surfaces, and lines consist of a finite number of "atoms". Pythagoras said these atoms were points without sizes, and the sizes of finite figures were created by the distances between them. According to Democritus these atoms were particles with very small but finite sizes. In medieval Islam the ideas of mathematical atomism were held by Muslim scholastics, the *muͨtazila* and *mutakallimūn*, who wanted to find a rational explanation for Islam. They believed that time consists of a separate "now" and explained by means of this view that God creates the world anew every instant. Among the *muͨtazila* there were adherents of both types of mathematical atomism. The first school was headed by Abū'l-Qāsim al-Kaͨbī (d. 932) whose nickname al-Kaͨbī means "cubical"; the second was headed by Abū'l-Ḥāshim al-Jubbāͨī (820–933). Democritus' ideas were also held by the philosopher and alchemist Abū Bakr al-Rāzī (865–952). The idea of mathematical atomism was also mentioned by al-Shīrāzī in his commentaries on a treatise by al-Ṭūsī.

Islamic mathematicians often attempted to prove Euclid's fifth postulate on which the theory of parallel lines in his *Elements* is based. This postulate is much more complicated than the first four. It asserts that, if a straight line falling on two straight lines makes the interior angles on the same side together less than two right angles, the two straight lines, if produced indefinitely, meet on that side in which the angles together are less than two right angles. Attempts to prove this axiom as a theorem were made by Archimedes (third century BCE), Posidonius (second to first centuries BCE), Ptolemy (second century AD), Proclus (fifth century), and Simplicius (sixth century). In their proofs there was the logical error of *petitio principii*, i.e., the implicit use of an assertion equivalent to the one being proved.

The first Islamic mathematician who attempted to prove the fifth postulate was al-ʿAbbās al-Jawharī (first half of the ninth century). In his *Iṣlāḥ li-kitāb al-Uṣūl* (Improvement of the Book "Elements") he proposed a proof based on the assertion that a straight line intersecting both sides of an angle can always be drawn through any point inside this angle.

Thābit ibn Qurra made two attempts to prove the fifth postulate. His two treatises on parallel lines were written in Syriac and then translated by him into Arabic. The first proof is based on the assertion of the existence of "a simple motion"; i.e., a parallel translation equivalent to the existence of equidistant straight lines and to the existence of a rectangle. The second proof is based on the assertion that, if two straight lines diverge on one side of a line falling on them, they necessarily converge on the other side. From this follows the existence of a parallelogram. An analogous error was made by al-Faḍl al-Nayrīzī (d. 922) in his *Risāla fī bayān al-muṣādara al-mashhūra min Uqlīdis* (Treatise on the Proof of the Known Postulate of Euclid).

Ibn al-Haytham also made two attempts to prove the fifth postulate. One attempt was based on the same error as in Thābit's first treatise. In this proof Ibn al-Haytham first considered quadrangles with three right angles ("the Lambert quadrangles") and three hypotheses about their fourth angle. The hypotheses of acute and obtuse angles were refuted by means of the existence of a rectangle. The second attempt was written in his last years. Here was the first proof of the fifth postulate which was free from logical error. At first the postulate was replaced by another more evident one and was proved by means of it. This new postulate was: two intersecting straight lines cannot be parallel to a third line. This postulate in the form "if the point A and a straight line a are given, it is impossible to draw more than one not intersecting line through A in their plane." This is now known as "the Playfair postulate" or "the strong Hilbert axiom of parallels," after Europeans who later came up with the same axiom.

Also free from logical error was ʿUmar al-Khayyām's proof of the fifth postulate in his *Sharḥ mā ashkala min muṣādarāt kitāb Uqlīdis* (Commentaries on Difficulties in Introductions of Euclid's Book). In this work Khayyām proved the postulate on the basis of a postulate which he called the "fourth principle of the philosopher (Aristotle)." "Two converging lines intersect and it is impossible for them to converge in the direction of divergence." In this proof he first considered equilateral quadrangles with two right angles at their low bases (which we now call "the Saccheri quadrangles") and three hypotheses about their equal upper angles. The hypotheses of acute and obtuse angles are refuted by means of this fourth principle. These two hypotheses, which are analogous to those of Ibn al-Haytham (his quadrangles are halves of Khayyām's), are fulfilled in hyperbolic and elliptic non-Euclidean geometries, respectively. Ibn al-Haytham and Khayyām actually proved some theorems of these geometries first.

Naṣīr al-Dīn al-Ṭūsī considered the theory of parallel lines. In the treatise, al-Ṭūsī explained the proofs of al-Jawharī, Ibn al-Haytham (only the second) and Khayyām (not completely), and considered the same quadrangles and the same three hypotheses as Khayyām. However, he made the same logical error *petitio principii*. In the book written after the critical letters of Qayṣar al-Hanafī (ca. 1170–1251) he explained the same proof, but before it he formulated the postulate similar to Khayyām's, and thus does not make a logical error.

Al-Shīrāzī also made an attempt to prove the fifth postulate based on a logical error: he supposed that the distance between lines which do not intersect is constant.

We saw that in the proofs of the fifth postulate by Thābit ibn Qurra and Ibn al-Haytham "a simple motion" was used. The application of motion to geometry was used by Pythagoreans who considered lines as traces of moving points and surfaces as traces of moving lines. However, this application was rejected by Aristotle, who considered geometric solids as abstractions from physical bodies, surfaces as abstractions from thin solids, lines as abstractions from narrow surfaces, and points as abstractions from short lines. Following Aristotle, Euclid tried in his *Elements* to avoid the application of motion. Khayyām criticized the application of motion by Ibn al-Haytham.

We also saw that Thābit ibn Qurra and his grandson Ibrāhim ibn Sinān used affine transformations in their geometric treatises, and al-Bīrūnī also used projective transformations.

An astronomical instrument called an astrolabe was very popular in the Middle Ages. It was based on the projection of the celestial sphere onto its plane. Many treatises on the construction of astrolabes contain descriptions of different projections. In the *Kitāb ṣanʿa al-aṣturlāb* (Book of the Construction of the Astrolabe), Aḥmad al-Farghānī (d. 861) described the stereographic projection. That and others were described by al-Bīrūni in his *Exhaustive Ways of Constructing an Astrolabe*. Al-Bīrūnī applied a stereographic projection for determining the azimuth of *qibla* (the direction to Mecca). He also used the stereographic and some other projections of a sphere on to a plane in his *Risāla fī tasṭiḥ al-ṣuwar wa tabṭiḥ al-kuwar* (Treatise on the Projection of Designs on to a Plane and on the Map of Spheres on a Plane), which was devoted to problems of cartography.

In the *Elements*, Euclid used the plane geometrical algebra inherited from the Pythagoreans. In this, he represents the products $a \times b$ as rectangles with sides a and b and provides a geometric representation of algebraic equalities. For instance, there is a representation of the formula $(a+b)^2 = a^2 + 2ab + b^2$ by decomposing the square $(a + b)^2$ on two squares a^2 and b^2 and two rectangles $a \times b$. In Archimedes' *Lemmas* there is an analogous decomposition of a circle with diameter $a + b$ on two circles with diameters a and b and two "arbelons." Analogous representations of the formula $(a+b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$by decompositions of the cube $(a + b)^3$ and of the sphere with diameter $a + b$ were proposed by Abū Saʿīd al-Sijzī (ca. 950–1025).

Apparently the idea of "geometric" names for powers, square–square for x^4, square–cube for x^5, cube–cube for x^6, and so on, was borrowed from Diophantus' *Arithmetics*.

Islamic mathematicians used rectangular and oblique coordinates connected with conics: the axes of these coordinates were one of the diameters of a conic and the tangent line at one of its ends. Each point of a conic was determined by half of its chord conjugate with this diameter from a given point to the diameter and by the segment of this diameter from its end (vertex) to the meeting point of the chord with the diameter. They called these coordinates "ordered lines" and "line cut from the vertex," respectively. (Our terms "ordinate" and "abscissa" came from Latin translations of these expressions.) These coordinates were used by Khayyām in his *Risāla fī'l-barāhīn ʿalā masā'il al-jabr wa'l-muqābala* (Treatise on Demonstrations of Problems of Algebra), which was devoted to the solution of cubic equations by means of the intersection of conics.

Islamic astronomers and geographers following Ptolemy used the geographical coordinates longitude and latitude for the surface of the Earth, and analogous ecliptical coordinates with the same names, the horizontal coordinates azimuth and altitude, and the equatorial coordinates right ascension (or horary angle) and declination for the celestial sphere. Thābit ibn Qurra determined the positions of the ends of the shadows of the gnomon on the plane of a plane sundial by rectangular coordinates which he called, by analogy with the geographical coordinates, longitude and latitude, and by polar coordinates which he called azimuth and length of shadow.

Muḥammad al-Khwārizmī in his geographical treatise *Kitāb ṣūra al-arḍ* (Book of the Picture of the Earth) proposed the classification of curved lines and used the names of different kinds of lines in his descriptions of rivers, seacoasts, and islands between points with given geographical coordinates.

In addition to their original contributions, Muslims made many translations of Greek works. In many cases, the Arabic version of the work is the only one extant today. The most important Greek geometric work, Euclid's *Elements*, was translated into Arabic in the ninth century AD by al-Ḥajjāj ibn Yūsuf ibn Maṭar and Iṣḥāq ibn Ḥunayn al-ʿIbādī. The last translation was edited and supplemented by Thābit ibn Qurra (836–901), who was also the translator of other works of Euclid, of many works of Archimedes, of the *Conics* of Apollonius, and of many Greek mathematical works. These, together with a geometric treatise of his teachers the brethren Banū Mūsā and his *Kitāb al-mafrūḍāt* (Book of Assumptions) constituted the so-called "middle books" which were studied between Euclid's *Elements* and Ptolemy's *Almagest*. Later many Muslim revisions of other Greek mathematical works appeared.

See also: ►al-Shīrāzī, ►Sundials, ►ʿUmar al-Khayyām, ►Naṣīr al-Dīn al-Ṭūsī, ►Astrolabe, ►Conics, ►Sexagesimal system, ►Mathematics in Islam, ►Thābit ibn Qurra, ►al-Bīrūnī, ►Banū Mūsā, ►al-Khwārizmī, ►Maps and Mapmaking in Islam, ►Geography in Islam, ►Atomism in Islam, ►al-Farghānī, ►al-Qūhī, ►Ibn al-Haytham, ►al-Rāzī, ►al-Kāshī, ►*Elements*, ►Ibrāhīm ibn Sinān, ►al-Sijzī, ►*Almagest*, ►al-Māhānī, ►al-Khujandī

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Geometry in Japanese Mathematics

Yoshimasa Michiwaki

Western mathematics is concerned very much with logic based on proof and demonstration. Japanese mathematics in the Edo period (1603–1867), which is called *Wasan*, has its origin in China, and from the beginning put its emphasis on application, mainly on application in daily life. At the beginning of *Wasan*, experts studied practical aspects of mathematics, such as deriving the areas of figures and the volumes of solid bodies. However, in the developing period, they began to devise questions which provided conclusions based on the beauty of figures and complicated calculation. They especially liked questions on geometrical figures, and they had their own ways of studying. When they studied circles, they tried to increase their number, change their positions, and consider them as ellipses. They also tried to expand into three dimensions. Because of the national isolation policy of Japan, *Wasan* experts were kept in guild-like groups. The study of *Wasan* became very complicated; practitioners could not concentrate on the main themes but had to act as if their studies were rather like a hobby.

Wasan was formulated in the latter half of the seventeenth century by a Japanese mathematician, Takakazu Seki (or Kowa Seki) with the text *Jinko-ki* as its basis. The interest of *Wasan* experts in those days was to solve the questions left unsolved in *Jinko-ki* and other mathematical texts: that is, to calculate the areas and volumes of planes and solid figures, and also the length of chords and arcs and the area surrounded by them. Takakazu Seki, before he succeeded in systematizing *Wasan*, tried hard to solve those questions, and in the process studied parabolas, hyperbolas, and also the spirals of Archimedes. And he partially succeeded in measuring ellipses.

In the field of algebra, Seki used a determinant of five dimensions in his work *Kaifukudai-no-ho* published in 1683. In the area of geometry, he derived a relative equation between a side of a regular polygon and radii of an inscribed circle and a circumscribed circle. This arose from a theory on regular polygons. He also made great accomplishments in the field of *Enri*: this word may be translated as "circle principle" or "circle theory", being derived from the fact that the mensuration of the circle is the first subject that it treats. He repeated doubling the numbers of the side of an inscribed, regular polygon, and achieved the correct number for π. He devised a calculation method for circles – integral calculation – studying the relation among the chord, the arrow, and the arc. He also worked in other fields, such as the calendar.

After the publication of such works as *Seiyo Sampō*, *Shinpeki Sampō*, *Sampō Kokon Tsuran*, and *Sampō Tensei-ho Shinan*, interest in *Wasan* was very much aroused. For example, *Sangaku* (Mathematical Tablets) were dedicated to shrines and Buddhist temples. Some of these are beautiful, with figures of red, blue, and yellow. The definitions of the figures are not written on the tablets, but the drawn figures (questions) themselves illustrate the things necessary to solve the questions. These questions posed by *Wasan* experts are combined questions, such as a square and a square, a straight line and a circle, a circle and plural circles (or ellipses). There are questions on the length of a square side, a straight line, and the radius of a circle. There are also questions on the number and areas of circles put into one circle. These questions are expanded from "plane" to "solid" and from "limited" to "unlimited."

Wasan experts tried to derive the theorems to solve questions, and in the process they reached general laws by something like an inductive method. They sought a general equation with some sort of inspiration. One of these *Wasan* experts, Nushizumi Yamaji, stated in his *Sampo Ruiju* (Vol. 3) the same ideas as in Descartes' circle theorem but in a different way. A theorem like Descartes' was introduced in the mathematical texts of the first half of the nineteenth century, such as *Kokon Sankan* by Gokan Uchida.

Wasan in the Bunka and Bunsei period (1804–1818–1829) was at its peak. In *Suri Mujinzo* by Nagatada Shiraishi, one finds a technique or theorem called *Bosha Jutsu*, which has exactly the same idea as Casey's. This theorem is considered an extension of Ptolemy's.

Shingen Takeda wrote *Shingen Sampō*. In the first volume of this work, there is a problem called Clever Ways to Cross the Twenty-Eight Bridges in Naniwa (now Osaka).

Another *Wasan* expert, Zen Hodoji, learned many things through visiting various districts and teaching students in each district. In one of his works, *Kanshinko Sanhen*, there are questions which are close to the present "inversion" formula. We are not sure how he reached the inversion formula, but the result was correct.

As was stated before, *Wasan* experts were inspired to find a solving technique. *Kyokkei Jutsu* and *Henkei Jutsu* should be introduced here. *Kyokkei Jutsu* is explained in *Sampo Kyokkei Shinan* written by Hiroshi Hasegawa and his student, Giichi Akita. Special figures – *Kyokkei* – are used in this method. Beside this, Hasegawa wrote *Sampo Henkei Shinan* with his student, Teishin Heinouchi. In this, you find a sentence which says that "Questions with reasonable conditions, that is, questions with conditions enough to solve them are called "complete questions" while others with too many or too few conditions are called "incomplete questions." Some of these questions can be solved with insufficient conditions, and they are called *Kyoku Dai* (special questions). This book deals mainly with variations of *Kyoku Dai*. Both *Kyokkei Jutsu* and *Henkei Jutsu* deal with figures in special cases instead of general figures, but each technique is different. *Kyokkei Jutsu* has a tendency to make a mistake by trying to get an answer; *Henkei Jutsu* has no such tendency, but you find it difficult to get a *Kyoku Dai*. Each method is unique as a method of geometrical studies.

In the Meiji period (1868–1911), the new education system established in 1872 eliminated *Wasan* studies from public education, and adopted western mathematics.

However, in the Taisho and Showa periods (1912–1928–1988) mathematical leaders such as Tsuruichi Hayashi and Matsusaburo Fujiwara collected materials and wrote theses on various themes of *Wasan*, and its popularity was revived. The History of Science Society of Japan was established in 1941 and Kin-nosuke Ogura, counselor of the society, insisted that Japanese mathematics history be carefully considered. The Mathematics Club, later The History of Mathematics Society of Japan, was established in 1958 mainly to study *Wasan*. Seminar groups appeared in many districts, and magazines and theses were published. In 1979, the *History of Japanese Mathematics before the Meiji Period* (5 Vols.) edited by the Japan Academy was completed. All of the works mentioned in this essay can be found in this set.

See also: ►Seki Kowa

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Geometry in Mesopotamia and Egypt

Jens Høyrup

This article concentrates on the geometrical knowledge of the scribal traditions, not on what *could* have served for the construction of buildings. It must be observed that high technical precision is often achieved through the combination of quite elementary mathematics and sophisticated non-mathematical techniques. Anyone who has played with rulers and compasses knows that a regular pentagon can easily be made more precise through trial and error than by "exact" construction with all its accumulated errors. It is therefore next to impossible to extrapolate from the high precision of for example prestige buildings to the particular kind of geometry used in their design, unless some kind of blueprint has survived. Even in such cases, when the tracing of a ground plan has subsisted or the building can be seen to be planned around base lines geared to the standard brick, all that may be concluded is often that *some kind* of geometrical knowledge is involved.

On the other hand, in Mesopotamia as well as Egypt, written texts with geometrical contents have survived, most of which are scribe school problems. Even when unambiguous (which is not always the case), they confront us with a problem of bias: scribal mathematics consisted in calculation; the texts always aim at the determination of a number (an area, a volume, the number of man-days needed to dig a ditch, etc.). Geometrical construction was not the concern of the scribes.

Mesopotamia

The sources for our knowledge of Mesopotamian geometry reach back to the later fourth millennium BCE. The earliest sources are not very informative, but they demonstrate that the length and area metrology, together with the basic techniques for area computation, go back to the first phase of writing. Sources from the third millennium become more copious, in particular towards its end. Sophisticated scribe school problems dealing with complex volumes only turn up in the Old Babylonian period (early second millennium) and disappear again from the horizon after 1600 BCE. Finally, some interesting texts have survived from the later half of the first millennium BCE.

Length metrology may have been created in the same process as writing and written administration. Already in the earliest written documents, area metrology is keyed to the length system – but some of its units appear to be old "natural" (irrigation, ploughing, or seed) measures which have been normalized so as to fit, while others have been created anew. These systems survive until the end of the Old Babylonian period. In the late period, new quasi-natural measures (seed measures) allowing easier practical computation take over.

The basic volume measures coincide with the area measures, which are tacitly imagined as provided with the height 1 cubit. The system of hollow measures, on the other hand, is perplexingly complex, involving both traditional measures that have been normalized so as to fit the length system, and corrections introduced in order to facilitate practical computation of rations, cylindrical volumes, etc. A Mesopotamian specialty is the multiplicity of "brick measures", using the terminology of volume measures but referring in fact to the number of bricks, for which several standard dimensions coexisted.

The Old Babylonian texts show us that square and rectangular areas as well as right triangles and trapezia were calculated as we would do it. No unambiguous standard term for the height of a triangle or a trapezium is present, and field plans show us that complex areas, including skew triangles and trapezia, were subdivided into "practically rectangular" quadrangles and "practically right" triangles. No concept of a quantified angle is present, the field plans seem simply to distinguish "right" from "wrong" angles.

In practical mensuration, working in an always slightly uneven terrain and not in an abstract Euclidean plane, what is laid out as a rectangle with traditional methods mostly turns out to have slightly different opposing sides. In this situation, the Mesopotamian scribes calculated the area according to the "surveyors' formula": average length times average width. The result always exceeds the true area, but not significantly if the angles of the quadrangle are approximately right. In school problems, where the formula served as a pretext for calculation, it was occasionally used in situations where the outcome was absurd. In practical field measurement, a single instance is known where the error is at least 100%; whether this reflects general carelessness or the ignorance of a single scribe is not clear (it is even possible that a number written along a side is really meant to be the height, in which case there is no error in the computation but only a somewhat careless diagram). Most often, the circular area was determined as 1/12 of the square on the circumference (which is often the dimension most easily determined in practice by means of a piece of string). Translated into our idiom, this means that 4π was approximated as 12, or that $\pi = 3$. Other computations, such as the determination of the diameter from the circumference, agree with this; the Babylonians were thus aware that the circular area was the semi-product of the radius and the circumference.

Simple volumes (prisms, cylinders) were determined as the product of the base and the height – the formulation being that the base was "raised" to the height. Raising is a general term for multiplication based on considerations of proportionality – derived originally from volume determinations but in general use. The idea which underlies volume determination is indeed one of proportionality, since the base was understood as already provided with a standard height of 1 cubit. Similarly, a length could be understood as provided with a standard width of one length unit, and area computations (when not implicit in the construction of a rectangle) were hence also done by raising.

Complex volumes, such as truncated pyramids and cones, were determined by ad hoc methods, not always correctly or consistently. Several texts determine the volume of a truncated cone as that of a cylinder whose diameter is the average of the diameters of top and bottom. One of them determines the volume of a truncated square pyramid in the same way, but adds a correction term that makes the computation accurate (it is not quite sure whether the underlying reasoning is also correct). Other texts determine the volumes of truncated cones and pyramids by raising the average between top and bottom area to the height.

No later than the Old Babylonian period, the Pythagorean theorem was known and used for diagonal calculations. The purpose of a table text making use of Pythagorean triples is not fully decided, but it seems to be arithmetical rather than geometrical.

Already in the twenty-third century BCE, it was known that the square on the parallel transversal which bisects a trapezium is the half-sum of the squares on the parallel sides. No text tells us how this formula was reached, but it follows without difficulty from consideration of two squares of which one is embedded concentrically in the other. Similar naïve-geometric reflections may have led to the discovery of the Pythagorean theorem; their presence is well attested in the so-called "algebra" texts.

A few texts testify to an interest in geometrical arrangements and in regular polygons; in the actual cases, however, the texts always calculate something (mostly an area). A text with a regular hexagon draws a height in one of the six isosceles triangles from which it is composed and computes its length and uses this in the determination of the area.

The few late Babylonian texts exhibit some changes in the area techniques, such as a more general use of heights in area determination.

Egypt

Third-millennium sources for Egyptian geometry are rare, and even though the precision of the great pyramids demonstrates both architectural and geometrical skill, they tell us little about the geometrical techniques that were in use.

The important mathematical texts – the *Rhind Mathematical Papyrus* and the *Moscow Papyrus* – date from the early second millennium BCE. Together with some minor texts and fragments and with what can be grasped from administrative documents, they present us with a coherent picture. In spite of some unsolved problems of interpretation and the presence of still open questions, nothing suggests that new sources might change our understanding of Egyptian mathematics radically. Nor does Egyptian technology, in spite of its indubitable sophistication, ask for *mathematical* knowledge beyond what we know from the papyri.

The evidence for the length and area metrologies of the third millennium is meager, but sufficient to show that they were intricate; the metrologies of the early second millennium derive from and expand a subset of the third-millennium systems.

In this "classical" period, the most widely used length unit was a "royal cubit" of seven palms. Also in use was a "short cubit" of six palms, together with units equal to the diagonal and semi-diagonal of a square with side equal to the royal cubit.

Area units were derived from the length units. The basic unit for land measurement was $(100 \text{ cubit})^2$; for practical purposes, however, the Egyptians would often think in terms of strips with a standard breadth, as the Babylonians might also do.

Volume and capacity units were also keyed to the length system, but in a way that shows them to have originated independently – how else are we to explain that the basic volume unit was not 1 cubit^3 but 2/3 cubit^3?

The areas of squares, rectangles and right triangles were calculated from length and width. The areas of trapezia and isosceles triangles were found as the product of height and average width, and the Rhind Mathematical Papyrus explains that this calculation of the triangular area means that the triangle is transformed into a rectangle. It should be noted that the height is a given or measured number, not the outcome of a computation.

The area of the circle was found as $(8/9d)^2$, where d is the diameter. Translated into modern terms this means that the interesting constant was not π but $\sqrt{\pi/4}$, which was approximated as 0.888… (where the true value is 0.8862…).

One problem (concerned with a "basket") has been interpreted as the correct determination of the surface of a semi-sphere (equal to twice the cross section of the sphere). Another interpretation is that the text wants to determine the curved surface of a semi-cylinder, which will then also be correct, and would imply that the semi-circumference of the circle was found in agreement with the determination of the area.

Volumes of prisms and cylinders were found as the product of base and height (multiplied with a metrological conversion factor 3/2. The *Moscow Papyrus* gives a correct determination of the truncated pyramid as $(a^2 + ab + b^2)\,(h/3)$ (where a and b are the sides of the upper and lower square and h the height).

Pyramid slopes were measured as horizontal recess, measured in palms, per cubit increased height. Most often, in texts as well as practice, the value is 5 1/4, corresponding to a ratio 3:4 in pure numbers. Countless attempts have been made to demonstrate that the Cheops pyramid hides knowledge of either π or the Golden section (or both!) in its proportions. The proximity of certain ratios to these "mystical" numbers is, however, a mere consequence of the simple determination of the slope. Moreover, as we have seen, the Egyptians were not interested in the ratio π but in the equivalent number $\sqrt{\pi/4}$. There is no reason to believe that the pyramids testify to occult mathematical knowledge beyond the level revealed in the mathematical papyri. As Otto Neugebauer has pointed out, nothing is less secret than the "secret" knowledge of the Egyptians, the Greek magicians, the Gnostics, etc., all of whom have left an immense number of texts on occult topics, exceeding by far anything these cultures ever wrote on mathematics. Had the Egyptians possessed secret mathematical knowledge, we would certainly have been informed, as we are about the secret spells to be used in the Netherworld.

Even the oft-claimed Egyptian knowledge of the Pythagorean theorem (or at least of the fact that a 3-4-5-triangle is right) should be treated with circumspection. No single text suggests so. One of the arguments in favor of the assumption has been that this knowledge *might* have been used to construct right angles. This trivially correct observation made by Moritz Cantor has since then been quoted as information that they did so. The other is that the pyramid recess of 3:4 could have been chosen for this reason. As we have seen, however, the actual number used by the Egyptians was 5 1/4; if the vertical distance was measured in cubits and the horizontal in palms, what was then to be done with the hypotenuse?

All of this concerned the mathematics of the scribes. Egypt, however, offers an exception to the rule that non-scribal geometrical techniques cannot be decoded. This exception regards not least the use of square grids, first of all in the pictorial arts but also in architectural planning. In the pictorial arts the grids were connected to a so-called "canonical system" for the proportions of the human body. That is, whereas scribal geometry aimed at finding numbers from geometrical configurations, the artists determined geometrical configurations from numbers. Quarries and buildings also carry marks in large quantity that inform us about some of the measuring techniques that were used.

General Observations

Histories of mathematics tend to distinguish "exact" from "approximate" formulae. In so far as we are dealing with school traditions built on some kind of didactical argument, this distinction may be defended. Both Babylonian and Egyptian scribal training certainly involved argument, even though it was not deductive. However, when making this distinction we forget that formulae can only be exact with regard to ideal mathematical objects; when it comes to applying the formulae in real-life practice, *all* formulae become approximate.

Histories of mathematics – in particular general histories – also tend to translate into familiar terms. To a certain extent this is necessary, but it hides from view the fact that other cultures may use conceptualizations which are different from ours but just as good and consistent. Speaking of a Babylonian and an Egyptian "value for π" suggests that the Babylonians, as we, looked for the ratio between the circumference and the diameter of a circle. However, to the Babylonians, the fundamental ratio was the ratio between the area of the circle and the area of the square on the circumference, and the terminology they used demonstrates that they really thought of this as a constructed geometrical square. The Egyptians, for their part, were interested in the ratio between the sides of the squared circle and that of the circumscribed square. Both conceptualizations are fully legitimate, also according to the gauge of mathematical theory, but they are certainly different from ours. If we neglect this, we only use the foreign culture as a mirror where we see – ourselves.

Later Developments

In the first millennium BCE, Egypt was conquered first by the Assyrians, then subdued by the Persian armies, and finally – after Alexander – ruled by a Greek dynasty. We cannot follow the phases of this in detail in the rare mathematical texts, but we observe that the Assyrian or Persian administrators and tax collectors brought some of their own methods to Egypt, such as, for instance, the "surveyors' formula". We also see that the practical geometries of the Babylonian and Egyptian cultures served as inspiration for the Greeks when they developed their theoretical geometry. But Greek theoretical development did not influence geometrical practice significantly, in spite of the real or affected efforts of certain Alexandrian mathematicians to educate the practitioners (in particular Hero). The ancient mathematical theoreticians were never sincerely interested in the problems encountered when geometry was to be practised – how to make sure that a ruler is straight, what to do if the compass opening is insufficiently large, how to prevent that the unavoidable imprecision in geometrical construction sums up to something unacceptable (in Euclid's *Elements*, a circle is never drawn; it is presupposed to have been drawn by an anonymous "helping hand", as pointed out by C. M. Taisbak). The synthesis between geometrical theory and geometrical practice was only achieved by the mathematicians of the Islamic Middle Ages, from al-Khwārizmī to al-Kāšī.

See also: ►Surveying, ►Algebra, surveyors', ►Geometry in Islam, ►Mathematics in Egypt

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Glass in India

Alok Kumar Kanungo

Development of Glass in India

Indian Glass

Foreign travel accounts like Pliny's *Naturalis Historia* (73–77 AD; translated by Bostock and Riley as *The Natural History of Pliny* in 1890), *Periplus Maris Erythraei* (considered to be earlier than *Naturalis Historia*; translated by Schoff as *Periplus of the Erythrean Sea* in 1912) and *Geography of Strabo* (17–23 AD; translated by Jones and cited in Majumdar 1960: 279, 394) considered Indian glass to be of high quality as it was made of pounded quartz rather than silica. It has long been suggested that this may have been the reason behind the high silica content in ancient Indian glass (Stern 1987: 28). In Gudur (Andhra Pradesh), the government glass factory till recently produced glass from crystal. Dr. Brill of the Corning Museum believes that glassmakers throughout Iran, Mesopotamia, and central Asia (cited in Stern 1987: 28) routinely used pebbles instead of sand as the source of silica. In fact, in a Herat (Afghanistan) factory in 1977, the glassmakers still used pebbles collected in the riverbed as their source of silica.

Although glass was commonly made in the west Asian Bronze Age, there is some controversy concerning its manufacture in the Indus valley civilization (Glover and Henderson 1994). Some scholars have tried to trace the origin of Indian glass to the Harappan civilization on the basis of finding glazed pottery and quartz beads. Harappans made glazed pottery, which is ceramic with a thin layer of glass on the surface (Tite et al. 1983). Though no true glass has been found in India from the Protohistoric periods at Mohenjodaro and Harappa, the second millennium BCE saw its people able to mould and fuse excellent articles of faience and glazing their quartz beads with frit, a material similar to glass. All three materials—glass, glaze, and faience—consist of silica and lime, although special modern glass need have neither. Glass and glazes always contain soda or some or the other alkali, whereas faience generally contains only very small quantities of soda. In the evolution of glass, frit, faience, and glaze might have signified certain stages of development (Beck 1934; Forbes 1957: 223; Brill 1963: 120; Biek and Bayley 1979).

Glaze

There is little doubt that glass was an outcome of glaze. Glass and glazes are chemically identical but they are worked and used differently (Forbes 1957; Tite et al. 1983). The glazing technique marks the emergence of the first glass or synthetic material (Barthelemy and Bouquillon 1994). However, a glaze is a glassy layer applied to a core or base of some other material. This is in some cases mixed with the material before firing and in many cases applied to the body after firing. In the fourth millennium BCE glaze was used extensively within the context of the Badarian civilization in Egypt, the Jemdet Nasr period in Mesopotamia and in the third millennium BCE, the Indus valley civilization. The method of grinding quartz and mixing it with a little alkali before firing and producing faience occurred somewhat later in Egypt, in the early pre-Dynastic period (Lucas 1926; Forbes 1957). Marshall (1931: 578, 582, 692) states that the glazing of pottery is an Indian invention and a craft which appears to have been practiced for the first time on the bank of Indus. No example of it has come to light in Mesopotamia before 1000 BCE, nor in Egypt before the Roman period, although in Nubia there is said to be evidence of glazed ware as early as the XII dynasty (1991–1928 BCE). On the strength of the available material at Mohenjodaro and Harappa, Marshall (1931) went on to say that they are so closely allied to glass that it hardly seems possible that glass could have long been delayed. Bhardwaj (1979: 31) thought that the four pieces of glazed pottery found at Mohenjodaro were the handiwork of a potter who was well acquainted with the process of glazing and able to carry it to a high degree of perfection. High temperature stoneware bangles and some glazed pottery have also been recorded from Lothal, Bhagwanpura, Sanghol, Banavali, Bara, Ropar, Chanhudaro, Hulas, and Mithathal (Dayton 1989).

Faience

Faience is nearer to glass in the process of evolution. It is reported from many ancient sites and is likely to have been the predecessor of glass (Brill 1963: 120). In the archaeological sense it is generally agreed that faience consists of a lightly sintered core of crushed quartz grains coated with a translucent blue-to-green glaze, both fluxing due to soda. Such material needs a firing temperature of some 1000°C and a certain amount of sophistication in making it (Biek and Bayley 1979: 3). Crystalline quartz grains with a small amount of glassy material predominate in the case of faience. A few simple variations, whether accidental or deliberate, would have resulted in true glass (Basa 1991). Stone and Thomas (1956: 37) proposed that glass could be produced by heating faience too much or for too long, while adding a little surplus of alkali. They further suggested that it is most probable, then, that the faience makers found this out by simple observation and so became the first makers of real glass. Forbes (1957) and Bhardwaj (1979) have proposed to call most of ancient objects dubbed faience to be glazed siliceous ware, as they have a body consisting of powdered quartz covered with a layer of glaze. This material has been reported from most of the ancient civilizations including Egypt, Mesopotamia, and India (Lucas 1926; Sofianopoulas 1952). Faience was certainly made in India and fashioned into a variety of objects such as amulets, bangles and inlay, segmented beads, spindle-whorls, fluted disc beads, seals, animal figurines, and pots. In the Indus valley itself the people of Mohenjodaro and Harappa are known to have made extensive use of articles from faience, a composition resulting from powdered quartz grains fused at low temperature with the addition of lime. Some of the articles like beads and inlays were found treated with a glaze or frit which does not materially differ from glass. Marshall (1931: 683) and Mackay (1931: 576, 578 and 582) are of the opinion that though no true glass has been recovered from Mohenjodaro and Harappa, the authors of these cultures had perfected a composition which very nearly approached glass. Experiments conducted by McCarthy and Vandiver (1991) have revealed that the Harappan faience has a quite dense body with a continuous glassy phase and a relatively thin skin of glaze. Intentional addition of glass frit and clay are postulated. The Harappan faience bodies are particularly strong, compared with contemporary faience from west Asia and Egypt. A similar technology is not found in Egypt until much later during the New Kingdom, about 1450 BCE.

Brill (1987: 2) gives two reasons in support of the belief that glassmaking grew out of faience manufacture. (1) Both processes involve the pyrotechnology of the same materials (silica and alkali), and (2) faience was made for some fifteen centuries before glass was made. In this regard, the data gathered at Mehrgarh and Nausharo are of great interest since they allow the study of the local evolution of the glazing techniques through time, from the Chalcolithic to the Mature Indus period (Barthelemy and Bouquillon 1997: 63).

Ancient Indian Glass

Bhardwaj (1987) and Singh (1989), on the basis of glazed pottery from Mohenjodaro, have argued that the Harappans were aware of glass making. Bhardwaj

(1987) regards a number of vitreous materials unearthed from Mohenjodaro as weathered unworked glass, but more finds from well-dated contexts are needed before we can be sure that the Harappans had truly mastered the secrets of glassmaking (Singh 1989), and it is possible that glass could have decomposed to the point where it looked like faience.

Singh (1989) cautioned about the possibility that some glass beads might have been classified wrongly as stone beads. Even if the Harappans had this knowledge it seems to have been lost with the collapse of the urban Bronze Age civilization, and the subsequent finds of glass from the subcontinent come only with the Harappan-PGW (Painted Grey Ware) overlap phase at Bhagwanpura in Haryana, datable to about 1450–1200 BCE (Joshi 1976). From this time onwards, glass beads and bangles were regularly made in many parts of the subcontinent (Lal 1987). However, here thorough investigation of faience objects from Chalcolithic sites is required as they are reported to have yielded an enormous quantity of burnt steatite and paste, sometimes also glazed. Here it is important to mention that some of the beads that had been interpreted as shell beads (Wheeler et al. 1946; Casal 1949) have now been identified as corroded glass (Francis n.d.). Too much soda will yield a kind of glass that will be easily corroded by water, though ancient glasses often have a large percentage of soda to achieve a low melting point (Forbes 1957). In some cases faience is also wrongly identified as glass; for example faience excavated in Baoji and Fufeng country of China dated to eleventh to tenth century BCE was for a long time considered to be the earliest glass finding of China (Brill 1995: 270).

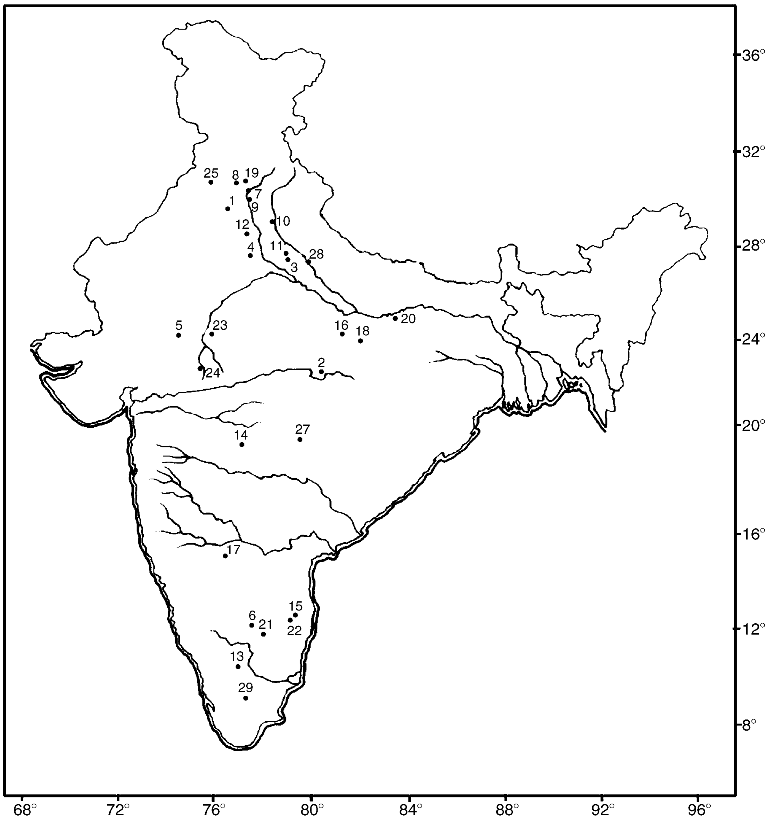
From the analysis of 38 specimens found at Alamgirpur (undated), Brahmagiri (Megalithic and Andhra culture), Hastinapur (period V, eleventh to fifteenth century AD) and (period III, sixth to third century BCE), Sar Dheri, Arikamedu (ca. 200 AD), Kausambi (200 BCE–200 AD and 100–200 AD), Bihar (first to second century AD), Orissa (200 AD), Rupar (1000–700 BCE and 200 BCE–600 AD), Vankali (Sri Lanka 1200–1250 AD), Brill (1987) comments that if glass found in India has a high alumina content (Al_2O_3) i.e., 3.5–4.0% or greater, it probably was made in India and that a low lime content (CaO) can also be considered as evidence of local manufacture. Francis (1985, 1990a, 1990b, 1991, 1994, 2002, n.d.) based on his extensive work on Arikamedu glass beads, argues that glass beads from Arikamedu were made from local glass because of the presence of high potassium that was rare in the western glass of that period. In Egypt and the Roman Empire glass consisted of sodium oxide as alkali, whereas in India and Vietnam, as evident from Arikamedu (India) and Oc-Eo (Vietnam), both sodium and potassium oxide were utilized (Francis 1990a). Lead as a coloring agent or opacifier in glass is found more in the West than in India. Glass from Khairadih, dated between 700 BCE to second century AD (Singh and Abdurazakov 1988), Nevasa (Varshney et al. 1988) and Arikamedu (Glover and Henderson 1994) are found to have low lime content. Furthermore, on the basis of scientific analysis of some of the early glass samples, Francis (n.d.) opines that both imported and indigenous glasses were used for bead production at Arikamedu and other contemporary south Indian sites.

In ancient India fragments of glass slag and other debris of glass production have been noticed at Khairadih, period II (*IAR* 1981–1982: 68, Singh and Abdurazakov 1990), Kopia (Roy and Varshney 1953; Dikshit 1969: 39; Sen and Chaudhuri 1985: 64–65; Abdurazakov 1987; Lal 1987: 45), Rajghat (Narain et al. 1976; Singh 1989) and Taxila (Marshall 1951) in the North; Ahmednagar (Chaudhuri 1986: 97), Bhokardan (Deo and Gupte 1974: 197), Brahmapuri (Kolhapur) (Sankalia and Dikshit 1952), Nevasa (Sankalia et al. 1960: 355, 383–85), and Paunar (Deo and Dhavalikar 1968: 82–83) in the Deccan; Sirpur and Tripuri in Central India; Hulas Khera (Tewari et al. 1995–1996); Maheswar (Sankalia et al. 1958) and Nagra (Mehta and Shah 1968: 132–37) in the West; and Arikamedu and Karaikadu in the South. Thus, it is evident that ancient India was not only manufacturing by-products of glass but was also making glass for its use.

Regarding the glass furnace in ancient India, our information is meager. A solitary reference comes from Nevasa, where a glassmaking kiln dated to the period ca. 3rd—and 4th AD was unearthed. It is a circular oven 2′-6″ in diameter with 1′-7″ depth and is made of burnt clay. Around it an abundance of bichrome glass, slag, lime, cow-dung, etc. was found (Sankalia et al. 1960). At one of the points near the periphery was a channeled projection evidently to insert the pipe for the bellows (Deo 2000: 11). Chaudhuri (1986: 99) remarked that most of glass furnaces in ancient India are open-fired type, using solid fuel, and the melting was carried out in a clay pot.

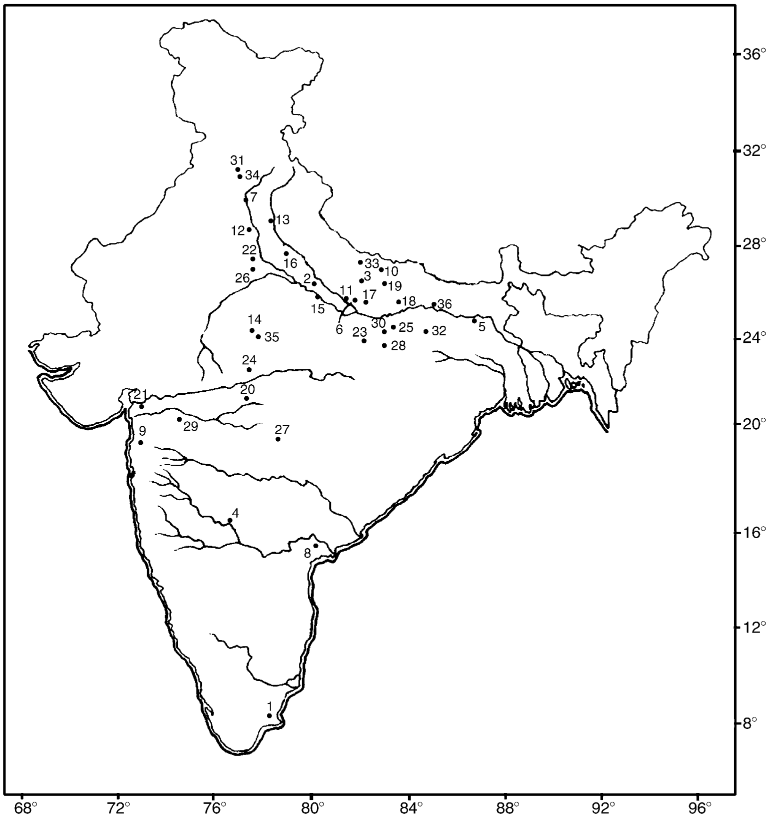
Ancient Literature

Mention of glass (*kāca*) and its by-products, most prominently that of beads, occurs in early *Brāhmaṇical* (Sanskrit) and Buddhist literature. Mukharji (1888), Ghosh (1924), Chaudhuri (1986), Dikshit (1964–1965, 1969) and Deo (1987, 2000) list a few of them; for instance in the *Yajurveda* (c. 1200 BCE) *kāca* is mentioned as one of the articles of which female ornaments were made by means of stringing with gold thread. In *Śatapatha Brāhmaṇa* (c. 800 BCE), the word *kāca* refers to glass beads which were used for decoration of horses in the *Aśvamedha* sacrifice. There are references to women wearing glass beads and to the



Glass in India. Map 1 Evidence of Glass and Glass Beads in Indian Archaeology Between 1200–600 BCE.
1. Alamgirpur, 2. Amahata, 3. Atranjikhera, 4. Autha, 5. Bagor, 6. Banahalli, 7. Bhagwanpura, 8. Brass, 9. Daulatpur, 10. Hastinapur, 11. Jakhera, 12. Jhatikra, 13. Kodumanal, 14. Kotra, 15. Kunnattur, 16. Manikpur, 17. Maski, 18. Munahi, 19. Nagiari, 20. Narhan, 21. Pairyampalli, 22. Pallavamedu, 23. Pasewa, 24. Runija, 25. Sanghol, 26. Sarhat, 27. Shirkanda, 28. Sravasti, 29. T-Kallupatti

wearing of or threading of one hundred and one beads of glass. The *Taittiriya Brāhmaṇa* also refers to the wearing of glass. Coming to the Sutra period (ca. 600 BCE), one comes across references to glass beads in the *Baudhayana Srauta Sūtra* and in *Manava Srauta Sūtra*. The *Māhavagga* section of the Buddhist text *Vinaya Piṭaka* (fifth to fourth century BCE) alludes to the use of shoes ornamented with glass as being forbidden to the Buddhist *bhikshus* (monks). The *Chullavagga* similarly forbids the use of glass bowls. One of the earliest South Indian texts, *Manimekalai* (3, 64), refers to *palingu*, meaning glass or quartz in Tamil, which is possibly a corruption of the Sanskrit word *sphatika*, although the prakrit *phalika* (quartz), occurs in the Bhattiproru inscription of the second century BCE (Srinivasan and Banerjee 1953: 113). *Rāmayaṇa* refers to the makers of glass, the '*kachakara*'. Kautilya's *Arthaśāstra* (third century BCE) alludes to the making of glass at two places. (1) *Adhikarana* 14, *Adhyāya* 1, *Sūtra* 12, says that in order to punish the enemy, obstacles like the smoke of Puti, Karañja leaves.… as in the manufacture of glass, by burning cow dung etc., should deliberately be created. (2) Another passage in the *Adhikarana* 2, *Adhyāya* 14, *Sūtra* 45, though somewhat corrupt, refers to the process of making gold-foiled glass beads. It describes the piercing of glass beads in a molten stage for the purpose of setting ornaments and the setting of glass-fragments (*kśepana*) in gold ornaments for the preparation of the glass gems. Amongst the various punishments inflicted for stealing, it is ordained that a person stealing articles made of copper, bronze, tin, glass and ivory was to be fined 46–96 *paṇas*. Glass is also mentioned in the *Māhābhārata*, and in *Yuktikarata*. The effects on the human system of drinking water out of a glass tumbler are stated to be the same as those of drinking out of a crystal cup. Some of the Puranas such as the Matsya, the Vishnu, and the Bhagawata, assigned to the Gupta period (third to fifth century AD), refer to *kāca*. *BṛhatSaṃhitā* (sixth century AD) also mentions glass. Apart from these, references to glass vessels for preserving medicines can be seen in texts like *Charaka* and *Śusruta Saṃhitā*. In the *Amarakośa* (seventh century AD) mention of glass vessels, cups and dishes are made. In later period, Somnath Kavi (ca. 1446–1539 AD) mentions spectacles in his *Vyasoyogi Charita*.



Glass in India. Map 2 Evidence of Glass and Glass Beads in Indian Archaeology Between 600–300 BCE.
1. Alagankulam, 2. Amethi, 3. Ayodhya, 4. Benagutti, 5. Champa, 6. Danwa, 7. Daulatpur, 8. Dharanikota, 9. Dhatva, 10. Ganwaria and Salargarh, 11. Gauriganj, 12. Harnol, 13. Hastinapur, 14. Hulas, 15. Jajmau, 16. Jakhera, 17. Kadipur, 18. Kheradih, 19. Kopia, 20. Kotra, 21. Malvan, 22. Mathura, 23. Munahi, 24. Nadner, 25. Narhan, 26. Noh, 27. Paunar, 28. Prahaladpur, 29. Prakash, 30. Rajghat, 31. Singh Bhagwanpur, 32. Sonepur, 33. Sravasti, 34. Sugh, 35. Tumain, 36. Vaisali

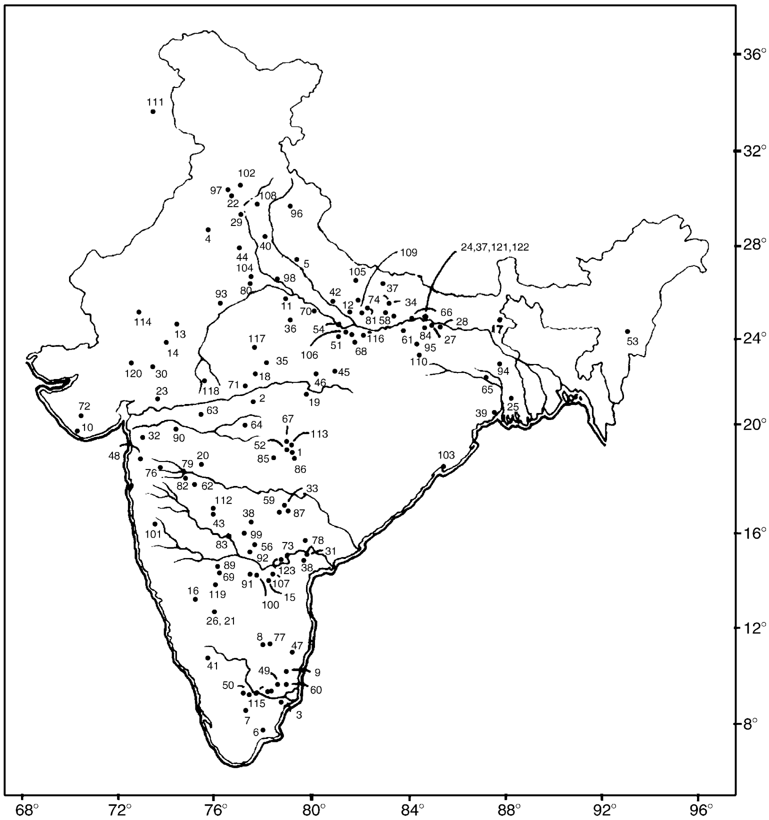
Spread of Glass in India

On the basis of glass findings at Taxila and Arikamedu, Marshall (1951) and Wheeler et al. (1946) thought them to be of foreign origin. On the contrary, typical Indian designs on some early glass specimens of Taxila, Mohenjodaro's glazed pottery and evidence of glass in the Chalcolithic level at Maski, and at Painted Grey Ware sites (supposed to be devoid of any foreign association) have led Dikshit (1969), Bhardwaj (1987) and Singh (1989) to argue for indigenous origin of glass (Kanungo 2000–2001, 2002a, 2004c). Deo (2000: 26) takes a middle path by mentioning that though much of the glass at Taxila was imported into India through its foreign settlers, there is reason to believe that some of the beads are indigenous. It is difficult to say how far early foreign contacts were responsible for the introduction of glass but the stray specimens reported do not point to anything definite.

The *Periplus* mentions Roman export of both raw glass and glassware. The ancient Indian literary records are silent on importing glass from the western world. However, the archaeological data on Roman glass in India strongly corroborates the references in the *Periplus* to glass imports into India (Gupta 1997). Stern (1986) suggests that it was convenient for Mediterranean shippers to bring raw glass to India as it served as good ballast for transport vessels. On reaching India, Mediterranean glass found a ready market because of the existence of a highly evolved glass working industry in the subcontinent. On their part, the Indians, besides marketing glass products of Roman glass in the domestic arena, exported the products to Southeast Asia and the Mediterranean. Probably, some of this glass really was imported, but there are good reasons for believing that much of this early glass was actually made in India (Brill 1987: 2).

The Indians learned the technique of glass, probably independently, only around 1200 BCE. Since then evidence of glass has been unearthed from more than 200 ancient Indian sites. Kanungo (2002a: 54–120, 2004b, 2004c) lists 204 sites which have yielded evidences of glass. Glass beads occur in about 150 sites and 36 are claimed to have been manufacturing sites (Kanungo 2004a: 123).

The earliest evidence of glass beads (two well-made unweathered black and white tabular eye beads) in

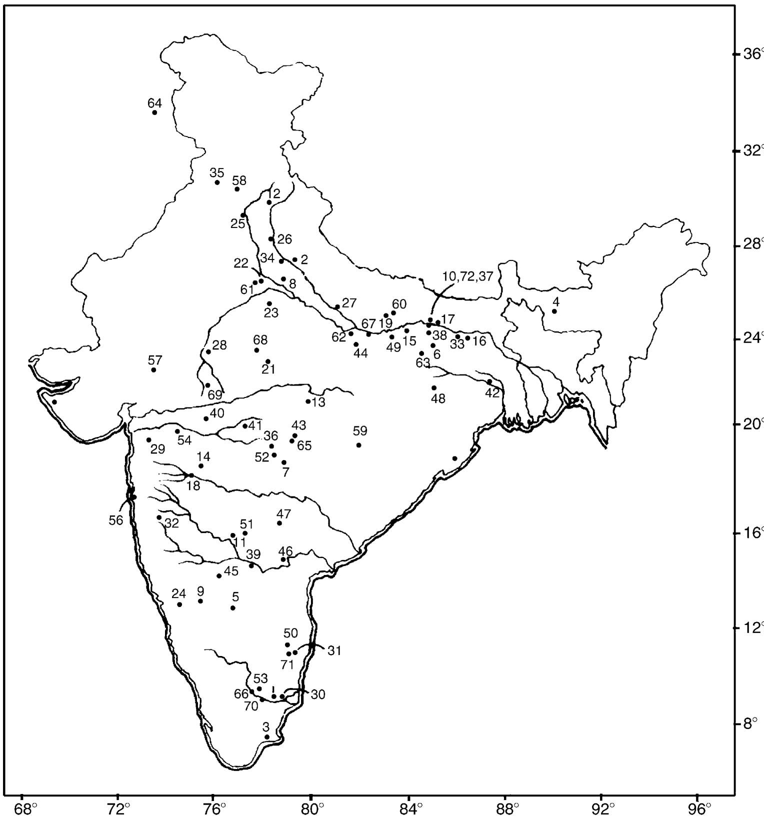


Glass in India. Map 3 Evidence of Glass and Glass Beads in Indian Archaeology Between 300 BCE–400 AD. 1. Adam, 2. Adamgarh, 3. Adiyamankottai, 4. Agroha, 5. Ahichchhatra, 6. Alagankulam, 7. Alagarai, 8. Appukalu, 9. Arikamedu, 10. Arni, 11. Aunhan, 12. Ayodhya, 13. Bagor, 14. Balathal, 15. Banahalli, 16. Banavasi, 17. Basarh, 18. Besnagar, 19. Bhita, 20. Bhokardan, 21. Brahmagiri, 22. Brass, 23. Broach, 24. Chandahadih, 25. Chandraketugarh, 26. Chandravalli, 27. Chechar, 28. Chirand, 29. Daulatpur, 30. Devnimori, 31. Dharanikota, 32. Dhatva, 33. Dhulikatta, 34. Dhuriapur, 35. Eran, 36. Erich, 37. Ganwaria and Salargarh, 38. Garapadu, 39. Hari-narayanpur, 40. Hastinapur, 41. Hemmige, 42. Hulas Khera, 43. Irla, 44. Jhatkira, 45. Jhusi, 46. Kakrethta, 47. Kanchipuram, 48. Karad, 49. Karaikadu, 50. Karur, 51. Kausambi, 52. Khairwada, 53. Khangabok, 54. Khartuni, 55. Kheradih, 56. Kohir, 57. Kolhua, 58. Kondapur, 59. Kotalinga, 60. Kudikadu, 61. Kumrahar, 62. Kusan, 63. Maheshwar, 64. Malhar, 65. Mangalkot, 66. Manjhi, 67. Mansar, 68. Masaon, 69. Maski, 70. Matin - Mahadev, 71. Nadner, 72. Nagara, 73. Nagarjunakonda, 74. Narhan, 76. Nasik-Jorwe, 77. Nattamedu, 78. Nelakondapalli, 79. Nevasa, 80. Noh, 81. Orai, 82. Paithan, 83. Pandigadda, 84. Pataliputra, 85. Paunar, 86. Pauni, 87. Peddabankur, 88. Perur, 89. Piklihal, 90. Prakash, 91. Puduru, 92. Pydigutta, 93. Raiah, 94. Rajbadidanga, 95. Rajghat, 96. Ratura, 97. Sanghol, 98. Sankisa, 99. Sannati, 100. Satanikota, 101. Satara, 102. Singh Bhagwanpur, 103. Sisupalgarh, 104. Sonkh, 105. Sravasti, 106. Sringaverapura, 107. Srisailum, 108. Sugh, 109. Sultanpur, 1108. Taradih, 111. Taxila, 112. Ter, 113. Tharsa, 114. Tilwara, 115. Tirukkambuliyur, 116. Tripuri, 117. Tumain, 118. Ujjain, 119. Vadagaon - Madhavapur, 120. Vadnagar, 121. Vaisali, 122. Virpur, 123. Yeleswaram

India is reported from Bhagwanpura in the Harappan-Painted Grey Ware overlap phase (period I), *c*. 1400–1000 BCE (Joshi 1993). The occurrence of one glass bead in period II (Protohistoric) at Navdatoli shows that glass was not unknown to the people of this period (Deo 1955: 10). The evidence of glass in the Chalcolithic period is very poor, found only at Maski. During the next cultural phase of Indian history, i.e., Painted Grey Ware, we find that the occurrence of glass is quite common and widespread. It is found at several sites in India, which are widely separated from each other. Glass finds, although limited in number, have been a constant feature in all the levels from the sixth century BCE onwards. However, sites of Ochre Colored Pottery (OCP) culture have yielded only a few beads (Niharika 1993).

The evidence of stratified eye beads from Northern Black Polished Ware (NBPW) phase, which form the next important stage in the study of glass in India, possibly supports the impression that mature glass came to India from the Mediterranean countries.

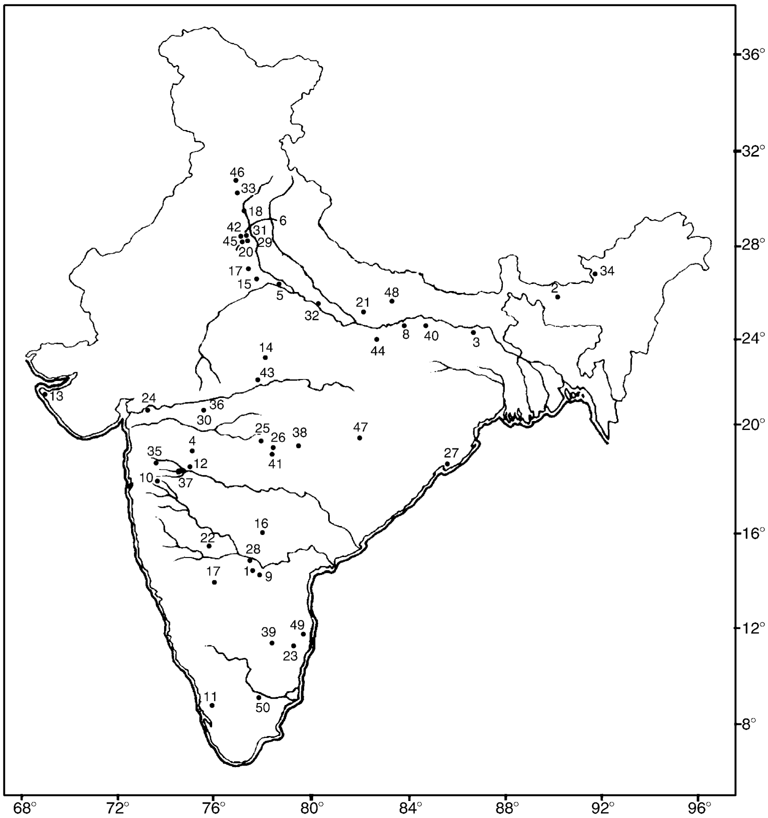
The technique of glass manufacture was well known since the seventh to sixth century BCE (Margabandhu 1971: 1219, 1985: 327). Once the manufacturing



Glass in India. Map 4 Evidence of Glass and Glass Beads in Indian Archaeology Between 400–1300 AD.
1. Adiyamankottai, 2. Ahichchhatra, 3. Alagankulam, 4. Ambari, 5. Anantapur, 6. Apsad, 7. Arambha, 8. Atranjikhera, 9. Banavasi, 10. Basarh, 11. Benagutti, 12. Bharat Mandir, 13. Bhita, 14. Bhokardan, 15. Buxar, 16. Champa, 17. Chechar, 18. Daulatabad, 19. Dhuriapur, 20. Dwarka, 21. Eran, 22. Fatehpur Sikri, 23. Gilaulikhera, 24. Gudnaput, 25. Harsh–ka-tila, 26. Hastinapur, 27. Hulas Khera, 28. Indragarh, 29. Jokha, 30. Kambarmedu, 31. Kanchipuram, 32. Kanheri, 33. Karnachaura, 34. Kashipur, 35. Katpalon, 36. Khairwada, 37. Kolhua, 38. Kumrahar, 39. Kundavelli, 40. Maheshwar, 41. Malhar, 42. Mangalkot, 43. Mansar, 44. Masaon, 45. Maski, 46. Nagarjunakonda, 47. Nagnoor, 48. Nalanda, 49. Narhan, 50. Pallavamedu, 51. Pandigadda, 52. Paunar, 53. Perur, 54. Prakash, 55. Ratnagiri, 56. Sanjan, 57. Shamalaji, 58. Singh Bhagwanpur, 59. Sirpur, 60. Sohgaura, 61. Sonkh, 62. Sringaverapura, 63. Taradih, 64. Taxila, 65. Tharsa, 66. Tirukkambuliyur, 67. Tripuri, 68. Tumain, 69. Ujjain, 70. Uraiyur, 71. Vadavur, 72. Vaisali

processes were standardized, during the latter half of the first millennium BCE glass objects were produced on a mass scale. The very material and objects made of the glass found during this period bear an eloquent testimony to the fact that the making of glass in a furnace and later remaking and shaping them to beads had been fully understood and utilized to the maximum extent by the artisans of the times (Margabandhu 1975: 73). The site of Kopia in Santh Kabir Nagar district (earlier part of district Basti), dated to about fifth century BCE, has yielded innumerable glass beads, thousands of glass fragments, fragments of clay crucibles with glass sticking to them, big pieces of glass and lumps of unworked glass (Roy and Varshney 1953; Dikshit 1969: 39; Sen and Chaudhuri 1985: 64–65; Abdurazakov 1987: 38; Lal 1987: 45). One large block of glass weighs about 76 kg and measures 45×30×22.5 cm (Lal 1987: 45). Unfortunately, a few excavation reports of Indian sites yielding glass objects have discussed the manufacturing techniques involved and none the basis of the same (Kanungo 2000–2001, 2001, 2004a).

From 500 BCE onwards and particularly during the Maurya period, glass objects of all kinds came to be manufactured widely (Lad 1983: 67). In Mauryan (fourth to second centuries BCE) and Sunga (second to first centuries BCE) periods, beads of all kinds were plentiful including those made of glass (Alkazi 1996: 7). The best evidence is that of glass seals from Maheshwar, Patna, Ujjain and three glass seals from the Mauryan phase at Taxila. The seals are mostly green and pale blue, carefully moulded and subjected to annealing to remove the internal strain. Spool (externally grooved) shaped earplugs, beads and bangles constitute the bulk of the glass articles known from specimens from Ahichchhatra, Kausambi, Patna and Rajghat.



Glass in India. Map 5 Evidence of Glass and Glass Beads in Indian Archaeology Between 1300–1800 AD. 1. Alampur, 2. Ambari, 3. Antichak, 4. Bahal, 5. Batesvara, 6. Bijai Mandal, 7. Brahmapuri, 8. Buxar, 9. Chagatpur, 10. Chandoli, 11. Chermanparambu, 12. Daulatabad, 13. Dwarka, 14. Eran, 15. Fatehpur Sikri, 16. Golconda, 17. Hampi, 18. Harsh–ka-tila, 19. Hemmige, 20. Jhatkira, 21. Kadipur, 22. Kadkal, 23. Kanchipuram, 24. Karvan, 25. Kaundanpur, 26. Khairwada, 27. Khalkata - patana, 28. Kundavelli, 29. Lalkot, 30. Maheshwar, 31. Makhdum Sahib's Mosque, 32. Matin - Mahadev, 33. Nagiari, 34. Naksaparvat, 35. Nasik-Jorwe, 36. Navdatoli, 37. Nevasa, 38. Pachkheri, 39. Padavedu, 40. Pataliputra, 41. Paunar, 42. Purana Qila, 43. Raisen fort, 44. Rajghat, 45. Salimgarh Fort, 46. Singh Bhagwanpur, 47. Sirpur, 48. Sohgaura, 49. Tiruverkadu, 50. Uraiyur

The beginning of the Christian era witnessed the ushering of foreign cultural elements into Indian life. This is reflected not only in new shapes, but also in the introduction of new materials like the Mediterranean fine-grained corals and glass (Deo 2000: 6). Use of glass became quite common. Findings at Arikamedu, Nevasa, Taxila and other sites present evidence for this. Excavations at Chandravalli, Karad, Kolhapur, Kondapur, Maski, and Nasik have each yielded valuable materials of high quality from the Satavahana period (first century BCE to early third century AD). Wound and drawn beads are often found (Deo 2000: 27). Beads with white stripes are known to have come from Kolhapur, Kondapur, Maski, Nevasa, Prakash and Ter in the Deccan. These beads are common enough at Tripuri and Ujjain. By the dawn of the Christian era, the use of glass for beads became more popular. Many techniques were adopted for the manufacture of beads and ornaments during this period (Margabandhu 1985: 203).

Abdurazakov (1987: 38) speaks of finding fragments of Middle Age glass at nine archaeological sites in India: Ahichchhatra, Arikamedu Assam, Jaipur, Kausambi, Kurukshetra, Nalanda, and Udaigiri. He mentions the evidence of glass and clay pots (used for glass production) at Dargai in Pakistan too.

By the time of Harsa (seventh century AD), glass was no longer a luxury as it must have been in the Satavahana period and was even used by mendicants and aboriginals (Agrawal 1953: 186; Kanungo 2002b). In Deccan, with the establishment of the Sultanates (twelfth to thirteenth century AD), the country witnessed the rise of small-scale cottage industries for the fabrication of glass beads, as evidenced by the discoveries at Kolhapur and Nevasa in Maharashtra, and Maski in Karnataka and Sirpur in Madhya Pradesh (Deo 2000: 6). The lacuna in our knowledge about the other contemporary Indian glass objects is almost certainly due to inadequate excavations of historical sites.

Chemical analysis of the specimens of about eighteen areas shows that Indian workers were well acquainted with the raw materials and coloring agents used for the preparation of glass. In some of the specimens of Taxila glass, the presence of lead oxide and in some of the Tripuri specimens (200 BCE) the presence of barium oxide has been found. Presence of lead in glass gives rise to the formation of crystal glass and that of barium imparts to glass high resistance to heat.

In comparison with commonly occurring archaeological material such as pottery or metals, the glass in ancient sites occurs less frequently. Glass was never produced, on a very large scale, or over so wide an area as other materials. This is due to the fact that it required advanced technological skills to generate and maintain the required temperature for production of glass for long periods. This very often mirrors the general technological level of society. However, considering the spread of proto glass and its by-products in Protohistoric, its contemporary and later periods there is every possibility that glass might have developed independently in India. Glass seems to have appeared 500 to 1,000 years later than in Mesopotamia and Egypt.

In the Indian context, literary data and archaeological evidence point to the same time period for the occurrence of glass. Reference of *kāca* comes from the *Brahmana* group of texts which are assigned to the same time period as that of the Painted Grey Ware. Glass becomes more common in the Northern Black Polished Ware period. This is also reflected in literary data of the fourth to fifth century BCE, which abounds in references to glass.

In the early Christian era glass was not only found throughout the country but its by-products like beads were also produced using indigenous techniques. Subsequently, many places emerged as production centers of a flourishing glass industry, as it had become by now an article of common use and was no longer a precious and rare commodity. Glass is more abundantly seen at the dawn of the Christian era.

No archaeological site except Nevasa has as yet given evidence of a glass furnace. This is probably due to the fact that since production of glass requires a high temperature for a long time period, and in earlier days furnaces were generally made of clay, they collapsed or broke down at a fast rate. Thus in the archaeological context, not only does glass need to be classified and recorded, but the debitage[1] also needs to be carefully collected and catalogued.

The evidence of glass in Indian archaeology is spread in both time and space. Though there have been claims at regular intervals by different authors about the glass being introduced to India from outside, sometime in the Indo-Roman period, the evidence from as many as 29 sites gives ample evidence that glass was known much earlier and could have been produced locally (Map 1). Besides, there is also stray evidence of glass in Bhagwanpura (Painted Grey Ware-Harappan overlapping), Dwarka (late Harappan) and Maski (Chalcolithic), which are of much earlier cultures. Likewise there are 34 sites, which have evidence of glass beads in association with the Northern Black Polished Ware period or in the period in between 600–300 BCE (Map 2). However, with the beginning of the early Historic phase, and more particularly in the early Christian centuries, the evidence of glass from as many as 119 sites suggests large-scale use (Map 3). This period is between 300 BCE and 400 AD and is characterized by red ware, red polished ware, russet coated painted ware, red and black slipped ware, black slipped ware and rouletted ware. All the same, during the Medieval Period there is clear indication that glass was becoming quite common as evidenced by its presence at 70 sites in the early Medieval period (400–1300 AD) (Map 4) and 49 sites in the late Medieval period (1300–1800 AD) (Map 5) (for details see Kanungo 2002a, 2004c). Considering such spread of glass and its by-products in ancient India, it is highly likely that around the early Christian era there should have been more regional major producers of glass other than the established site of Arikamedu in the south. In this regard Kopia in the north with its strategic location, abundance of glass, glass beads, crucibles and other debitage on the surface stands apart, and further work followed by a systematic excavation of this site could result in better understanding of ancient glass technology in India.

Acknowledgements

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[1] Debitage is the collective term used by archaeologists to refer to the sharp-edged waste material left over when someone creates a stone tool (knaps flint). Debitage is probably the oldest artifact-type recognized by archaeologists; the term is a French one but widely used by archaeologists the world over.

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See also: ►Beads

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Globes

EMILIE SAVAGE-SMITH

The celestial globe is the oldest form of celestial mapping, for its origins can be traced to Greece in the sixth century BCE. The stars were perceived as though attached to the inside of a hollow sphere enclosing and rotating about the earth. The earth, known from early classical antiquity to be spherical, was imagined at the center of the globe, while the stars were placed on its surface. Since this three-dimensional model of the skies presented the stars as seen by an observer outside the sphere of stars, the relative positions of the stars on a celestial globe are the reverse, east to west (or right to left), of their appearance when viewed from the surface of the earth. The sequence of the zodiacal constellations will be counterclockwise when the globe is viewed from above the north pole.

No celestial globes from antiquity have survived, but the basic principles of their design were maintained, with some modifications and elaborations, in the Islamic world, where the earliest preserved celestial globes were made. By the ninth century celestial globes were being made in the Arabic-speaking world. The most important early Islamic center of globe-making was the city of Harran, between the northern reaches of the Euphrates and Tigris rivers. In the ninth and tenth centuries it was an important town at the intersection of major caravan routes and had a prominent Sabian community whose pagan religious interest in the stars and sun was perhaps conducive to the study of astronomy. Many of the early astronomical instrument-makers were members of the Sabian sect at Harran. Several Arabic treatises were composed in the ninth century on the design and use of celestial globes, including one by the famous astronomer of Harran, al-Battānī who was known in the Latin world as Albategni, and others by Ḥabash al-Ḥāsib and Qusṭā ibn Lūqā in Baghdad. In the following centuries, additional treatises on the subject were composed, including one by ʿAbd al-Raḥmān ibn ʿUmar al-Ṣūfī (d. 983) whose treatise on constellations became the model for constellation iconography in the Islamic world.

Over 180 Islamic celestial globes are known to be preserved today. The earliest was made in AD 1080 in Valencia, Spain, and the most recent in Ottoman Turkey in 1882. Regardless of date, the stars represented on Islamic globes are those listed in the medieval star catalogs, and only the 48 constellation outlines recognized in antiquity are indicated. When constellation outlines are drawn around the stars, the clothing and faces of the human figures, such as Orion or Virgo, reflect the artistic conventions common in the artisan's day. Since the positions of the stars change over time with the precession of the equinoxes, the star positions on a globe, correct when the globe was made, remain valid for only three-quarters of a century.

In addition to the celestial equator and the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), the Tropic of Cancer and the Tropic of Capricorn were also frequently shown on Islamic globes, as well as the north and south equatorial polar circles. On some later globes the ecliptic equivalents of tropic and polar circles were indicated, apparently in an attempt to complete the symmetry. On every Islamic globe preserved today there is also a set of six great circles at right angles to the ecliptic – six ecliptic latitude-measuring circles, reflecting the common use of ecliptic-based coordinates for measuring star positions. To function as an instrument, the sphere needed to be placed in a ring assembly, allowing for adjustment to a particular location. If supplemented by a gnomon or quadrant providing the altitude of the sun, the globe could then be used by an astronomer or astrologer to determine a range of astronomical data, including the length of the unequal day-time hour for a given day and location, or the time elapsed on a certain day, or data for a horoscope. It is questionable, however, whether many of the globes preserved today were of more than didactic or artistic value.

In terms of design, Islamic celestial globes fall into several distinct categories. The first includes the largest and the most elaborate artifacts, all of which display the 48 constellation outlines and approximately 1,022 stars. Those in the second category do not have constellation outlines. Only a selection of the most prominent stars, usually between 20 and 60, are shown.

The third type of design is one in which the globe has neither constellation outlines nor any stars. In general these globes are the smallest. They have on them only the great and lesser circles (ecliptic, equator, tropic, and polar circles), all of which are labeled. This design is not mentioned in any of the written sources, and evidence so far available suggests it originated in Iran in the late seventeenth or early eighteenth century.

Only a few painted wood or papiermâché Islamic globes have survived, all of them hand drawn or painted. The method that dominated globe making in Europe – namely, laying printed paper gores over a wood or fiber core – seems not to have been practiced in the Islamic world. The vast majority of Islamic globes are hollow metal spheres and were made in two ways: from two hemispheres of cast or raised metal, or cast in one piece by the lost wax process. While globes made of wood or papiermâché or with metal hemispheres are of considerable antiquity, seamless globes, on the basis of evidence so far available, appear to have originated in northwestern India toward the end of the sixteenth century, the earliest confirmed date for one being AD 1589–1590. They became the hallmark of all workshops in the Punjab and Kashmir areas of India through the nineteenth century. The workshop that excelled in this technique was a four-generation family of instrument makers in Lahore (in modern Pakistan). During more than a century, this remarkable workshop produced numerous astronomical instruments, including 21 signed globes (the earliest made in AD 1622). The technique of making seamless globes continued to be practiced in India after this workshop ceased to make them.

Throughout the ten centuries of their production in the Islamic world, celestial globes maintained the medieval tradition of displaying only the classical constellations and stars. On metal globes the stars were usually indicated by inlaid silver points. None of the surviving Islamic celestial globes records the stars and constellations of the southern hemisphere first mapped by Europeans during explorations of the sixteenth century.

While the production of celestial globes was widely and continuously practiced in the Islamic world, there was no comparable tradition of terrestrial globe making. There seems to have been little interest in terrestrial globes until the sixteenth century, when early modern European terrestrial globes became known to Ottoman Turkish astronomers and in the next century to those at the Mughal Indian court.

See also: ►al-Battānī, ►Precession of the Equinoxes, ►Qusṭā ibn Lūqā, ►al-Ṣūfī, ►Quadrants,►Ḥabash al-Ḥāsib

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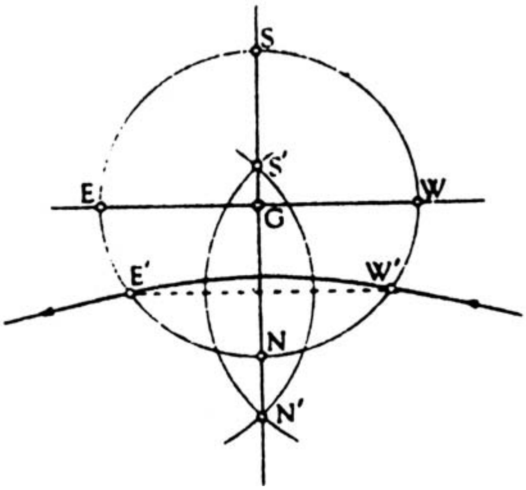

Gnomon in India. Fig. 1 Finding the cardinal direction (Neugebauer 1971).

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Gnomon in India

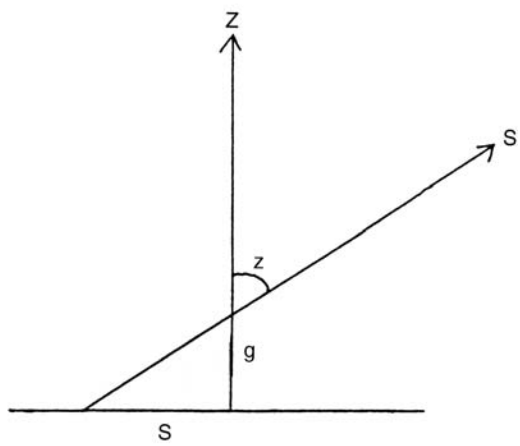
George Abraham

The gnomon is an instrument used widely in early astronomy. The shadow of a vertical rod on a horizontal plane determines the cardinal directions, the latitude of the place of observation, the celestial coordinates of the sun, and the time of the observation.

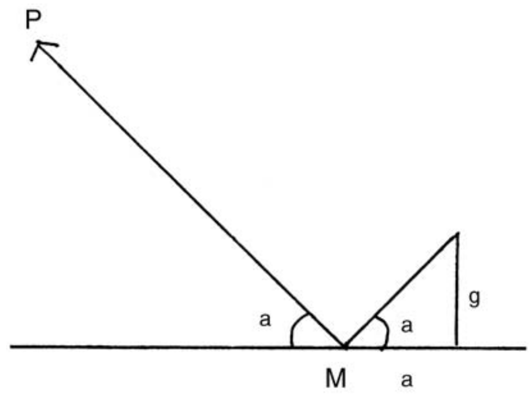
Varāhamihira gave a fairly complete account of its use in India in the *Pañcasiddhāntikā*. This was written in AD 505 and summarized the astronomical information current in India at that time. The *Āryabhaṭīya* of Āryabhaṭa also provides the main results of the theory of the gnomon, and these features appear again in the works of Bhāskara, Brahmagupta, and many later astronomers.

The Cardinal Directions

The procedure is illustrated in Fig. 1. G is the foot of the gnomon. The path of the end of the shadow enters and leaves a circle, center G, at W and E. Then the line EW is in the east–west direction. With E, W as centers, circular arcs are drawn intersecting at N, S. Then NS, the perpendicular bisector of EW, is in the north–south direction and intersects the circle at N and S, the north and south points. The east and west points, E and W,



Gnomon in India. Fig. 2 The noon shadow.



Gnomon in India. Fig. 3 Determining the altitude of the moon or planets.

can be found by the same procedure since they are on the perpendicular bisector of NS.

This method depends on the symmetry of the shadow path about the north–south line. It does not take into account the small change in the declination of the sun during the day. Brahmagupta prescribed a correction for this error in the *Brahmasphuta Siddhānta*. This method of finding the cardinal directions, described in the *Pañcasiddhāntikā*, is found in a much earlier treatise, the *Śulbasūtra*, which contains mathematical topics related to the construction of sacrificial altars. The *Pañcasiddhāntikā* also has an approximate method for finding the meridian direction from any three positions of the shadow. This method assumes that the path of the shadow is a circle, whereas in India, it is a hyperbola.

The Noon Shadow

Trigonometric formulas enable us to find the latitude of the observer and the sun's declination from the shadow of the gnomon at noon, when the sun is on the local meridian. In Fig. 2, g is the height of the gnomon, s the length of the shadow, Z the zenith, S the sun, and z the zenith distance of the sun. On any day, the zenith distance at noon is $z = \o \pm \delta$, where $\o$ is the observer's latitude and δ the declination of the sun. The Indian formula is

$$\sin z = \frac{Rs}{\sqrt{s^2 + g^2}},$$

where the sine of an angle is defined as R times the modern sine function, R being a constant angle, taken to be 120 min in the *Pañcasiddhāntikā*. When the sun is on the equator, $\delta = 0$, and the formula above gives us the latitude in terms of the length of the noon shadow. On other days, the formula yields the change $\pm\delta$, in the zenith distance, as a function of the noon shadow. On the days of the solstices, the declination has the maximum value, ε, the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course).

When the sun is on the prime vertical (the great circle on the celestial sphere through the east and west points and the zenith), let z_1 be the zenith distance, and $\alpha_1 = 90 - z_1$, the altitude of the sun, and λ, the longitude of the sun. Then the *Pañcasiddhāntikā* formulae are

$$\sin a_1 = \frac{R \sin \delta}{\sin \phi} = \frac{\sin \lambda \sin \varepsilon}{\sin \phi}.$$

With these two formulae, we can find the declination and longitude of the sun from the shadow length, when the sun is on the prime vertical.

With the gnomon, it was also possible to find the time after sunrise, from the length of the shadow, using formulae which are equivalent to those used in modern spherical astronomy.

The second formula above gives the sun's longitude λ and declination δ, when it is on the prime vertical. λ and δ can be determined at any time, from the length of the gnomon's shadow and the distance of its endpoint from the east–west line. The *Pañcasiddhāntikā* also gives an approximate empirical algebraic formula which would have been useful in very early astronomy:

$$\frac{d}{2t} = \frac{s - s_0}{g} + 1.$$

This gives t, the time after sunrise in the morning or the time before sunset in the afternoon, s_0 is the noon shadow, and d the length of daylight. This formula is derived from the following considerations:

1. There is a linear relation between s and $1/t$
2. At noon $2t = d$

3. $s - s_0 = g$ at $4t = d$

The *Yavanajātaka* of Sphujidhvaja also has this formula. Chapter 20 of Kauṭilya's *Arthaśāstra* gives the relation between the time after sunrise and the gnomon shadow. The *Arthaśāstra* also gives the rule for the uniform variation of the noon shadow from zero at the summer solstice to g, the gnomon height, at the winter solstice, a reasonable approximation for an observer on or near the Tropic of Cancer, for example at Ujjain. However, the rule for the uniform variation of the length of daylight from 12 to 18 *muhurtas*, also found in the two books above, implies a latitude of about 35°, which suggests a Babylonian origin.

The theory of the gnomon presented above can be applied to the moon and planets also. The altitude of the moon or planet is determined in the following manner, illustrated in Fig. 3.

The moon or planet (P) is seen reflected in a mirror M in the same horizontal plane as the foot G of the gnomon of height g at a distance d from the gnomon. Then the altitude a is given by the formula

$$\sin a = \frac{R_g}{\sqrt{g^2 + d^2}},$$

d is called the *reversed shadow* and takes the place of the shadow length s in the case of the sun.

The eleventh-century Arabic scholar al-Bīrūnī wrote *Kitāb fī ifrād al-maqāl fī umr al-ẓilā* (The Exhaustive Treatise on Shadows), which contains a comprehensive account of the theory and applications of the gnomon shadow. Al-Bīrūnī refers to many Indian sources, for example:

1. The method described above for finding the cardinal directions. He calls it the method of "the Indian circle."
2. The algebraic formula.
3. The time from the shadow. Al-Bīrūnī follows the procedure of Brahmagupta.
4. Al-Bīrūnī gives the approximate Indian method for determining the meridian from three positions of the shadow. In addition, he describes the procedure, for the same problem, given by Diodorus of Alexandria, a mathematician of the first century BCE. An important result in al-Biruni's book, not mentioned in his Indian sources, is the condition for the shadow path to be a parabola, ellipse, or hyperbola, depending on the latitude of the observer and the declination of the sun.

See also: ►Astronomical Instruments in India, ►Varāhamihira, ►Āryabhaṭa, ►Bhāskara, ►Brahmagupta, ►*Śulbasūtras*, ►Sphujidhvaja, ►al-Bīrūnī

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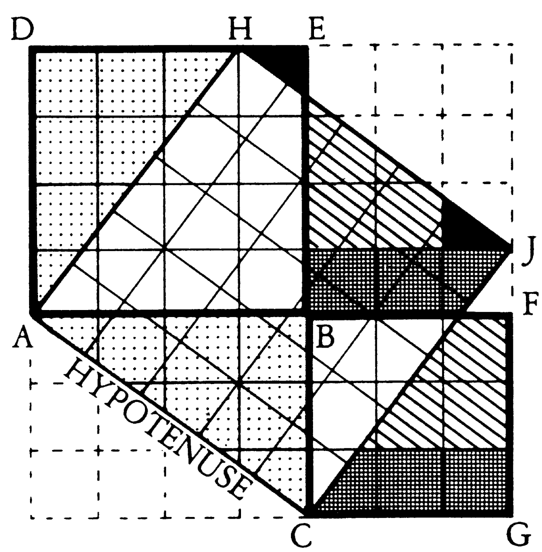

***Gou-Gu* Theorem. Fig. 1** The *Gou-Gu* theorem based upon the *Xian Tu* = *Xian* diagram, meant to accompany the *Zhoubi Suanjing* (see Fig. 3). Note that the square AHJC on the hypotenuse of the right triangle ABC is comprised of 25 unit squares, equal to the sum of the two squares on each side of the triangle, ADEH (16 unit squares) and CBFG (9 unit squares) (drawing by the author).

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Gou-Gu Theorem

Joseph W. Dauben

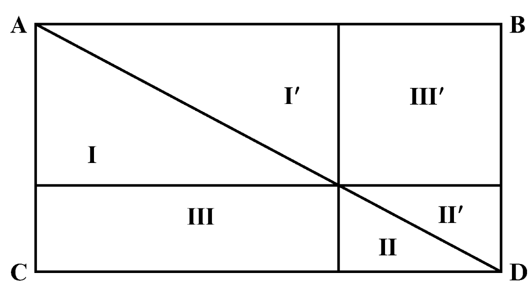
One of the basic theorems of geometry in both the East and West concerns the relationship between the sides of a right triangle and their squares, known in the West as the "Pythagorean" theorem, but understood in an equivalent form as the *Gou-Gu* theorem in China. The ancient Egyptians, Babylonians, and Chinese probably discovered this remarkable property of right triangles by empirically examining the simplest case of 3–4–5 triangles. Whether in its geometric form or more familiar algebraic expression, $3^2 + 4^2 = 5^2$, the theorem concludes that the sum of the squares on either "side" of the right angle is equal to the square on the hypotenuse (*Xian*). In China, this was established for right triangles in general, i.e., not just for the 3–4–5 triangle, or for those with sides of integer lengths. The Greek made this discovery as well, but proved it rather differently in the argument presented at the end of the first book of Euclid's *Elements*, Proposition I-47.

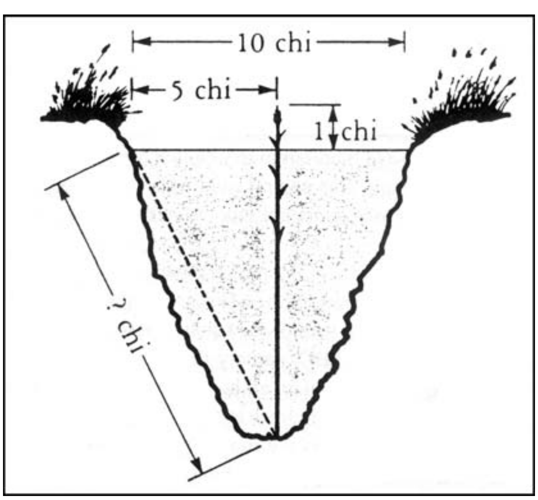
One of the great treasures of Chinese mathematics is the *Jiuzhang Suanshu* (Nine Chapters on the Art of Mathematics). It is the final chapter that is the most famous, in which the *Gou-Gu* theorem is introduced. Even before the *Nine Chapters* was written, results dealing with right triangles had been presented in an earlier astronomical–mathematical work, the *Zhoubi Suanjing* (The Arithmetic Classic of the *Zhou Gnomon*). The *Nine Chapters*, however, goes well beyond the simple applications found in the *Zhou Gnomon* text, which is concerned primarily with applications in astronomy. In fact, Chapter 9 contains 24 problems, each of which deals primarily with right triangles and solutions of quadratic equations. One of these is a variation on one of the oldest of China's mathematical problems (this is Problem 6 in Chapter 9 of the *Nine Chapters*) (see Fig. 1):

> In the middle of a pond that is ten "*chi*" in diameter, a reed grows one "*chi*" above the surface of the water. When pulled toward the edge of the pond, the reed just reaches the perimeter. How long is the reed?

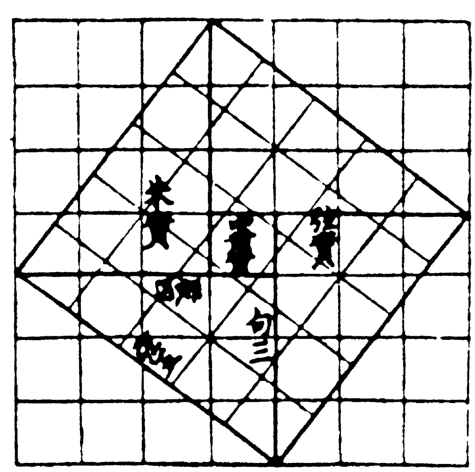
The solution to this problem is a straightforward application of the *Gou-Gu* theorem.

In commenting on a passage from the *Nine Chapters* that reads, "Combining each square of *Gou* and *Gu*, taking the square root will be *Xian* (the hypotenuse)," Liu Hui explains the *Gou-Gu* theorem as follows:





Gou-Gu **Theorem. Fig. 2** A problem that can be solved by applying the *Gou-Gu* theorem (see text: How long is the reed?) (drawing by the author).



Gou-Gu **Theorem. Fig. 3** The *Xian* figure.

> The *Gou*-square is the red square (*Zhu fang*), the *Gu*-square is the blue square (*Qingfang*). Putting pieces inside and outside according to their type will complement each other, then the rest (of the pieces) do not move. Composing the *Xian*-square, taking the square root will be *Xian* (the hypotenuse) (Guo 1990).

The reference to moving pieces inside and outside is related to a diagram, no longer extant, and makes use of the so-called "Out–In" method which was taken as an axiom by ancient Chinese mathematicians. The power of this axiom can be seen, however, from the following illustration, where the two triangles ABC and ACD are equal (Fig. 2):

Since the areas I and I′, II and II′ are equal, then it follows from the "Out–In complementary principle" that III must be equal to III (Wu 1983).

This now helps to explain Liu Hui's commentary on the *Gou-Gu* theorem. First of all, his references to colored squares are similar to colors mentioned in the diagrams illustrating the *Gou-Gu* theorem in the *Zhoubi Suanjing*. There, in the "*Xian* figure," the central square is yellow, while the squares of the *Xian* square are red. Often the *Gou* square is blue (Fig. 3).

Applying the "Out–In" complementary principle to the *Xian* figure, and following Liu Hui's commentary on the *Gou-Gu* theorem, the sum of the squares based on each leg of the right triangle ABC, namely the squares ADEB and BFGC, is equal to the square of the hypotenuse AC, namely the square AHJC (see Fig. 1 above). In accordance with the "Out–In" principle, if we move those parts of the two small squares (ADEB and BFGC) that are on the outside of the large square (AHJC) to its inside, we can see that they fill the inside exactly and that the combined areas of the two small squares equal that of the larger one. Since the areas are analogous to the squared sides of the triangle, the sum of the squared legs equals the squared hypotenuse.

It has been argued that geometry never developed further in China than it did with Liu Hui's commentary because this was sufficient for Chinese needs. After Liu Hui, Chinese geometry does not seem to have made much further progress. Although some authors suggest that this was due primarily to the practical orientation of ancient Chinese mathematics, it may have been its actual success, its comprehensiveness, that caused the stagnation of any further development. As D. B. Wagner has suggested:

> Liu Hui's conceptual framework was adequate, for example, to deal with a much broader range of geometric solids than those which he actually considers in his commentary. Had he felt a need to push his methods to their inherent limits, he would surely have contributed a great deal more to the mathematical tradition. Here we can see the double influence of the enormous prestige of the *Chiu-chang suan-shu*: it provided a challenge and an inspiration; but it was often a strait jacket which confined the interests of mathematicians to certain specific problems.

Like Euclid, Liu Hui summarized his art so successfully that his successors may have felt little need, or room, for improvement.

See also: ►Liu Hui and the *Jiuzhang Suanshu*, ►*Zhoubi Suanjing*

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Gunpowder

Ho Peng Yoke

Gunpowder was probably discovered in China accidentally. Since the Han period (202 BCE–AD 220) Chinese alchemists attempted to make gold or to prepare an elixir of immortality. Sulfur and saltpeter were among the raw materials used for their experiments, and charcoal was among the different types of fuel used in their laboratories. The *Zhenyuan miaodao yaolue* (Classified Essentials of the Mysterious Dao of the True Nature of Things), a book of the late Tang but probably containing material from much earlier dates, carries a note of caution to the alchemists warning them to exercise due care when dealing with sulfur, saltpeter, and charcoal because there were cases where the operators had their hands scorched or their thatched huts set on fire.

In China gunpowder found its early use in amusements, in religious and ceremonial functions, taking the form of fireworks and rockets, and in construction works, such as blasting rocks in the opening of waterways and roads. For example explosives were used by Gao Ping to open a rocky water route linking Guangdong province and Annam in the ninth century. There are no records that show the use of gunpowder in the battlefield before the tenth century. An early fire weapon that the Chinese used was the "incendiary arrow" (*huojian*) to send a variety of ignited substances to the enemy camp. At first naphtha was one of the combustion agents used. By 919 there appeared the force pump that could throw flaming petrol, or "Greek Fire," directed toward the enemy. Both naphtha and "Greek Fire" were imports from the West.

The *Songshi* (Official History of the Song Dynasty) mentions that in 970 Feng Jisheng submitted to the emperor a report on the manufacture of "incendiary arrows" and that in 1000 Tang Fu made "incendiary arrows," "fire balls" (*huoqiu*), and "thorny fire balls" (*huojili*). These were bombs and grenades containing gunpowder for hurling over enemy walls and camps by means of trebuchets. Later on the bombs progressed from those with weak casings to those with stronger ones.

In the middle of the tenth century the "fire-lance" (*huoqiang*) was invented. At first it consisted of a bamboo tube with its septa cleared. Then it was filled with rocket composition and capable of shooting out flames horizontally. According to Needham the "fire-lance" had enormous repercussions in China for some 700 years from the middle of the tenth century, playing prominent roles in many battles. It also marked a transition from the bulky petrol flame-thrower to a much lighter and portable weapon using gunpowder, and heralded the use of the principle of the tube in military technology. Bamboo tubes gradually gave way to barrels made of metal. The "fire-lance" took a big step forward in 1259 when the "fire-emitting lance" (*tuhuoqiang*) was developed. This type of "fire-lance" could fire scrap metal and break porcelain, if not also small darts or arrows, on which poison was sometimes applied. The range of the projectiles was short compared to a single bullet from a gun barrel. The Chinese later developed a similar firearm with a large barrel mounted on a carriage, rather like a field gun but which emitted a large quantity of projectiles instead of a single shell. Again these projectiles could be scrap metal, stone, broken porcelain, arrows, and poisonous or noxious substances.

The earliest document giving the gunpowder formula and describing its applications in various forms of firearms is the Song military compendium, *Wujing zongyao* (Collection of the Most Important Military Techniques), written by Zeng Gongliang in 1044. It describes with illustrations a number of weapons using gunpowder, such as the grenade, the bomb, etc. and gives several gunpowder recipes. The compositions suggest that the earlier Chinese gunpowder was more of the deflagratory type. A much higher ratio of saltpeter for explosives was used later.

Around the year 1000, gunpowder weapons were deployed on the battlefield in China. Large quantities of gunpowder were prepared and stored up during the Northern Song (960–1126). In 1232 the "thunderclap bombs" were brought into action. In the early twelfth century knowledge of gunpowder was acquired by the Jurchen people who eventually occupied northern China and established the Jurchen empire (1115–1234). In 1232 they used the "thunder-crash bomb" and the "flying fire-lance" (*feihuoqiang*) to defend their capital Bianjing against the Mongol invaders. Bianjing fell the next year. Gunpowder and firearm technicians were captured by the Mongols and taken into their service. The Mongols invaded Europe from the year 1236, deploying firearms of the offensive type. For example trebuchets were used on at least two occasions, in July 1237 at the battle of Ryazau, and in July 1241 "incendiary arrows" were used at the battle of Wahlstadt. The Mongols also used their firearms against the Arabs. In 1258 they used "fire-jars" to attack Baghdad, probably a reference to the thunder-crash bombs, which the Mongols also used against the Japanese in a sea battle near Kyushu in 1272. The next important city to fall after Baghdad was Damascus. The Muslims set up the Mamluk caliphate in Cairo and in 1260 defeated the Mongols in a battle in Syria. From then on, the two sides made little headway against each other for some years, during which the Mamluk caliphate turned its attention to military affairs and weaponry. Some Mongolian soldiers surrendered and some firearms and technicians fell into the hands of the Muslims. The Muslims thus acquired the technique of making firearms. They used them successfully against the Sixth Crusade (1248–1254).

By the latter part of the thirteenth century the narrow cylindrical tube of the fire-lance had already developed into one with much wider bore for the cannon (*huopao*). For example cannons were deployed when the Mongolian fleet went to Java in 1292 and 1293. Many examples of Chinese cannon, both of bronze and iron, are known from 1330 onward. Several types of cannons are described in the fourteenth-century military book, the *Huolongjing* (Fire Dragon Manual).

During the second half of the fourteenth century Chinese firearms were unmatched anywhere in East Asia. They were used by Zhu Yuanzhang, the founder of the Ming dynasty, to overthrow the Mongols and to suppress local rebellions. After his victory he kept his firearms in secret arsenals. There was no need to improve these weapons as they met no challenge, so that he only saw the necessity of guarding both the weapons and the knowledge from falling into undesirable hands. This happened during a period when Europe was undergoing great social change and when European firearms began to come to ascendancy. Traditional Chinese weaponry is now something of the past, but firework displays that we see on auspicious occasions around the world today remind us of the original role played by gunpowder in China.

See also: ►Military technology

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Guo Shoujing

Ho Peng Yoke

Guo Shoujing (1231–1316), an astronomer, mathematician, and hydraulic engineer, was born in Xintai (in modern Hebei province). The names of his parents are not known, although records show that his grandfather, Guo Yong, was knowledgeable in the classics, in mathematics, and in water works. As a boy of 14 Guo Shoujing was able to construct an advanced type of clepsydra, or water clock, for his time: the *lianhualou* (lotus clepsydra), so named because the top of the receiver was in the shape of a lotus flower. In about the year 1251 he restored an old bridge across the Dahuoquan River north of Xinzhou, also in Hebei.

In 1260 Guo accompanied his friend Zhang Wenqian (1217–1283), who was sent by Qubilai Qan to Daming to pacify the local population. There he began to construct astronomical instruments, such as a bronze clepsydra and a bamboo armillary sphere. The same year Zhang Wenqian recommended him to Qubilai for his expertise on irrigation. Guo was soon commissioned to improve irrigation and water communication within the region south of the capital Dadu (modern Beijing) and north of the Yellow River. The mission was successfully accomplished. In the year 1264 Guo again accompanied Zhang to the Circuit of Xixia (in modern Gansu province) to restore the irrigation canals that had been blocked or damaged during the years of war. He reported on what he saw during his travels and made many recommendations to Qubilai on the improvement of irrigation and water communication systems.

There was an urgent need to reform the existing calendar, the *Damingli*. In 1276 Qubilai captured the Southern Song capital, Linan (modern Hangzhou) and thought that the time was ripe to promulgate a new calendar. Guo and Wang Xun (ca. 1235–1281) were commissioned to lead a special bureau established for the project. Guo Shoujing built 17 new astronomical instruments to obtain more accurate astronomical observations on which the accuracy of the new calendar would depend. Thirteen of the instruments were used in the capital Dadu, and four were used for fieldwork. In 1279 Qubilai established an Astronomical Bureau at the capital. Zhang Wenqian was appointed Director, while Guo and Wang Xun were made the two co-Directors. A new observatory was built at the capital along with new bronze astronomical instruments. Guo organized a large-scale measurement of the length of the shadow of the gnomon cast by the sun in different latitudes, from the capital in the north to Nanhai (modern Guangzhou) in the south, to determine the length of the meridian.

Guo used spherical trigonometry and the method of finite difference involving a cubic equation to do his calculations. The new calendar, the *Shoushili*, was completed in 1280. This was the most accurate calendar ever made in traditional China. It was promulgated the next year. Guo Shoujing was promoted to the Directorship of the Astronomical Bureau.

In 1292 Guo held a joint appointment as head of the water works bureau in the capital. The same year he constructed water locks and canals linking various cities to the capital. The Qan was greatly pleased on completion of the project. While he was in the capital Guo made a clepsydra whose bells and drums would chime and sound on the hours for his master. After the death of Qubilai, Timur also sought Guo's advice. Guo died in 1316.

See also: ►Armillary Spheres, ►Clocks and Watches, ►Bamboo, ►Calendars, ►Time

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G

Ḥabash Al-Ḥāsib

Lawrence Souder

Ḥabash al-Ḥāsib was one of the earliest Muslim astronomers and a major contributor to the development of trigonometry. He was born in Marw, Turkestan (modern Mary, Turkmenistan) and died between AD 864 and 874. Ḥabash lived during the Abbasid empire, when the caliphs became the stewards of civilization. This empire preserved ancient science and philosophy by translating ancient Greek, Syriac, Sanskrit, and Persian texts into Arabic. Ḥabash himself based his work and methods on Ptolemy's *Almagest*. Ḥabash held Ptolemy in high regard, calling him "the wise Ptolemy" and describing his work as having the "utmost in research and precision" (Langermann 1985). Ḥabash led the way in the Arabic development of astronomy and computational techniques.

As an astronomer Ḥabash worked at calculating more precise celestial distances and at developing more accurate ways of calculating these distances. He calculated such values as the circumference of the earth, the diameter of the moon, and the distance of one minute along the orbit of the sun. Ḥabash's work in trigonometry consisted of calculating tables of trigonometric values and developing new trigonometric functions. He calculated tables (called *zījes*) of sine values at one-degree intervals to three places, and he is considered to be the first to construct a table of tangent values.

In Ḥabash's time much of Muslim science served the needs of the religion. For example, Islam requires the faithful to face Mecca when they pray. To this end Ḥabash developed an analemma, or graphical, method for finding the azimuth to Mecca, called the *qibla*. Muslim calendars were dependent upon the appearance of the new crescent of the moon. Ḥabash is thought to be the first astronomer to calculate when the new crescent appears. Islam also requires the faithful to make a pilgrimage to Mecca. Ḥabash once calculated what he called the distance "by the straight arrow," or the great-circle distance between Baghdad and Mecca to be 677 miles, while the actual overland distance was known to be about 712 miles. In one of his few surviving works, *Kitāb al-ajrām wa-l-ab ͑ad* (The Book of Bodies and Distances), Ḥabash reported that al-Maʾmūn, the caliph at the time and Ḥabash's patron, was pleased with the small difference between the two distances considering the uneven terrain between the two cities.

See also: ►*Almagest*, ►Trigonometry, ►*Qibla* and Islamic Prayer Times, ►Calendars

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Hair in Egypt

G. J. Tassie

The ancient Egyptian hairstylist was expected to be able to style hair, as well as cure baldness, make hair (of a rival) fall out, get rid of head lice and cover up the signs of aging by dyeing grey hairs. Ancient Egyptian clients would also require more mundane tasks, such as cleansing and scenting the hair.

Tinting

The Egyptians used natural dyes which are known to coat and partially penetrate the hair's 6–14 layers of cuticles. These natural semi-permanent tints do not leave roots as they wash out of the hair, although a virtually permanent tint may be achieved with frequent application. The main colour the Egyptians would probably have wanted to achieve was black, emulating the dark brown colour of their youthful hair. One recipe was an ointment made of juniper berries and two unidentified plants kneaded into a paste with oil and then heated. The natural blue-purple colouring agent in the plants would rub off on the hair, while the astringent properties of the juniper would stimulate the scalp (Manniche 1989: 46).

Indigotin (*Isatis tinctoria*) is a blue dye that is found in both indigo and woad, and is an obvious choice for Egyptian hair dye as indigo occurs naturally across much of northeastern Africa. There is considerable epigraphic evidence to suggest that deep blue-black was the colour towards which most Egyptians aspired, and this is the colour that is achieved by putting blue dye on the Egyptians' natural dark brown hair. This would have been used on both the person's own natural hair and on hair used to make wigs, as Fletcher (1995) has found traces of indigotin on both. Indigotin also has antiseptic properties and was widely used all over the Middle East on clothing and directly on the skin. As the Egyptians had considerable expertise in so many natural medicines, they are unlikely to have been unaware that trichological (hair science) application of indigotin had a positive side effect as an anti-bacterial agent. On one of the two blonde-haired mummies Petrie found at Gurob was a large black sprang (sprang is closely related to braiding, but it is done on threads which are stretched on a frame, so that the braided fabric builds from both ends towards the middle) headcover that he claimed was worn to cover the person's own blonde hair, possibly to hide the fact that the individual was foreign (1890: 39). However, Fletcher's examination of the hair and head-covering revealed the fact that the blonde hair had been enhanced with yellow henna, and that the sprang headcover was dyed a dark blue-black using indigotin and a small amount of madder (1995: 469).

The later periods of Egyptian Pharaonic history saw the use of tannin to tint hair a dark brown colour, usually in conjunction with iron mordents (Fletcher 1995: 469). A mild form of natural bleach may have been used to enhance or define a style, or to pre-lighten the hair so it could be dyed a brighter colour (Fletcher 1992: 16). Such a substance may have contained natron and lemon juice, a lightening substance that is still used today.

Henna (*Lawsonia inermis* L.; *Lawsonia alba* L.) was also used in the Pharaonic era, but it would be unwise to use this to support the oft-made assertion that Egyptians commonly used henna to die their hair, as we know that that black (see above) rather than red was the favoured hair colour in ancient Egypt. However, while red was seen as being a dangerous colour for most of Egypt's history, henna was certainly used as a hair colorant (although probably not widely) by the higher echelons of society at least. This is reinforced by the iconographic record and actual wigs and hair of mummies, which show very little use of henna up to the end of the New Kingdom (1069 BCE). Brunton suggests that the light red-brown hair of an elderly woman from the Badarian (4500 BCE) cemetery at Mostagedda might have been brought about by an application of henna dye (1937: 45). Smith believes that the brilliant reddish colour of Henttawy's hair and the dark reddish-brown hair of Thutmose IV were tinted with henna (1912: 19 and 44). However, it should be considered that various types of henna produce different colours, from yellow through to nearly black, and that other ingredients can be added in order to produce different effects. The yellowish hue of Ramesses II's hair is not the result of the mummification process, as once believed, but was the result of henna or one of its derivatives being applied to the King's grey hair (Balout 1985: 256) to resemble the King's natural hair colour in his youth.

The hair of Nesikhons was found to have been "thickly strewn with powdered red resin" (Smith 1912: 109). A similar case of a coloured powder being used in this manner was found on the hair of the mummy of the Priestess Tansertemsutenpa, who was found with a thick coat of yellow ochre over the top of her hair, possibly concealing a small bald patch as well as colouring the remaining hair (Smith 1912: 158). While it may be difficult to distinguish intentional dyeing ingredients from naturally occurring materials that inadvertently found their way into the hair, it has been suggested that a small sachet of a fine dark powder, manganese dioxide and quartz – found in the wig-makers workshop at Deir el-Bahari – was sprinkled over the hair for cosmetic reasons (Laskowska-Kusztal 1978: 119–120).

Hair Care

The hair of an ancient Egyptian woman was literally her crowning glory as can be attested to by a number of literary and epigraphic sources where men's apparent fascination with long, sweetly smelling dark hair is made abundantly clear. However, if women had a vested interest in keeping their hair in good order for the benefit of men, it is also evident that men also wished to boost their trichological endowments, paying considerable attention to the many medical recipes for the care and restoration of hair. There is a whole section within the Ebers Papyrus that concerns baldness, hair preservation and general welfare of the hair and scalp, including this one to prevent baldness: "castor oil; the fat from a hippopotamus, cat, crocodile, snake and an Ibex and rub this mixture on your head" (Wreszenski 1913 Spell EB 465). The care of the scalp usually involved various oils such as castor oil or moringa oil (*ben* oil) mixed with other ingredients. Another hair treatment for maintaining the good health of the hair (and scalp) was prepared from “a red mineral; kohl; myrtle berries (?); oil or fat; gazelle dung and hippopotamus fat, mixed to make a paste” (Manniche 1989: 125 Spell EB 471). The most effective ingredient was the oil, which moisturised and nourished the scalp at the same time making the hair feel soft and smooth and look shiny and healthy. The red mineral and kohl may have also added a slight dark reddish hue to the hair.

Head lice (*Pediculus humanus capitis*) were a common parasite in ancient Egypt, and were a major cause of head shaving because washing alone does not kill or remove them from the hair. Head lice are particularly common in children and live just behind the ears and in the nape of their host’s head, preferring clean hair to dirty or oily hair. The Egyptian habit of oiling the hair may have had a preventative effect on louse infestation (Dayagi-Mendels 1989: 76–78), while many other parasites like fleas and flies were trapped by the glutinous substances (including beeswax and resin) which were used to set the hair. Both the Hearst and Ebers medical papyri contain possible recipes to remedy louse infestation or “*hnsyt*-illness of the head”, such as this one: “fruit of the castor-oil plant; ox fat; moringa oil. Combine and mix into a paste, use as an unguent every day” (Wreszenski 1913 Spell EB 437; Hearst 24). The term *hnsyt* has been translated as “that which moves about on the head”. The application of the ointment would probably have improved the condition of the ailment; in the case of head lice it would not only remove the adult lice, but loosen the egg cases as well. While we do not know the composition of all the ancient Egyptian oils used, natural insecticides such as quassi, derris, sassafras and stavesacre (Fletcher 1995: 39) may have been used, probably in collaboration with the de-nitting combs mentioned above.

Highly diluted natron[1] may have been used as a detergent for dissolving greasy deposits when washing the hair (Ghalinoungui 1983: 153), as a fragment of this substance was recovered from the wigmakers’ workshop at Deir el-Bahari, and tests confirmed that it still retained its detergent properties (Laskowska-Kusztal 1978). The use of these harsh detergents may explain why some women had bald patches.

Ancient Egyptians used beeswax and resin to style their hair, although this appears to have been done every few weeks rather than on a daily basis. Beeswax is commonly found in hair and wigs, and as it seems unsuitable for oiling or perfuming the skin, it is probable that it was used to set the hair (possibly at a ratio of 2/3 wax to 1/3 resin (Fletcher 1995; Lucas 1962)). It is unlikely that this mixture of wax and resin comprised the “scent cones” popular in the New Kingdom, as the body/environment would have been unable to reach the melting temperature of wax (60° C = 140°F) in order for it to melt naturally and flow over the hair and body. Lucas therefore concludes that the wax and resin mixture must have been warmed up first and then rubbed into the hair and as it cooled set it in style (Lucas 1962: 31).

From Late Neolithic times (4500–3050 BCE) to the Graeco-Roman Era (332 BCE–AD 306), both men and women would scent and oil their hair. The oiling of the hair to keep it supple and pleasant smelling was done on a daily basis as part of the morning toilette ritual. Lucas’ (1962: 89) examination of residues found in cosmetic containers found palmitic and stearic acids, which probably represented perfumed ointments made of animal fat mixed with scent. The most frequently cited hair oil was a substance known as *Qemi,* which came from the Red Sea region and found widespread use in the anointing of aristocratic coiffures throughout the New Kingdom. The importance of keeping the hair in good order cannot be overstated, judging from the frequent literary references made to divine hairstyles. For example, in “The Song of the Perfumed Hair”, the fragrant locks of the Goddess Shentayt are alluded to thus: “There is perfume, there is perfume in your hair, O holy Shentayt, perfume in your hair” (Nachtergael 1981: 593). In the New Kingdom tomb of Rekhmire the harpist sings: “Put myrrh on the hair (or curls) of Ma’at” (Davies 1943: 60–61). There is also mention of oils being poured over people’s hair during the Old Kingdom (2613–2181 BCE), such as in the Dynasty V tomb of the Vizier Senedjemib where an inscription states that King Djedkare Isesi “Caused that I be anointed with fat” (Breasted 1907: 122).

Although scented oils could be rubbed into the hair by hand, scent cones are commonly depicted in New Kingdom art (Fig. 1). Scenting or festal cones were first introduced into Egypt during the Middle Kingdom (2040–1650 BCE), where they are depicted on a Dynasty XIII (ca. 1795 BCE) stela relief of Amenysonb from Abydos, where his Asiatic brewer Irsi is seen wearing a smallish lump of unguent on his cropped hair (Fletcher 1995: 446). However, scent cones only start to be depicted in any real number from the reign of Hatshepsut (Dynasty XVIII, from 1473 to 1458 BCE) and become even more popular during the reign of Amenhotep III (1390–1352 BCE). Throughout the New Kingdom (1550–1069 BCE) and up to the Ptolemaic Period scent cones were worn (Maraite 1992). They are most frequently represented on tomb scenes, but can also be found on temples and stelae reliefs (Maraite 1992). A sculpted version can be found on figures of nobility such as the statues of Neferhotep and his wife (Davies 1932, frontispiece) and Khay and

[1] Natron was a salt (sodium carbonate and sodium bicarbonate) that was used in the mummification process to dry out the body of the deceased in order to assist in its preservation.

H

Hair in Egypt. Fig. 1 Guests at the banquet with scent-cones on their heads, Tomb of Nakht (TT52) (author's own photograph).

his wife (Muhammed 1966: pl. 8). Cones are sometimes shown being worn by *ushabtis*[2], i.e. those of Tuty (Kozloff and Bryan 1992: 259). The ancient Egyptian name for these cones was *bt*. The cones were worn by men, women and children alike, and they were not just limited to the elite classes, but are shown being worn by musicians, dancers and servants as well. Although Fletcher (1995: 446) has proposed that they were just symbolic of the scenting and oiling of the hair, some Nubian peoples (Bisarin) are known to wear similar scented cones (Keimer 1953: 342 *ff*.). Although in later depictions they become highly stylised and unrealistically tall and thin, it is likely that a small, round tablet of scented animal fat was indeed placed on the hair at banquets and other festive occasions to keep the hair sweet smelling and in good condition. The custom of using scent cones was probably introduced into Egypt from Nubia because of the Egyptian expansion into the region during the Middle Kingdom (2040–1650 BCE).

In ancient Egypt, there was an emphasis on being or looking young, fit, healthy and able. This emphasis is demonstrated by the king having to prove his fitness to rule by running the *heb sed* court on his jubilee. Receding or greying hair is rarely depicted in tomb scenes, particularly on the elite, although the lower orders were sometimes shown in this manner to mark the social distinction between them and the tomb owner (Janssen and Janssen 1996; Robins 1996). The various remedies against baldness and concoctions to colour greying hair show that the youthful ideal was not just an artistic principle but a pivotal part of Egyptian socio-economic culture. The maintenance of the black hair of one's youth was equated with vitality, fertility and potency; receding (completely bald or shaved heads reflected piety and cleanliness) and grey hair were symbolic of disempowerment.

[2] Ushabtis were small figurines made from wood or clay, or occasionally stone or ivory. Often the ushabtis were depicted with tools, or in some act of work. They were buried with Egyptians, so that, if the deceased were called to work in the afterlife, the ushabti would take the deceased's place performing the task.

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Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs

G. J. Tassie

The practice of hairstyling in Egypt can be traced back to the Predynastic Period (4000–3050 BCE), and was accompanied by a series of technological changes reflecting this new tradition, especially copper and bronze tools. The oldest tools were bone and wood combs and hairpins, with flint or obsidian blades being used to cut the hair. Although hairstyling was initially mainly utilitarian, Egyptian society's growing complexity led to a proliferation of more extravagant styles. Like most other social status markers, hairstyles helped to maintain and reinforce a person's social position and maintain their privileged access to goods and materials (Trigger 1993). Hairstyles can therefore be grouped with body decoration, clothing, and jewellery in that they all inform the onlooker as to gender, age, status, class, sexuality, ethnicity, and ritual affinities (Fletcher 1995; Robins 1999; Tassie 2002).

There are five main operations that can be performed on hair:

(1) It can be curled or left curly;
(2) It can be straightened or left straight;
(3) It can be plaited, twisted, or teased;
(4) Hair can be added; and
(5) Hair can be taken away.

These five operations may be used separately or in any combination. Accessories may also be added, including hairpins, combs, and fillets.[1] Tinting of the hair may also occur, although this does not come into the above categories of hairstyling. The ancient Egyptians also developed wigs and hairpieces to supplement their own hair, enabling them easily to change their hairstyles to suit the occasion. However, the use of the term "wig" to describe all ancient Egyptian hairstyles is incorrect. Certain statues depict the owner's own hair protruding from beneath a full wig (particularly in the Old and New Kingdom) but other depictions of figures, such as those on the Erotic Papyrus and many of the workers in the fields and other secular tomb scenes are clearly not wearing wigs (Fig. 1). Therefore, unless one is certain that the person is actually wearing a wig, the term "hairstyle" should be used. Wig manufacture and wearing are discussed further below.

The types of hairstyles worn by men and women changed throughout time and space. The social significance of hairstyling became codified after the period of unification, allowing only certain status

Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs. Fig. 1 Close-up of the head of Nofret showing her real hair exposed beneath her full, bobbed wig. Meidum, Dynasty IV, Old Kingdom (photograph by author copyright Egyptian Museum of Antiquities, Cairo).

[1] A fillet is a ribbon or narrow band of fabric worn around the head across the forehead, as an ornament or to hold back the hair.

groups to wear particular hairstyles. Constraints were placed upon the choices of hairstyles that individuals were allowed to wear both by society and the technology open to the ancient Egyptian hairstylist. The hairstyles that a person could wear were temporally dependent upon a person's social position and status. A form of sumptuary laws existed in Egypt regulating social etiquette with regards to what forms of hairstyle were permissible by various classes and statuses of individuals at certain occasions. These laws were not written down but were governed by social and courtly modes of behavior. The hairstylists through their creation of hairstyles and wigs helped to perpetuate the hegemonic situation and reinforced the social relations, even when creating new styles.

During the Old Kingdom shaved heads were sported by both men and women of all status groups, as well as cropped hairstyles. Short, round, curly styles were primarily worn by low to middle class men. The various lengths of bobs were worn by both elite men and women, although with slight variations in the actual dressing. The long tripartite hairstyle was worn by women of any class, but only sacred men (i.e., gods, kings, and the dead). The tripartite hairstyle was symbolic of fertility and rejuvenation. Therefore women as child bearers and sacred men (king – Egypt's fertility, deities – humanities creation, and fertility and the deceased – rebirth) were allowed to wear the style. During Dynasty XVIII (1550–1295 BCE) the gala hairstyle was introduced for elite women, as was the duplex style for elite men. The Nubian hairstyle became popular just before the Amarna Period of the New Kingdom (1352–1323 BCE), during the reign of Amenhotep III, and remained the standard elite hairstyle of both men and women until the reign of Horemheb (1323–1295 BCE) (Aldred 1957). The classic children's hairstyle – the sidelock of youth – remained popular throughout Pharaonic history (Tassie 2005) (Fig. 2).

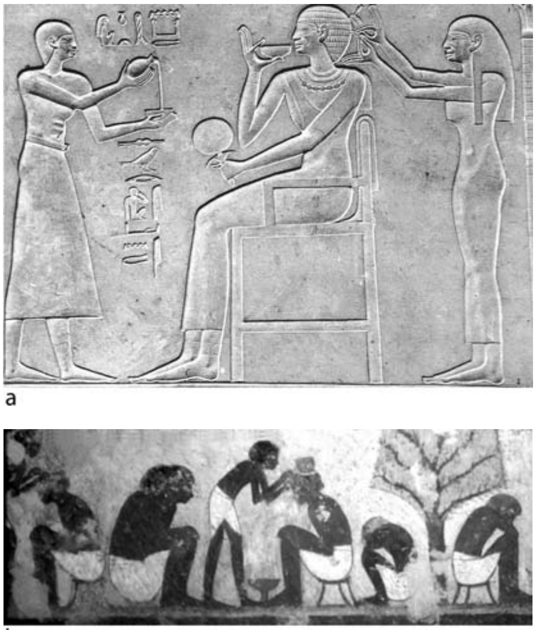
Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs. Fig. 2 Dyad of Meryneith (Meryre) and his wife Iniura, found in his Saqqara tomb by the Dutch Mission. His title is the "Scribe of the Aten Temple in Akhetaten and Memphis." Her titles are "The favorite and Beloved Wife" and "The Great Lady of the House." Note the more naturalistic rendering of hair at this period in three-dimensional art; Meryneith has a duplex style and Iniura a gala hairstyle. Amarna Period, Dynasty XVIII, New Kingdom, Saqqara, now in the Cairo Museum (author's own photograph? copyright Egyptian Museum of Antiquities, Cairo).

The Ancient Egyptian Hairstylist and Barber

Due to hair's apparent social importance, many hairstylists and barbers plied their trade throughout ancient Egypt. The elites usually had a hairstylist attached to their staff or arranged for one to visit their homes, whereas poorer people would go to a traveling hairstylist. For everyday care and attention, the elite women would have had a maidservant trained to do the dressing. Poorer people would have to rely upon a relative or friend to style their hair. The work of the barber (*h'ḳy*) was not thought to be as highly skilled as that of the hairstylist. Barbers would set up beneath the shade of a tree, placing their stools, and cutting the hair of their clients. Tomb scenes and inscriptions from the Old Kingdom (2613–2181 BCE) the Middle Kingdom (2040–1650 BCE) the New Kingdom (1550–1069 BCE) and Late Period (646–332 BCE) bear witness to the fact that certain hairstylists held a high social rank (Gauthier-Laurent 1935–1938). All except two of these inscriptions refers to men. The word used to describe him is *ir-šn(y)*; the rarely found feminine form is *irt-šn(y)* – literally hairmaker, hairdoer, or wigmaker. There is usually a modifying determinative after the word *ir-sheeny*, denoting that the bearer of the title was either a "royal hairstylist" or an "overseer of hairstylists" (Riefstahl 1952, 1956). Other related words are *nšt*, hairdresser, and *nšy*, which means "to dress hair." These words are used occasionally from the Middle Kingdom onwards, but usually refer to a casual hairdresser. In ancient Egypt hairstylists were frequently important officials who held important offices in addition to their tonsorial duties (Riefstahl 1956) (Fig. 3).

Wigmaking

Although many publications refer to any Egyptian hairstyles as "wigs," true wigs were in fact fairly rare, and then almost exclusively the preserve of the elite. That the rulers of the proto-kingdoms were probably using extravagant hairstyles, wigs, and headdresses to signify status is evidenced by the elaborate hairstyle of the elite Naqada II (ca. 3600 BCE) woman in Burial 16 at HK43. This is the earliest palaeoethnotrichological evidence for the wearing of false hair so far recovered in Egypt. The hair was shoulder length, tinted with henna, and augmented with a considerable number of false hair swatches. The finished hairstyle was very



Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs. Fig. 3 Hairstylists and Barbers. (a) Queen Kawit having her hair styled by a maidservant while at breakfast. Scene on her limestone sarcophagus, Cairo Museum, originally from her tomb at Deir el-Bahari, Dynasty XI, Middle Kingdom (author's own photograph ? copyright Egyptian Museum of Antiquities, Cairo). (b) Army recruits having their hair cut (note bowl with water between barber and client for keeping the hair moist), Tomb of Userhet (TT56), Dynasty XVIII, New Kingdom (author's own photograph).

voluminous with matted tresses (reminiscent of modern dreadlocks) and with a lot of height. Another Naqada II female mummy from Hierakonpolis (Burial 333) had what we now call a Mohican-type hairstyle.[2] Also found at Hierakonpolis HK43, in the double burial 154, is the oldest toupee so far found in Egypt – early Naqada II. This hairpiece was made of either "goat or sheep's wool" and had been secured in place over the bald patch of an elderly man's scalp by weaving strands of the man's own hair into the hairpiece (Friedman 2001: 12). The intricacy of the styling techniques involved in creating these styles indicates that it took many hours of work and was probably performed by a professional hairstylist (Fletcher 1998). There is also epigraphic evidence of wig wearing. On the famous pair of Dynasty IV (ca. 2613 BCE) statues of Rahotep and Nofret from Meidum, Nofret's own hair can be seen combed flat beneath a full bob wig. Archaeologists found a wig dating from the First Intermediate Period (2181–2040 BCE), in the Dynasty VIII tomb of Hefefi at El-Hagarsa. This wig was shoulder length and black, consisting of long, straight braids made of twisted flax fiber and set with beeswax and resin (Kanawati 1993: 21, 65). The archaeological record shows an increase in the number of wigs surviving from the Middle Kingdom; notable examples include the numerous wigs found in their original wig boxes in the Dynasty XII (1985–1795 BCE) tombs at Lisht. These wigs were made of human hair and were styled into long braids (Lansang 1933). The records show a dramatic increase in the amount of false hair that survives from the New Kingdom, as do subsequent periods. However, there is evidence that the wearing of wigs fell out of favor during the Late Period (Fletcher 2000a, b).

Human hair was the main material used for constructing wigs and hairpieces, sometimes in association with date palm fiber, reeds, and linen (especially during the Graeco-Roman Period – 332 BCE–AD 306; Tassie 2002). No animal hair was ever used (apart from the HK43 toupee) (Lucas 1930, 1962; Eisa 1953), and in every case except that of Maiherpri, cynotrichous (Caucasian) rather than heliotrichous (Negroid) hair was used in wig construction (Fletcher 2000a, b). There are epigraphic indications that wigs were valuable assets: they were listed alongside gold and incense in the account lists from Kahun (Fletcher 2000a, b), while a single wig (probably of fiber) constituted two-thirds of a woman's dowry in a marriage contract from 219 BCE (Tassie 2002). Although false braids could be made from the wig owner's own hair, the vast amount of hair used in wig manufacture was probably shaved from the heads of foreign captives or was sold to the wigmakers by its impoverished prior owners. Hair was traded extensively throughout the Roman Empire, and was sufficiently valuable to cause a specific custom duty to be paid on it (Fletcher 2000a, b).

Once the hair had been processed, cleansed and detangled, it was ready to be made into wigs and postiches (hairpieces). The processed lengths of hair would then have been styled into plaits, curls, and wefts before being fastened directly onto the head or onto a wig foundation. The wig foundations were usually made of plaited hair (or, more rarely, incorporating leather straps and linen strings) as an open-mesh base or a series of knotted wefts of hair. These mesh bases and wefts were then often sewn on to a linen cap with a drawstring, so that it could be secured to the head

[2] The author has only seen a photograph of this hairstyle and has not examined the mummified remains. Mohican-like was how the director of Hierakonpolis - Dr Renée Friedman - described the hairstyle in a lecture. The modern-day Mohican hairstyle is shaved at the sides with a line of hair sticking up from the center of the skull, like a cockerel's comb, whereas a Mohawk is shorter and normally squared off with the central section of hair starting just above the occipital bone. The photograph of the hairstyle in Grave 333, HK43 did not appear to have shaved sides but was combed into the medial line of the head giving a Mohican-like appearance to this hairstyle.

(Tassie 2002). There was considerable variability across time and space in terms of wig manufacture. For example, Merit's wig consists of wefts of hair knotted together to form a kind of marteaux or diamond mesh around a medial plait with a central parting (Chiotasso et al. 1992), while the British Museum wig is composed of some 300 locks of hair (each containing about 400 hairs) on a foundation of finely and tightly plaited human hair forming a hair net with rhomboidal apertures (Fig. 4).

Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs. Fig. 4 Wigs in the Cairo Museum: (a) *left to right*: lady Istemkhebs short curly wig – JE26252h, duplex wig – JE26252g, Ahmose-Hentempet short curly wig JE46913; (b) wig of thick triple braids (JE23412) found in side-chamber of Amenhotep II's Tomb (KV35), New Kingdom and Third Intermediate Period (photographs courtesy Joris van Wetering ? copyright Egyptian Museum of Antiquities, Cairo).

The root end of each lock was secured by looping it around part of the mesh, pressing it back against the hair stem and fastening it with substrands of the root section; this was then locked in place with beeswax and resin (Cox 1977). The greatest collection of ancient Egyptian wigs is in the Egyptian Museum of Antiquities, Cairo where there are 23 full wigs and numerous hairpieces (Tassie 2002). The Egyptians protected their wigs by keeping them in wig boxes, such as Merit's large rectangular cupboard-like wig box found in her husband Kha's tomb in Thebes with poles to hang the wig from (Chiotasso et al. 1992) or Tutankhamun's square wig box found in his tomb KV62 with a mushroom-like stand in the center for hanging the wig on (Reeves 1990: 193) (Fig. 5).

While our knowledge of wig morphology and structure is considerable, the details of the wig construction process were unclear until the discovery of a wigmaker's workshop dating to between 1800 and 1700 BCE in a crevasse overlooking the Temple of Mentuhotep II at Deir el-Bahari. The workshop contained four alabaster vases in a linen sack with various wigs in different stages of production, tufts of hair, hair wefts (on threads), swatches (tied up with fibers), and a thread net-foundation. A papyrus case found in the workshop held a bronze awl, five bone hairpins, and fragments of two flint knives. In another container

Hair in Egypt: People and Technology Used in Creating Egyptian Hairstyles and Wigs. Fig. 5 Large wig box recovered from the tomb of Yuya and Thuya in the Valley of the Kings, Thebes. It is made of papyrus stalks supported by reeds, and measures 107 cm long by 51 cm deep. The box stands on four reed legs, and had an outer lid, and an interior double leaved lid opening from the middle to form a tray. This lid was tied down with linen thread and sealed with black clay seals. The front of the wig box is ventilated by three windows, one at each and the other in the middle of the front panel. The wig box may originally have held Yuya's duplex wig CG51185, which was found in a niche in his tomb KV46, Dynasty XVIII, New Kingdom, Cairo Museum (photograph courtesy Joris van Wetering ? copyright Egyptian Museum of Antiquities, Cairo).

were pieces of linen (probably for the skullcap), solid soda "soap," leather straps, bone beads, and other oddments. A unique model head made of wood was also found and is believed to have been used for laying out the wigs while in production. Black lines had been traced to show the outline of the wig's attachment and its long and short axis (Laskowska-Kusztal 1978).

Hairstyling was not done for fashionable reasons but was used to convey the class and status of the wearer. However, the hairstyles of the ancient Egyptians were far from static, and evolved to express changes in Egyptian society. This flux gave rise to a large assemblage of tools, unguents and hair products that can be seen in many of the world's museums, along with the mummies whose hair was treated in the ways discussed above. Some museums may hold only a hand-mirror or a razor, whereas others, such as the Metropolitan Museum of Art, New York include whole wigs in their displays of ancient Egyptian hairdressing and beauty paraphernalia.

The art of hairdressing was already well developed by 3000 BCE in Egypt. The social importance of hair was such that ancient Egyptian hairstylists were highly regarded, especially those allowed to work on the hair of the pharaoh. There was even a goddess of hair and hairstyle (Khonsut) and a god of the royal beard and barbers (Duwar).

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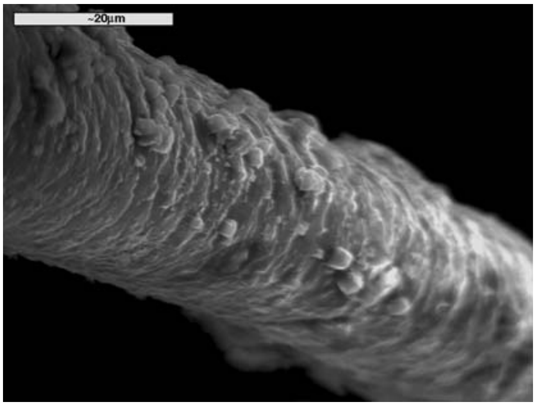
Hairstyling Technology and Techniques Used in Ancient Egypt

G. J. Tassie

Three types of cutting equipment were available to ancient Egyptian hairstylists: the razor, the "composite tool" (a combination of scissors and hair-curler) and the comb. Of these, the razor was the main implement used for cutting the hair. The hairstylist would probably take the bulk of the unwanted hair away using the razor, using a bodkin (hairpin) to separate the hair not being worked on. They would then work on the free section, sculpting with the razor and snipping off any stray hairs with the scissor part of the composite tool before releasing the next section to be cut. The process worked around the hairline first, then up to the crown. The client would view the results in a bronze hand-mirror (Fig. 1).

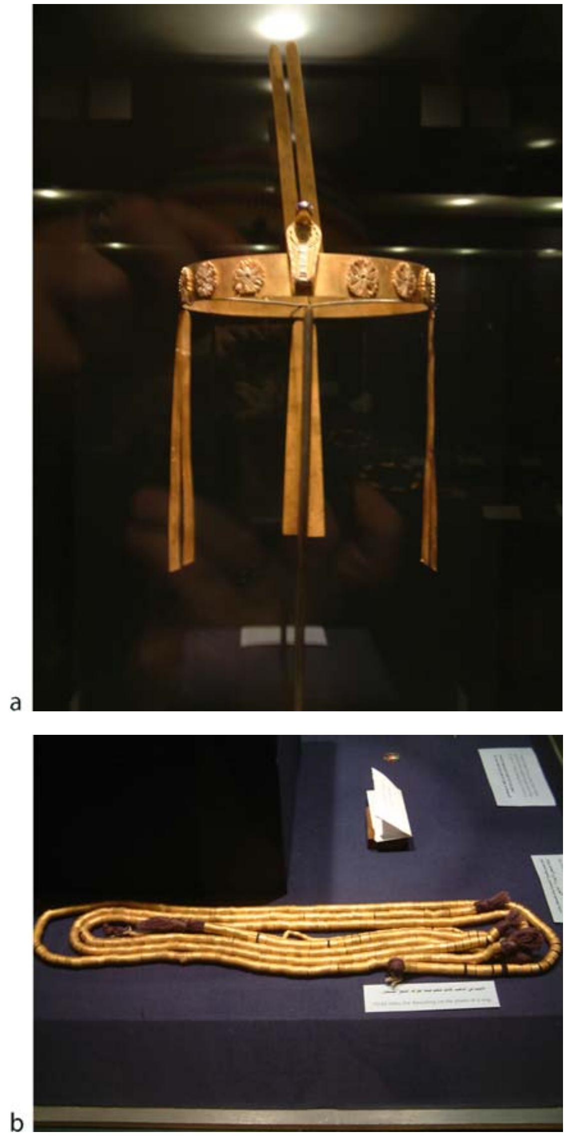
Microscopic examination of the cut ends of hair on wigs and mummies has revealed the majority to be of the tapered variety and very clean-cut (Fig. 2). This indicates that it was cut with a sharp razor while wet (Fletcher 1994a), as the razor requires the lubrication of water to make it glide over the hair and give a clean cut. There are modern parallels: many Indian hairstylists and barbers use a razor against a piece of wood, combing the hair flat across the wood, then pulling the razor across it to give a straight line and a smooth-looking finish to the style. However, no depictions of ancient Egyptian hairstylists cutting long hair have been found, so the method employed must remain just supposition at the moment.

After cutting, the next step was plaiting or curling the hair. The former would probably be done wet, whilst the hair would be dried before carrying out the latter. The curling would be done using curling-tongs (composite tool), then dressed and set using beeswax and resin and an assortment of hair accessories such as combs, hairpins or more ornamental head dresses (Fig. 3).



Hairstyling Technology and Techniques Used in Ancient Egypt. Fig. 1 Scanning electron microscope (SEM) photographs at 1,100X magnification of Romano-Christian hair, ca. third century AD, Egypt. The ends of the hair in this period have been cut using scissors leaving a blunt end. The cortex (central part of hair) and medulla (middle segment of hair shaft) have virtually disappeared due to calcification, which can clearly be seen on the surface of the cuticles (outside layers) (Photo by author).

Hairstyling Technology and Techniques Used in Ancient Egypt. Fig. 2 Egyptian copper mirrors in the Petrie Museum. Dynasty XII mirror with Hathor column handle (UC13286).



Hairstyling Technology and Techniques Used in Ancient Egypt. Fig. 3 Hair ornaments of Princess Sithathoriunet, a daughter of King Senusret II, Dynasty XII, Middle Kingdom, found with other jewels near her father's pyramid at Lahun now in the Cairo Museum: (a) Gold diadem; (b) Gold tubular hair ornaments that were threaded on the tresses of hair (Photo by author copyright Egyptian Museum of Antiquities, Cairo).

Tools Available to the Ancient Egyptian Hairstylist

The Razor – Form and Development

The copper razor (*s3*) had its beginnings in the Protodynastic Period (3350–3050 BCE). It was probably derived from the copper flaying knife (Petrie 1917) rather than the lithic "razor" which was no more than a side scraper. Originally there were two types of razor: an asymmetrical variant with a single lateral cutting edge and a symmetrical spatula-like tool (Fig. 4a) with parallel sides and a rounded cutting edge (Davies 1977: 110). The asymmetrical type soon fell out of use, and by the end of the Old Kingdom (2613–2181 BCE) had been almost completely replaced by the symmetrical type. This form went through a series of variations; in general terms, the sides proceeded to splay out (Stead 1986: 50) throughout the Old Kingdom.

During the Middle Kingdom (2040–1650 BCE) the cutting edge of the symmetrical razor began to protrude laterally (Fig. 4b). Coming in at this time (Dynasty XII, 1985–1795 BCE) is the scalpel-like razor or *dg3* type razor (Davies 1977). This type was made of a thin strip of metal (Fig. 4e), sharpened at one end, which later incorporated a loop (often in the form of an animal, bird or deities' head), in which to rest the little finger in order to help rotate the razor (Petrie 1917: 50). By Dynasty XVIII (1550–1295 BCE), the *mh'k* razor - one of the most characteristic pieces of toilette equipment of the New Kingdom (1550–1069 BCE) – had evolved into a hatchet-like form, with a wooden handle almost at a right angle to the cutting edge and a spur projecting from the rear of the razor. This is thought to have served as a counter-weight, to ensure proper balance and handling (Stead 1986: 50) and also as a little finger rest. Petrie called this type of razor the (horizontal) rotating razor (Fig. 4c). The rotating strip metal razor resembled the later splayed symmetrical razor and proceeded to evolve throughout the New Kingdom, with small varieties becoming more popular. Eventually the symmetrical razor evolved into a vertical rotating form, with its cutting edge splaying out even more to form a half-moon arc (Fig. 4d). By the end of the New Kingdom (ca. 1069 BCE), the rotating razor had superseded the scraping form. From the Middle Kingdom the handles of the scraping form were made in increasingly ornate forms, and by the New Kingdom the handles displayed zoomorphic designs and representations of deities of love and birth such as Bes and Taweret.

The Razor–Usage

The early razors were all of the scraping variety and were used with the hand grasping the handle or the end of the cutting edge (which was either on the inferior or lateral aspect of the tool). The development of the strip and rotating razor saw a technical change: the razor was grasped in the middle of the blade (by the handle or the blade itself) and rotated around the grip in a sawing motion, pushing the cutting edge through the hair. Epigraphic evidence and razor morphology suggest that the stylist would shave off the bulk (or all) of the hair using the large rotating razor and would possibly even style the hair/wig with it as well. The small razor was probably for personal use, and for the precision cutting of the intricate areas of the head and body that the larger razor could not safely reach. The inclusion of both types of razor in the toilette sets of the New Kingdom – such as those of Tutankhamun (Davies 1977) and Kha and Merit (Schiaparelli 1927) – seem to support the differing functions of the *mh'k* and *dg3* razors (Davies 1977).

Razors were sharpened on a whetstone made of tapered grained crystalline stone, (i.e. quartzite, diorite, basalt or even hard sandstone) using water and/or oil as

Hairstyling Technology and Techniques Used in Ancient Egypt. Fig. 4 Examples of the various types of razors: (a) Spatula razor, symmetrical, parallel sides and ivory handle (UC 40660) - scraping type, Old Kingdom; (b) Protruding or axe-shape razor (UC 40539) - scraping type, Middle Kingdom; (c) Horizontal rotating razor (UC 38368), New Kingdom; (d) Vertical rotating razor (UC 30134) with the God Bes for the handle, New Kingdom; (e) Looped strip metal rotating razor with goose head as handle (UC 40657), New Kingdom (Photos by author copyright Petrie Museum of Archaeology, University College London).

a lubricant. To stop the razor becoming blunt too quickly, it could be kept in a wooden razor case inside a leather pouch or case.

The Composite Tool (Curling-Tongs) and Tweezers

Other types of tools were available for the removal of unwanted hair, including tweezers and the composite tool. Tweezers are known from Dynasty I (ca. 3050 BCE) onwards; they had either pointed or squared ends, and varied in length from 2 cm to 10 cm, depending on the part of the body they were to be used on. The tweezers are made of a single piece of copper, bronze, iron or – more rarely – gold. The shape of the tweezers varied from triangular with sharp ends to more ornate varieties with paddle-like ends (Petrie 1917). These tweezers were easily bent out of shape, so were often set around a tapered bone, ivory, stone or wooden block that was shaped to fit the interior of the tweezers and thus prevent them from being misshapen (Fig. 5a). Tweezers would be used to remove any hairs not completely shaved off by the razor and to shape the eyebrows.

The most peculiar tool used by the Egyptian hairstylist was the composite tool or curling tongs, consisting of two metal (bronze) elements pegged together with a pin. One element is a trough-shaped piece of metal pointed at both ends, while the other element has a flat knife-like blade at one end and a cylindrical point at the other (the latter was sometimes omitted and replaced by a zoomorphic figure – Petrie 1917). The knife-like blade fit neatly into the other section, and could thus be used like scissors, while the other ends acted like tongs (Fig. 6a). As well as curling tongs, these instruments could also be used as a razor or as scissors, for cutting off any stray ends. These composite tools are found from Dynasty IV onwards and vary in size from about 5 cm to 20 cm in length, with various circumferences for giving different-sized curls. They were not as effective as scissors – which are not found until the Roman Period – because the cutting edges were not sharp enough and do not meet precisely enough for this purpose. As Petrie (Petrie 1917: 49) notes, the knife-like blade was the least important part of the tool, as it is diminished or is entirely absent in some later forms, being replaced by figures of a running jackal, galloping horse, running leopard, a pelican, or crane (with the hinged opening representing the jaws) or the Goddess Taweret (Fig. 6b). Some rather large knife-like blade types are found in Dynasty XVIII, and were used as curling tongs. The technique involved heating the tool over an open fire or brazier in order to set the curl, but this must have been tempered by a hot plate or boiling water – to avoid burning the hair – as the tongs show no sign of having been exposed to open flames. Some of these tools may have been set in wooden handles, as suggested by a gift list

Hairstyling Technology and Techniques Used in Ancient Egypt. Fig. 5 Tweezers: (a) Large pair of tweezers with a wooden block to keep its form (UC 40666), Middle Kingdom; (b) Small pointed tweezers for more delicate work (UC 40655), Early Dynastic Period (Photos by author copyright Petrie Museum of Archaeology, University College London).

Hairstyling Technology and Techniques Used in Ancient Egypt. Fig. 6 New Kingdom composite tools from the Petrie Museum of Archaeology: (a) Large, plain composite tool (UC 40664); (b) Panther and lotus blossom decorated medium sized composite tool (UC 30134) (Photographs by author copyright Petrie Museum of Archaeology, University College London).

in the Amarna Letters, which states, '29 spatulas of silver with handles of boxwood and ebony with which one curls the hair' (Kozloff and Bryan 1992: 428). Another indication that these tools were indeed used to curl hair is an example in the Manchester Museum which still has a curl of hair attached to it.

Combs and Hairpins

Pins and combs were used to keep the hair in place whilst it was being dressed, cut or styled, and for decorating it afterwards. These implements have their origins in the Predynastic but seem to have become very popular throughout the Pharaonic Period, where numerous combs and hairpins have been found in association with other beauty (cosmetic) equipment in houses and tombs throughout the country. The majority of well-provenanced combs are dated to the Ramesside Period (1295–1069 BCE) (Kozloff and Bryan 1992: 360).

The ancient Egyptian word for comb was originally *nši*, but this changed in the New Kingdom, where the *"n"* was replaced by a *"p"* to give *pši* or "divider" (Janssen 1975: 178–9). Combs were usually made of wood, ivory or bone. The choice of material and design suggest that they were designed to bend slightly in order to avoid splitting, some incorporating a long handle and a tapering effect from the top of the handle down to the tip of the teeth. Predynastic combs tended to be fairly ornate in design, and were sometimes made in two pieces and with large grip handles (Figs. 7a and b). The handles were often elaborately decorated and could constitute up to ¾ of the comb's total length, while the teeth lengths and widths were also highly variable. One comb with extremely long teeth of Naqada I date (3900–3700 BCE) is now in the Bolton Museum, No. 76.09.5 (Adams 1988). However, predynastic combs with very narrow handles and short teeth have also been discovered (Petrie 1896). Pin-tail combs first appear in the Naqada I Period, and consist of a square comb (usually of wood or ivory) with a long, thin "tail" protruding from the middle of the comb's body (Fig. 7d). This type of comb could be used as decoration in the hair with the teeth keeping it in place or to style the hair, the tail being used to tuck in the hair tips and arrange the hair, to select sections of hair to be styled or even for scratching the scalp.

Bird designs were by far the most popular motif in the Early Predynastic Period: a particularly fine example of an ivory comb with a double bird emblem is now in the British Museum, EA 18666. Spade and wild animal motifs were also present in the Naqada I Period; two ivory examples can be seen in the British Museum (EA 63075 - spade, and EA 63406, ibex). Anthropomorphic, zoomorphic and animal-headed designs including cow (probably the Goddess Bat or Hathor) headed designs increased in popularity during the Late Predynastic, although all designs were present throughout the period (Adams 1988; Garetto 1955). Early Dynastic combs tend to be shorter with the teeth cut more closely together, some as close as 2 mm (Garetto 1955), although some large ornate examples can still be found. One of the finest examples of such a comb (assigned to King Djet) has a very large handle, a centrally positioned niche palace facade *serekh*, with two *was*-sceptres and an *ankh* on the sides (Fig. 7c). The teeth of the comb are fairly fine and not very long in comparison with the handle (Emery 1961; Garetto 1955).

Hairstyling Technology and Techniques Used in Ancient Egypt. Table 1 Egyptian Chronology

Date	Period	Culture/Dynasties
7,000 BCE	Epi-Palaeolithic (7,200–6,000 BCE)	Qarunian
6,000 BCE		
5,000 BCE	Neolithic (5,200–4,000 BCE)	Merimdian, Faiyumian, Badarian, Omarian
4,000 BCE	Predynastic (4,000–3,050 BCE)	Maadian, Naqada I–III
3,000 BCE	Early Dynastic (3,050–2,613 BCE)	Dynasties I–III
	Old Kingdom (2,613–2,181 BCE)	Dynasties IV–VI
	First Intermediate (2,181–2,040 BCE)	Dynasties VII–X
2,000 BCE	Middle Kingdom (2,040–1,650 BCE)	Dynasties XI–XIII
	Second Intermediate (1,650–1,550 BCE)	Dynasties XIV–XVII
	New Kingdom (1,550–1,069 BCE)	Dynasties XVIII–XX
1,000 BCE	Third Intermediate (1,069–664 BCE)	Dynasties XXI–XXV
	Late Period (664–332 BCE)	Dynasties XXVI–XXX
500 BCE	Ptolemaic (332–30 BCE)	Ptolemaic Dynasty
	Roman (30 BCE–AD 306)	Roman Emperors
AD 500	Late Antique (AD 306–AD868)	AD641 Islamic Conquest
	Middle Islamic (AD869–1250)	
	Mameluk (AD1250–1517)	
	Ottoman (AD1517–1798)	

Hairstyling Technology and Techniques Used in Ancient Egypt. Fig. 7 A variety of combs: (a) Predynastic ibex comb (JE29805 and JE52861), Cairo Museum; (b) Predynastic combs in the Ashmolean Museum, Oxford; (c) King Djet's comb (JE47176), Cairo Museum; (d) Predynastic (Naqada II) pintail comb from Naqada/Ballas, Petrie Museum; (e) Roman denitting comb (UC58604), Petrie Museum. All photos by the author except C, which is courtesy Joris van Wetering, objects D and E copyright Petrie Museum of Archaeology, University College London.

Old and Middle Kingdom combs were simplified, with the handle becoming thinner and the teeth relatively longer, more similar to modern combs except for the highly ornate decoration with semi-precious stones or faience beads (Fletcher 1995: 441; Garetto 1955). From the New Kingdom onwards, comb designs became increasingly variable, generally becoming more ornate and with more stylistic categories. The comb's teeth start to vary in length, width and spacing, reflecting the fact that they were designed to serve different purposes rather than the all-purpose combs of earlier eras. The combs with short, closely spaced teeth would have been used for denitting and grooming. The combs with long, widely spaced teeth were primarily designed to be worn in the hair (as reflected in their usually high level of decoration) once it was dressed, or for detangling the hair. The intermediate form (medium length, intermediately-spaced teeth) would have been used to comb the hair into style. A fine wooden example with incised lotus petals on the handle, originally with blue paste filling the spaces, was found at Abusir el-Malek. Measuring 17cm long by 5cm high, this comb is dated to Dynasty XVIII, JE 36233 - CG 44316 (Freed 1987: 182). Other examples of these simple combs were found in the tomb of Kha. The two small combs belonging to his wife Merit were 7.5 cm × 4 cm and were undecorated, except for a slight trace of gilding (Garetto 1955). Rectangular double-sided combs without any handle also appeared in the New Kingdom and were usually designed to be multifunctional with closely spaced teeth on one side and widely-spaced teeth on the other (Fig. 7e). Pintail combs also reoccur in the New Kingdom.

Hairpins or bodkins were usually made from ivory or wood and measured between 10 cm and 16 cm. They derived their Egyptian name (*3b*) from the term for ivory *3bw*, although they were also made of copper, bronze, bone, or sometimes tipped with gold or other precious metals. Predynastic and Early Dynastic hairpins were often ornately decorated with zoomorphic or anthropomorphic figures and geometric designs (Fig. 8). The Old Kingdom and Middle Kingdom hairpins tend to be less ornate, with a simple engraved top, minimal (or absent) incised decoration and a bulbous or pommel head. While plain pins were used throughout Egyptian history, the range of new designs and decorations in New Kingdom pins is marked. Made from a range of materials including gold (both leaf and solid), elite versions were often decorated with zoomorphic or anthropomorphic designs. Precious metal examples include several gold hairpins that were found in Kha's tomb (Schiaparelli 1927), while a fine example of a well-executed zoomorphic design in ivory is that of a hairpin head upon which an ibex turns her head with affection to observe her suckling calf. The recurring image of the ibex (i.e., the comb mentioned above) reflects the importance of Hathor to rituals of beauty and the artefacts related to those rituals. This fine hairpin is 9.5 cm long and is exhibited in the Boston Museum of Fine Arts (Freed 1981).

Hairstyling Technology and Techniques Used in Ancient Egypt. Fig. 8 A variety of different hairpins in the Cairo Museum, Predynastic Period (Photo by author copyright Egyptian Museum of Antiquities, Cairo).

The hairpins were used both to dress (keeping locks in place) and to decorate (after dressing) the hair. Depictions of hairpins in use are again rather limited, although more numerous than those depicting combs. One of the finest examples is the Middle Kingdom hairdressing scene where Queen Neferu's maidservant Henut has pinned the top section of her mistress's hair out the way with an ivory bodkin whilst weaving a braid into the hair (Riefstahl 1956: pl. IX).

By the middle of the Old Kingdom, the increasing availability of copper tools meant that ancient Egyptian hairstylists were able to cut, curl, tint, set, and plait the hair in numerous ways. As technology and alchemy progressed and the Egyptian empire expanded in the New Kingdom, hairstylists developed new styles as well as various ways to perfume and dress the hair fostered by emulation and increasing social complexity.

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To find out more about the author's work please visit the Website of the Egyptian Cultural Heritage Organisation: ►http://www.e-c-h-o.org

Haridatta

K. V. Sarma

Haridatta was the promulgator of the Parahita system of astronomical computation widely used in Kerala in South India, from where it spread to the neighboring state of Tamil Nadu. There are two basic texts of the system: the *Grahacāranibandhana* and the *Mahāmārganibandhana*, the latter of which is no longer extant. Haridatta inaugurated the system, as the legend goes, on the occasion of the 12-yearly religious festival held at the temple town of Tirunāvāy on the banks of the Bhāratappuzha River in AD 683. The system was called *Parahita* (suitable to the common man), because it simplified astronomical computation and made it accessible for practice even by ordinary people.

Haridatta based his system on the *Āryabhaṭīya* of Āryabhaṭa (b. 476), but made it simpler in several ways. First, he dispensed with the rather cumbersome and terse numerical symbolism used by Āryabhaṭa and substituted the facile, easily manipulated *ka-ṭa-pa-yā-di* system of notation. In this system, specific letters were used for representing digits, which could be arranged to form meaningful words and even sentences, which could be remembered with much less possibility of error.

Computations in Indian astronomy involved long numbers for planetary revolutions and other parameters for the aeon. To avoid these long numbers in multiplication and division, Haridatta ingeniously introduced a subaeon of 576 years or 210,389 days, and accurately determined the zero-correction for this subaeon for the mean motion of the several planets. In actual practice, Haridatta directed the aeonary days for any current day being divided by the subaeonary days. The quotient would then give the number of completed subaeons, and the remainder the days in the current subaeon. The above quotient multiplied by the subaeonary zero-corrections of the several planets would give the mean planets at the commencement of the current subaeon. In order to make calculation easier, when a large number of years passed, Haridatta gave these zero-corrections for chunks of six subaeons. To find the mean motion of the several planets for the completed days in the current subaeon, Haridatta gave certain sets of simple multipliers and divisors. The mean motion arrived at using these, when added to the mean position at the commencement of the current subaeon, would give the mean planet for the current date. In order to obviate the large numbers that would accumulate to mean planets when the Āryabhaṭan parameters were used, Haridatta prescribed a corrective called *Vāgbhāva* (Corrections to be Applied to the Different Planets from AD 523).

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The Parahita system promulgated by Haridatta has been extremely popular in Kerala, and a very large number of texts and tracts based on the system have been produced in that part of India, both in Sanskrit and in the local language Malayalam. The system has also been regularly used for the computation of the daily almanac.

See also: ►Astronomy in India, ►Āryabhaṭa

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Ḥasdai Crescas

TONY LÉVY

Ḥasdai ben Abraham Crescas (1340–1412) was one of the most influential personalities of Spanish Jewry in the end of the fourteenth century. As chief rabbi of the Aragonian Jewish communities during the persecutions of 1391, he was responsible for their reconstruction. Although his literary work was not very large, it constitutes an important contribution to the history of philosophical and scientific ideas, mainly as a critique of medieval Aristotelianism.

Under the influence of Maimonides' *Guide for the Perplexed* (translated from Arabic into Hebrew in the beginning of the thirteenth century), Aristotelianism had spread in Jewish circles, raising many controversies. Besides those who opposed the study of philosophy only on the ground that it undermined religious beliefs, others invoked scientific and philosophic arguments to give support to their own critique of philosophy. Crescas is certainly the most important of the latter critics.

Apart from a short composition, *Biṭṭul ʿIqqarey ha-Noṣrim* (Refutation of the Principles of Christianity), Crescas' main work is his *Or Adonay* (Light of the Lord) completed in the last years of his life. In the first part of this book the fundamental concepts of Aristotle's physics and metaphysics, as adapted by Jewish philosophers, were analyzed and criticized.

Crescas' main purpose was to establish that the existence of God, His unity and His incorporeality could not be fully proved by demonstrative reasoning, as Maimonides had argued: "it is impossible to arrive at a perfect understanding of these principles except by way of prophecy, …, and yet it will be shown that reason agrees with the teachings thus arrived at." In this sense, one could say that Crescas did not criticize philosophy as such, but rather the intellectualization of religion by Aristotelian scholastics. Actually, in many respects, Crescas opposed to Aristotelian philosophical notions other philosophical notions, more relevant – according to him – to the purposes of philosophy itself.

The main importance of Crescas' contribution lies in his critique of Aristotle's concept of the infinite, and its applications to the notions of space, number and time.

There are three main conclusions of Crescas' analysis which are relevant to history of science. The first is in opposition to Aristotle who had argued that the place of a body (i.e., space) was the inner limit of the enclosing body, Crescas asserted that space was prior to bodies and that the place of a body was equivalent to its extension. Thus the existence of a void was not self-contradictory. Secondly, again in opposition to Aristotle who had argued that the universe was finite, because nothing could be infinite, neither a body nor a substance, Crescas claimed that there was no absolute limit to space. Space was an infinite receptacle, which could contain many other worlds. By analogy, space could be thought of as God's omnipresence. Finally, Aristotle and Aristotelians argued that an infinite quantity was impossible, because it would lead to the absurd conclusion of one infinite quantity being greater than another. Crescas' reply was of importance since it could be viewed as anticipating some modern concepts: the relations "equal to," "greater than," and "smaller than" do not apply to the infinite, in the same manner that they apply to finite quantities. Thus, the notion of an actual infinity is not self-contradictory.

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Hay'a

F. Jamil Ragep

The Arabic term *hay'a* had several distinct significations when used in the medieval astronomical context. Its basic meaning is "structure" or "configuration"; it was used as such to connote the physical structure of the universe as a whole (*hay'at al-ʿālam*) or a distinct part of that structure, as in the *hay'a* of the Earth or of Venus. It also referred to those works of theoretical astronomy in which that structure is dealt with in detail. As part of the phrase *ʿilm al-hay'a* (the science of *hay'a*), it came to refer, especially after the eleventh century, to astronomy in a general sense. This is an indication of the importance given to physical cosmography in Islamic astronomy. Here the main focus will be on *hay'a* in the sense of the Islamic astronomical genre devoted to cosmography.

Before proceeding, it is important to note two points. Although the term *hay'a* was occasionally used to indicate a religious cosmology, works on *hay'a* are mainly cosmological in the scientific and not the religious sense. Second, this tradition, though departing from it in numerous ways, owes its origins and inspiration to the Hellenistic scientific tradition.

The main ancient sources for the Islamic *hay'a* tradition were the cosmological writings of Aristotle, in particular his *De Caelo* and his attempt in the *Metaphysics* to give a coherent structure to the models of Eudoxus, and the astronomical writings of Ptolemy, especially his *Planetary Hypotheses*. These works provided the fundamental assumption of Islamic theoretical astronomy, namely that the subject matter of astronomy was the simple *physical* bodies, both celestial and sublunar. An astronomer writing in the *hay'a* tradition was charged with transforming mathematical models of celestial motion, usually those of Ptolemy's *Almagest*, into physical bodies that could be nested, along with the sublunar levels of the four elements, into a coherent cosmography (*hay'a*). Despite the obvious connection and dependence on Greek natural philosophy, this "astronomical" (or external) cosmology was often contrasted with both the tradition of Aristotle's *De Caelo* and the astrological corpus, both of which were held to deal with the essential (or internal) aspects of the bodies. Note that because *hay'a* was intended to give a general picture of the universe, it also dealt with the "configuration" of the four sublunar elements. Thus most general treatments of astronomy after the eleventh century came to have a section on the "configuration of the Earth" that included general discussions of geography.

The prevalent *hay'a* was that the universe was a plenum composed of nine contiguous, solid, spherical bodies called orbs, all concentric with an immobile, spherical Earth. The lowest of these, that of the moon, enclosed the four sublunar levels of the four elements: fire, air, water, and earth. Each of the "concentrics" had embedded within it additional, nonconcentric, spherical orbs called eccentrics and epicycles, the former hollowed-out spheres surrounding the Earth, the latter full spheres within the eccentrics. There was one concentric each for the seven "planets" in the following order – moon, Mercury, Venus, sun, Mars, Jupiter, Saturn – another for the fixed stars, and a starless ninth that was the source of the daily motion. Except for the sun, which was embedded within an eccentric, the planets were situated on the inside surface of their epicycles. Opinions varied as to how motion occurred but generally this was held to result from a combination of the proper motion effected by the orb's own soul and the accidental motion that was a consequence of being contained inside other orbs. All the celestial orbs were composed of a special fifth element called "aether," unlike the four sublunar elements, it could only rotate with uniform motion. Among the most famous and influential works on *hay'a* were the *Hay'at al-ʿālam* (Configuration of the World) by Ibn al-Haytham (d. ca. 1040), the *Tadhkira fī ʿilm al-hay'a* (Memoir on Astronomy) by Naṣīr al-Dīn al-Ṭūsī (d. 1274), and *Al-mulakhkhas fī al-hay'a al-basīṭa* (Epitome of Plain *hay'a*) by al-Jaghmīnī (thirteenth or fourteenth century).

Although the above cosmography derived for the most part from Ptolemy's *Planetary Hypotheses*, Islamic theoreticians found much to complain about and proposed numerous alternatives that were meant to reform or supersede his models. In his *Doubts About Ptolemy*, Ibn al-Haytham pointed to certain devices that Ptolemy had introduced in the *Almagest*, such as the equant, that violated the principle of uniform circular motion; as such, it was not possible to physicalize such models in any straightforward way. In the thirteenth century, a number of writers, beginning with Naṣīr al-Dīn al-Ṭūsī, who was the first director of the Mongol-sponsored Marāgha observatory, proposed alternative models that were meant to reform the Ptolemaic system. These efforts continued for at least three more centuries and included the work of his colleague Mu'ayyad al-Dīn al-ʿUrḍī, his student Quṭb al-Dīn al-Shīrazī, Ibn al-Shāṭir, the timekeeper of the Umayyad Mosque in Damascus during the fourteenth century who proposed an astronomy without eccentrics, and a number of people associated with the Samarqand observatory in the fifteenth century.

A much more radical attempt to transform the Ptolemaic system occurred in twelfth-century Islamic Spain. A number of Aristotelians, including the famous philosopher Averroes (Ibn Rushd), sought a radical reform of Ptolemaic astronomy that would rid it of epicycles and eccentrics altogether. The motivation was to return to a purer astronomy in which there was only a single center of celestial motion. The end product of this movement was the work of al-Biṭrūjī. His system, reminiscent of that of Eudoxus, was not very successful from a mathematical point of view, but it was quite influential in the Latin West.

This was not the only case in which Islamic *hay'a* influenced science in other cultures. Byzantine astronomers were certainly aware of this tradition; we also know of several *hay'a* works that were translated into Sanskrit in the eighteenth century. Given that the *Planetary Hypotheses* was unknown during the Latin Middle Ages, it is clear that the main source for the European *theorica* tradition was Islamic *hay'a*; Ibn al-Haytham's *Configuration of the World* was certainly quite influential. In recent years, very strong similarities between the models and motivations of several Renaissance astronomers (including Copernicus) and the late *hay'a* tradition have been discovered, and it now seems quite likely that the former were influenced by Ṭūsī, Ibn al-Shāṭir, and other post twelfth-century writers on *hay'a*. However, because their works seem not to have been translated into Latin, the most likely means of transmission is through Byzantine sources that made their way to Italy (and perhaps Vienna) in the fifteenth century.

See also: ►Astronomy in the Islamic World, ►*Almagest*, ►Geography in the Islamic World, ►Ibn al-Haytham, ►Naṣīr al-Dīn al-Ṭūsī, ►Marāgha, ►alʿUrḍī, ►Ibn al-Shāṭir, ►al-Biṭrūjī

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Hazama Shigetomi

Jochi Shigeru

Hazama was a Japanese mathematician and astronomer in the Edo era. He was born at Osaka, the sixth son of Toichiya Gorobei, on March 8, 1756. His family were merchants and managed the Shichiya (bank) at Osaka.

In 1795, the Shogun government planned to make a new calendar using Western astronomy. The former calendar, the Horeki calendar (1754), was a quite traditional Eastern Asian calendar, although Shogun Tokugawa Yoshimune (1684–1751, eighthShogun, r. 1716–1745) wanted to use Western science. But there were no astronomers who had mastered Western astronomy in the Bakufu Tenmongata (Shogun's Astronomical Observatory). They asked Asada Goryu (1737–1799) to make a new calendar. However, Asada was already over 60 years old, so he recommended two students, Takahashi Yoshitoki (1764–1804) and Hazama Shigetomi.

Takahashi was a *Doshin* (police officer) and a Samurai warrior. As Hazama was a merchant, Takahashi did the main work, and Hazama supported him financially. They worked in the Bakufu Tenmongata at Asakusa, Edo. Then Takahashi went to Kyoto to observe in 1796, and Hazama remained at Edo. They

Hazama Shigetomi. Fig. 1 Hazama Shigetomi's picture at the Osaka Museum of History.

Hazama Shigetomi. Fig. 2 Hazama Shigetomi's Tomb at the Tokoku-ji temple, Chausuyama, Tennoji, Osaka.

wrote the *Rekiho Shinsho* based on Kegler's (Part 2 of) *Li Suan Quan Shu* (1742, China, the same name as Mei's book) in 1797. They began using the Kansei calendar the next year.

There were two original points in this calendar. 1) They observed the position of the sun from its under edge when they observed the solar eclipse. 2) They defined the twilight, saying that it was two and half *Koku* (one day was 100 *Koku* at that time) before the sunrise and sunset on the Spring and Autumn Equinox Day in Kyoto.

Hazama also promoted the engineering of astronomical tools.

He died on March 24, 1816[1] in Osaka.

[1] Nihon Gakushiinn (1960): 211 describes that he died in 1838, but we obey Nihon Gakushiinn (1954) vol.4: 141, that is to say, in 1816.

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Health Sciences in India: Traditional Health Sciences and their Contemporary Application

Darshan Shankar, Padma Venkat

The healthcare scenario in urban India and globally is undergoing dramatic transformation, evolving into systems that emphasizes preventive health, customized care, body-mind medicine and the use of natural products. It is in this context that there has been in recent decades a resurgence of interest in the traditional Indian systems of medicine (ISM). The ISMs are based on the use of natural products. They view the human being and other life forms holistically in terms of both body and mind. They assess the uniqueness (*prakṛti*) of each individual and their universal principles can be tailored to the needs of every individual.

The transformation that is taking place in the healthcare scenario is reflected in the marketplace. The global market for herbal products is booming. The *Task Force Report of the Indian Planning Commission on Conservation and Sustainable Use of Medicinal Plants* (2000) estimated it to be about 62 billion per annum and rising at the rate of 15% per annum. A large percentage of the population in Asia, Africa and South and Central America also depend on traditional knowledge and medicinal plants for their primary health care needs (WHO 1993). This dependence is likely to continue, as rising costs of conventional healthcare make the traditional plant-based solutions the most viable, safe and affordable option.

Observers of the health sector believe that any societal model of healthcare based on a single system of medicine will soon become obsolete unless it broadens out to combine with complementary systems of medicine. The world's oldest codified and living systems of healthcare are Āyurveda, of Indian origin, and Traditional Chinese Medicine.

It is in the context of this growing consumption of traditional products that questions regarding quality standards have become a matter of concern to policy makers, consumers and to the regulatory authorities. Due to the difference in epistemologies, centuries of clinical evidence and practical methods for quality assurance that are available in the traditional ISM cannot automatically be transferred onto the parameters of western biomedicine, and such translations need to be supported by serious inter-cultural research and epistemologically sensitive methodology. An inter-cultural approach is inevitable because most herbal products originate from non-Western health sciences.

The English word "science" refers to a special kind of knowledge, which is clarified through reason and analysis. We find that our unclarified perceptions of the world are often too narrow, and that our assumptions and beliefs are all too often prejudiced. Accordingly, we use our scientific reason in two ways. On the one hand, we can put our narrow perceptions together, thus building them into broader pictures of the world. The world is thus described objectively, by relating objects in conceptual pictures. Through systematic reasoning, these pictures grow into coherent fields of knowledge. Each field of knowledge has its own consistency, as a conceptual system, and each one has its place among the other fields.

On the other hand, in order to correct mistakes, our scientific reasoning can function in reverse. Instead of building pictures up, it can reflect back down, in order to investigate assumptions and beliefs. This reflective reason is essentially subjective. Its purpose is to educate, by asking questions that correct the questioner's own understanding. In Sanskrit, this corrective education is described by the word *śāstra*. Literally, "śāstra" means "correction" or "governance", but it is often used as a traditional word for science. It thus conceives of science as a correcting governance that is administered reflectively, through inward-turning reason.

These two ways of using reason have a long history of working together, since the beginnings of ancient science. But in the last few centuries, the objective way has prevailed. Unfortunately, the development has been one-sided. Our modern sciences have a tendency to emphasize the objective and calculating use of reason. So there has been a corresponding neglect of subjective education. It could well be argued that our current environmental crisis comes from this neglect of a more deeply reflective education, which is now needed to make better use of our specialized objective capabilities. The neglect has gone so far that the word "subjective" is routinely assumed to mean just "personal", and a subjective use of reason is thus put outside the essential and proper functioning of science.

Since science is essentially concerned with knowledge, it cannot be just personal. The problem is that our personal faculties are partial. They are partial faculties of body, sense and mind, which show us partial and differing appearances. No such appearance is entirely correct. Each bodily or sensual or mental appearance needs correction, to allow for different points of view. Therefore an impersonal standardization is essential to all sciences. But it can be approached in two ways, which are again objective and subjective. The objective approach is directed externally, by prescribing standard techniques and instruments in the external world. The subjective approach is turned back in, through a reflective investigation of common principles that different people share, beneath the differing phenomena that nature manifests to them.

In the modern physical sciences that have developed in the last few centuries, the standardization is restrictedly objective. It requires that all theories are tested and applied through standardized instruments and machines, which we fabricate and use in the external world. Subjective reflection is specifically confined to the intuitive creation of ideas and theories. Once the theories are created, they must be tested and applied through their calculation of predicted results, which are measured and observed by a mechanical technology.

In older sciences, which have been developing for some thousands of years, more use is made of subjective reason. Here, reason works through education. Ideas are tested and applied in a living process of learning from experience, through common principles that underlie the variations of personality. The older sciences are based upon that inward investigation, towards a depth of knowing which is both subjective and impersonal. That depth of subjectivity is described by the Sanskrit words *ātma* and *ātmīya*.

The word "*ātma*" means "self". It describes the self as a knowing subject at the inmost depth of personality, beneath the outward appearances of body, sense and mind. The word "*ātmīya*" means "subjective". It refers to an inmost subjectivity, which is attained by reflecting back within. Here the word "subjective" is not being used to mean just "personal". The self-called *ātma* is an inner principle of consciousness or spirit, and the word "*ātmīya*" thus means "spiritual". It refers to a pure spirit that is found by inward detachment from outgoing personality[1].

[1] The above discussion on science, vijñana and on objective and subjective standards has borrowed from the unpublished article on Knowledge Before Printing and After of Ananda Wood, an eminent scholar and philosopher of science.

To place the above discussion in the specific context of healthcare, Table 1 gives a picture of the different epistemological foundations of western biomedicine and Āyurveda. It is important to appreciate these epistemological differences per se and not in terms of which is right or wrong or more superior or less. They represent different ways of knowing and viewing nature.

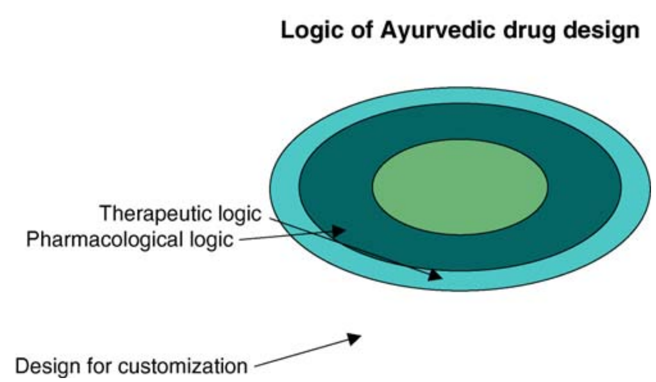
The traditional Indian systems of healthcare also have their own internal quality standards and logic for drug design and therapeutics. Table 2 illustrates the different logic of drug design and therapeutics used in Āyurveda.

Āyurveda is primarily based on the notion of "homeostasis". This outlook is different from the

Health Sciences in India: Traditional Health Sciences and their Contemporary Application. Table 1 Two different knowledge systems

	Āyurveda, Indian health system	**Biomedical science**
Differing foundation	Based on nine existential entities: Earth (*pṛthivī*), Water (ap), Fire (agni), Air (*vāyu*), Space (*ākāśa*), Mind (manas), Time (*kāla*), Direction (dik), and the Soul (*ātman*)	Based on three existential entities: Matter, time and space
Differing worldview	Recognizes physical, biological and spiritual worlds	Recognizes physical and biological worlds
	Sāṃkhya	Logical positivism and later schools
Differing logical system	Nyāya *Vaiśeṣika*	Aristotelian logic and its evolution
Differing categories	*Guṇa*	Phyto-chemistry and pharmacology
Differing pathogenesis	Loss of homeostasis	Infection via bacteria, parasite, virus

Health Sciences in India: Traditional Health Sciences and their Contemporary Application. Table 2 Logic of Ayurvedic drug design



Therapeutic logic
- To break the chain of pathogenesis of a particular disease
- To alleviate specific symptoms of particular disease
- To block progression of the disease
- To reduce complication or associated diseases

Pharmacological logic
- To select principal drugs and adjuvants having balanced therapeutic action
- To enhance bioavailability, spread and penetration, through appropriate dosage forms, time of administration, method and route of intake
- To design a combination of ingredients that does not cause unintended side effects

Design for customization
- Drugs should suit Prakriti (genotype), age, customs, mental poise of the patient
- Drugs should suit local habitat and climate in which the patient resides
- Drugs should suit the digestive capacity (agni) and food habits of the patient

Source: based on the *Carakasaṃhitā*.

theoretical approach of western medicine, which is largely based on disease causation due to infection, structural damages and systemic disorders whose etiology is poorly understood.

It is Āyurveda's hypothesis that any disease, whether acute, chronic, degenerative, infectious or functional, occurs only when there is an internal imbalance or loss of equilibrium in the physiological or psychological functions of the body. The Āyurvedic treatments are designed to restore the specific kinds of imbalances caused by a particular disease. They are designed not only to resolve the immediate problem of the patient but also contribute to his/her sustained quality of health (*Āyushyam*). A drug is only one part of treatment. A holistic treatment also includes diet, non-drug therapies (like yoga and pancakarma) and life style changes.

In an emerging era of medical pluralism the project of developing modern inter-cultural standards for quality, safety and efficacy of traditional ISM is not only important for Indians but also for global consumers. This article outlines the strategy for building upon traditional knowledge to create internationally acceptable modern quality standards.

Do Traditional Quality Standards Really Exist?

Any living, evolving system of traditional medicine which has served society for several millennia – such as we see in Asia, Africa and Latin America – could not have survived without possessing quality standards of its own. In most societies in these regions, health traditions remain undocumented because they are transmitted orally from generation to generation. This oral transmission, despite its remarkable efficiency, outreach and cost-effectiveness, is poorly understood. There are also codified medical traditions with theory and clinical practice documented in the form of thousands of medical manuscripts in India and China.

In all traditional health cultures, quality standards do exist. They are expressed in the form of descriptions, advice and recommendations for identifying, collecting, processing and therapeutic use of natural products. The criteria for collecting plants, for instance, may include the best season and stage of growth for the plant to be most therapeutically active, and the best regions for gathering them in order to heighten their medicinal potency. There are also standards for storage, post-harvest, processing, and for finished products. Standards also exist for safety and efficacy.

In traditional societies, the health functionaries – the plant collectors, those who store the plants, and the physicians who prepare and administer the medicines – usually belonged to the same community as their customers. In earlier times the knowledge and integrity of the collectors and physicians served as an assurance of high standards. Today, the traditional quality standards can no longer be applied as those involved in preparing the medicines never meet their millions of customers face to face. Moreover, many more people are involved in the production and distribution chain. There is also a problem of soil, water and air pollution that can contaminate the raw materials.

The Inter-Cultural Approach to Building Quality Standards

An inter-cultural approach involves the use of the modern scientific tools of physics, chemistry and biology to establish universally verifiable quality standards. The identification of the quality parameters that are to be standardized, however, does necessarily need to be based on the traditional knowledge systems from which the products are originally derived.

The evolution of inter-cultural standards is not an easy task as it assumes cross-cultural understanding and needs to engage experts in traditional knowledge and modern science in a mutually respectful dialogue. This is not a short-term task; institutions for inter-cultural research need to be created. The starting point for creating quality standards is to establish the identity of the raw materials that go into the making of natural product. To identify the raw material (a plant, for instance), a reliable traditional source – texts as well as traditional knowledge holders – must be consulted. Tradition identifies materials by vernacular names and descriptions. It is necessary to link the vernacular names and descriptions of plants to the appropriate botanical entity. For example *Tulasi* is the vernacular name of a plant which when pointed out to a botanist would be correlated to *Ocimum sanctum.* In the case of certain vernacular names, however one vernacular name may correspond to more than one botanical entity. For example in the case of the plant referred to as *brahmi,* the Āyurvedic texts correlate this name to two distinct botanical entities *Baccoba monneri* (Neer brahmi) and *Centella asiatica* (Mandūkaparni) (Sastri 1993). Other vernacular names like *pashan bhed* and *śankhapushpī* also have several botanical sources and acceptable regional substitutes, which are different species that possess similar pharmacological activity. There is another kind of complexity connected with vernacular names. This is the problem of synonymy wherein a single traditionally used plant entity may have as many as 70 vernacular synonyms, and one needs the help of traditional scholars to group all the vernacular synonymy that refers to a particular plant. This can be best illustrated by citing the case of a very important Āyurvedic text called the *Carakasaṃhitā*. In this text there are 12,000 plant names, but after resolving the problem of synonymy, these 12,000 vernacular names refer to only around 620 unique plant entities (Gopal 2004). These are the kinds of problems that are involved in establishing the botanical identity of a vernacular plant name. It should be clear from the above that in order to establish the correct identity of a plant it is essential for botanists and traditional physicians to work very closely with each other because the inter-cultural correlation between vernacular names and botanical entities needs the intelligent involvement of both.

Since biological materials possess genotypic and phenotypic variability, while establishing standards in the case of a species with either a wide distribution range or even in the case of endemic populations, the sampling size should be adjusted to represent this diversity. For example *Phyllanthus emblica* is distributed right from the coastal plains to sub-tropical habitats and therefore standardizing such a material would require a statistically valid sampling strategy for this purpose.

The next stage in quality assurance of a raw material is to standardize collection procedures based on traditional recommendations regarding season, region and maturity of collection. and how it is processed and stored. Traditional medical texts under the topic *deśa vicara* specify the collection of raw materials at specific times of the plant's life cycle or advise collection from specific habitats. For example, the traditionally recommended mature tubers of the plant *Ipomea mauritiana* are richer in terms of both their bioactivity as well as in phytoconstituents than their immature counterparts (Venkatasubramanian 2004). Another similar case involves the difference between the bioactivity of fresh and dry brahmi. Another example of collection standards is the case of Turmeric (*Curcuma longa* L.) whose rhizomes for therapeutic purposes are collected at nighttime. Preliminary studies indicate that bioactivity of turmeric collected at night was significantly different from that collected during the day. *Neem* (Azardicta indica) manifests its best therapeutic properties when collected from hot, dry and arid habitats (e.g. Rajasthan) than when it is collected from a high rainfall area (e.g. Kerala).

The more complex aspect of quality assurance arises in respect to the standardization of the finished product. Traditional products of different cultures use a wide range of processing techniques and also dosage forms, from simple powders made from a single plant, to extracts made from many plants. The finished products may be aqueous extracts, herbal wines, herbal oils, baked products, plant starches or alkalis. Standardizing all these myriad process and products poses a real challenge to modern scientists. An interesting example of the relevance of traditional advice regarding processing can be seen in the case of an important pepper (*Piper longum*). This species is very widely used in Āyurveda. The extract of this plant in milk rather than water is better for therapeutic application. Bioassays indicate that the extract of the plant in milk is 27 times more active than the aqueous extract.

The Inter-Cultural Gap in Pharmacoepias

Today's Western-knowledge based pharmacopoeias – official handbooks on medical treatments – of traditional medicine like the US Pharmacopoeia, WHO monographs and even the Āyurvedic Pharmacopoeia of India, largely fail to adopt a comprehensive inter-cultural approach in setting quality standards. The quality standards they lay out for the drugs are limited to the presence of particular ingredients that are assumed to be active rather than the whole range of compounds that may be responsible for the drugs therapeutic actions. Most pharmacopoeias list aspects such as morphology, microscopy, physicochemical characteristics, nature of phytoconstituents and chromatography profiles, but are not as yet much informed by, or sensitive to collection protocols that are critical for the quality standards established by traditional health cultures. They are usually silent on the standards for several traditional dosage forms and online processes involved in their manufacture. This is partly because the information on traditional quality standards is not available in one place as a "ready reckoner" but mainly because an inter-cultural perspective is absent in their design.

International Regulations on Traditional Medicine

The biggest challenge lies in setting modern standards for evaluating a traditional drug's efficacy. This probably calls for a paradigm shift by designing a more holistic approach undertaking clinical trials. Most systems of traditional medicine adopt a multi-pronged approach to treatment. This involves drugs, diet and non-drug therapies. They aim at improving both mental and physical well-being. Furthermore, the causes of disease and their classification in traditional systems of medicine do not have a one-to-one correlation with Western counterparts. Finally traditional treatments are designed to achieve homoeostasis, rather than to eliminate a single invasive agent.

These differences in the approaches to treatment give rise to two issues. The first is that unconventional evaluation protocols are needed to assess an entire treatment "package", rather than one specific drug. The second is the need to use appropriate clinical, physiological, psychological or biochemical indices for evaluating outcomes which correlate well with the traditional understanding of cure.

In cases where differential diagnosis and treatment is indicated by TM for patients who from the western biomedicine perspective are suffering from the same disease, the conventional double-blind, placebo-controlled clinical trials might not always be necessary or appropriate. Case studies and observational studies –in which a clinical investigator monitors the effectiveness of treatment – can be valuable (Chaudhury and Chaudhury 2002). Clinical trials need to be generally designed to evaluate a management

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regime, rather than a particular drug, although in the case of OTC drugs, the conventional design of drug trials is perhaps relevant.

In recent times regulatory authorities in importing countries such as Germany have restricted the role of traditional medicines to supplements that can be used only for "indications such as invigorating and strengthening" and which cannot be "intended to cure or treat disease" (Blumenthal 1998). This is because investing in efficacy studies based on inter-culturally sensitive research models has not been recognized as an important enough area. In clinical research, most of the pharmacopoeial standards that are now available have been restricted to single plant extracts or at most extracts of five herbs as fixed combinations. This restrictive approach to the use of traditional medicine is depriving consumers round the world of many of the benefits of several sophisticated poly-herbal traditional remedies.

With respect to safety, traditional remedies will need to be assessed within the same parameters now used for modern pharmaceutical, nutraceutical and cosmeceutical products. The WHO has accepted that traditional medicines may need less rigorous preclinical toxicological evaluations since their safety of use has been documented historically (Venkatasubramanian 2004). However in the case of traditional products that are based on the use of metals and minerals, whereas they are known to be therapeutically potent, it is extremely important to ensure that the traditionally prescribed processes are rigorously adhered to else the products can result in toxic side effects. In fact the traditional pharmacy texts themselves underline the need for such rigor. For example in the case of *bhasmas* the particle size of the finished products is expected to be smaller than the intracellular space and the products should no longer carry any trace of the metal in its original form. Modern tools like the electron microscope and atomic absorption spectrometer can aid in the evaluation of such products.

The latest EU regulations on traditional medicine state that traditional products must be safe and meet prescribed standards of quality if they have been used for at least 30 years. A catch in this legislation is that 15 years had to be within the European Community itself (Chaudhury and Chaudhury 2002). This is in principle a progressive rule because it recognizes the value of traditional knowledge. Its practice however needs to be worked out in a way that is fair and makes best use of traditional medical cultures that are located outside the European Union.

Policymakers and medical researchers should understand that the evaluation of traditional systems of medicine and their inherent standards involves intercultural research. This is a vital pursuit, as it can enrich the field of medical pluralism – which in its turn seems to be the best route towards the advancement of world medicine.

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Holography[1]

JEHANE RAGAI

"Appearance and Reality"

This article attempts to show that an ancient period of human creativity as expressed in Egyptian art has an analog in the twentieth century discovery of holography. Parallels are perceived between both the "frontal-profile stance" and the "canonical tradition" of Egyptian art and the model of the hologram. These analogies appear on both the "empirical" and "conceptual levels".

Recent breakthroughs in modern physics (Capra 1980; Zukhav 1980; Jones 1983) have drawn attention to the innumerable parallels between the new ways of interpreting modern physics and Eastern mysticism. Capra (1980) in his Tao of Physics reflects this trend when he observes:

> …The basic elements of the Eastern world view are also those of the world view emerging from modern physics… Eastern thought provides a

[1] It is to be noted that an earlier version of this article appeared in 1986 both in English and in French, in Aujourd'hui l'Egypte. Permission to reproduce an updated version was granted to the author by the editor of Aujourd'hui l'Egypte: Mr. Jean Chamas.

consistent and relevant philosophical background to the theories of contemporary science…

Similar to modern physics, holograms also lead to a world view which is essentially mystical (Bohm 1980). The roots of such a view can be found in an earlier period of human creativity, that of Ancient Egypt, where the belief in the mystical reality of art gave impetus to the unparalleled artistic productivity of its people. Through the examination of the frontal-profile stance and the canon, we will demonstrate how the hologram and Ancient Egyptian works of art, which at first glance may seem totally unrelated, share many common features. The paper concludes by suggesting that these two complementary manifestations of the human mind are united in their mystical view of the world.

It is hoped that the ideas expressed in this paper will prove relevant in showing that there is an essential harmony and complementarity between the humanities and science leading to a better understanding of the world around us.

Frontal-Profile Stance in Ancient Egyptian Art

To the Ancient Egyptians an intimate relationship existed between art and the fundamental belief of how to live and die. Where an obsessive horror of death and extinction was reconciled with an absolute faith in immortality, art played an active role.

The Egyptian artist was concerned not with representing a fleeting impression captured transiently, but with what he regarded as an individual's personal eternity. Principal figures were shown at an undefined age, conforming to preconceived standards of bodily health and vigour. Individual features showed little variation and personal traits were generally avoided. Figures in general were not intended as portraits of the deceased but "…symbolic representations of a perfect man and his family…" (David 1975) a representation of what was expected to exist for perpetuity.

Each individual object had therefore to be represented in its entirety, as a "whole", with no parts hidden or distorted by shifts of perspective, "because parts omitted were considered missing and bound to mar the eternal image of the objects they represented" (Iversen 1975).

This led to one of the fundamental features of Ancient Egyptian art: the principle of "frontal images" or the "aspective" (Shafer 1974) as opposed to the "perspective" approach.

Egyptian artists selected in their two-dimensional renderings, only those possibilities which were free from the illusion of perspective, in which characteristic individual parts of an object were set unforeshortened almost as a series of juxtaposed phases.

Applied to human figures, this "frontal-profile" aspect was expressed in an extraordinary treatment of the human body. Apart from rare instances the head and the neck were invariably represented in profile yet the eye was presented full face (Fig. 2). The torso was turned square to the spectator with the nipple seen in profile and the navel "en face". Legs and feet were represented in profile with the left leg foremost (Fig. 2).

Such an impossible physical contortion avoided the perspectival solution to the problem. Through the integration of the front and side views, Ancient Egyptians thus managed to achieve a three-dimensional representation of objects on a plane surface.

It is in this "aspective" expression of Egyptian art, where each element of the representation was scrupulously reproduced that a first analogy may be perceived with modern holography. To clarify this point and demonstrate the parallels, a few words of explanation about holograms are in order.

Holography is a method of lenseless photography in which the wave field of light scattered by an object is recorded as an interference pattern. When the photographic record called a "hologram" is placed in a light beam, the original pattern is regenerated and the observer sees a three-dimensional picture that is an amazingly realistic image of the original object.

If one moves one's head, one can see a top, bottom and side view, just as if the object actually existed in space before one's eyes.

To make a hologram, one starts with a single monochromatic and coherent beam of light from a very small source:

> …This single beam is then split into two components, one of which is directed towards the object, the other is directed to a suitable recording medium, usually a photographic emulsion. The component beam that is directed to the object is scattered, or diffracted by that object. The wave that proceeds directly to the recording beam is termed the "reference beam". Since the object and reference waves are mutually coherent, they will form a stable interference pattern when they meet at the recording medium… the detailed permanent record of this interference pattern on the photographic emulsion, which we call the "hologram" consists of a complex distribution of clear and opaque areas corresponding to the recorded interference fringes. When this in turn is illuminated with a beam of light which is similar to the original reference wave, light will only be transmitted through the clear areas, resulting in a complex transmitted wave. The latter conveniently divides into three separate components, one of which exactly duplicates the original object wave. Thus "holography" is a two-step process by which images can be formed.
>
> In the first step a complex interference pattern is recorded and becomes the hologram. In the second

> step, the hologram is illuminated in such a way that part of the transmitted light is an exact replica of the original object wave (Smith 1975) (Fig. 5).

The concept of three-dimensional realism with only two in use is therefore encountered in both Ancient Egyptian art and modern holography.

Such a parallel becomes even more evident by considering De Rachewiltz's (1960) description of Ancient Egyptian two-dimensional representations:

> …on a flat surface (space) an image is drawn which at the same moment (time) evokes a plurality of individual visions. It is almost as if the figure were visualised from several sides, seen simultaneously in profile and from the front in its essential "reality" which is derived from one vision of the various sides synthesized on the flat surface.

Canons as Holograms

Another striking feature of Egyptian Art, both in the sculpture and in the painting, is the serenity and immutability of the people and the scenes.

A sense of inner life and power imbued with calmness emanates from the various art works. The representation of the human figures suggests that the Egyptian artist's aim was to establish for all times the laws of harmony and perfection. Such harmony was expressed in idealized human figures free from physical defects and enjoying the blessings of life (Fig. 1).

Holography. Fig. 1 Triad of king Menkaure (picture taken by Dr. John Swanson and reproduced through his permission and that of the director of the Cairo museum Dr. Wafaa al Sadek).

Technically, such standards of beauty were reached by making use of the well-known "artistic canon". The latter was encountered in Ancient Egyptian art since the beginning of the dynastic times and represents a system of proportions which was used to indicate the mutual relations of the different parts of the body in its artistic representation. According to Iversen (1975) and Harris (1971), the problem faced by the Egyptians of how to scale the various parts of the body was solved by resorting to an accurate standardization of the natural proportions of the body.

His arguments were based on the premise that within distinct types and ethnic groups, the relations of the various parts of the human body are constant and immutable in all individuals, irrespective of any differences in size and dimensions.

Recent investigations (Robins and Miszellen 1976) have, however, indicated that Egyptians gave their figures idealized proportions which reflected certain standards of beauty and were not necessarily totally in correspondence with the natural proportions of the body.

Here we are reminded of Plato (1963), according to whom "…Egyptian artists abandoned the truth and gave their figures not the actual proportions but that which they considered beautiful…". Whether or not such was the case, there definitely existed a standardized relation between the various parts of the represented figures and these were based on anthropometric measurements.

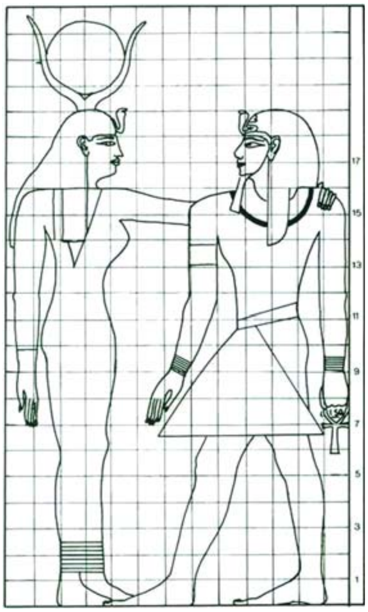
For the practical application of such a system the Egyptians invented the so-called "grids", a system of squares in which the width of the grid square was taken as a rough guide for the width of the fist:

> On the rectangular blocks intended for sculpture in the round, the squares were drawn or incised on at least two sides, and on the plane surfaces prepared for two-dimensional representations, they were either ruled with a straight edge or marked by means of strings dipped in red ochre (Robins and Miszellen 1984).

A canon of proportions thus evolved as early as the Old Kingdom (3200–2280 BCE), and from the Middle Kingdom (1991–1786 BCE) onwards it became normal practice to relate the parts of the body to a grid consisting of 18 squares from the soles to the hairline (Robins and Miszellen 1983; Fig. 2).

Such a "classical" grid was from the 26th Dynasty (664 BCE), replaced by the "late" grid, known as the "Saite Canon", dividing the height of the male figure into 21 squares from the sole to a new measuring point at the root of the nose.

Without changing the mutual relations of the parts, the dimensions of all proportions of any figure could be altered indefinitely by the simple process of changing the length of the modular square (1/18 or 1/21 of the height depending on what canon was used).



Holography. Fig. 2 The Ancient Egyptian canon of proportions.

Egyptian artists were therefore able, for more than two millennia, “to find a complete harmonious expression within a single tradition, without once changing its principles and ideas – with the sole exception of the Amarna age” (Harris 1971).

Robins and Miszellen (1983) recently showed that during the latter period a canon of proportions based on 20 squares from the sole to the hairline was introduced.

It is in this canonical tradition of Ancient Egyptian art that a further analogy may be perceived with modern holography. To appreciate such a similarity let me point out another crucial property of holograms.

In holography the light scattered from each point of the object spreads out as to cover the entire photographic plate. This means that there is no longer a one-to-one correspondence between a portion of the hologram and a region of the object. The information of any single point is recorded over the “whole” plate.

Because of this only a small portion of the hologram is required to form an image of the whole object (Smith 1975; Develis and Reynolds 1967; Butters 1971). If the hologram were to be shattered into thousands of splinters of glass, it would still be possible to form, on any small particle of glass, the entire representation.

This key new feature which is apparent in holography, that of an unbroken wholeness, where each part contains information about the entire object, is also apparent in the Ancient Egyptian canon of proportions. Any small part of the artistic figure gives, through its dimensions, information of the whole.

The following argument will also show that just as in a hologram, the representation is “everywhere” in the glass plate, shot through it, the communication or message conveyed by the canon is contained everywhere in the work of art (Ross 1982).

The observation of Egyptian representations as well as a detailed reading of published work (David 1975; Iversen 1975; Shafer 1974; Smith 1975; De Rachewiltz 1960; Harris 1971; Robins and Miszellen 1976, 1983, 1984; Plato 1963; Ross 1982; Aldred 1980; Davies 1982; Steindorff 1949; Kielland 1955; Romano and Bothmer 1958) on Ancient Egyptian art convinces us that through the symbols and metaphors embodied by the canon, a “mystical” message is conveyed that is highly consonant with modern physics (Capra 1980; Zukhav 1980). Such a message incorporates the ideas of the interrelatedness of all things, the transcendence of the notion of an individual self-coupled with the firm belief that all observations are but manifestations of the same ultimate reality and finally the idea that space and time are constructs of the mind.

That all things and events perceived by the senses are interrelated and connected is, by virtue of the canon, metaphorically suggested throughout the Ancient Egyptian work of art. The standardized relation between the various parts of the figures such as the relation of thumbs to fingers, fingers to palm, palm to forearm, forearm to height and breadth symbolically confirms this interdependence. All things are seen as inseparable parts of this cosmic whole.

The canonical tradition, by allowing the tomb owner and his family to be represented as idealized humans with slender bodies and youthful beauty free from physical defects and devoid of individual and personal traits, expresses a transition from differentiation to sameness. What appears to be different finally is seen to be the same. The canon, throughout the art work, allows the individuality to be dissolved into an undifferentiated oneness where the notion of an individual self is transcended leading to an identification with the same ultimate reality (Figs. 1 and 4).

Iversen (1975), referring to the lack of specification of Ancient Egyptian works of art in the spatio-temporal plane, writes:

> In order to prevent any temporal aspect to influence the existence of the individual representations the indications of any particular moment in their corruptible state was studiously avoided…

Ancient Egyptian works of art, created out of their spatio-temporal appearances, suggest that space and time are constructs of the mind. Such a message can be shown to be “hologrammed” by the canon.

Indeed a close observation of Ancient Egyptian figures suggests that each single part in the Ancient Egyptian work of art is given a form that is appropriate to its meaning, conveying to the figure as a whole a message valid for eternity.

Starting with the representation of the "feet" (Fig. 2), it is observed that the arch which is generally closed on the outside is shown to appear from the exterior, also "legs" are in most cases depicted as being a pace apart, even when surrounded by seated or kneeling people. Observation of Fig. 2 also suggests that the "hand" hanging open behind the back is mostly so placed that the thumb is turned away from the body. Shafer (1974), commenting on the position of the hands, makes the following conclusions:

> …This strange positioning of the hands poses great problems as long as the human figure is taken to be the rendering of a single real view. But it does the artist an injustice to consider his work in this way…

The intermingling in these representations of the concepts of "back" and "front", "inner" and "outer" as well as those of "rest" and "movement" indeed does suggest an arrest in time and space.

In their depiction of "parts" as well as of the "whole" in figures, Egyptian artists were thus inclined not to follow their visual impressions. Instead they sought to convey the significance of a subject by portraying it in an abstract manner, outside space and time (Fig. 3).

Holography. Fig. 3 Queen Nefertari.

It is also noteworthy that in these artistic renderings facial representations were generally devoid of all signs of emotion and of details specifying human feelings and passions (Fig. 4).

Holography. Fig. 4 Tutmsosis III (picture taken by the late Dr. Bernard Bothmer) reproduced by permission of Mrs. Bothmer and Mrs. Sanaa Ahmed Ali (director of the Luxor museum).

The images had a tone of extreme dignity, almost of a higher existence which has been achieved and of which the subject was completely aware. Here, once more, we become aware of artistic expressions taken out of their ephemeral temporal representations.

It becomes clear that the adaptation of the artistic production to a "canon", considered as an expression of the divine law of harmony, has allowed the full expression of an unbroken wholeness through which is "hologrammed" a highly mystical message. The artist fashioned an image that expresses in generalized terms the nature of "man" as such.

His prime concern being to create not a likeness but first and foremost "a symbol".

Conclusion

This article has attempted to link an ancient period of human creativity, as expressed in Egyptian art, with a modern twentieth century discovery: holography. Ancient Egyptian works of art and holograms are seen to have striking parallels both on an "empirical" as well as on a "conceptual" level.

Both techniques, in spite of their different approaches, have succeeded in achieving a mapping of three dimensions on to two. Ancient Egyptian artists did not base their representations on perspective but were rather concerned to communicate all of the details of the figure by giving every vital part its full definition. If the head were shown frontally the definition of the nose would be lost for eternity. Similarly the eye and torso had to be exhibited in their most characteristic light and were therefore shown frontally legs and feet which would have been foreshortened if shown frontally were indicated in profile. Such an approach thus gave the "complete" information about the represented figure.

Similarly, holography by reproducing an exact replica of the original object provided an illusion of three-dimensional concreteness from which could be extracted the "whole" information relating to the object.

An additional property, common to both holograms and Ancient Egyptian works of art and also evident on an empirical level, is that: just as in a hologram any fragment, which is very small, gives information on the whole object, in Ancient Egyptian works of art by virtue of the canon, any part of the figure allows the computation of the dimensions of the other parts and of the whole.

From a conceptual point of view, both holograms and Ancient Egyptian works of art similar to modern physics lead to an essentially mystical world view.

Thus as observed by Bohm (1980):

> Holograms provide an immediate perceptual insight into what is meant by undivided wholeness in which the classical idea of the analyzability of the world into separately and independently existing parts is denied.

In an analogous manner Ancient Egyptian art works are "…created as a UNITY in which every detail and measurement is determined in relation to the whole…" (Kielland 1955). The interdependence and interconnectedness of all things are again made evident here.

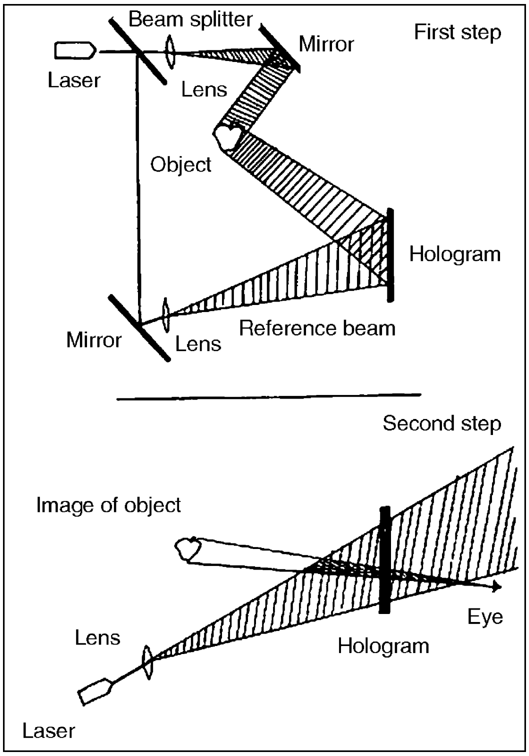
This highly mystical approach is not only conveyed by considering the Ancient Egyptian art work in its entirety, but is also seen to be "hologrammed" throughout the individual parts.

As Plato suggests:

> The Egyptians managed to penetrate a reality beyond the "merely" seeming presenting this comprehensive intuition in artistic form, as a vision of underlying order in the universe (Plato 1963; Davies 1982).

In the same line of thought, we may reflect on Bohm's suggestions that the "universe itself may be a hologram", a realm of frequencies and potentialities underlying an illusion of concreteness, or what he calls the "enfolded" order.

What we actually "see" is the "unfolded" order giving recognisable images of "whole" objects (Bohm 1980; Milbourn unpublished). Bohm suggests that our reality is of objects rather than waves "because our senses are lens systems" (Fig. 5):



Holography. Fig. 5 Creating a hologram.

> If the universal reality is based on the holographic principle, then what is needed to tune into this reality is a means of bypassing the lens system of the senses and experience the waves of the enfolded order directly (Milbourn unpublished).

We are reminded here of Steindorff's (1949) description of Egyptian non-perspectival art as an art "that concerns itself with the object not as it appears to the eye, but as it exists in the imagination of the artist", representing a mental image that transcends the world of senses.

Thus both Ancient Egyptian works of art and holograms may be conceived as resulting from an awareness raised to a level above the brain's sensory input, in which the different aspects of nature, whether recorded as an interference pattern of scattered light or whether resulting from what may be termed the "holographic activity" of the Ancient Egyptian brain, have led to a blurring of the demarcation line between "appearance" and "reality".

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Honey and Medicine

Rachel Hajar

There is evidence that man has long known that honey is a valuable food source. Early rock paintings on cave walls in Africa and eastern Spain show people gathering honey from trees or rock crevices while bees fly around them (Crane 1999). A rock painting called the "Man of Bicorp" shown in Fig. 1 was discovered in 1921 in the *Cueva de la Arana* (Spider Cave) in Valencia, Spain. The painting depicts a human figure near a cavity where there is a beehive. Hanging on three lianas, he is picking up honeycombs, while nearby are some stylized bees. The painting is believed to be over 15,000 years old and dates back to the end of the Paleolithic Period. Rock art from other caves has been found, which shows figures surrounded by bees without being stung.

Prehistoric honey gatherers probably learned by accident that bees are driven away from the honeycomb by smoke as an offshoot of using fire for "warding-off" or driving other animals. Most likely early humans observed the habits of bees and learned that wild bees made their home in the hollow limbs of trees or in hollow places in the trunks of trees. Even now, bee trees often can be found by walking through the woods on

Honey and Medicine. Fig. 1 "Man of Bicorp" ca. 15000 BCE. Paleolithic rock painting showing honey collection from a wild nest, Cueva de la Arana, Bicorp, Valencia, Spain (Drawing E. Hernandez-Pacheco). ►http://www.rupestre.net/tracce/bicorp.html.

bright sunny days and looking into the tops of the trees and watching for the bees coming and going.

The "Man of Bicorp" cave painting is clear proof that early humans actively sought honey as part of their diet. We do not know, however, whether prehistoric man used honey for medicinal purposes.

Honey hunting is an ancient tradition that is still practiced in isolated cultures in Africa, the Indian subcontinent, Southeast Asia, Australia, and South America. Reports of such activities in the popular press describe the practice as heavily permeated with ritual. This is not surprising since the tradition was passed down for generations and has its origins from our distant past.

Honey hunting is a dangerous pursuit since a bee sting could be fatal. Throughout history, there have been alternatives to honey as a sweetener, such as dates and figs. Yet, humans seem to prefer honey and one wonders why humans like honey so much.

Honey in Mythology and Religion

The widespread perception that honey is "good" has its genesis from folklore. Myth has played an important role in folklore. Oral and written records abound with the life-giving qualities of honey.

Quantitative studies of hunter–gatherer diets are scarce. The *Veddas*, or Wild Men, of Sri Lanka esteem honey so highly that they regularly risk their lives to obtain it. The results of a study among some Australian aboriginal tribes reveal that wild honey is regularly consumed although it is difficult and challenging to obtain. Unfortunately, research into the nutritional role of honey is scanty. However, studies of primitive tribal diets indicate that honey is highly nutritious. For example, among the Guayaki Indians of Paraguay honey is the very basis of their diet and culture (Fallon and Enig 1999).

Mythology offers rich insights into the perceived life-sustaining qualities of honey. In Greek mythology, Zeus, mightiest of the Greek gods, was hidden from his father who wanted to devour him and was raised on honey and milk by the bee-nymph, Melisseas. Honey made him so strong and tough that when he grew up he seized his father's throne.

Another myth is that *ambrosia* was the food of the gods and goddesses. Since their gods' food consisted only of ambrosia, the ancient Greeks attributed the immortality of their gods to ambrosia, which they believed consisted of honey, milk, and nectar. Ambrosia was thought to be a nine-fold extract of honey – a sweet treat enjoyed by mortals throughout the ages. Honey was a divine symbol for the Greeks and honey mixed with blood was the sweetest oblation.

Besides its nutritious benefits, the ancients may have believed that honey had properties to preserve or enhance beauty. It is claimed that many of Cleopatra's cosmetics were honey-based. Many women in Arabia still believe honey softens their skin and regularly apply it as facial mask.

In Egyptian mythology, "when the God Re wept, his tears fell to the ground and were turned into bees. The bees began to build and were active on all flowers of every kind belonging to the plant kingdom. Thus wax came into being, thus was created honey from the tears of the God Re" (Ancient Egyptian beekeeping).

The ancient Egyptians offered their gods honeycombs overflowing with honey as a valuable gift to show devotion and worship. In the twelfth century BCE, Ramses III offered 15 tons of honey to Hapi, the god of the Nile. Jars of honey were buried with the dead as sustenance for the afterlife. Archaeologists have found clay pots filled with honey in a Pharaoh's tomb in the city of Thebes. The inscription on the clay pot read: *Good Quality Honey*. Large quantities of honey in jars were also found in the tomb of Tutankhamen (Salim 1988). Burying the dead (especially nobility) in or with honey was common practice in Egypt, Mesopotamia [Iraq], and other regions. It is rumored that Alexander the Great was buried in honey.

The Pharaohs also used honey in their wedding celebrations. This custom was passed on to Greco-Roman culture and handed down to Medieval Europe. Newlyweds drank honey wine (mead) for a month after the wedding ceremony for good luck and happiness. The ritual gave rise to the word *honeymoon*. Egyptian hieroglyphics dating back at least 3,000 years indicate that honey was used as the principal sweetener in the Egyptian diet and as a base for medicinal unguents. The Egyptians also collected beeswax for use in molding wax images for metal casting and in the "varnishing" of pigments (Shaw and Nicholson 1995).

The first written record of beekeeping can be traced back to Egypt from about 2400 BCE. Fig. 2 depicts a

Honey and Medicine. Fig. 2 Beekeeping in Ancient Egypt (Tomb of Pabasa). Relief shows cylindrical hives made of clay. © Kenneth J. Stein Illustration from ►http://nefertiti.iwebland.com/timelines/topics/beekeeping.htm.

H

relief of hives in ancient Egypt, which are very much similar to the woven wicker baskets covered with clay that are still used in Sudan today.

Temples kept bees in order to satisfy the demand for honey as offerings to the gods as well as for other domestic uses such as mummifying, boat, and ship building, and as a binding agent for paints and in metal casting. However, the Egyptians valued wild honey more than the homegrown variety. A passage from the Papyrus Harris reads, "I appointed for thee archers and collectors of honey, bearing incense to deliver their yearly impost into thy august treasury" (Breasted 1906).

Honey is frequently mentioned in the Bible. Moses led his people to the "land of milk and honey." Solomon in Proverbs 24:13 advised, "My son, eat honey; it is good. And just as honey from the comb is sweet on your tongue, you maybe sure that wisdom is good for the soul. Get wisdom and have a bright future." The Jews believed honey made a person "mentally keen."

In early Christianity, honey had a deep mysterious meaning and it was given in christening ceremonies as a symbol of renovation and spiritual perfection. When St. John, the Baptist, was in the desert, he lived on honey and locusts. Bees were revered because of their ability to produce wax and therefore provide light, in many cases for religious practices. Before the advent of electricity, candles were important for lighting. In many religions, candles are still used for religious ceremonies. The Roman Catholic Church regarded the bee as an example of godliness and believed beeswax to be "pure" since virgins – i.e. nonmating worker bees – produce it. Monks kept bees to provide beeswax to make candles for the church.

Honey as Medicine in History

It is possible that prehistoric human's experiences with honey as a valuable food source became encoded in our mythology. In time, the mythic belief that honey was the "food of the gods" passed into ancient writings. Since it was the food of the gods, it must contain the ingredient of immortality, fostering the perception that honey contains the secret to a long and healthy life. It was prescribed as panacea for various ailments and diseases.

"Healing for Mankind"

"Thy Lord taught the Bee to build its cells in hills, on trees and in man's habitations; Then to eat of all the produce of the earth… From within their bodies comes a drink of varying colors, wherein is healing for mankind." (*Qurʾān*, Surah XVI: 68–69). The prophet Muḥāmmad advised his followers to "Use the two curatives: honey and Qurʾān."

Likewise, the Bible contains many references to honey. "But Jonathan [son of Saul]… reached out the end of the staff that was in his hand and dipped it into the honeycomb. He raised his hand to his mouth, and his eyes brightened." (1 Samuel 14:24).

The Hindu Vedas, composed about 1500 BCE and written down about 600 BCE, speak of "this herb, born of honey, dripping honey, sweet honey, honied, is the remedy for injuries; moreover it crushes insects." In the section on *Hymn To All Magic And Medicinal Plants*, honey is used as a universal remedy: "The plants… which remove disease, are full of blossoms, and rich in honey" (Blomfield 1973).

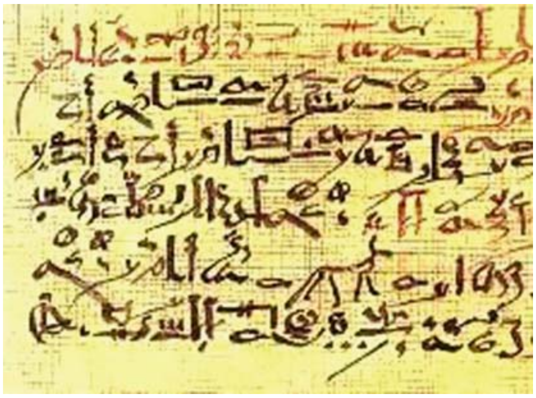
All the sacred books, including those of China, praise honey as food, beverage, and medicine (Jones 2001).

Ancient Writings

There are abundant references to honey as medicine in ancient scrolls, tablets, and books. It was prescribed for a variety of illnesses. Excavated medical tablets from Mesopotamia indicate that honey was a common ingredient in many prescriptions. In ancient Egyptian medicine, honey was the most frequent ingredient in all the drug recipes for both internal and external uses listed in the Ebers and Edwin Smith Papyri (Estes 1993). Honey was used for treatment of stomach pain, urinary retention, and as an ointment for dry skin. It was used for wounds and burns, skin irritation, and eye diseases.

The author of the Smith Papyrus shown in Fig. 3 directed that honey be applied topically, with few if any other possibly active ingredients, to wounds. An example appears below:

> Instructions Concerning A Wound In His Head, Penetrating To The Bone:
>
> If thou examinest a man having a gaping wound in his head, penetrating to the bone, thou should'st



Honey and Medicine. Fig. 3 Excerpt from the Edwin Smith Papyrus (Illustration taken from Ancient Egypt. The Edwin Smith Surgical Papyrus. ►http://nefertiti.iwebland.com/timelines/topics/smithpapyrus.htm)

> lay thy hand upon it (and) thou should'st palpate his wound. If thou findest his skull uninjured, not having a perforation in it…
>
> Thou shouldst bind fresh meat upon it the first day, thou shouldst apply two strips of linen; and treat afterward with grease, honey, (and) lint every day until he recovers.

In ancient Egypt, honey was the only active ingredient in an ointment described in the Ebers Papyrus for application to the surgical wound of circumcision. Ebers also specifies that an ointment for the ear be made of one-third honey and two-thirds oil. The concentration of honey in seven oral remedies in the Chester Beatty VI Papyrus ranges from 10 to 50%, while its proportion in other remedies ranges from 20 to 84%. Honey could very well have provided some kind of protection from the kinds of bacteria most likely to infect wounds, at least enough protection to permit wounds to begin healing on their own.

The ancient Egyptians were not the only people who used honey as medicine. The Chinese, Indians, ancient Greeks, Romans, and Arabs used honey in combination with other herbs and on its own, to treat wounds and various other diseases.

Aristotle (384–322 BCE) believed that eating honey prolonged life (Jones 2001). Dioscorides (AD 40–90), a Greek physician who traveled as a surgeon with the armies of the Roman emperor Nero, compiled *De Materia Medica* (shown in Fig. 4) around AD 77. *De Materia Medica* was the foremost classical source of modern botanical terminology and the leading European pharmacological text until the fifteenth century.

In addition to excellent descriptions of nearly 600 plants and 1,000 simple drugs, Dioscorides described the medicinal and dietetic value of animal derivatives such as milk and honey. Dioscorides stated that honey could be used as treatment for stomach disease, a wound that has pus, hemorrhoids, and to stop coughing (Salim 1988).

> Honey opens the blood vessels and attracts moisture. If cooked and applied to fresh wounds it seals them. It is good for deep dirty wounds. Honey mixed with salt could be dropped inside a painful ear. It will reduce the pain and swelling of the ear. It will kill lice if infested children's skin is painted with it. It may also improve vision. Gargle with honey to reduce tonsil swelling. For coughing, drink warm honey and mix with rose oil (Dioscorides 65 AD).

A tenth century Arab philosopher mentioned uncooked honey for swollen intestines whereas cooked honey was good to induce vomiting when a poisonous drug had been ingested. Al Rāzī (Rhazes, AD 864–932), a renowned Muslim physician famous for writing a treatise distinguishing measles from smallpox, claimed that honey ointment made of flour and honey vinegar was good for skin disease and sports nerve injuries, and recommended the use of honey water for bladder wounds (Salim 1988). His book, *Al Hāwī* (Encyclopedia of Medicine), a comprehensive medical textbook of medicine, which was translated from Arabic to Latin in the thirteenth century and became a standard textbook of medicine up to the 1700s stated:

> Honey is the best treatment for the gums. To keep the teeth healthy mix honey with vinegar and use as mouth wash daily. If you rub the teeth with such a preparation it will whiten the teeth. Honey does not spoil and could also be used to preserve cadavers.

Ibn Sīnā (Avicenna), another famous Muslim physician whose great medical treatise, the *Canon*, was the standard textbook on medicine in the Arab world and Europe until the seventeenth century, wrote:

> Honey is good for prolonging life, preserving activity in old age. If you want to keep your youth, take honey. If you are above the age of 45, eat honey regularly, especially mixed with chestnut powder. Honey and flour could be used as dressing for wounds. For lung disease, early stage of tuberculosis, use a combination of honey and shredded rose petals. Honey can be used for insomnia on occasions.

Throughout the ages, honey was prescribed for a variety of uses, frequently mixed with herbs, grains, and other botanicals. Remedies were passed down through the millennia because they seemed to be effective. Many ancient remedies survive today, lumped

A B

Honey and Medicine. Fig. 4 (A) Dioscorides, *De Materia Medica*, 15th c. Iviron Monastery, Mount Athos, Greece (18.25 Dioscurides, *De Materia Medica* (Books I-V) 15th c. Iviron Monastery, Cod. 216 Illustration from ►http://www.culture.gr/2/21/218/218er/e218er25.html. (B) Illustration from *De Materia Medica* of Dioscorides, Baghdad, AD 1224. (Arabic Translation of Discorides' *De Materia Medica*. Iraq, Abbasid Period, 13th Century ca. 1224) together by modern medicine under the term "folk medicine" since their effectiveness has not been scientifically proven through clinical trials.

The belief in honey as a remedy for ailments is still pervasive. Honey for coughs and sore throats remains a popular remedy around the world. Honey is frequently mixed with tea and cinnamon as remedy for cold and sore throat. Some antiseptic lozenges contain honey.

In underdeveloped countries, where synthetic medicines are expensive, honey is one of the cornerstones in their pharmacopoeia. For example, lotus honey is used for eye diseases in India. It is used as topical eye ointment in measles to prevent corneal scarring (Molan 2001). Honey is used to treat infected leg ulcers in Ghana and earaches in Nigeria. Other uses include treatment of gastric ulcers and constipation (Getz 1991).

Honey in the Twentieth Century Before Antibiotics

In the early part of the twentieth century, the medical literature contained reports on the antimicrobial and healing properties of honey. Russian soldiers during World War I used honey to prevent infections in wounds and to accelerate healing (Bergman 1983). The effectiveness of honey to heal wounds spurred research into its antimicrobial activity, which was attributed to "inhibine." In 1963, inhibine was identified as hydrogen peroxide (White et al. 1963), a powerful oxidizer that kills bacteria, viruses, and fungi. During the first half of the twentieth century, there were many research papers documenting the wound-healing properties of honey. The medical profession did acknowledge the value of honey in the treatment of wounds, leg ulcers, and burns. The introduction of antibiotics shifted the focus to synthetic and mass-produced treatment. The medical uses of honey as effective treatment in wounds were forgotten.

Revival of Honey in Medicine

In 1976, an editorial in the *Archives of Internal Medicine* on medical folklore arrogantly dismissed honey as a "worthless but harmless substance" (Soffer 1976). Over the last two decades, reports from different parts of the world affirmed the effectiveness of honey in treating various wounds, burns, and serious infections. These reports and the emergence of drug resistant infections stimulated a number of scientists to conduct studies on honey, bringing about a resurgence of interest in the medical uses of honey. Recent research on honey has shed light on the mechanisms underlying its antimicrobial effects (Molan 1992). In summary, the antibacterial effects are due to

- *Osmotic effect*: Honey is a supersaturated sugar solution of fructose and glucose, which comprise 84%. The interaction of the sugar molecules with water molecules leaves very little water available to support the growth of microorganisms.
- *Acidity*: Honey is acidic, with a pH ranging from 3.2–4.5 which is low enough to inhibit the growth of many pathogens.
- *Hydrogen peroxide* is the major antibacterial compound in honey. Bees secrete the enzyme glucose oxidase from nectar. It converts glucose in the presence of water and oxygen to glucoronic acid and hydrogen peroxide. Both the acid and hydrogen peroxide preserve and sterilize the honey during the ripening process.
- *Nonperoxide antibacterial factors*: There have been reports of isolation of various antibacterial chemical substances from honey that are not hydrogen peroxide but their concentration is reportedly too low to contribute much antibacterial activity.

Honey has been reported to have an inhibitory effect to around 60 species of bacteria including aerobes and anaerobes, gram-positives and gram-negatives (Subramanyan 1991).

There are differences in the antibacterial activity of different honeys. Honey is produced from many different floral sources and its antibacterial activity varies with origin and processing. Long ago, both Aristotle and Dioscorides recommended that honey collected in specific regions and seasons, and presumably from different floral sources, be used for the treatment of particular ailments. Research has since shown that honey has certain organisms sensitive to it while others are resistant, and the sensitivity varies depending on the source of the honey. *Staphylococcus aureus* is one of the species most sensitive to the antibacterial activity of honey (Cooper et al. 2002).

Other beneficial effects of honey include (Molan 1992):

- Stimulation of the healing process, especially leg ulcers and diabetic ulcers.
- Speedy clearance of infection when used as dressing on infected wounds. Honey is reportedly extremely effective in the treatment of wounds infected with antibiotic resistant bacteria.
- Cleansing action on wounds: Honey has a debriding effect (removing dead, contaminated tissue) on wounds so that surgical debridement is unnecessary or only a minimum is required.
- Stimulation of tissue regeneration: Honey promotes the formation of clean healthy granulation tissue and growth of epithelia over the wound, thus helping skin regenerate. It has also been reported that dressing wounds with honey gives little or no scarring.
- Comfort honey dressings: Honey is nonirritating and the pain or discomfort associated with changing dressings is minimized.

The current main medical use of honey is in the treatment of infected wounds, chronic leg and skin ulcers, bedsores, especially in settings of drug-resistant infections (Cooper et al. 2002). The effectiveness of honey in wounds and ulcers has been known empirically for thousands of years and has recently been documented in clinical studies.

Honey is reportedly used by ophthalmologists for treating corneal ulcers in India and Russia where it has been used for chemical and thermal burns to the eye, conjunctivitis, and infections of the cornea.

Other traditional folklore medical indications of honey include peptic ulcers and gastroenteritis. At least two studies demonstrated that natural honey, but not commercial honey, was bactericidal against the bacterial isolates obtained and that different types of honey exhibited varying bactericidal concentrations (Haffejee and Moosa 1985).

Much of the wisdom of folk medicine has its roots in ancient beliefs held by people who understood neither chemistry nor anatomy. Honey is just the latest of the ancient remedies to be "rediscovered." There are abundant references in ancient writings indicating the beneficial effects of honey and other bee products.

The humble bee makes honey from countless varieties of plant blossoms, and it is logical to assume that by-products from the beehive such as honey contain many substances of medicinal value that modern medicine has yet to discover.

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Huangdi Jiuding Shendan Jing

Fabrizio Pregadio

The *Huangdi jiuding shendan jing* (Book of the Divine Elixirs of the Nine Tripods of the Yellow Emperor) also known as *Jiudan jing* (Book of the Nine Elixirs) is one of the earliest extant Chinese alchemical texts. Quotations and other references in Ge Hong's *Baopu zi neipian* suggest that the text circulated in a form at least substantially similar to the current one by the end of the third century. The extant version, dating from the latter half of the seventh century, is found in the *Daozang* (Daoist Canon). It is followed by an extended commentary that represents in its own right a compendium of early medieval Chinese alchemy.

Besides its early date, the *Book of the Nine Elixirs* is significant as it provides one of the most complete descriptions of the alchemical practice in China, from the preliminary rituals to the compounding and ingestion of the elixirs. The ritual features include purifications, interdictions, secrecy, retirement, choice of time, delimitation of space, and ceremonies for transmitting the text, for starting the fire, and for ingesting the elixirs.

The compounding begins after the preliminary ritual practices. The first step consists in the preparation of an amalgam of refined lead and mercury, said to contain the essences of Heaven and Earth, or *Yin* and *Yang*. This compound is used as a layer in the crucible together with the ingredients of the elixirs. Then one prepares a mud used for sealing the crucible and prevent the loss of *qi* (energy), thus recreating inside the vessel conditions similar to those of primeval chaos.

The methods of the Nine Elixirs proper are based on processes of sublimation (*fei*). The substances most commonly used are mercury, orpiment, realgar, malachite, arsenolite, magnetite, cinnabar, alum, and hematite. The ingredients are first placed in a tightly sealed crucible, and heated on a fire progressively made more intense. After the required number of days, the crucible is left to cool and is opened. The essence is carefully collected from the higher part of the crucible, and mixed with a moistening substance. The elixirs should be ingested at dawn, facing the sun. Their ingestion is said to bestow eternal life, command over gods and spirits, protection from calamities, and sometimes magical powers. Some of the Nine Elixirs can be transmuted into alchemical gold. The text emphasizes that the purpose of this final transmutation is to make sure that the compounds have been correctly prepared.

See also: ►Alchemy in China, ►Ge Hong, ►*Yinyang*

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Huangdi Neijing

RICHARD BERTSCHINGER

The *Huangdi Neijing* (Yellow Emperor's Inner Canon) is the most famous and oldest medical classic of China, being complied by various unknown authors from the period of the Warring States (475–221 BCE) onward. The book consists of two main sections, each of 81 chapters: the *Suwen* (Plain Questions) and *Ling Shu* (Miraculous Pivot), the latter being earlier entitled the *Zhen Jing* (Needling Classic).

These texts are the very earliest to be written on Chinese medical theory. However, Keegan has shown conclusively that none of the *Neijings* now extant are the original. Lu and Needham also summarized the evidence and considered that the corpus was probably already well formed by the first century BCE.

The Canon achieved something close to its known form with the recension (ca. AD 762) which came about with the editorship of Wang Ping during the Tang dynasty. Another edition, the *Huangdi Neijing Taisu* (Great Simplicity), recently discovered in Japan, may be considered closer to the original text. The insertion of chapters into the text, including those on *wuyun liuqi* (The Theory of the Five Elemental Cycles and Six Climates), undoubtedly took place some time close to the mid-tenth century (Lu and Needham 1980). Since this date, however, the contents have been fixed.

The book takes on a question and answer form, in which the legendary Yellow Emperor questions his ministers about the need for a medical reformation, in accord with the prevailing tone of Han thought. In the opening paragraphs the Emperor questions his minister-physician Qi Bo:

> The Yellow Emperor asked: "I have heard that the men of ancient times lived through a hundred springs and autumns, and remained active and did not reach senility. Now our men only reach half that age and they are senile. Are we so very different? Or have we missed something?"
> Qi Bo replied: "The men of ancient times, they understood the Way, they modelled themselves on Yin and Yang and were at peace with the arts of guiding their destiny. They ate and drank in moderation, they rose and retired at regular hours, neither made wild schemes, nor wearied their bodies at work… The men of the present day are not the same. They drink liquor to excess, they take wild thinking as the norm. When drunk they perform the act of love, seeking to exhaust their energies and waste their lives. They do not know how to be content. They have no time to control the passage of their thoughts, looking only for what cheers – not for the joys of health" (Ch. 1).

This sets the tone for the preventative and rehabilitative character which dominates Chinese medicine. Later in the chapter, the same need for ataraxia (peace of mind) is stressed:

> Detach and be at peace, humble and empty – and the true energies will follow. The vital spirit, guard it within! How then can disease arrive?

Among the Canon's other ideas are the well-developed tract system of 12 main channels and numerous collaterals (the *jingluo*); and the science of the five elements (*wuxing*): fire, earth, metal, water, and wood. It also introduces the classificatory dialectical tool of *Yin/Yang* (earth/heaven, dark/light, night/day, solid/hollow, etc.). Many chapters also describe the relationship between human beings and their environment, and refer in great detail to circadian, or internal, rhythms within the body. These biological clocks foreshadowed the modern science of chronobiology.

Surgery is also mentioned, and the *bian* stone needle as the forerunner of acupuncture. The Canon accurately identifies gangrene in the feet and says it is more common in the toes, where it advises amputation to save lives. This is just one of the many ideas prevalent in the book which accords with modern medical theory.

See also: ►Acupuncture, ►*Yin/Yang*, ►Five phases

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Huangfu Mi

Hong Wuli

Huangfu Mi was born in 215 in Anding Chao'na (now Pingliang County, Gansu Province) and died in 282. He was born to a poor family and did not receive any education until he was twenty years of age, after which he devoted all his time to reading, extensively and intensively, all kinds of ancient literature. He eventually became a great master in the art of classics.

During the period 256–260, he suffered *Feng Bi* or apoplexy and became hemiplegic. From then on, he began to study medicine. In view of the overlapping of many texts in several medical classics, he decided to compile a new book on the art of acupuncture and moxibustion under the principle of "sorting out the similarities, excluding the meaningless and useless words and sentences, deleting unnecessary repetition and extracting the essence". He did this by incorporating the relevant portions from the three classics, namely *Huangdi Neijing su wen* (*Plain Question of Huangdi's Inner Canon*), *Zhenjing* (*Classic of Acupuncture*), and *Ming tang kong xue zhen jiu zhi yao* (*Essentials of Treatment for Acupuncture and Moxibustion with Anatomical Charts and Acupoints*). A twelve-volume *Zhen jiu jia yi jing* (*A–B classic of Acupuncture and Moxibustion*) was written and divided into two parts. One of them deals with the physiology of the human body, indications for each acupoint, diagnostic measures, way of puncturing, and pathophysiology. The other part is devoted to clinical knowledge, including internal medicine, surgery, pediatrics, and gynecology, with special reference to internal medical science. Emphasis is laid on the unification of channels and acupoints and on exploration of indications and contraindications for acu-moxibustion therapy. This work, from which most of the works on acupuncture and moxibustion of later ages were derived, exerted great influence on the development of the art of acupuncture and moxibustion in successive generations. Erudite and learned, Huangfu Mi was very productive in his writings, including works on history and classical literature.

During his time, it was a custom to swallow processed stone remedies for seeking longevity and as an aphrodisiac. Huangfu Mi also practiced this behavior and was brought to the brink of death after a critical illness. After he fortunately recovered, he wrote a book, *Han shi san lun* (*On Stone Powder To Be Swallowed Cold*) to advise people to avoid such harmful and potentially fatal behavior.

See also: ►Medical texts in China

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Ḥunayn Ibn Isḥāq

Albert Z. Iskandar

Abū Zayd Ḥunayn Ibn Isḥāq al-ʿIbādī (Johannitius AD 808–873), a physician, philosopher, and translator, was born in al-Ḥīrah (Hira), now southeast of al-Najaf (Iraq). He and his ancestors were Syrians who belonged to the Nestorian church. The family nickname, al-ʿIbādī, is derived from "al-ʿIbād," a Christian Arab tribe.

Ḥunayn studied medicine in his youth in Baghdad. The thirteenth-century medical historian, Ibn Abī

Uṣaybiʿa, author of the book *ʿUyūn al-Anbāʾ fī Ṭabaqāt al-Aṭibbā* (Sources of Information about the Classes of Physicians), gives a lively account of the difficulties that confronted Hunayn as a student of medicine. Yūḥannā Ibn Māsawayh (Mesue d. AD 857) was a famous physician and a highly respected teacher of medicine. He conducted classes in a vast room in his large house. Questions from young Hunayn, who was very keen on amassing knowledge, interrupted the serenity of Mesue's lessons. Mesue reprimanded Hunayn several times without effect, then finally ordered him out of the classroom and told him to give up medicine. Mesue advised him to trade in coins instead, which he believed would be financially more rewarding than the practice of medicine. Mesue had in mind the fact that most of the residents of Hira were merchants and money changers. So far as one can tell, Hunayn abandoned Mesue's tutorship and decided on self-education.

Bakhtīshūʿ Ibn Jibrāʾīl, a contemporary of Ḥunayn, held regular meetings at which physicians and philosophers debated questions and problems raised by Caliph al-Mutawakkil (d. AD 861). Ḥunayn was invited to attend these meetings at which he showed medical acumen. Al-Mutawakkil is reported to have endowed a school of translation, and appointed Hunayn as its head. Among the members of this school were Ḥunayn's son, Isḥāq Ibn Ḥunayn (d. AD 910), who translated from Greek into Syriac and Arabic. He also took charge of revising, against the original Greek, translations by his colleagues. It is worth noting that Isḥāq's translations were carefully revised and corrected, whenever necessary, by Ḥunayn himself. Towards the end of his life, Ḥunayn embarked on an Arabic translation of Galen's *De partibus artis medicativae* (*On the Parts of Medicine; Fī Ajzāʾal-Ṭibb*), of which he had earlier rendered the Greek text into Syriac. Death prevented him from completing his translation. Isḥāq attended to Ḥunayn's unfinished work.

Another eminent translator in Ḥunayn's school was his nephew, Ḥubaysh Ibn al-Ḥasan al-Aʿsam, who was involved in translating Galen's (d. ca. AD 200) *De anatomicis administrationibus* (*On Anatomical Procedures; Fī ʿAmal al-Tashrīḥ*) into Arabic. This work consists of 15 books. It was translated into Syriac by Ayyūb al-Ruhāwī (Job of Edessa) for Jibrāʾīl Ibn Bakhtīshūʿ (d. AD 828–829). A revised Syriac translation was made by Ḥunayn himself for Yūḥannā Ibn Māsawayh. It is generally accepted that Ḥubaysh produced an Arabic version about the end of Ḥunayn's life, and with his active collaboration.

Ḥunayn's school of translation helped to establish a firm foundation upon which medieval Arabic medicine and allied sciences were securely built. Renowned Arabic-speaking physician–philosophers, like al-Rāzī (Rhazes d. AD 925) and Ibn Sīnā (Avicenna d. AD 1037), and many others, owe Ḥunayn and members of his school a great debt for rendering fundamental Greek texts of antiquity into Arabic, the language of learned men at the time.

Al-Mutawakkil elevated Ḥunayn to the post of Chief Court Physician and dismissed Bakhtīshūʿ Ibn Jibrāʾīl. The latter conspired against Ḥunayn, and, unfortunately, Ḥunayn fell from grace. Al-Mutawakkil ordered the sequestration of Ḥunayn's entire library.

Ḥunayn was 48 when he compiled the first draft of his *Risālat Hunayn Ibn Isḥāq ilā ʿAlī Ibn Yaḥyā fī Dhikr mā Turjima min Kutub Jālīnūs bi-ʿIlmih wa-baʿd mā lam Yu-tarjam* (Missive to ʿAlī Ibn Yaḥyā on Galen's Books Which, so far as Ḥunayn Knows, Have Been Translated, and Some of Those Books Which Have Not Been Translated). The fact that Ḥunayn's *Missive*, which presents impressive information about some of his predecessors and contemporaries, was compiled, he says, after the loss of his library, indicates his complete dedication to his work. ʿAlī Ibn Yaḥyā, to whom Ḥunayn's *Missive* was dedicated, was a powerful friend and a private confidant of Caliph al-Mutawakkil. Through his intercession, Ḥunayn later recovered his own library.

The following are a few examples to shed light on the depth of Ḥunayn's involvement in translating Galen:

- The *Pinax* (*Index; Fīnaks*) was translated into Syriac for a doctor named Dāʾūd and into Arabic for Muḥammad Ibn Mūsā
- *De ordine librorum suorum* (*On the Order of His Books*; *Fī Marātib Qirāʾat Kutubih*), into Arabic for Aḥmad Ibn Mūsā
- *De sectis ad eos, qui introducuntur* (*On Sects; Fī'al-Firaq*, into Syriac when Ḥunayn was 20 years of age, and another translation for Ḥubaysh when Ḥunayn was 40
- *De febrium differentiis* (*On the Types of Fevers; Fī Aṣnāf al-Ḥummayāt*), the first book to be translated by Ḥunayn, into Syriac, and another translation for his son when he discovered textual gaps which he filled in by collating against other manuscripts, and again into Arabic for Abu'l-Ḥasan Aḥmad Ibn Mūsā
- *De crisíbus* (*On Crisis; Fī'al-Buḥrān*). First Ḥunayn corrected a Syrīac translation by Sergius of Resaina (d. AD 536), then produced an Arabic version for Muḥammad Ibn Mūsā. All these and many more are discussed in detail in Ḥunayn's *Missive*

In spite of his fame as a translator, he was scoffed at by doctors when he wished to practice the art of physic. They admitted that he was an excellent translator, yet he was not a doctor, in the same way that a blacksmith could forge a beautiful sword without himself being a swordsman.

Ḥunayn was also a medical author in his own right. His books are mainly based on Greek sources, such as: *Fī Awjāʿ al-Maʿidah* (*On Stomach Ailments*) and *al-Masā'il fi'l-Ṭibb li'l-Muta'allímīn* (*Questions on Medicine for Students*). His book entitled *al-'Ashar Maqālāt fi'l-'Ayn* (*The Ten Treatises on the Eye*), covering both the theory and practice of medicine, ranks highly among medieval books of ophthalmology.

Historians of medicine and science are greatly indebted to Ḥunayn and his school of translation. Without their efforts, many of the works of antiquity would have probably been lost forever. Two examples will suffice. Galen's *On Anatomical Procedures* (*Fī'Amal al-Tashrīḥ*) of which Books IX (in part) and X–XV (inclusive) are lost in the original Greek, is preserved in its entirety in Arabic manuscripts. Again, Galen's book *De optimo medico cognoscendo* (*On Examinations by Which the Best Physicians are Recognized*) is entirely lost in the original Greek. Ḥunayn's Arabic version has survived in two manuscripts.

See also: ►Isḥāq Ibn Ḥunayn, ►al-Rāzī, ►Ibn Sīnā, ►Ibn Māsawayh

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Huntian

Christopher Cullen

Huntian is the Chinese name for a scheme of cosmography, often mentioned as in opposition to the *gaitian*. According to explanations of this scheme, heaven is a sphere surrounding a flat earth whose upper surface lies across its diametral plane. Heaven is therefore continuous (*hun hun ran*), unlike the situation described by the *gaitian*, under which heaven has a boundary. The heavenly sphere rotates once daily about an axis inclined at 35° to the horizontal, carrying with it the heavenly bodies, whose risings and settings occur as they move above and below the plane of the earth's surface. The Chinese observer is imagined to be at the center of the earth, and hence at the center of the heavenly sphere. Since the latitude of most ancient Chinese capitals was about 35° north, the *huntian* universe acts as a sort of cosmic planetarium for the official astronomers at those capitals. Observers near the edge of the earth would see a very odd and asymmetrical series of celestial phenomena, but the diameter of the sphere is so large (one version gives a figure equivalent to over 140,000 mile) that the entire inhabited world is effectively at the center of the universe.

The first full account of the *huntian* cosmography is that of Zhang Heng, written ca. AD 117. Thereafter it is the usual scheme referred to by those concerned with mathematical astronomy, and a number of texts point out its advantages compared with the *gaitian*. The innovation of the *huntian* was apparently connected with the introduction of the armillary sphere in China at some time after 100 BCE. The nested rings of such an instrument are highly suggestive of the skeleton of the celestial sphere. It would be a mistake, however, to see debates on cosmography as a crucial concern for astronomers in China, since the algebraic/arithmetic character of Chinese mathematical astronomy meant that the detailed geometry of the cosmos was much less of an issue than it was in ancient Greece and Rennaissance Europe.

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H

I

Ibn ʿAbbād

Zeina Matar

Abū al-Qāsim Ismāʿīl Ibn ʿAbbād Ibn al-ʿAbbās Ibn ʿAbbād Ibn Ahmad Ibn Idrīs, also known as Kāfī al-Kufāt, and al-Ṣāḥib, was a famous vizier and man of letters of the Buwayhid period. There is disagreement about his place and date of birth, but he was probably born at Iṣṭakhr on 16 Dhū'l-qaʿda 326/14 September 938. His family included high dignitaries, and his own father had been a *kātib* (clerk) and then vizier, or minister of state, under the Buwayhid Prince Rukn al-Dawla (r. 35/946–366/976).

Ibn ʿAbbād himself became the disciple and secretary of Abū'l-Faḍl Ibn al-ʿAmīd (d. 360/970), the father of the Buwayhid vizier Abū'l-Fatḥ Ibn al-ʿAmīd (b. 337/948–9). His close relationship to the Buwayhid *amīrs* (princes) is said to have begun in 347/958, when he accompanied Mu'ayyid al-Dawla (reigned 366/976–373/983) to Baghdad as a clerk. He was later confirmed in this office when Mu'ayyid al-Dawla became governor of Isfahan. Ibn ʿAbbād's career took a more significant turn when he was appointed vizier, replacing Abū'l-Fatḥ Ibn al-ʿAmīd.

Ibn ʿAbbād served two rulers: Mu'ayyid al-Dawla and Fakhr al-Dawla (reigned 373/983–387/997). The main source for the study of his vizierate remains the volume of the *Rasāʾil* (ʿAzzam 1946), which is a collection of administrative pieces, appointment, and other official letters by Ibn ʿAbbād. According to the sources, the personality of Fakhr al-Dawla was not really compatible with that of Ibn ʿAbbād, although he recognized the latter's administrative skills and talents. When Ibn ʿAbbād died on 24 Safar 385/30 March 995, Fakhr al-Dawla confiscated his property, and from that time onward, no other member of his family was to be appointed to a high official position.

Ibn ʿAbbād was not only a statesman and a politician, but he was also a talented writer whose works cover a very wide spectrum. In their article in the *Encyclopedia of Islam*, Claude Cahen and Charles Pellat give a classification of his works: dogmatic theology, history, grammar and lexicography, literary criticism, poetry, and belles-lettres.

In Abū Ḥayyān al-Tawḥīdī's *Mathālib al-Wazīrayn*, a comprehensive list of Ibn ʿAbbād's works is given. Some of the most important are:

- *Kitāb al-Muḥīṭ bi-ʿl-lugha* (The Comprehensive Treatise About Language) in 10 vols
- *Kitāb Dīwān rasā'ilihi* (Collection of Letters) in 10 vols
- *Kitāb al-Kāfī. Rasāʾil* (The Book of al-Kafī [that which is sufficient]. Letters [or Correspondence])
- *Kitāb al-Aʿyād wa-faḍā'il al-Nowrūz* (The Book of Feasts and the Excellent Qualities of New Year's Day)
- *Kitāb al-Wuzarāʾ* (The Book of Viziers)
- *Kitāb Dīwān Shiʿr(ihi)* (Collection of Poetry)

In the *Yatīmat al-dahr* (III, 204), al-Thaʿālibī commented on a *Risāla* on medicine said to have been written by Ibn ʿAbbād:

> I found that it combined beauty of style, elegance of expression, and mastery of the subtleties and particularities of medicine, and it showed that he was thoroughly familiar with this science, and had a penetrating knowledge of its intricacies.

Ibn ʿAbbād often inspired very contradictory opinions and feelings as is shown by Abū Ḥayyān al-Tawḥīdī's hostility on the one hand, and by al-Thaʿālibī's praise and admiration on the other. However, regardless of personal like or dislike, he certainly was a highly exceptional personality in Muslim history. Maybe one can refer to him as a "patron-vizier", a talented individual who had the ability to mix politics and literature, and a poet whose court once counted as many as 23 poets.

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Ibn Al-ᶜArabī

William C. Chittick

Muḥyī al-Dīn ibn al-ᶜArabī is one of the most influential Muslim thinkers of the past seven hundred years. Born in Murcia in present-day Spain in 1165, he set out for the western lands of Islam in 1200, traveled in the Arab countries and Turkey, and, in 1223, settled in Damascus, where he lived until his death in 1240. He wrote voluminously and attracted the attention of scholars and kings during his own lifetime. His magnum opus, *al-Futūḥāt al-makkiyya* (The Meccan Openings) – inspired sciences that were "opened" up to his soul during his pilgrimage to Mecca – will fill some 15,000 pages in its new edition. His most widely studied work, *Fuṣūṣ al-ḥikam* (The Bezels of Wisdom), is a short explication of the various modalities of wisdom embodied by 28 of God's prophets, from Adam to Muhammad.

Ibn al-ᶜArabī's writings investigate every dimension of Islamic learning, from the *Qurʾān* and the *ḥadīth* (the sayings of Muḥammad) to grammar, law, philosophy, psychology, and metaphysics. His basic intellectual project was to illustrate the unity of all human endeavors and the underlying, interrelated functions of all human thinking. He cannot be classified as a philosopher, theologian, scientist, or jurist, though his works address most of the basic epistemological issues of these disciplines. He saw himself as an inheritor of the wisdom of the prophets, but one who was given the duty of explaining this wisdom in the subtlest intellectual discourse of the day – at a period that is looked back upon as the high point of Islamic learning. He provides no system, but rather a unified vision that is capable of spinning off innumerable systems, each of them appropriate to a given field of learning or level of understanding. He offers many ways of approaching the basic questions of human existence, such as the nature of reality itself, the role of God, the structure of the cosmos and the human psyche, the goal of human life, and the relationship of minerals, plants, and animals to other creatures. In short, he provides basic patterns for establishing complex systems of metaphysics, theology, cosmology, psychology, and ethics.

Ibn al-ᶜArabī was followed by a number of major thinkers who systematized his "openings" in various ways, depending upon their own orientations and intellectual contexts. The diverse interpretations given to his works are especially obvious in a series of over 100 commentaries that have been written on his *Bezels of Wisdom* from the thirteenth century down to modern times. His stepson Ṣadr al-Dīn Qūnawī (d. 1274) had probably the keenest philosophical mind among Ibn al-ᶜArabī's followers. Qūnawī in turn trained many disciples, several of whom wrote widely influential works. Saᶜīd al-Dīn Farghānī (d. 1296) provided systematic expositions of the teachings of both Qūnawī and Ibn al-ᶜArabī in Arabic and Persian. Fakhr al-Dīn ᶜIrāqī (d. 1289) was a poet who wrote a delightful summary of Qūnawī's teachings in mixed Persian prose and poetry that helped popularize Ibn al-ᶜArabī's teachings. Muʾayyid al-Dīn Jandī (d. ca. 1300) wrote in Arabic the first detailed commentary on Ibn al-ᶜArabī's *Bezels of Wisdom*. The intellectual tradition established by Ibn al-ᶜArabī and Qūnawī gradually merged with various branches of Islamic philosophy, yielding a wide range of intellectual perspectives that dominated the Islamic wisdom tradition down to the coming of Western colonialism.

In order to grasp Ibn al-ᶜArabī's importance for the history of scientific thought in Islam, one needs to understand his basic accomplishment, which was to establish an honored place in the Islamic intellectual tradition for supra-rational knowledge. From their inception in the eighth and ninth centuries, the mainline schools of theology and philosophy in Islam had endeavored to understand the Quranic revelation on the basis of rational modes of investigation taken over from the Greek heritage. Parallel to this, there developed a more practical, existential approach that found the goal of human life in direct experience of the presence of God. This second approach, which came to be called by the umbrella term "Sufism," laid stress upon supra-rational modes of knowledge that are collectively known as *kashf* (unveiling), i.e., the lifting of the veils that separate the human soul from God. Unlike some Sufis, Ibn al-ᶜArabī was not opposed to acknowledging the authority of reason. However, he maintained that unveiling was a higher form of knowledge, because it grows out of the unmediated perception of God's actuality. In Ibn al-ᶜArabī's way of looking at things, reason tends innately to divide and discern. It eliminates connections between God and the cosmos and understands God as distant and transcendent. In contrast, unveiling works by seeing sameness and presence; hence God is perceived as near and immanent. Perfect knowledge of God and of reality as a whole depends upon a happy balance of reason and unveiling. Only through this balance can God be perceived in appropriate modes as both absent and present, near and far, transcendent and immanent, wrathful and merciful. Ibn al-ʿArabī's works are devoted largely to explaining the vast range of these appropriate modes.

The long term effect of the marriage between reason and unveiling effectuated by Ibn al-ʿArabī is symbolized by his meeting when still a boy – of perhaps 15 years – with the philosopher Ibn Rushd (Averroes d. 1198). Ibn al-ʿArabī had already experienced the opening of the unseen worlds, and Ibn Rushd, who was a friend of his father, had asked to meet him. In the brief exchange that took place, Ibn Rushd asked if unveiling and reason achieved the same goals. Ibn al-ʿArabī replied, "Yes and no." Then, in cryptic language, he affirmed that reason was a valid route to achieve knowledge of the nature of things, but he denied that it exhausted the possibilities of human knowing. In the West, the teachings of Ibn Rushd were employed to help establish nature as an autonomous realm of intellectual endeavor. Under the discerning eye of reason, God was abstracted from perceived reality, eventually becoming a hypothesis that could be dispensed with. The world of nature was now the proper site for rational analysis and dissection, and the result has been the ever-increasing fragmentation of human knowledge, with a total divorce between science and ethics. In contrast, Ibn Rushd was forgotten in the Islamic world, but Ibn al-ʿArabī and his followers succeeded in establishing a harmony between reason and unveiling. Hence Muslim intellectuals were never able to conceive of nature as a realm cut off from God. If God is present in all things, then the ethical and moral strictures that he establishes through revelation need to be observed at every level. It becomes impossible to investigate the natural world without at the same time investigating its relationship with God and recognizing the moral and ethical demands that this relationship entails.

Ibn al-ʿArabī's career and teachings exemplify the dimensions of Islamic learning. The worldview to which he gave detailed expression provided a perspective from within which Muslim intellectuals were able to answer the deepest questions of the human mind. Ibn al-ʿArabī's achievements contributed to an intellectual equilibrium that refused to subordinate the spiritual demands of human beings to corporeal demands and that gradually established a vast framework within the context of which the intellectual disciplines came to be ever more united and interrelated. This holistic perspective on knowledge in turn prevented the fragmentation of the Islamic worldview and allowed no room for "declarations of independence" by specific schools of science or philosophy. Given that ethics, morality, and spiritual development lay at the heart of this perspective, it was impossible to divorce any branch of science or learning from these concerns.

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►www.ibnarabisociety.org.

Ibn Al-Aʿlam

Raymond Mercier

Ibn al-Aʿlam, Abū'l-Qasim ʿAlī ibn ʿIsa al-Husain, al-ʿAlawī, al-Sharīf was a tenth century astronomer, apparently established in Baghdad. The year of his death is recorded by Ibn al-Qifṭī as 375/985. The *Zīj* (astronomical handbook with tables) which he wrote is lost, but substantial information about it may be gleaned from notices in the work of other astronomers. His work was patronized by the Būyid ruler ʿAḍūd al-Dawla but suffered from lack of support in the disturbed period which followed his death in 372/982.

A near contemporary, the great astronomer Ibn Yūnus of Cairo, reports that Ibn al-Aʿlam had fixed the length of the year as 365; 45, 40, 20 days, determined the position of Regulus (α Leonis) in the year 365/975–6 as 15; 6 Leo, and also fixed the rate of precession, one degree in 70 Persian years. He remarks that Ibn al-Aʿlam was known everywhere for the exactitude of his observations and the extent of his geometrical knowledge.

Al-Bīrūnī in his work *Tamhīd al-mustaqarr li-taḥqīq maʿnā al-mamarr* (On Transits) gives the name of his *Zīj* as *al-ʿAdūdī*, and incidentally provides values for the radius of the epicycles for each of the planets.

In spite of the loss of the *Zīj* full information about its parameters may be obtained from two sources compiled in the fourteenth century, the Persian *Zīj-i Ashrafī*, and an anonymous Arabic collection known as the *Dastūr al-Munajjimīn*. Information is also available from Greek sources, in which Ibn al-Aʿlam is referred to as Alim (‘*Αλημ*). The Greek manuscripts are of the fourteenth and fifteenth centuries, but they preserve texts older than the Persian and Arabic compilations. These include *scholia* to the *Almagest* datable to AD 1032 which refer to tables composed for the Greek calendar from the work of Ibn al-Aʿlam, as well as two horoscopes for the years AD 1153 and AD 1162 which have been calculated from such tables, apparently for the Emperor Manuel Comnenus. The tabulation of the equations indicates that the technique of “displacements” was used in order to provide values of the equations which were always positive.

See also: ►*Zij*, ►Ibn Yūnus

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Ibn al-Bannāʾ

Emilia Calvo

Ibn al-Bannāʾ al-Marrākushī, Abū-i-ʿabbās Aḥmad ibn Muḥammad ibn ʿUthmān al-Azdī was born in Marrakesh, Morocco on 29 December 1256 and died, probably in Marrakesh, in 1321. He studied the Arabic language, grammar, the *Quʾrān*, *Ḥadīth* (commentaries of the prophet), and also mathematics, astronomy, and medicine; but his fame is due to his knowledge of mathematics. His teachers in this field were Muḥammad ibn Yaḥyā al-Sharīf, Abū Bakr al-Qallūsī, and Abū ʿAbd Allah ibn Makhlūf al-Sijilmāsī. He also studied medicine with al-Mirrīkh.

Among his disciples were al-Lajāʾī, teacher of Ibn Qunfūdh, Muḥammad ibn Ibraḥim al-Abūlī, Abū-l-Barakāt al-Balāfiqī, and Ibn al-Najjār al-Tilimsānī.

He is credited with having written more than 80 works. Among them are an introduction to Euclid, a treatise on areas, an algebra text, a *Kitāb al-anwāʾ* (about asterisms and stars used in meteorology and navigation), an almanac, two abridgements of treatises by Ibn al-Zarqāllu on the use of the *ṣafīḥas* (astrolabes) *zarqāliyya* and *shakkāziyya* entitled, respectively, *Risālat al-ṣafīḥa al-mushtaraka ʿalā al-shakkāziyya* (Epistle on the Shakkāziyya Plate), in 23 chapters, and *Taqbīl ʿalā risālat al-ṣafīḥa al-zarqāliyya* (Epistle on al-Zarqālī’s Plate). However, his two most important works are the *Minhāj* and the *Ṭalkhīṣ*.

The *Kitāb minhāj al-ṭālib li taʿdīl al-kawākib* (The Way of Him Who Seeks the Equation of the Planets) is a very practical book for calculating astronomical ephemerides. This *zīj* (astronomical handbook with tables) is based on the one by Ibn Isḥāq. The two of them are highly dependent on Ibn al-Zarqāllu’s astronomical theories.

The *Talkhīṣ aʿmāl al-ḥisāb* (Summary of Arithmetical Operations) was widely diffused in the Arabic world because of its conciseness, which makes it easy to memorize. Al-Qalaṣādī, among others, wrote an important commentary on it. A different version of this work, more extensive and complete, has been edited recently by Saidan (1984) under the title *Al-maqālāt fī ʿilm al-ḥisāb li-Ibn al-Bannāʾ* (The Treatises on the Science of Computation by Ibn al-Bannāʾ). The procedures found in the *Talkhīṣ* are studied here in a more detailed way.

See also: ►Ibn al-Zarqāllu, ►Ibn Qunfūdh

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Ibn al-Bayṭār

Emilia Calvo

Ibn al-Bayṭār al-Mālaqī, Ḍiyāʾ al-Dīn Abū Muḥammad ʿAbdallāh ibn Aḥmad, was a pharmacologist born in Málaga, Spain at the end of the twelfth century (ca. AD 1190–1248). He studied in Seville with Abū-l-ʿAbbās al-Nabātī, ʿAbdallāh ibn Ṣāliḥ, and Abū-l-Hajjāj. He was interested in the works of al-Ghāfiqī, al-Zahrāwī, al-Idrīsī, Dioscorides, and Galen.

Around AD 1220 he migrated to the East and, in 1224, arrived in Cairo where he was named chief herbalist by the Ayyūbid Sultan al-Kāmil. He traveled through Arabia, Palestine, Syria, and Iraq. Ibn Abī Uṣaybiʿa was one of his followers and left a mention of his teacher full of praise in his *ʿUyūn*.

Among Ibn al-Bayṭār's works we can mention *Al-Mughnī fīʾl-adwiya al-mufrada* (The Complete Book on Simple Drugs), dedicated to al-Kamil's son, Sultan al-Ṣāliḥ and dealing with the simple medicines, and *Al-Jāmiʾ li-mufradāt al-adwiya wa-l-aghdhiya* (Compendium of Simple Drugs and Food), which enumerates alphabetically some 1,400 animal, vegetable, and mineral medicines, as well as some 150 authorities including al-Rāzī and Ibn Sīnā.

Ibn al-Bayṭār's main contribution is the systematization of the discoveries made by the Arabs during the Middle Ages in this field. He was also concerned with synonymy, finding the technical equivalents between the Arabic and Persian, Berber, Greek, Latin, and Romance languages. The *Jāmiʾ* had great influence in the Near East, but less in the West. Andrea Alpago used it in his works on Ibn Sīnā.

Other works of Ibn al-Bayṭār, less known than the aforementioned two, are *Mizān al-ṭabīb* (The Measure of the Physician), *Risāla fīʾl-aghdhiya waʾl-adwiya* (Treatise on Food and Medicines), *Maqāla fīʾl-laymūn* (Treatise on the Lemon), and *Tafsīr kitāb Diyusqūrīdis* (Explanation of Dioscorides' Book) in which he inventories 550 medicines found in the first four books of Dioscorides.

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Ibn al-Hāʾim

Julio Samsó

ʿAbd al-Ḥaqq al-Ghāfiqī al-Ishbīlī is known as Ibn al-Hāʾim. He was an Andalusian astronomer, probably from Seville. He dedicated (ca. 1204) his very important *al-Zīj al-Kāmil fīʾl-Taʿālīm* (The Perfect Handbook on Mathematical Astronomy) to the Almohad Caliph Abū ʿAbd Allāh Muḥammad al-Nāṣir (1199–1213). This work, which is extant in a unique and incomplete manuscript in the Bodleian Library at Oxford University, was influential in the Maghreb and contributed to the development there of a new kind of astronomy in the Andalusian tradition. As a *zīj* (astronomical handbook with tables), it is exceptional in Western Islam, because it contains a highly technical and complete exposition of Ptolemaic astronomy with geometrical demonstrations, and not a simple set of instructions for the use of the tables. It also conveys new information on the astronomical works of the Toledan school of the eleventh century, the main representative of which was Ibn al-Zarqāllu/Azarquiel (d. 1100), as well as new planetary parameters. Ibn al-Hāʾim appears as a defender of Zarqāllian orthodoxy and harshly criticizes Ibn al-Kammād (fl. beginning of the twelfth century) for his modifications of Ibn al-Zarqāllu's doctrines. Ibn al-Hāʾim's *zīj* contained numerical tables (three have been preserved in the *zīj* of Ibn Isḥāq, who flourished in Tunis at the beginning of the thirteenth century) but an incomplete copy must have circulated early for Ibn al-Raqqām (d. 1315) states that Ibn al-Hāʾim did not include any tables in his work.

See also: ►Ibn al-Zarqāllu, ►Ibn al-Raqqām

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Ibn Al-Haytham (Alhazen)

Roshdi Rashed

Among the mathematicians of classical Islam, few are as famous as al-Ḥasan ibn al-Ḥasan ibn al-Haytham (Alhazen in the Latin West). A physicist and astronomer as well as mathematician, he quickly gained a wide reputation, first in Arabic, in the Islamic East as well as the Islamic West, and then from the translations of his works in optics and astronomy into Latin, Hebrew, and Italian.

But his renown, completely justified by the importance of his contributions and especially of the scientific reforms accomplished in them, contrasts singularly with the paucity of information we have on the man, his teachers, or his scientific milieu. Also, the significance of his works surrounded the man with the aura of a legend. Sources available to us consist of narratives recounted by ancient bibliographers where legend becomes mixed up with the rare historical evidence. These same narratives are precisely what modern bibliographers continue to reproduce partially or totally until today. After a critical reading of these sources, very little information remains: born in Iraq, most likely in Bassorah, sometime in the second half of the tenth century, Ibn al-Haytham arrived in Cairo, under the reign of Faṭimid al-Ḥākim. He proposed a hydraulic project to control the waters of the Nile, but it was rejected by the Caliph. He continued to live in Cairo until his death, after 432/1040.

From the thirteenth century until today, biographers have confused al-Ḥasan ibn al-Haytham with Muḥammad ibn al-Haytham, a philosopher and theorist of medicine who lived in Baghdād at the same time. This confusion, due undoubtedly to similarity of the two names of these contemporary authors, is serious as it brings into question the authenticity of certain writings attributed to al-Ḥasan ibn al-Haytham.

Biobibliographers, notably al-Qifṭī, cite 96 titles of Ibn al-Haytham, not all of which have survived. Half of his writings are in the field of mathematics, 14 on optics, including the authoritative and voluminous *Kitāb al-Manāẓir* (Book of Optics), 23 on astronomy, two in philosophy (one on the *Place* and the other on the *Indivisible Part*), three on statics and hydrostatics, two on astrology, and four on various other topics. This accounting shows clearly that Ibn al-Haytham grappled with all the mathematical sciences of that time, or at least the most advanced part of this discipline. We will see that he was always at the leading edge of research or at the culmination of one tradition and the beginning of a new period. It is precisely this quality which distinguishes his contributions. Ibn al-Haytham lived at a privileged time, his work following a century of intense research in these fields by eminent scholars such as the Banū Mūsā, Thābit ibn Qurra and his grandson Ibrāhīm ibn Sinān, al-Qūhī, and Ibn Sahl, to name a few. We will now briefly examine the principal aspects of his research.

Mathematics

Ibn al-Haytham's mathematical research was particularly in the field of geometry and not of algebra. Ancient biobibliographers attributed a boọk on algebra to him, but it has not survived. From the outset, geometers wanted to combine closely the study of the positions of figures and their metric properties: in other words, to combine the geometry of Apollonius with that of Archimedes. This combination is not a static synthesis, but a new organization of geometry which possessed a real heuristic value. Already initiated by al-Ḥasan ibn Mūsā and followed by Thābit, this work led to the study of geometric transformations and of projective methods. It was this work which Ibn al-Haytham developed further in his own geometrical studies.

The contributions of Ibn al-Haytham in geometry can be divided into several groups, the most important of which are in infinitesimal mathematics and the theory of conic sections and their applications. He composed 12 treatises on infinitesimal mathematics and then on conic theory. To those can be added a third area in which Ibn al-Haytham takes up several problems relating to the foundations of mathematics and their methods in his treatise *Maqāla fī'l-taḥlīl wa 'l-tarkīb* (On Analysis and Synthesis), his *Kitāb fī al-ma 'lūmāt* (On the Known Things), his *Sharḥ Uṣūl Uqlīdis fī 'l-handasa wa 'l-ʿadad wa talkhīṣuhu* (Commentary on the *Elements* of Euclid), and his *Kitāb fī Ḥall shukūk Kitāb Uqlīdis fi 'l-uṣūl wa-sharḥ maʿānīh* (Solutions to Doubts) again concerning Euclid. In these books, he deals as much with the constitution of a new discipline, a kind of proto-topology, as with the theory of the demonstration within the difficulties raised by the fifth postulate of Euclid, or with the theory of parallels. Ibn al-Haytham also edited an important paper on number theory, four treatises on arithmetic, and the same number on practical geometry.

Of the 12 papers on infinitesimal mathematics, only seven have survived. The first three are devoted to the study of lunes and the quadrature of a circle. Note that the calculation of the area of lunes involves the calculation of sums or differences of areas of sectors or of triangles, the comparison of which has recourse to that of the ratio of angles or of the ratio of segments. In the most important of the three papers, Ibn al-Haytham begins by setting up four lemmas, the results of which demonstrate the role of the function f, defined as

$$f(x) = \frac{\sin^2 x}{x}$$

in the study of lunes.

In his study *Tarbīᶜ al-dāʾira* (On the Quadrature of a Circle), he examines the relationship between proving the existence of a magnitude or a property and the question of effectiveness of its construction.

Other treatises on infinitesimal mathematics deal with the volume of a solid curve: *Misāḥat al-mujassam al-mukāfiʾ* (The Measurement of a Paraboloidal Solid) and *Misāḥat al-kura* (The Measurement of a Sphere). In calculating the volume of a paraboloid, Ibn al-Haytham deals rapidly with the volume of a revolving paraboloid, which had already been studied by Thābit ibn Qurra and al-Qūhī. He then moves on to his own invention: how to calculate the volume of a paraboloid obtained from the rotation of a parabola around its ordinate. He shows that this volume is 8/15 of the volume of the circumscribed cylinder. His calculation is equivalent to that of the integral

$$\pi \int_a^b k^2 (b^2 - 2b^2 y^2 + y^4) \mathrm{d}y = \frac{8}{15} \pi k^2 b^5 = \frac{8}{15} V,$$

with V being the volume of the circumscribed cylinder.

Ibn al-Haytham proceeded in this study with the help of the method of integral sums, which he also applied in calculating the volume of a sphere. In order to do this calculation, Ibn al-Haytham generalized the proposition X-1 of Euclid's *Elements*. He devoted the seventh paper in this group to that. This group includes an important treatise devoted to isoperimetric and isepiphane problems. It was the most advanced mathematical work of its time and for several centuries following. In it, to study these *extrema*, he had to undertake the first substantial research on the theory of a solid angle. Moreover he combined both a projective method and an infinitesimal method.

Ibn al-Haytham's second group of mathematical writings dealt with the theory of conic sections. He was well acquainted with the *Conics* of Apollonius and had copied them in his own hand, so he knew that, in Greek, the eighth and last book was lost. He tried to reconstruct the book according to the indications of Apollonius. In addition to his writings on conics, he applied the theory of the intersection of conics to the resolution of problems which cannot be constructed with a compass or ruler, problems either passed down (for example, the regular heptagon) or posed by him (for example, the solution of a solid arithmetic problem). Ibn al-Haytham was one of the first mathematicians who insisted on demonstrating the existence of the point of intersection of two conics in these last examples.

It is impossible in this space to explicate the mathematical results of Ibn al-Haytham's work. But let us simply note his expression of what is called Wilson's theorem, and the converse of Euclid's theorem for perfect numbers.

Indeed, in the course of solving the problem called the Chinese Remainder, he stated Wilson's theorem, which can be written as:

n is prime

$$(n-1)! - 1 (\mathrm{mod}\, n).$$

As for the converse of Euclid's theorem of perfect numbers, he tried to show that any even perfect number is in Euclidean form, in other words in the form $2^p(2^{p+1} - 1)$ with $(2^{p+1} - 1)$ prime.

Optics

A brief look at the work of Ibn al-Haytham on optics reveals not only its revolutionary nature but also its comprehensiveness, touching all the known branches of optics: optics in its proper sense in his *Book on Optics* and his *Discourse on Light*; catoptrics, notably burning mirrors (parabolic and spherical burning mirrors); dioptrics, in *al-Kura al-muḥriqa* (The Burning Sphere); and meteorological optics in *Dawʾal-qamar* (The Light of the Moon), *Aḍwāʾ al-kawākib* (The Light of the Stars), *Fī ṣūrat al-kusūf* (On the Shape of the Eclipse) and *al-Hāla wa-qaws quzaḥ* (The Halo and the Rainbow). With this extension, Ibn al-Haytham modified the meaning of optics. Optics is not any more reduced to a theory of direct vision, a geometry of the gaze with which a theory of vision is associated, but also bears significantly on the theory of light, its propagation, and its effects as a material agent. This leads us to the revolution accomplished by Ibn al-Haytham in optics and more generally in physics.

Ibn al-Haytham sought to bring about a program of reform, which led him to take up a whole range of different problems. The basic aspect of this reform was to clarify the difference between the conditions of the propagation of light and the conditions of the vision of objects. This led, on the one hand, to giving physical support to the rules of propagation – making a firm mathematical analogy between a mechanical model of the movement of a solid ball thrown against an obstacle and that of light – and on the other hand to proceeding geometrically at all times, both by observation and by experimentation. Optics consisted henceforth of two parts: one, a theory of vision and the associated physiology of the eye and psychology of perception, and the other, the theory of light to which are linked geometric optics and physical optics. The organization of the *Optics* reflects this new situation: there are chapters devoted entirely to propagation, such as the third chapter of the first book and books IV to VII; others deal with vision and related problems. This reform also resulted in the emergence of new problems, such as Alhazen's problem in catoptrics, the examination of the spherical lens and the spherical diopter, not only as burning instruments but also as optical instruments in dioptrics, and to experimental control, viewed as much as a general practice of investigation as the norm of a proof in optics, and more generally in physics. Let us now take a quick look at how this reform in optics was carried out.

Ibn al-Haytham rejected any doctrine of a ray stemming out from the eye, called a visual ray, in order to defend the intromissionist theory of visible forms. But unlike the intromissionists of antiquity, he did not believe that objects sent off "forms" or totalities which emanated from the visible under the effect of light. He saw them rather as forms reducible to their elements: a ray emanating toward the eye from every point of a visible object. Looked at thus, the eye becomes a simple optical instrument. Ibn al-Haytham then explained how the eye perceives the visible with the help of its rays emitted from all points. In the *Optics* he devotes the first three chapters to the foundations of this theory. In the three following chapters, he deals with catoptrics. The seventh and last chapter is devoted to dioptrics. His theories rest on two qualitative laws of refraction and on several quantitative rules, all controlled experimentally with the help of an instrument which he designed and built himself. The two qualitative laws, known to his predecessors Ptolemy and Ibn Sahl, can be stated as follows:

1. The incident ray, the normal at the point of refraction, and the refracted ray are in the same plane; the refracted ray gets closer (respectively, far away) from the normal, if light passes from a milieu less (respectively, more) refringent to a milieu more (respectively, less) refringent
2. The principle of inverse return

Instead of pursuing the path opened up by his predecessor Ibn Sahl, Ibn al-Haytham returned to a study of angles in order to establish the quantitative rules. He devoted a substantial part of the seventh book to a study of the refracted images of an object, notably if the surface of separation of two milieux is either planar or spheric. It was in the course of this study that he fixed his attention on the spherical diopter and the spherical lens. He returned to the spherical lens in his treatise *On the Burning Sphere*, one of the high points of research in classical optics, in order to improve upon certain results that he had already obtained in his *Optics*. This treatise was the first deliberate study on the spherical aberration for parallel rays falling on a glass sphere and giving off two refractions.

Astronomy

By their number, their thematic variety, the power of the analysis they show, and by their results, the works of Ibn al-Haytham in astronomy yield nothing to his works in mathematics or optics. It should be noted only that an elementary treatise of Muḥammad ibn al-Haytham, the *Commentary on the Almagest* is often erroneously attributed to Ibn al-Haytham. The attribution of the book *On the Configuration of the Universe* to him is also doubtful. The authentic works of Ibn al-Haytham have not yet been seriously studied, *a fortiori*, apart from a few rare and particular contributions, such as the *Samt al- ibla bi-al-ḥisāb* (Determination of the Direction of Mecca by Calculation). It remained for subsequent astronomers, notably al-ʿUrḍī, one of the founders of the school of Marāgha, to recognize their debt to Ibn al-Haytham's book *al-Shukūk ʿalā Baṭlamyūs* (Doubts on Ptolemy). Before assessing his contribution in astronomy, we must wait until his books have received the editing and study that they deserve.

The impact of the work of Ibn al-Haytham varies according to the field. In mathematics, his influence can be seen in the works of Ibn Hūd, al-Khayyām, Sharaf al-Dīn al-Ṭūsī, and al-Samaw'al, among others. But we do not know anything of successors who might have tried to follow up on his research on lunes, the solid angle, or the measurement of figures and solid curves. In optics, the Latin translation of his *Optics* (under the title *Perspectiva* or *De Aspectibus*, reedited in 1572 under the title *Opticae Thesaurus*) and his treatise *On Parabolic Burning Mirrors* provided a basis of research for centuries of scholars such as Witelo, Roger Bacon, J. Peccham, Frederick of Fribourg, Kepler, and Snell, among many others. In Arabic, there is the commentary of Kamāl al-Dīn al-Fārsī. Finally in astronomy, there is the work of al-ʿUrḍī which shows the influence of his work. It is too soon to measure the impact of the writings of Ibn al-Haytham on his successors in this field also, but they appear to be immense.

See also: ►Geometry, ►Physics, ►Optics, ►al-Khayyām, ►Sharaf al-Dīn al-Ṭūsī, ►*Almagest*

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Ibn al-Kammād

Julio Samsó

Abū Jaᶜfar Ahmad ibn Yūsuf ibn al-Kammād was an Andalusian astronomer who flourished in Cordoba toward the end of the eleventh century and the first half of the twelfth. He was probably a direct disciple of Ibn al-Zarqāllu/Azarquiel (d. 1100) as well as the student who helped him in observations made in Cordoba during his last years. He compiled three sets of astronomical tables (*zījes*) of which only one (*al-Muqtabis*) is extant in a Latin translation made by Johannes of Dumpno in Palermo (1262). In it he appears as a follower of the Zarqallian tradition, although he often corrects his master's parameters. Toward 1204, Ibn al-Hāᵓim makes a strong criticism of one of his other two *zījes* (*al-Amad ᶜalāᵓl-abad*, Valid for all Eternity) because of his departures from Zarqallian orthodoxy. Also extant, in Arabic, is a small astrological work in which Ibn al-Kammād studies the problem of the length of human pregnancy and the determination of the exact moment of the conception.

His work was influential in late Maghribean and Egyptian astronomy, for quotations and tabular materials from his *zījes* appear in the thirteenth century *zīj* of Ibn Isḥāq al-Tūnisī in Abūᵓl-Ḥasan ᶜAlī al-Marrākushī's treatise on *mīqāt* (Astronomy Applied to Muslim Worship) and in a fourteenth century anonymous Egyptian treatise on the same topic.

See also: ►*Zīj*, ►Ibn al-Hāᵓim

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Ibn al-Majūsī

Sami Khalaf Hamarneh

Abū'l-Ḥasan ᶜAlī ibn al-ᶜAbbās ibn al-Majūsī was considered one of the leading Muslim physicians of his time. He was of Zoroastrian ancestry, and therefore called the Magian, and he is known in Latin as Haly ᶜAbbās. He was born in the old Persian city of Arrajān, in the southwest of Iran, at the end of the first quarter of the tenth century. He studied medicine under a leading medical tutor (*shaykh*) named Abū Māhir Mūsā ibn Yūsuf ibn Sayyār, who died ca. AD 983.

When he had developed a reputation for excellence and skill, Ibn al-Majūsī was invited to become a physician-in-ordinary at the palace of King ᶜAḍud al-Dawlah Fannā Khusraw, who reigned from AD 949 to 983 in Shīrāz. He was the Buwayhid Shāh who founded al-ᶜAḍudī Bīmāristān, the famous hospital in Baghdad that lasted for almost three centuries. In that period, the Buwayid Dynasty's power and glory reached their apex.

In recognition of the King's generosity and patronage to the sciences and the arts, Ibn al-Majūsī dedicated his medical encyclopedia, *Kāmil al-Ṣināᶜah al-Ṭibbīyah*, known also as *Kitāb al-Malikī* (Latin *Liber regius*, presented to the King's royal library) in Shīrāz.

The book comprises two parts, the theoretical and the practical, each of which has ten treatises. It brought together original contributions on public health, preventive medicine, dietetics, materia medica, therapy, surgery, clinical observations, and practical medicoethical procedures. *Kitāb al-Malikī* was first rendered into Latin by Constantine Africanus (AD 1020–1087) under the title *Pantegni*, without giving credit to its original author. Al-Majūsī was fully recognized when the book was translated from Arabic into Latin by Stephen of Antioch in 1127. Since then, many editions in Latin and Arabic have appeared, and a facsimile edition was published in 1985 in two volumes.

Among the Arabic compendia on the theme of the healing arts in Islam, Majūsī's *Kitāb al-Malikī* stands as one of the leading texts in its style, systematization, and precision. It was well read among students and practitioners alike. The judge and historian Ibn al-Qifṭī praised Majūsī by saying that he "excelled in the study of medicine, [and] worked hard to comprehend its doctrines and laws from the original sources."

Ibn al-Majūsī died in Shīrāz in AH 384/AD 994, leaving behind an essential document in the Arabic legacy to the history of the medical sciences in this golden age.

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Ibn al-Nafīs

Albert Z. Iskandar

Ibn al-Nafīs, ʿAlāʾ al-Dīn Abu'l-Ḥasan ʿAlī Ibn Abī al-Ḥazm al-Qurashī, was born in a village near Damascus (Syria). He studied medicine at the Great Nūrī Hospital (*al-Bīmāristān al-Nūrī*) in Damascus, founded by the Turkish ruler Nūr al-Dīn Maḥmūd Ibn Zankī (d. AD 1174). He chose to live, practice, and teach medicine in Egypt, where he eventually became a Chief of Physicians, and was also a personal doctor to the then-ruler al-Ẓāhir Baybars (r. ca. AD 1260–1277).

In addition to practicing medicine, he was a Shāfiʿī jurist, thoroughly educated in Islamic theology and jurisprudence at the Masrūriyya School (*Madrasa*) in Cairo. Hence, he is classed as a "jurist physician," thus deviating from the traditional image of the physician–philosopher Galen (d. ca. AD 200), which was so faithfully emulated by many medieval Arabic-speaking doctors, as for example al-Rāzī (Rhazes, d. AD 925) and Ibn Sīnā (Avicenna, d. AD 1037).

Ibn al-Nafis was a prolific author. Among his medical works is *Kitāb al-Shāmil fi 'l-ṣināʿa al-Ṭibbiyya* (Comprehensive Book on the Art of Medicine). He jotted down preparatory notes for this voluminous book in 300 volumes, of which he managed to publish only 80. Its manuscripts, so far unpublished, are to be found in Cambridge University Library (Cambridge, England), the Bodleian Library (Oxford, England), and al-Muthaf al-ʿIrāqī (Iraq). In 1960, three autographed manuscripts of this book were discovered in the Lane Medical Library (Stanford University). The first, referred to by Ibn al-Nafis himself as the 33rd *mujallad* (bound volume), is dated AH 641/AD 1243–1244. According to the author, the two other manuscripts are its 42nd and 43rd volumes.

It is of historical significance that Ibn al-Nafīs, in *Kitāb al-Shāmil*, divides the procedure to be followed by doctors in surgical operations into three stages: first, the "stage of presentation for clinical diagnosis"; second, the "operative stage"; and third, the "postoperative period," during which the patient remains under the doctor's supervision until full recovery is achieved.

Another important work is *Sharḥ Tashrīḥ Kitāb al-Qānūm fi 'l-Ṭibb li-Ibn Sīnā* (Commentary on Anatomy in Avicenna's Canon of Medicine). In it he gives the earliest known account of pulmonary circulation: "…This is the right cavity of the two cavities of the heart. When the blood in this cavity has become thin, it must be transferred into the left cavity, where the pneuma is generated. But there is no passage between these two cavities, the substance of the heart there being impermeable. It neither contains a visible passage, as some people have thought, nor does it contain an invisible passage which would permit the entry of blood, as Galen thought. The pores of the heart there are compact and the substance of the heart is thick. It must, therefore, be that when the blood has become thin, it is passed into the arterial vein (pulmonary artery) to the lung, in order to be dispersed inside the substance of the lung, and to mix with the air. The finest parts of the blood are then strained, passing into the venous artery (pulmonary vein) reaching the left of the two cavities of the heart, after mixing with the air and becoming fit for the generation of pneuma…"

Ibn al-Nafīs' discovery of pulmonary circulation antedates the accounts mentioned by Michael Servetus (AD 1553), Realdo Colombo (AD 1559), and Andrea Cesalpino (d. AD 1603). Andreas Vesalius (d. AD 1564), who does not mention blood circulation, refutes Galen in his statement: "…I do not see how even the smallest amount of blood could pass from the right ventricle to the left ventricle, through the interventricular septum…" We now say it was William Harvey (d. AD 1657) who, through experimentation which lasted almost 20 years, discovered the entire path of blood circulation.

Ibn al-Nafīs wrote a large textbook, *Al-Muhadhdhab fi 'l-Kuḥl al-Mujarrab* (The Polished Book on Experimental Ophthalmology), divided into two sections: "On the Theory of Ophthalmology," followed by detailed accounts of "Simple and Compounded Ophthalmic Drugs."

A very popular and concise book was Ibn al-Nafīs' *Mūjiz al-Qānūn fi 'l-Ṭibb* (Abstract of Ibn Sīnā's Canon of Medicine). It has been claimed – probably unfairly – that the tedious prolixity of Ibn Sīnā's *Canon of Medicine*, together with the incomprehensibility of some of its statements, and Ibn al-Nafīs' *Abstract of Avicenna's Canon of Medicine*, with its undue brevity and popularity among Arabic-speaking students of medicine, led to the decline of late medieval medical education.

On the philosophy of religion, Ibn al-Nafīs wrote *Al-Risāla al-Kāmiliyya fi'l-Sīra al-Nabawiyya* (Missive on the Complete Prophetic Conduct), also known by the title *Fāḍil Ibn Nāṭiq*. It was written along the lines of Ibn Ṭufayl's (d. AD 1185) *Ḥayy Ibn Yaqẓān*. In it, Ibn al-Nafīs imagines the generation – inside a cave on a deserted island – of a human being. The author guides the reader to the way in which this lone human being would arrive at the discovery of science and philosophy, then the knowledge of prophecies, and particularly the *Sīra* (conduct) of the Prophet Muḥammad, and the legal doctrines of Islam.

In his old age, Ibn al-Nafīs bequeathed his own house, including an extensive private library, to the Qalāwūn Hospital, founded in AD 1284 by Sultan Qalāwūn (r. AD 1279–1290). Ibn al-Nafīs died in his 80s, a bachelor who devoted all his time to the practice of medicine on which he wrote several books. He died on 17th December 1288 (11th Dhu'l-Qaᶜdah 687).

See also: ►Ibn Sīnā, ►al-Rāzī

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Ibn al-Quff (al-Karakī)

Sami K. Hamarneh

Abū'l-Faraj ibn Yaᶜqūb ibn Isḥāq Ibn al-Quff al-Karakī was born on the 22nd of August 1233, in the city of Karak (hence the name al-Karakī) in the district of Transjordan in larger Syria (*Bilād al-Shām*). The first and most intimate biography, by a friend of al-Karakī's family, was by Abū'l-Faraj's first teacher in the healing art – the prominent physician and historian of medicine Ibn Abī Uṣaybiᶜah (d. 1270). The meeting between al-Karakī's family and Uṣaybiᶜah took place in Ṣarkhad, Syria. As Uṣaybiᶜah was the physician-counselor to the governor (*wālī*) of Ṣarkhad and the entire province, al-Karakī's family moved from Karak north to Ṣarkhad. The father was summoned by the governor to serve as a secretary to the Department of Welfare (*dīwān al-birr*). A very close friendship developed between the physician as a leading and resourceful practitioner, and Yaᶜqūb al-Karakī as an able secretary, adviser, historian, linguist, and man of letters.

At that time, the son Abū'l Faraj was 11 or 12 years of age, a bright fellow who had acquired the basics in education in Karak. The father asked the physician if he would teach his son the healing art, and Uṣaybiᶜah willingly accepted the challenge. He soon taught him the basics of the field: the theory and practical aspects of medicine, methods of treatment, and the identification of causes and symptoms of diseases.

The major texts which were studied included some of the writings of Hippocrates (known as the Hippocratic *corpus*, such as the *Aphorisms and Prognoses*) and some of the medically important catechisms, such as *Al-Masāʾil* by Ḥunayn ibn Isḥāq (809–873), and the major writings of al-Rāzī (Latin Rhazes, 865–925), particularly the clinical and therapeutic texts.

After the fall of the Ṣarkhad province into the hands of the Ayyūbid King, al-Ṣāliḥ Najm al-Dīn (1245–1249), al-Karakī's family moved to Damascus (the Syrian capital of the Ayyūbids) where the father was promoted to a higher position. The son continued his study under some of the most illustrious physicians at the time. Damascus had great hospitals, including the hospital located in the Citadel for the Royal family, civil servants, and army personnel. There Ibn al-Quff had his training to become a physician.

This medieval period had witnessed great cultural, political, and technoscientific changes. There was the fall of the prestigious Fātimiḍ (Shīᶜite) dynasty in Cairo, and the rise of the Ayyūbid (Sunnite) dynasty in Cairo and Damascus under the leadership of Sultān Ṣalāḥ al-Dīn (Saladin, r. 1171–1193) and his successors. There was also the rise of the *Bahri Mamluks* (slave sultans 1250–1381). However, the true founder of the "Slave" dynasty was Sultān al-Ẓahir Baybars (d. 1277), who was first purchased to serve in the Ayyūbid army and then became their ruler. During this time, the healing arts reached new heights.

Having had excellent training and having become a worthy practitioner-surgeon, Ibn al-Quff was summoned in about 1262 (at the age of 29) to be the physician-surgeon in ᶜAjlūn, his home country in Transjordan. There he served the profession for a decade, at the end of which he published his first medical encyclopedia *Al-Shāfī-al-Ṭibb* (The Comprehensive of the Healing Arts), completed in early 1272. It is composed of 12 treatises encompassing the entire medical field. It was a significant contribution to the field at the time and contained many timely observations and innovations.

From ᶜAjlūn, al-Karakī was summoned to the Syrian capital, Damascus. There he served at its Citadel and hospital from 1272 until his untimely death in early July 1286 at the age of 52. We know that many medical students came to hear his lectures and listen to his eloquence. He also continued to fulfill his duty in caring for the sick and the wounded and continued his research and publications. Among these are two commentaries: one on the Hippocratic *Aphorisms*, entitled *al-Uṣūl*, edited in Cairo, and the other a commentary on the generalities of the *Qānūn* of Ibn Sīnā (d. 1037). The last *Sharh* was complete about 1274.

His other work is *Jamiᶜ al-Gharaḍ*, on preventive medicine and the preservation of health in 60 chapters, completed about 1275. It is extant in several manuscripts. This is possibly the finest work of its kind in medieval times, and it needs translation into English for wider audiences.

Al-Karakī's best and most renowned manual is *al-ᶜUmdah* on surgery. It was published in Hyderabad, India, in 1356 AH/1937 and ranks second after *al-Taṣrīf* (The Thirtieth Treatise) by al-Zahrāwī (Abulcasis, ca. 939–1013).

Only recently have al-Karakī's literary contributions begun to draw wider recognition. His writings should place him among the greatest physician-surgeons and public health experts during the Arab-Islamic Golden Age.

See also: ►Ibn al-Majūsī

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Ibn al-Raqqām

Julio Samsó

Muḥammad ibn al-Raqqām al-Andalusī (d. 1315) was an Andalusian astronomer, mathematician, and physician. He was probably born in Murcia and left the city when it was conquered by Alfonso X in 1266. He lived in Bejaia (Algeria), Tunis and, after 1280, accepted the invitation of Muḥammad II (1273–1302) and established himself in Naṣrid Granada where he taught mathematics and astronomy (as well as medicine and law). Among his students in astronomy we find king Naṣr (1309–1314). His son, Ibrāhīm ibn Muḥammad ibn al-Raqqām, was an astrolabe maker: one of his instruments (made in Guadix in 1320) is still preserved in Madrid.

Among his extant works we should mention his *Risāla fī ʿIlm al-Ẓilāl* (Treatise on the Science of Shadows) as well as two sets of astronomical tables (*zījes*), the first of which was probably compiled in Bejaia in 1280–1281, while the second was made in Tunis and later adapted to the coordinates of Granada. His book on *Shadows* is a brilliant treatise on Gnomonics where Ibn al-Raqqām explains how to build all kinds of sundials (among which we find a portable sundial which includes a compass) using projections on a plane which, ultimately, derive from Ptolemy's *Analemma*. The first of his *zījes*, entitled *al-Zīj al-Shāmil fī Tahdhīb al-Kāmil* (A General Set of Astronomical Tables in which [Ibn al-Hā'im's] Kāmil Zīj is Corrected), follows narrowly the theoretical contents of Ibn al-Hāʾim's *al-Zīj al-Kāmil fī'l-Taʿālīm* to which Ibn al-Raqqām adds the numerical tables which had been lost in the manuscript of Ibn al-Hā'im's work. His second *zīj al-Zīj al-Qawīm fī Funūn al-Taʿdīl wa-l-Taqwīm* (The Solid Handbook to Calculate Equations and Planetary Positions) is a summary and adaptation of the first one to the coordinates of Tunis and Granada. Both works bear witness to the diffusion of Ibn al-Zarqāllu's astronomical ideas in the Maghreb and Andalusia.

See also: ►Ibn al-Zarqāllu, ►Alfonso X, ►*Zīj*, ►Sundials

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Ibn Al-Shāṭir

David A. King

Ibn al-Shāṭir, ʿAlāʾ al-Dīn ʿAlī ibn Ibrāhīm was born in Damascus ca. 1305. He was the most distinguished Muslim astronomer of the fourteenth century. Although he was head *muwaqqit* at the Umayyad mosque in Damascus, responsible for the regulation of the astronomically defined times of prayer, his works on astronomical timekeeping are considerably less significant than those of his colleague al-Khalīlī. On the other hand, Ibn al-Shāṭir made substantial advances in the design of astronomical instruments. Nevertheless, his most significant contribution to astronomy was his planetary theory.

In his planetary models Ibn al-Shāṭir incorporated various ingenious modifications of those of Ptolemy. Also, with the reservation that they are geocentric, his models are the same as those of Copernicus. Ibn al-Shāṭir's planetary theory was investigated for the first time in the 1950s, and the discovery that his models were mathematically identical to those of Copernicus raised the very interesting question of a possible transmission of his planetary theory to Europe. This question has since been the subject of a number of investigations, but research on the astronomy of Ibn al-Shāṭir and his sources, let alone on the later influence of his planetary theory in the Islamic world or Europe, is still at a preliminary stage.

Ibn al-Shāṭir appears to have begun his work on planetary astronomy by preparing a *zīj*, an astronomical handbook with tables. This work, which was based on strictly Ptolemaic planetary theory, has not survived. In a later treatise entitled *Taʿliq al-arṣād* (Comments on Observations), he described the observations and procedures with which he had constructed his new planetary models and derived new parameters. No copy of this treatise is known to exist in the manuscript sources. Later, in *Nihāyat al suʾl fī taṣḥiḥ al-uṣūl* (A Final Inquiry Concerning the Rectification of Planetary Theory), Ibn al Shāṭir presented the reasoning behind his new planetary models. This work has survived. Finally, Ibn al-Shāṭir's *al-Zīj al-jadīd* (The New Astronomical Handbook), extant in several manuscript copies, contains a new set of planetary tables based on his new theory and parameters.

Several works by the scholars of the mid-thirteenth century observatory at Maragha are mentioned in Ibn al-Shāṭir's introduction to this treatise, and it is clear that these were the main sources of inspiration for his own non-Ptolemaic planetary models.

The essence of Ibn al-Shāṭir's planetary theory is the apparent removal of the eccentric deferent and equant of the Ptolemaic models, with secondary epicycles used instead. The motivation for this was at first sight aesthetic rather than scientific, but his major work on observations is not available to us, so this is not really verifiable. In any case, the ultimate object was to produce a planetary theory composed of uniform motions in circular orbits rather than to improve the bases of practical astronomy. In the case of the sun, no apparent advantage was gained by the additional epicycle. In the case of the moon, the new configuration to some extent corrected the major defect of the Ptolemaic lunar theory, since it considerably reduced the variation of the lunar distance. In the case of the planets, the relative sizes of the primary and secondary epicycles were chosen so that the models were mathematically equivalent to those of Ptolemy.

Ibn al-Shāṭir also compiled a set of tables displaying the values of certain spherical astronomical functions relating to the times of prayer. The latitude used for these tables was 34°, corresponding to an unspecified locality just north of Damascus. These tables display such functions as the duration of morning and evening twilight and the time of the afternoon prayer, as well as standard spherical astronomical functions.

Ibn al-Shāṭir designed and constructed a magnificent horizontal sundial that was erected on the northern minaret of the Umayyad Mosque in Damascus. The instrument now on the minaret is an exact copy made in the late nineteenth century. Fragments of the original instrument are preserved in the garden of the National Museum, Damascus. Ibn al-Shāṭir's sundial, made of marble and a monumental 2 × 1 m in size, bore a complex system of curves engraved on the marble which enabled the *muwaqqit* to read the time of day in equinoctial hours since sunrise or before sunset or with respect to either midday or the time of the afternoon prayer, as well as with respect to daybreak and nightfall. The gnomon is aligned towards the celestial pole, a development in gnomonics usually ascribed to European astronomers.

A much smaller sundial forms part of a compendium made by Ibn al-Shāṭir, now preserved in Aleppo. It is contained in a box called *ṣandūq al-yawāqīt* (jewel box), measuring 12 × 12 × 3 cm. It could be used to find the times (*al-mawāqīt*) of the midday and afternoon prayers, as well as to establish the local meridian and the direction of Mecca.

Ibn al-Shāṭir wrote on the ordinary planispheric astrolabe and designed an astrolabe that he called *al-āla al-jāmiʾa* (the universal instrument). He also wrote on the two most commonly used quadrants, the astrolabic and the trigonometric varieties. Two special quadrants which he designed were modifications of the simpler and ultimately more useful sine quadrant. One astrolabe and one universal instrument actually made by Ibn al-Shāṭir survive.

A contemporary historian reported that he visited Ibn al-Shāṭir in 1343 and inspected an "astrolabe" that the latter had constructed. His account is difficult to understand, but it appears that the instrument was shaped like an arch, measured three-quarters of a cubit in length, and was fixed perpendicular to a wall. Part of the instrument rotated once in 24 h and somehow displayed both the equinoctial and the seasonal hours. The driving mechanism was not visible and probably was built into the wall. Apart from this obscure reference, we have no contemporary record of any continuation of the sophisticated tradition of mechanical devices that flourished in Syria some 200 years before his time.

Ibn al-Shāṭir died in Damascus ca. 1375. Later astronomers in Damascus and Cairo, none of whom appears to have been particularly interested in his non-Ptolemaic models, prepared commentaries on, and new versions of, his *zīj*. In its original form and in various recensions this work was used in both cities for several centuries. His principal treatises on instruments remained popular for several centuries in Syria, Egypt, and Turkey, the three centers of astronomical timekeeping in the Islamic world. Thus his influence in later Islamic astronomy was widespread but, as far as we can tell, unfruitful. On the other hand, the reappearance of his planetary models in the writings of Copernicus strongly suggests the possibility of the transmission of some details of these models beyond the frontiers of Islam.

See also: ►al-Khalīlī, ►*Zīj*, ►al-Jazarī, ►Astronomical Instruments

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Ibn al-Yāsamīn

AHMED DJEBBAR

The name of this mathematician is Abū Muḥammad ʻAbdallāh ibn Muḥammad ibn Hajjāj al-Adrīnī, more commonly known as Ibn al-Yāsamīn. As his name indicates, he was originally from a Berber tribe from the Maghreb (North Africa), and, according to Ibn Saʿīd, he was black like his mother. We know nothing about the exact date of his birth, but can reasonably place it in the second half of the twelfth century. We also know nothing specific about his place of birth, which could have been in the Andalus (Spain) or the Maghreb. But since some historians have given him the surname al-Ishbīlī, he may have been born or grown up in Seville. In any case, Ibn Saʿīd states that his formative education occurred in Seville.

This education was not restricted to mathematics, since we know he also became famous in the fields of law and literature, particularly in the Andalusian poetry of the Muwashshaḥāt. That being said, however, we know nothing of the context in which he received this rich education nor of his teachers. The only information we have is from Ibn al-Yāsamīn himself about one of his professors, Abū ʿAbdallāh Muḥammad ibn Qāsim al-Shalūbīn, who taught him algebra and the science of calculation.

We also do not know exactly when Ibn al-Yāsamīn began to publish his mathematical writings. Ibn al-Abbār tells us only that Ibn al-Yāsamīn's famous algebraic poem was drafted in Seville and that, in 1190 also in Seville, he was using it in his teaching.

Concomitant with his mathematical activities was Ibn al-Yāsamīn's dedication to poetry, and according to Ibn Saʿīd, some of his poems had even been set to music and sung at this time. It may have been his literary success which led to his frequenting the court of the third Almohad caliph Abū Yūsuf Yaʿqūb (1184–1199) and of his successor Muḥammad al-Nāṣir (1199–1213). These frequent court visits and the fame of his literary and mathematical publications probably gained Ibn al-Yāsamīn some enemies. Also some of his contemporaries accused him of leading a dissolute life. But none of these can be seen as the cause of his assassination in 1204 in Marrakesh.

The Mathematical Writings of Ibn al-Yāsamīn

The best-known work of Ibn al-Yāsamīn is a poem of 53 verses in rajaz meter entitled *al-Urjūza al-yāsmīnīyya fi al-jabr wa ʻl-muqābala* (Poem on Algebra and Restoration). In it the author defines the algebra known in his time – number, root, and sequence, then the six canonical equations of al-Khwārizmī with the processes of solving them, and finally, the operations of algebra – the restoration, comparison, multiplication, and division of monomials.

This poem has been widely read throughout the centuries both within the Maghreb and beyond. Thus, there are many commentaries on it by other famous mathematicians such as Ibn Qunfudh (d. 1407) and al-Qalaṣādī (d. 1486) in the Maghreb, Ibn al-Hāʾim (d. 1423) and Sibṭ al-Māradīnī (d. 1501) in Egypt and elsewhere.

For a long time, the contribution of Ibn al-Yāsamīn to mathematics was known only through his *Urjūza* in algebra. It is quite possible, moreover, that it was the success of this poem which led him to write a second one on irrational quadratic numbers and maybe a third on the method of false position. But the distribution of these last two poems was relatively modest, compared to that of the first one, and aside from the rare copies that exist, we have not yet found any explicit reference to the contents of the two other poems in any works on calculation written after the twelfth century.

The same situation exists for Ibn al-Yāsamīn's fourth written work on mathematics, entitled *Talqīḥ al-afkār bi rushūm ḥurūf al-ghubār* (Fertilization of Thoughts with the Help of Dust Letters [Hindu Numerals]). This work is much more important than his poems, as much in quantity as in quality. Indeed, it is a book of 200 folios which contains classic chapters on the science of calculation and on geometry. Among the works of the Muslim West which have come down to us, it is the only one which consolidates these two disciplines. Its importance is also due the nature of its materials and its mathematical tools which make it an original book and also one which is totally representative of this period of transition in which three mathematical traditions were juxtaposed – of the East, the Andalus, and the Maghreb – before they became blended in the same mold.

For example, the following elements contribute both to the originality of his work and to its being anchored in the great Arab mathematical tradition of the ninth to eleventh centuries:

In arithmetic, contrary to the Maghrebian tradition which prevailed from the fourteenth century on, Ibn al-Yāsamīn treats multiplication and division first, before addition and subtraction. This approach, which can be found again later in the work of Ibn al-Zakariyā' al-Gharnāṭī, seems to be based on Andalusian mathematical practice.

For fractions, the remarks and suggestions of Ibn al-Yāsamīn concerning the reading of certain expressions demonstrate that the symbolism of fractions had not been established definitively in his time. This was not the case, it appears, for the symbolism of equations which had been established relatively early, since there is no difference between the symbols used in the *Talqīḥ al-afkār* of Ibn al-Yāsamīn and those used in the *Bughyat aṭ-ṭullāb* (The Hope of Students) of Ibn Ghāzī al-Miknāsī (d. 1513).

As for the presence of geometry in a work on the science of calculation, this is not exceptional in regard to the Arab mathematical tradition, viewed in its entirely, in so far as similar chapters (i.e., chapters which deal with problems in metric geometry) had already been inserted in works edited in the East, such as the *Takmila fi l-ḥisāb* (Complement to Calculus) of ʿAbd al-Qāhir al-Baghdādī or the *Kitāb al-Kāfī* (The Sufficient Book) by al-Karajī.

In spite of what we have noted about the contents of *Talqīḥ al-afkār*, there has not been any explicit reference to the book in Maghrebian mathematical writing. There could be at least two possible explanations for this. First, a break in the tradition whose cause is to be found outside the scientific milieu of that time. This hypothesis is not implausible if one takes into account the personality of Ibn al-Yāsamīn and his controversial behavior and also his close ties to Almohad power.

The second reason, which is also plausible and which can be added to the first, can be found in mathematical practice after Ibn al-Yāsamīn, a practice which bore the strong imprint of mathematicians from Marrakesh, like Ibn Munʾim (d. 1228), al-Qāḍi al-Sharīf (d. 1282–1283), and Ibn al-Bannāʾ (d. 1321). We have observed this same phenomenon of the absorption of a mathematical tradition first in the East with the first written Arab arithmetical works from the ninth century and, in particular, with the work of al-Khwārizmī, and then in the Andalus with writings of the tenth century, like those of al-Majrīṭī and his pupils.

See also: ►Ibn al-Bannaʾ, ►al-Majrīṭī, ►al-Karajī

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Ibn Al-Zarqāllu

Emilia Calvo

Ibn al-Zarqāllu, Abū Isḥāq Ibrāhīm ibn Yaḥyā al-Naqqāsh, sometimes known as Azarquiel, was born in the first quarter of the eleventh century to a family of artisans. He entered the service of the *qāḍī* (judge) Ṣāᶜid of Toledo first as an artisan, and after as the director of a group which carried out astronomical observations. Ibn al-Zarqāllu lived in Toledo until ca. AD 1078, when he moved to Cordoba where he composed his last works under the patronage of the king of Sevilla al-Muᶜtamid ibn ᶜAbbād and where he died in AD 1100. His work exerted considerable influence on later authors such as Ibn al-Kammād, Abū'l-Ḥasan ᶜAlī Ibn al-Bannā', Abraham ibn ᶜEzra, Ibn al-Hāʾim, Ibn Isḥāq, and Ibn Bāṣo.

Ibn al-Zarqāllu's works are basically astronomical, although an astrological treatise by him is also extant. Other works of Ibn al-Zarqāllu are described below:

The *Almanac* is a reelaboration by Ibn al-Zarqāllu of the work of an unknown author called Awmātiyūs. It allows the determination of planetary longitudes, without computation, by combining Ptolemaic parameters with the Babylonian doctrine of the goal-years. The goal-years consisted of cycles peculiar to each planet. These cycles included an entire number of solar years which, in turn, comprised an exact number of synodic and zodiacal revolutions. These cycles were known by the Babylonian astronomers, and they are also found in Ptolemy's *Almagest*. The advantage of these cycles for astronomers is that the positions of the planets can be calculated for a complete cycle which will be repeated, so these positions will always be the same for a given date within the cycle.

Treatise on the Motion of the Fixed Stars is preserved in a Hebrew translation. It is probably the most complete medieval text on the trepidation theory. Trepidation consists of a back-and-forth vibration within fixed limits, which is supposed to account for the variation in velocity of the slow eastward motion observed in the fixed stars. The treatise proposed three different geometrical models to demonstrate this theory.

Fīsanat al-śams (On the Solar Year) was probably written between AD 1075 and 1080 and based on 25 years of solar observations. Here Ibn al-Zarqāllu established the proper motion of the solar apogee to be of 1° in 279 Julian years. The text is lost but it can be reconstructed from the works of later astronomers like Ibn al-Kammād, Ibn al-Hāʾim, Ibn Isḥāq, Ibn al-Raqqām and Ibn al-Bannāʾ.

Risālat al-ṣafīḥa al-zarqāliyya (Treatise on the Zarqaliyya Plate) and *Risālat al-ṣafiḥa al-shakkāziyya* (Treatise on the Shakkāziyya Plate) are two treatises on the use of a universal astrolabe called *ṣafīḥa* (plate). There is an Alphonsine translation in the *Libros del Saber de Astronomia* of the treatise on the use of the *ṣafīḥa zarqāliyya*. This instrument offers the possibility of making calculations for any given latitude by means of only one plate.

Kitāb al-ᶜamal bi'l-ṣafīḥa al-zījiyya (Treatise on the Plate for the Seven Planets) describes the equatorium, an instrument consisting of the representation, drawn to scale, of a planetary model, which is used to determine the position of a planet at a given moment. Both his treatise on its construction and his treatise on its use are extant.

He also took an active part in the elaboration of the *Toledan Tables* which seem to have been the result of the work of a group of astronomers directed by the *qāḍī* Ṣāᶜid.

Finally, he was probably the author of a treatise on the construction of the armillary sphere, translated or adapted by Isḥāq ibn Sīd, which was incorporated into the Alphonsine *Libro de las Armellas*.

See also: ►Ibn al-Kammād, ►Ibn al-Bannāʾ, ►Abraham ibn ᶜEzra, ►Ibn al-Hāʾim, ►Astrolabe, ►Armillary Sphere

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Ibn Baṭṭūṭa

Bilal Ahmad

Ibn Baṭṭūṭa (1304–1369) was the greatest Muslim traveler of his time. He was born in Tangier to a well-educated Moroccan family that produced many judges. After receiving basic education in his home town, at age 21 he headed toward Mecca both to make a pilgrimage and to study under some notable Muslim scholars in Egypt, Syria, and Hejaz. After reaching Egypt via Tunis and Tripoli, he decided to become a traveler to gain firsthand knowledge about as many parts of the world as possible. Ibn Baṭṭūṭa's fascination for travel took him to Syria, Iraq, southern Iran, and Azerbaijan. He then decided to spend the next 3 years (1327–1330) in the holy towns of Mecca and Medina in Hejaz. Ibn Baṭṭūṭa's next expedition (1330–1332) started from the seaport of Jidda. He sailed across the Red Sea to Yemen, traveled across Yemen by land, and from Aden he sailed along the coast to various trading ports of East Africa. On his way back, he turned his boat to the Persian Gulf area and concluded this trip by another pilgrimage to Mecca.

Ibn Baṭṭūṭa's travels were supported by the contributions of the rulers, governors, and other prominent residents of the places that he visited. After hearing of the benevolence of Muḥammad bin Tughlaq – the ruler of Delhi, India – Ibn Baṭṭūṭa decided to go to India. This time he adopted a very unusual route: by moving northward, he first passed through Egypt and Syria; he then traveled extensively in Anatolia (Asia Minor) and the territories of the Golden Horde where he was well received by the local sultans and other prominent people. Ibn Baṭṭūṭa's *Riḥlah* (Book of Travels) provides a clear and lucid picture of Constantinople, Saray (the capital of the Khan of the Golden Horde), and other Sultanates. After crossing the Steppes with a caravan, Ibn Baṭṭūṭa passed through the towns of Bukhara, Samarkand, Balkh, and Herat. He then crossed the Hindu Kush Mountains and visited many important towns and cities in the Indus Valley – particularly Sukkur, Multan, and Lahore – before he finally reached Delhi. Sultan Muḥammad bin Tughlaq received him with respect and presents. The Sultan also appointed him the chief justice of Delhi. Ibn Baṭṭūṭa enjoyed the patronage of the Sultan for several years.

In 1342, he appointed Ibn Baṭṭūṭa the ambassador to China. After his ship wrecked near Calicut on the Malabar Coast of India, he decided to go to the Maldives where he married into the royal family. In the following years, Ibn Baṭṭūṭa visited Sri Lanka (Ceylon), supported the Sultan of the Maldives in a war, went again to the Maldives, and visited Bengal, Assam, and Sumatra. The Sultan of Sumatra provided him with a new ship to go to China. He arrived at the Chinese port of Zaytun and reached Beijing via the inland waterways. On his return journey, he eventually reached Mecca via Sumatra, Calicut, the Persian Gulf, Baghdad, Syria, and Egypt. Ibn Baṭṭūṭa's narrative for this entire journey is sketchy and some scholars doubt that he ever reached Beijing.

In April to May of 1349, Ibn Baṭṭūṭa embarked for his home from Alexandria via Tunis, Sardinia, and Algeria. He eventually reached Fez (Morocco), from where he went to the Kingdom of Granada, in Spain. His next destination was western Sudan. After traveling across the Sahara, he visited the Empire of Mali and returned to retire in Fez.

Ibn Baṭṭūṭa was an outstanding adventurer. His education and experience earned him numerous honors and awards, including the position of judge in many parts of the Muslim world. After his retirement, he again held the office of *qāḍī* (judge) in a Moroccan town and dictated his recollections to Ibn Juzayy – a royal poet. Ibn Baṭṭūṭa's *Riḥlah* is a valuable document for understanding the ways of life in the fourteenth-century Muslim world.

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Ibn Buṭlān

Roger Arnaldez

Abū'l-Ḥasan al-Mukhtār ibn ʿAbdūn ibn Saʿdūn Ibn Buṭlān was a physician, philosopher, and Christian theologian from Baghdad (eleventh century). He had for a teacher a Nestorian priest, Abū'l-Faraj ibn al-Ṭayyib, a commentator on Aristotle, Hippocrates, and Galen, who was interested in botany and wrote on the humors, wine, and natural qualities. Teaching at the hospital founded in Baghdad by ʿAḍud al-Dawla, he directed his pupil in reading and the use of several medical works. He taught him so well that later, Ibn Buṭlān, in a controversy with the physician Ibn Riḍwān, maintained that one could understand the basic precepts of medicine by simply reading books.

On the subject of the *al-Masāʾil fi'l-Ṭibb fi'l-Mutaʿallimīn* (Questions on Medicine for Students) by Ḥunayn ibn Isḥāq, he believed that Ibn Riḍwān, who had refuted it, had not understood it at all, "because he didn't study it under the direction of masters in this art." That is why, in spite of his great knowledge of the works of the Ancients, he refused to conform blindly and to the letter. Also he asked why clear-sighted doctors had lost the habit of caring for certain maladies, as the Ancients had done, with warm medicines, and preferred to use cold ones. It seems also that Ibn Buṭlān was instructed in the practice of medicine by Abū'l-Ḥasan Thābit ibn Ibrāhīm al-Ḥarrānī, about whom many praises were said.

Ibn Buṭlān left Baghdad, crossed Syria, and arrived in Egypt, where he undertook several polemics with Ibn Riḍwān. These covered diverse subjects, touching in particular the philosophical questions and ideas of Aristotle concerning place, movement, and the soul on which Ibn Riḍwān had commented before. He returned to Constantinople, where he arrived in 446/1054, at the time of the schism which would eventually separate the Greek from the Latin church. The patriarch Michel Cérulaire asked him to edit a treatise on the Eucharist and the use of bread without leavening. That was also the year when a terrible epidemic of the plague broke out in the capital of the Byzantine Empire. Ibn Buṭlān kept a diary and cited the names of several savants who had succumbed to it. After this he went to Antioch where he directed the establishment of a hospital. Eventually he retired from traveling, and died in 460/1068.

His work is very diverse, covering theology, philosophy, logic, and medicine. His interpretation of the work of the Ancients is original and animated by a critical spirit. He relied on logic and the grammar of languages, and attempted to explain apparent opposition by showing that they had very different points of view. Thus Aristotle studied organic forces relative to their nature, while Galen did so relative to their perceptible action in the organs which were their instruments. Aristotle divided the organs according to their physical constitution, Galen in relation to the illnesses which affected them. In the same way, with regard to the "egg yolk" color of bile, Ibn Buṭlān tended to agree with Galen who explained it by the predominant action of heat, which rends the bile hotter and lighter. On the other hand, Ḥunayn ibn Isḥāq explained it as the result of a mixture of bile and phlegm. These differences can be explained by the ambiguity of the term *muḥḥ*, which signifies at the same time both the egg yolk alone and the entire interior of the egg, both the yellow and the white.

Ibn al-Qifṭī retained for us a list of the problems that Ibn Buṭlān posed. For example, he wondered about the chemical nature of the force of physical attraction between lovers. In the field of physiology, he questioned why it is that when men dream they are urinating, they wake themselves up without urinating in their beds, while when they dream of a sexual encounter, there is an emission of sperm. He wondered why this was so, when you consider how much easier it is to urinate than to ejaculate when one is awake.

Ibn Buṭlān's most important medical work is the *Taqwīn al-ṣiḥḥa* (Strengthening of Health), a treatise on hygiene dedicated to general questions on the four elements, the humors, and the temperaments. The author studied the nature and value of nutrition, as well as the influence of the environment, water, climate, and housing on health. The originality of the work lies in its form: it is presented in small tableaux. It was translated into Latin and German. Another noteworthy work is *Daʿat al-Aṭibbā* (The Physician's Banquet), on the subject of medical ethics, which included a satire on charlatans and ignorant physicians. There is also a treatise on the maladies caused by food, with recommended remedies used by monks. Finally, there is a treatise devoted to a discussion of whether a chicken is hotter than a smaller bird.

See also: ►Ḥunayn ibn Isḥāq, ►Ibn Riḍwān

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Ibn Ḥawqal

Emilia Calvo

Ibn Ḥawqal al-Nasibī Abū'l-Qāsim Muḥammad ibn ʿAlī was born in Nisibis (now Nusaybin, Turkey) in the second half of the tenth century. He worked as a merchant and traveled, beginning in AD 943, through the Muslim world, visiting the Maghreb and Andalusia between 947 and 951; Egypt, Armenia, and Azerbaijan around AD 955; Iraq, Persia, Transoxiana, and Khwarazm between 961 and 969. In AD 973, he was in Sicily.

Ibn Ḥawqal is the author of a book on geography entitled *Kitāb al-masālik wa'l-mamālik* (Book on the Routes and Kingdoms), also known as *Kitāb ṣūrat al-ʿarḍ*, which belongs to the category of the so-called *Atlas of Islam*. It consists of a description of the Islamic countries, although some non-Islamic regions of Sudan, Turkey, Nubia, and Sicily are also described.

Ibn Ḥawqal based his work on al-Iṣṭakhrī's book and incorporated new material from his travels which led to three successive revisions of his *Kitāb al-masālik*: the first one in AD 967, dedicated to Sayf al-Dawla; the second ca. AD 977, and the third ca. 988. The final result was a book whose descriptive part surpassed the works of earlier authors.

From the contents of his work, his sympathy with the Fāṭimid movement can be deduced. He showed a certain interest toward Fāṭimid politics, although he cannot be considered a Fāṭimid *dāʿī* (propagandist). He also gives economic information. His interests are focused not on rare or precious goods but on basic agricultural and artisanal products.

Ibn Ḥawqal's *Kitāb al-masālik* influenced the work of later geographers such as Abū'l-Fidā. He is also the author of a book on Sicily which is not preserved.

See also: ►Balkhī School, ►Geography

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Ibn Hubal

E. Ruth Harvey

Muhadhdhib al-Dīn Abū'l-Ḥasan ʿAlī ibn Aḥmad ibn ʿĀli ibn Hubal al-Baghdādī was a famous physician, medical authority, and accomplished poet. Born in Baghdad in 1121 (AH 515), he migrated to Khilat (modern Ahlat, on the shore of Lake Van, Turkey), and became very prosperous in the service of the local ruler. He later moved to Mardin to serve another lord, and died at Mosul (in modern Iraq) in 1213 (AH 610). His chief work, *Kitāb al-Mukhtār fī al-Ṭibb* (The Choice Book of Medicine), was written in about 1165. It resembles the medical encyclopedias of Ibn Sīnā and al-Rāzī in that it is a compendium of Galenic medical knowledge, supplemented by personal clinical practice. *The Choice Book* is divided into three main parts, comprising anatomy and general principles, a pharmacopoeia, and a list of maladies arranged according to the affected organs, running from head to foot. Although this large book does not seem to have been translated into Latin during the Middle Ages, the number, diffusion, and varying ages of the manuscript copies attest to its popularity. No copy appears to survive of Ibn Hubal's *Kitāb al-Ṭibb al-Jamāli* (Book of Medicine for Jamal al-Din al-Wazir). A short work on logic, *al-Ārāʾ wa'l-mushāwarāt*, in manuscript in Paris (B.N. MS 2348) is ascribed to him.

The manuscripts of *The Choice Book* in Leiden, Paris, Cairo, and India are listed in Brockelmann; there are also several copies in Turkey, and fragmentary ones in Princeton and the British Library in London (the London text starts with the diseases of the brain). The whole Arabic text was edited in Hyderabad 1943–1944, but Albert Dietrich maintains that a proper critical edition is still badly needed. Two chapters of Ibn Hubal's medical encyclopedia were published from the Leyden manuscript with an accompanying French translation; they describe the causes, symptoms, and treatment of stones in the kidneys and bladder. Ibn Hubal employs the usual medieval medical terminology derived from earlier Greek physicians: four fluids, or humors, within the body (blood, phlegm, choler (yellow bile), and melancholy (black bile)) are held to constitute in their balance and proportions the essential foundations of good health; pain and disease reveal an evil condition or imbalance among the fluids. Most remedies and treatments consist of trying to correct the malfunctioning fluid through diet, bleeding, or alteration of the patient's physical surroundings. In spite of what we might today consider the erroneous basis of his theoretical approach, Ibn Hubal shows an impressive concern for personal observations and clearly relies on extensive clinical practice. In discussing stones, for instance, he attributes the condition to excessive bodily heat which causes phlegm, a "thick fluid," to form deposits in the kidneys and bladder. He prescribes medicines such as horseradish, ginger, and chicken soup to break up the stones or cause them to be passed. He also cites his own personal experience of a more desperate remedy which he witnessed: a surgical operation to remove a bladder stone from a boy. He cites al-Rāzī and Rufus of Ephesus, but conveys the impression of a knowledgeable practical physician, mindful of the agonizing pain caused by the condition he is discussing.

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Ibn Isḥāq Al-Tūnisī

Julio Samsó

Abū-l-ʿAbbās Aḥmad ibn ʿAlī ibn Isḥāq al-Tamīmī al-Tūnisī was a Tunisian astronomer of the early thirteenth century. He compiled an impressive astronomical handbook with tables (*zīj*) a manuscript of which (copied ca. 1400) was discovered by David A. King. It contains an important set of tables (completed ca. 1218) which mark the starting point of a Maghribian (North Africa) astronomical school. Parts of these tables seem original and are based, according to the famous historian Ibn Khaldūn, on observations made by a Sicilian Jew. The rest is a miscellaneous collection of materials which derive from Andalusian sources, many of which seem lost, by Ibn al-Zarqāllu (d. 1100), Ibn Muʿādh al-Jayyānī (d. 1093), Ibn al-Kammād (fl. ca. 1125), Ibn al-Hāʾim (fl. ca. 1204) as well as others. The canons (instructions for the use of the numerical tables) were not written by Ibn Isḥāq but by some later author who also used materials derived from the aforementioned Andalusian *zīj*es. Ibn Isḥāq's *zīj* is, therefore, a first rate new source for the study of both Andalusian and Maghribian astronomy.

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Ibn Juljul

Emilia Calvo

Ibn Juljul al-Andalusī, Sulaymān ibn Ḥasan, was born in Córdoba in AD 943 and died ca. 994. He studied medicine with a group of Hellenists presided over by Ḥasdāy ibn Shaprūṭ, a Jewish physician and vizier of the Caliph ʿAbd al-Raḥmān III, and later became the personal physician of Caliph Hishām II (976–1009).

Ibn Juljul is the author of *Ṭabaqāt al-aṭibbāʾ wa 'l-ḥukamāʾ* (Generations of Physicians and Wise Men), the oldest extant summary in Arabic on the history of medicine (it was finished in AD 987), after Isḥāq ibn Ḥunayn's *Taʾrīj al-aṭibbāʾ* (History of the Physicians). It contains 57 biographies grouped into nine generations. Thirty-one of them concern Asian authors, and the rest refer to African and Andalusian scholars.

Ibn Juljul used Eastern sources (Hippocrates, Galen, Dioscorides) and Western ones (Orosius, Isidore) and established the chronological limits of the Latin influence on medicine in Andalusia. The work has chronological errors but provides interesting information about the oldest translations into Arabic, in the time of the Caliph ʿUmar II (AD 717–719).

Other works of Ibn Juljul are *Tafsīr asmāʾ al-adwiya al-mufrada min kitāb Diyusqūridūs* (Explanation of the Names of the Simple Drugs from Dioscorides' Book), written in 982, from which only a fragment is preserved, containing the transcription of the Greek names of 317 simple medicines, their translation into Arabic and their identification; *Maqāla fī dhikr al-adwiya al-mufrada lam yadhkurha Diyusqūridūs* (Treatise on the Simples not Mentioned by Dioscorides), which includes 62 simple medicines not mentioned in Dioscorides' *Materia Medica*; *Maqāla fī adwiyat al-tiryāq* describing the components of the theriaca; and *Risālat al-tabyīn fī-mā ghalaṭa fīhi baʿḍ al-mutaṭabbibīn* (Treatise on the Explanation of the Errors of Some Physicians).

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Ibn Jumayʾ

HARTMUT FAHNDRICH

A contemporary of the great Jewish doctor and philosopher Moses Maimonides, Ibn Jumayʾ, was one of the physicians in the service of Ṣalāh ad-Dīn. He was born of a Jewish family in Fustat (Egypt) and studied with another physician of some renown, ʿĀdnān ibn al-ʿAynzarbī (d. 548/1153). The relevant biographical dictionaries mention Ibn Jumayʾ's talents in medicine as well as his highly developed linguistic consciousness, inducing him always to carry al-Jawharī's *Kitāb aṣ-ṣaḥāḥ* (The Truthful Guide) to class so he could check words of which he was uncertain. Ibn Jumayʾ died in 594/1198.

In Ibn Abī Uṣaybiʾa's dictionary of medical doctors, *ʿUyūn al-anbāʾ fī ṭabaqāt al-aṭibbāʾ* (Sources of Information About the Classes of Physicians), Ibn Jumayʾ is presented as the author of eight works on medical or medicine-related subjects, the most important of them being *Kitāb al-irshād li-maṣāliḥ an-nufūs wa 'l-ajsād* (Guide to the Welfare of Souls and Bodies), a compendium of the different fields of the art of medicine. Others also deal with practical questions of the doctor's craft such as first aid or nutritive advice.

The only one of Ibn Jumayʾ's works published to date, *al-Maqāla aṣ-ṣalāḥīya fī iḥyā aṣ-ṣināa aṭ-ṭibbīya* (Treatise to Ṣalāḥ ad-Dīn/Saladin on the Revival of the Art of Medicine), is not mentioned by Ibn Abī Uṣaybiʾa. It is a deontological work, i.e., it deals with the doctor's profession on a more theoretical level.

This treatise, as Ibn Jumayʾ mentions in the introduction, owes its composition to a conversation he had with his sovereign on the deplorable state of medicine in his time, the reasons for this, and ways to ameliorate the situation. Thus, formally the work stands in the literary tradition of the epistle, a genre frequently employed by Ibn Jumayʾ in other works and by Arabic medical authors in general. Its contents – the complaints about the declining state of the art and considerations about its improvement – were not unknown in his time either. The theme goes back to Galen or even Hippocrates.

The treatise falls into three chapters: Chapter 1 concerns the presentation of medicine, including the qualities of medicine and the need for it, as well as the difficulties of medicine and their consequences; Chapter 2 deals with the reasons for the decline of medicine, including a brief presentation of its history; and Chapter 3 suggests ways to revive the art of medicine.

Whereas compendia of a more technical presentation of medicine in medieval Arabic literature are comparatively numerous, the same cannot be said about this kind of work, with its introductory and deontological character. In that lies the importance of this doctor of the twelfth century AD, Ibn Jumayʾ.

See also: ▶Moses Maimonides, ▶Medicine in Islam

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Ibn Khaldūn

CHARLES E. BUTTERWORTH

ʿAbd al-Raḥmān ibn Khaldūn (1332/732–1406/808) spent the first two-thirds of his life in North Africa and Muslim Spain, fleeing in 1382/784 to Egypt, where he remained until his death. Though he is best known for the lengthy Introduction (*Muqaddima*) to his massive philosophical history of civilization (*Kitāb al-ʿIbar*), Ibn Khaldūn spent much of his life in political activities. Born and raised in Tunis, he read the *Qur'ān* and studied the religious sciences as well as Arabic and poetry, then was educated in logic, mathematics, natural science, and metaphysics. He also received specialized training in court correspondence and administrative matters, subjects that allowed him to become a court secretary to the Marinid ruler Abū ʿInān in Fez at about the age of 22.

After some vicissitudes, including almost 2 years of prison, Ibn Khaldūn went to Grenada in 1362 to become an advisor and tutor to Muḥammad V. That position lasted only about 2 years, no longer than his subsequent position as prime minister or *ḥājib* to Prince Abū ʿAbd Allāh of Bougie. Following these forays into practical politics, Ibn Khaldūn endured several years of upheaval (1366/766–1375/776), settled for about 4 years in Qalʿat Ibn Salāma near Oran and began work on his history, then moved to Tunis under the patronage of Abū al-ʿAbbās in order to have access to documents and libraries. After a few years there, court intrigues led him to seek tranquility in Egypt.

During the next quarter of a century he served the Mamlūk Sulṭān Barqūq as judge (*qāḍī*) and chief judge (*qāḍī al-quḍā*), professor at various universities (including the prestigious al-Azhar), and one time university president. A few years before his death he met with the famous Mongol chieftain Tamerlane. But the period in Egypt was, above all, a time for revising his *Kitāb al-ʿIbar* and working on the Introduction (*Muqaddima*) to it.

The *Kitāb al-ʿIbar* is a multivolume effort that, in his words, sets forth "the record of the beginning and the suite of the days of the Arabs, Persians, Berbers, and the most powerful of their contemporaries." Its Introduction consists of six very long chapters that explore the character of human civilization in general and Bedouin civilization in particular, as well as the basic kinds of political associations, and then the characteristics of settled civilization, the arts and crafts by which humans gain their livelihoods, and, finally, the different human sciences. Ibn Khaldūn starts by explaining the merit of history and how to go about writing it. Properly speaking, the reason to write history or the "inner meaning of history" is, by means of reflection, to get "at the truth, subtle explanation of the causes and origins of existing things, and deep knowledge of the how and why of events." Though his enterprise is therefore "rooted in philosophy" and to be considered a branch of it, Ibn Khaldūn acknowledges a problem with the way history has come down. Many unqualified people have trammeled with the books of history written by competent Muslim historians; they have introduced tales of gossip imagined by themselves as well as false reports. Moreover, other historians have compiled partial reports of particular dynasties and events without looking to the way things have changed over time, without looking at natural conditions and human customs. Consequently, Ibn Khaldūn considers his task to be that of showing the merit of writing history, investigating the various ways it has been done, and showing the errors of previous historians. What needs to be known, and thus what he sets out to make known, are "the principles of politics, the nature of existent things, and the differences among nations, places and periods with regard to ways of life, character, qualities, customs, sects, schools, and everything else … plus a comprehensive knowledge of present conditions in all these respects … complete knowledge of the reasons for every happening and … [acquaintance] with the origin of every event." Yet in the end Ibn Khaldūn hints that he has almost digressed in the whole undertaking. What he wanted to do was to explain the nature of civilization and its accompanying accidents, but he fears he has strayed from his basic point.

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I

Ibn Khurdādhbih

Sayyid Maqbul Ahmad

Abuʾl-Qāsim ʿUbayd Allāh ibn Khurdādhbih (also spelled Ibn Khurradādhbih), the first scholar to write on world geography in Arabic, was born in ca. AH 205/AD 820 (or AH 211/AD 825), and died in ca. AH 300/AD 912. Probably born in Khurāsān, he was brought up in Baghdad. His grandfather, Khurdādhbih, was a Zoroastrian, latter converted to Islam, and his father was the governor of Ṭabaristān. When he grew up, he became the director of posts and information in Jibāl (Media) and subsequently became director-general of the same department in Baghdad and later in Sāmarrā (Iraq). He became a companion of the ʿAbbāsid Caliph al-Muʿtamid (AH 256–279/AD 870–892).

Ibn Khurdādhbih was a versatile writer; besides writing on geography, he wrote on history, genealogy, music, wines, and even on the culinary art. Al-Nadīm, in his *al-Fihrist*, lists at least eight works to his credit. The Arab historian Abuʾl-Ḥasan ʿAlī ibn al-Ḥusayn al-Masʿūdī (d. AD 956) considered him an *imām* (leader) in authorship and mentions his voluminous historical work dealing with the ancient kings and peoples of Iran (*Murūj* 1965). Ibn Khurdādhbih also claimed to have translated into Arabic the geographical treatise of Claudius Ptolemy (ca. AD 90–168) from a "foreign language" (probably Syriac or Greek), but the translation is not extant.

However, Ibn Khurdādhbih's major work on geography, entitled *Al-Masālik al-Mamālik* (Roads and Kingdoms), was published by M. J. De Goeje in 1889. In fact, this work is an abridgement (prepared not later than AD 885–886) of his larger work (not extant) written in ca. AD 846–847. Considering the vast amount of information contained in the work and the early date of its compilation, it may be said that Ibn Khurdādhbih was the father of Arab-Islamic geography; no work of such magnitude existed before him. *Al-Masālik al-Mamālik* deals briefly with mathematical and physical geography, but the major portion of the work is devoted to descriptions of land and sea routes in the four directions emerging from al-Sawād. Then, it deals with marvels of the world, seas and mountains, sources of the rivers, and reports on countries like India and Central Asia.

It is not unlikely that Ibn Khurdādhbih relied heavily for his information on the ancient Sassanian government records which must have become available to him as the person in charge of the department of posts and information in Baghdad and elsewhere. Again, in his methodology and arrangement of the material and in the use of geographical terms and Persian couplets, a distinct Persian influence is discernible. The ancient Persians used to divide the known world into seven circular regions called *kishvars* (kingdoms) with Irānshahr at the center and the remaining six circles drawn around it. Such an arrangement is observable in his descriptions of the various routes emerging from al-Sawād, which, he says, was called *dil-i Irānshahr* (the heart of Iraq).

Ibn Khurdādhbih was not only the first to write on geography in Arabic, but he also set the style for writing on descriptive geography. Several later Arab-Islamic geographers utilized his work as a major source of information.

See also: ►Geography in Islam

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Ibn Mājid

Sayyid Maqbul Ahmad

Shihāb al-Dīn Aḥmad ibn Mājid ibn Muḥammad ibn Amr ibn Faḍl ibn Duwayk ibn Yūsuf ibn Ḥasan ibn Ḥusayn ibn Abī Maʿlaq al-Saʿdī ibn Abu'l-Rakāʾib al-Najdī was the greatest Arab navigator of the fifteenth century AD and one of the greatest of the Middle Ages. We do not know the date of his birth or death, but he must have died at an advanced age sometime in the first decade of the sixteenth century. Born in Julfār (Oman), he belonged to an illustrious family of navigators. Both his father and grandfather were *muʿallims* (masters of navigation) of repute.

Ibn Mājid wrote a number of works, both in prose and poetry, on nautical theory and on describing the seas (mainly the Indian Ocean) which served as guides for the Arab navigators of later periods. Among his important works in prose is the *Kitāb al-fawāʾid fī ʿuṣūl ʿilm al-baḥr wa'l-qawāʿid* (The Book of Benefits on the Principles of the Science of Navigation), dated AH 895/AD 1489–1490. This book and many others have been reproduced in the editions mentioned in the bibliography.

Ibn Mājid considered himself the fourth of the great Arab navigators of the Middle Ages; the other three were Muḥammad ibn Shādān, Sahl ibn Abān, and Layṭ ibn Kahlān, who belonged to the Abbāsid period. He thought his own works were more accurate than theirs, since they were more current and since many of the ports mentioned in the older works no longer existed. Apart from his practical experiences as a navigator, he had studied and improved upon the work of his father (*al-Ḥijāzīya*) and had studied a number of earlier Arabic works on astronomy and geography.

On the practical side of navigation, it is not unlikely that Ibn Mājid was in contact with the Indian navigators of his time, the *Ṣūliyān* (Cholas of Tamil Nadu, India) and with the Gujarati and the Konkani (Maharashtra, India) navigators, whose *qiyāsāt* (readings of the ports and harbors) he seems to have known. He was particularly knowledgeable about Siam and Bengal, and these navigators frequented these regions more than the Arab navigators did.

In his works Ibn Mājid covered a number of subjects relating to navigation, nautical astronomy, oceanography, and geography. In his *Kitāb al-fawāʾid*, he pays special attention to subjects of a more general nature, like guidelines to navigators such as the prerequisites for sailing on the sea, and he describes the lunar mansions, the stars corresponding to the 32 divisions (*aqnān*) of the compass card, the winds and seasons of the seas, nautical instruments, and the essentials required by captains of boats. These include knowledge of the rising and corresponding settings of the stars (*al-anwāʾ*), latitudes and longitudes, landfalls, and tides. He emphasizes that before sailing, captains should see that their instruments are in perfect order, the sailors obedient, and the seasons suitable. They should be patient and soft-spoken, should not deprive merchants of their rights, and they should be courageous, literate, and well behaved. He also presents a systematic description of the sea coasts of the Oikumene (the known world at that time), which no geographer had done before. From his writings, it appears that he did not conceive that a *terra incognita* existed in the southern quarter of the earth, as other geographers of his time believed. He thought that the Indian Ocean was connected with the Atlantic through a sea channel, which he calls *al-madqal* (place of entry).

Ibn Mājid claimed to have made several contributions to navigation and to determining the direction of the *qibla* (Mecca) from different positions of the earth with the help of the compass card. He also claimed to have fixed a magnetized needle on the mariners' compass (probably on a day box). Ibn Mājid had met Vasco da Gama, and had guided him to Calicut, India. Although the Portuguese sources do not mention him by name in this regard, we know from an Arabic work, *al-Barq al-Yamānī fīʾl-fatḥ al-ʿUṭmānī* (The Yemenite Lightning on the Ottoman Conquest) by al-Nahrawālī that it was he who directed Vasco da Gama from Malindi (East Africa) to India.

See also: ►*Qibla*, ►Lunar Mansions, ►Compass

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Ibn Māsawayh

Danielle Jacquart

Abū Zakariyyāʾ Yūḥannā ibn Māsawayh was born in Baghdad during the caliphate of Hārūn ar-Rashid (786–809), and not in 777 as was stated by Leo the African. His father, Māsawayh, was a pharmacist in the service of the physician Jibrāʾīl ibn Baḫtishūʿ, with whom he came from Jundīshāpūr (in Persia) to Baghdad. His mother was a slave, named Risala, whom Māsawayh bought from the physician Dawūd ibn Sarābiyūn. Thus, Yūḥannā ibn Māsawayh belonged to the milieu of Christian Nestorian physicians, who played an important part during the eighth and ninth centuries. He married the daughter of his colleague Abdallāh at-Tayfūrī and had a son of poor intelligence. He was very famous as a teacher and practitioner; he became the personal physician of four successive caliphs from al-Maʾmūn to al-Mutawakkil. He died in Samarra in 857.

As for many other authors of this period, it is difficult to distinguish legend and history in his biography. It was said that he did translations from Greek into Arabic, but none is extant under his name; most probably, he only commissioned some of them. For instance, it is well attested that Ḥunayn ibn Isḥāq undertook the translation of Galen's *Methodus medendi* (Arabic *Kitāb hīlat al-burʾ*; Methods of Healing) at Ibn Māsawayh's request. The relationship between both physicians was nevertheless strained, at least at the beginning: Ibn Māsawayh is supposed to have driven Ḥunayn out of his teaching position, who then went traveling in order to learn Greek and purchase manuscripts. It was also reported by Arabic medieval historians that Ibn Māsawayh had the opportunity of dissecting an ape, which had been given to the caliph by the prince of Nubia in 836 as a present. Following in Galen's footsteps Ibn Māsawayh afterward wrote an anatomical monograph, which can perhaps be identified with his *Kitāb at-tashrīḥ* (Book of Anatomy). Apart from his knowledge of Greek medicine, Ibn Māsawayh had access to some Indian works: he quotes, for instance, Āryabhaṭa in his ophthalmological treatise *Kitāb dafal al-ʿain* (Book on the Defectiveness of the Eye).

Ibn Abī Uṣaybiʿa listed 42 works; some others were quoted by al-Rāzī and al-Bīrūnī. But only 31 are extant, as far as we know, and very few have been edited or studied. Those that have been edited – and sometimes translated into English or French – are the *Aphorisms*, the works on barley water, simple drugs, and perfumes, as well as the medical calendar; the ophthalmological treatises have also been analyzed. It seems that among the works which were translated into Latin during the Middle Ages under the names of "Mesuë" or "Johannes

Damascenus," only the *Aphorismi Johannis Damasceni* and some ophthalmological fragments can be attributed to Ibn Māsawayh; the other ones, mainly pharmacological, are probably apocryphal for the most part. The *Aphorismi* – a faithful translation of *Nawādir aṭ-ṭibb* – were largely diffused from the twelfth century; a second translation appeared as the sixth book of Rāzī's *Secrets of Medicine*: it was done during the thirteenth century by the Dominican Giles of Santarem.

Some original features of Ibn Māsawayh's medicine can be drawn from his *Nawādir aṭ-ṭibb*. Dedicated to Ḥunayn ibn Isḥāq and modeled on the Hippocratic *Aphorisms*, this short work was intended to give practical advice. The eight first aphorisms can be considered as a kind of commentary on the first Hippocratic aphorism: "Life is short, art long, opportunity fleeting, experiment dangerous, judgment difficult." They stressed the necessity for physicians to be both learned and skilled. Throughout the remaining 124 aphorisms the following topics are covered: the link between body and soul, the observance of astrological and climatological rules, the attention that physicians have to pay to the healthy nature of their patients, the numerical ratios which rule human temperaments, as well as natural substances used for treatment. It has to be noted that this last idea was deeply developed by Ibn Māsawayh's contemporary, al-Kindī. Ibn Māsawayh seems also to have been very much attached to the idea that physicians must mainly reinforce nature by using drugs similar to it; medical treatment with substances contrary to disease had to be prescribed cautiously and their sole goal was to purge. Physicians had to be cautious not to alter nature too much. For example, Ibn Māsawayh stated: "It is important that, against diseases, the strongest contrary is not introduced into the body, since this would be very harmful; it can be compared with a very cold wind which, during the same day, blows after a very hot one" (aph. 60). In the same manner, treatment by diet was preferred to pharmacopoeia: "If the physician can treat with food, to the exclusion of drugs, he will be very successful" (aph. 108). In addition to several pharmacological treatises, Ibn Māsawayh composed an important work on dietetics.

Ibn Māsawayh's works remain very little known, despite their importance in the history of Arabic medicine. Detailed studies would shed light on the decisive stage constituted by the beginning of the ninth century, before the spread of Ḥunayn's translations.

See also: ►al-Kindī, ►Leo the African

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Ibn Muʿādh

A. Mark Smith

Ibn Muʿādh al-Jayyānī, Abū ʿAbd Allāh Muḥammad (d. ca. 1093) has traditionally been assigned a birth date of 989. However, recent scholarship suggests that Ibn Muʿādh was born somewhat later, in the early eleventh century. The only secure date we have for him is 1079, the year of a solar eclipse he describes from first-hand observation. The ending "al-Jayyānī" to his name indicates that he was from Jaén in Andalusia, where he evidently served as a *qāḍī* (judge) for much of his life. Among his few surviving astronomical and mathematical works are included the *Tabulae Jahen*, a set of astronomical tables based on those of al-Khwārizmī and probably translated into Latin by Gerard of Cremona; *Maqāla fi sharḥ al nisba* (On Ratio), a commentary on Book 5 of Euclid's *Elements*; and *Kitāb majhūlāt qisiyy al-kura* (Determinations of the Magnitudes of the Arcs on the Surface of a Sphere), a work on trigonometry. Certainly the most original, and perhaps the most historically significant of his extant works, is the brief treatise *On Twilight and the Rising of Clouds*.

While no Arabic exemplar has yet come to light (the original title was probably *Ma'l-fajr wa'l-shafaq*), this work has nonetheless reached us in three other linguistic forms: a fourteenth-century Hebrew translation from the Arabic (represented by one manuscript), a late twelfth-century Latin translation from the Arabic, probably by Gerard of Cremona (represented by 25 manuscripts), and a fourteenth-century Italian translation from the Latin (represented by one manuscript). The sheer number of Latin manuscripts – plus the Italian translation – indicates the seriousness with which this treatise was received and disseminated in the medieval West. That it was commonly misattributed to Ibn al-Haytham, author of the magisterial *Kitāb al-manāẓir* (*De aspectibus*), may have had something to do with this. There is also clear, albeit indirect, evidence that *On Twilight* exerted its share of influence in the medieval East as well.

Ibn Muʿādh's purpose in *On Twilight* is to determine the height of the atmosphere under the assumption that the first light of dawn is produced when rays from the rising sun tinge vapors at the very upper edge of the atmosphere. Although he offers no practical justification for this inquiry, he does, in a couple of querulous asides, berate those (religious conservatives?) who would squelch rational inquiry out of mere ignorance. The determination itself depends upon four basic parameters: the depression of the sun below the horizon at first light (18°); the mean distance between earth and sun (1,110 terrestrial radii); the relative size of sun and earth (5.5:1 in terrestrial radii); and the circumference of the earth (24,000 mile). On the basis of these parameters and using simple trigonometric functions, Ibn Muʿādh calculates the atmosphere to be around 52 mile high. This figure remained canonical in the Latin West until the end of the sixteenth century, when Tycho Brahe raised the issue of atmospheric refraction to prominence. Within this context, it soon became clear that Ibn Muʿādh's calculation was useless because it failed utterly to take atmospheric refraction into account. Consequently, his figure of 52 mile was drastically reduced by Johan Kepler and succeeding astronomers.

See also ►al-Khwārizmī, ►Ibn al-Haytham, ►Astronomy in the Islamic World

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Ibn Munʿim

Ahmed Djebbar

The oldest mathematical work from the Maghreb which deals with combinatory problems is the *Fiqh al-ḥisāb* of Ibn Munʿim, a scholar originally from Andalusia, living in Marrakesh in the Almohad era. To our knowledge, his book was the first in the entire history of mathematics to have devoted a whole chapter to these types of problems and to have stated them and solved them according to a common procedure.

Aside from Ibn ʿAbd al-Malik, the biographers of the Maghreb do not mention Ibn Munʿim, even though they write at length about mathematicians of lesser significance, and they use the contents of his book. The little information we do have on Ibn Munʿim comes from his own introduction to his mathematical text, cited above, and from the book of Ibn ʿAbd al-Malik.

According to the latter source, Ibn Munʿim's full name was Aḥmad ibn Ibrāhīm ibn ʿAli Ibn Munʿim al-ʿAbdarī. He was originally from the town of Denia on the east coast of Spain, near Valencia, and he lived in Marrakesh where he taught and where he died in 626H/1228. He was known as one of the best scholars of his era in geometry and number theory. At the age of 30, he began to study medicine which he practiced successfully at the same time as his mathematical activities.

Only three of Ibn Munʿim's numerous mathematical texts and letters are known today: one on magic squares, another on geometry, and the third on the science of calculation. And of these, only the last, *Fiqh al-ḥisāb*, is extant. Ibn Munʿim wrote it under the reign of the fourth Almohad caliph, al-Nāṣir (1199–1213). During his reign celebrated scholars like the grammarian Abū Mūsā al-Jāzūlī, the algebraist Ibn al-Yāsamīn, and the doctors of the Ibn Zuhr family all lived in the Almohad capital, or even within the court itself. This leads one to believe that there was a variety of scientific activity, thanks to a generous and often enlightened patronage.

Combinatory analysis is taken up the 11th section of the first chapter of *Fiqh al-ḥisāb*, entitled "an accounting of words which are such that human beings can express them only by one of them." This section is not, however, in the eyes of this author, a complete overview of practical calculations. He takes care to explain, in the course of his exposition, that he proposes first to treat the problem in a general manner, even though he is obliged, in order to make his ideas clear, to formulate it in specific terms using the Arabic alphabet. In fact, this study goes beyond the linguistic framework in which it is formulated, as much by the way of posing the problems and linking them to each other, by the methods of reasoning used, as by the established results.

Ibn Munᶜim begins by setting out the problem as a mathematician; he defines precisely the framework in which he is stating the chosen hypotheses and the degree of generality researched. Then he establishes, using a set of colors of silk as an abstract model, a rule which enables one to determine all the possible combinations of n colors p times p. In order to do that, he constructs, in accordance with an inductive method, a triangular numeric table, identifies its elements, with the desired combinations, and deduces the relationships:

$$C_n^p = C_{n-1}^{p-1} + C_{n-2}^{p-1} + \ \ldots \ + C_{p-1}^{p-1}.$$

Thus, he presents, to our knowledge for the first time, the famous arithmetical triangle which algebraists from the Muslim East like al-Karajī (d. 1029) had already constructed but for other purposes and using another procedure.

Ibn Munᶜim's study continues by establishing, using induction, relative formulas with permutation, with or without repetitions, of a group of letters such that they give, by recurrence, the number of possible readings of a word of n letters, taking into account all the signs (vowels and sukūns for Arabic) used by a given language. This is the content of problems 2, 3, and 4. In problem 5, the author concludes the first part by establishing a formula of arrangements, without repetition, of n objects p times p, which take into account the vowels and the sukūn accompanying the letters.

The second part, much longer, seeks to enumerate the combinations with repetitions, adopting a method analogous to the preceding one and which necessitates recourse to the table of numbers. It was moreover this same method that the French scholar Mersenne rediscovered and applied to his work in the seventeenth century.

To set up problem 6, Ibn Munᶜim goes back to his model of bunches and proposes to solve a difficult dilemma, apparently removed from the initial problem and stated thus: being given threads of silk in n colors, we want to determine the number of bunches it is possible to make with p threads of k colors, so that $p_1, p_2, \ldots, p_k$ threads are, respectively, of the same color.

All these propositions, and even more the techniques, allow the resolution of the problem which Ibn Munᶜim formulates as follows: to determine the number of words of 1–10 letters which it is possible to make with the letters of the Arabic alphabet, including all possible repetitions of letters in a words, and including vowels and the sukūn which can appear on letters.

The third part of his study includes, along with several applications, a series of tables which enables the determination, more and more closely, of all the elements (P_n, A_n, C_n,…) which occur in the counting of words that it is possible to pronounce in a given language.

In addition to the results included in this chapter of *Fiqh al-ḥisāb*, the way in which Ibn Munᶜim established his results is also notable. In fact, he uses two types of reasoning which can be called inductive and combinatorial. While inductive reasoning is a traditional tool of Islamic mathematics with its privileged domains and unique stature, one cannot say the same for combinatorial reasoning which appeared, to our knowledge for the first time, in the *Fiqh al-ḥisāb*. His systematic use of combinatorial reasoning for establishing general propositions appeared as a clear acknowledgment of its mathematical character.

One can even suppose that if combinatorial reasoning had enjoyed a quantitative development in the field of application, it would have resulted in its explicit recognition as a process of reasoning beside analysis, synthesis, induction, and reasoning *ad absurdum*.

The elaborate nature of his procedures and results which appear in the *Fiqh al-ḥisāb*, as well as the spirit of the method which emerged from them leads to the theory that the beginning of the mathematization of combinatorial problems within the framework of Arabic science occurred prior to the work of Ibn Munᶜim.

While we await the confirmation, or correction, of this conjecture, the *Fiqh al-ḥisāb* remains the oldest known Arabic work from the Muslim West in which an autonomous chapter on combinatorial analysis appeared. But its importance does not end there: with regard to the linguistic tradition of the Maghreb, the book was a culmination in that it laid out a general solution to a given problem. Also, for mathematics, the work represents an important link, marking the end of one stage in the progress of combinatorics, that of calculation using tables, and the beginning of another stage, that of the extension of formulas and their use in solving problems.

See also: ►Combinatorics in Islamic Mathematics

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Ibn Qunfudh

Y. Guergour

Abū'1^ɔAbbās Aḥmed Ibn al-Ḥasan Ibn 'Ali Ibn al-Khaṭīb was known under the two names of Ibn Qunfudh and Ibn al-Khaṭīb. He was born in 710 AH (AD 1339) in Constantine, Algeria and came from an old family which was cultured and well to do. We know that Ibn Qunfudh began his studies with his father and his maternal grandfather, in order to follow them eventually under the direction of other professors from his same town.

After his elementary education, he returned to Fez, in Morocco, where he remained for 18 years. There he studied with several professors, covering different scientific themes, and teaching and publishing some of his own work. We know that it is in this city that he edited in 771 (1370) his most important mathematical work, the *Ḥaṭṭ an-niqāb* ^ɔ*an wujūh* ^ɔ*amāl al-ḥisāb*, which is a commentary on the *Talkhīṣ a*^ɔ*māl al-ḥisāb* of Ibn al-Bannā^ɔ, written in 721 (1321). We think that he acquired his advanced education either completely or partially during his stay in Fez.

During the period of famine which raged in all of Maghreb in 776 (1374), Ibn Qunfudh went back to Constantine in order to take up duties as a *khaṭib* (preacher), *mufti* (jurist), and *qāḍī* (judge). At the same time, he devoted himself to the teaching and editing of scholarly work. No information has come down to us on the subject of the contents of this teaching, and we do not even know if he taught the contents of his own mathematical writings at Constantine or in the cities where he was posted, or even if he was content only to edit them, following in that the tradtion of several older authors, who wrote on subjects which were very different from each other without having taught them.

What follows is an attempt to give a glimpse of Ibn Qunfudh's contributions to mathematics, of which we know only four titles:

1. *Mabād' as-sālkin fī sharh rajz Ibn al-Yāsamīn* (Principles for Those who are Concerned with the Commentary on the Poem of Ibn al-Yāsamīn). Ibn Qunfudh began this poem according to the traditional procedure of commentators of the Middle Ages. What is not traditional is his use of mathematical symbolism to resolve equations and to represent polynomials. This was to become normal practice during this period, since this commentary was adopted by his students. The symbolism was universally used in mathematical works from Maghreb. This hypothesis is reinforced by the presence of this same symbolism in the book *Ḥaṭṭ an-niqāb* and in the book written by Ya^ɔqūb al-Muwāḥidī *Tahṣīl al-munā fī sharh Talkhīṣ Ibn al-Bannā*.
2. *Bughyat al-fāriḍ min al-ḥisāb wa l-farā'id* (The Desire of the Genealogical Specialist to Know Arithmetic and Successional Division). To this day, no copy of this book has been found.
3. *at-Talkhīṣ fī shzarh at-Talkhīṣ* (Abridged Commentary on *Talkhīṣ*). This is a resume of *Ḥaṭṭ an-niqāb*, of which two copies are extant today.
4. *Ḥaṭṭ an-niqāb* ^ɔ*an wujūh* ^ɔ*amāl al-ḥisāb* (Lifting the Veil on the Operations of Calculation). Five copies of this work are extant.

Since this is Ibn Qunfudh's most important work, it is useful to describe certain aspects of its contents. Reading it permits us to make several important observations on mathematical writing in this era. The author begins his book with some advice and directions designed to facilitate the reading of any book; then he provides a detailed list of the writings of Ibn al-Bannā^ɔ. In the beginning of each chapter, he gives an abstract of its contents, something which one finds nowhere else in the literature of other mathematicians of this time. It is also important to note again the existence of Ibn Qunfudh's mathematical symbolism, particularly in the chapters on roots and on algebraic equations. However, recent research reveals that this symbolism had been used previously at the end of the twelfth or beginning of the thirteenth century, especially in Ibn Yāsamīn's book *Talqīḥ al-afkār*. Elsewhere, Ibn Qunfudh supplies arithmetic rules which one does not find in Ibn al-Bannā^ɔ's work, notably in the chapter on the product. Ibn Qunfudh's terminology also differs significantly from Ibn al-Bannā^ɔ's.

Finally, one finds in the work of Ibn Qunfudh an equation of which the second number is zero, an equation which had formerly been studied by Ibn Badr. His originality lies in the symbolic way in which he expressed it:

ـشـ
0 ـل 7 لا 8.

or, in modern symbols, 8.*r*–7 = 0.

Ibn Qunfudh died in 810 AH (AD 1407).

I

See also: ►Ibn al-Bannā

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Ibn Qutayba

Paul Kunitzsch

Ibn Qutayba, Abū Muḥammad ʿAbdallāh ibn Muslim, was born in 828 in Kufa or Baghdad, and died in 884 or 889 in Baghdad.

Ibn Qutayba was a scholar of typical Arabic–Islamic education. His studies included all branches of the traditional Arabic and Islamic knowledge of his time: religion, history, biography, philology, lexicography, literature, and some science. He left twenty works of varying lengths covering all the fields mentioned. In his career, for some years he was *qāḍī* (a judge according to Islamic rules) in Dinawar (northern Iran); later he lived and taught in Baghdad, where he also died. Of particular scientific interest is his *Kitāb al-anwāʾ* (Book on the anwāʾ). *Anwāʾ* are asterisms and stars used by the Arabs in pre-Islamic and early Islamic times to determine seasons, predict weather—especially rain, and guide them in their nightly desert travels. Many Arabic philologists and lexicographers wrote books of this type, but most of these did not survive. Therefore Ibn Qutayba's *Book on the anwāʾ*, which was printed in Arabic, in Hyderabad/Deccan (India) in 1956, is of great interest. In it, the author has assembled information on the popular astronomical and meteorological knowledge of the old Arabs, from the time before their acquaintance with Greek, Persian, and Indian astronomy. Facts, traditions, terminology, and nomenclature are amply described. Much of this material continued to be used later in the most active period of Arabic – Islamic astronomy. And some of it even lived on into our time, as, for example, the star name Aldebaran (for α Tauri).

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Ibn Riḍwān

Albert Z. Iskandar

Abu'l-Ḥasan ʿAlī Ibn Riḍwān ʿAlī Ibn Jaʿfar, a self-educated physician philosopher, was born in AD 998 at Gīzah, a suburb south of Cairo (al-Fusṭāṭ). He was the son of a poor baker (*farrān*) and had to earn money in his youth by practicing medicine, teaching, and telling people's fortunes from astrological signs. When he was 59, he wrote a book entitled *Fī Sīratihī* (On His Own Conduct). The work is now lost, but its text is partly preserved in Ibn Abī Uṣaybiʿa's *ʿUyūn al-Anbāʾ fī Ṭabaqāt al-Aṭibbāʾ* (Sources of Information About the Classes of Physicians).

In his youth, he believed in astrology (*ʿilm al-nujūm*) and was convinced that the stars at the time of his birth indicated a prosperous medical career. To realize his ambition, he first sought out a popular teacher in Cairo, who instructed Ibn Riḍwān to memorize Ḥunayn Ibn Isḥāq's (d. AD 873) *Kitāb al-Masāʾil fi'l-Ṭibb li'l-Mutaʿallimīn* (Questions on Medicine for Students). Ibn Riḍwān watched him teaching: pupils read the text; the teacher listened but did not utter one word of explanation and did not even bother to correct their errors. Ibn Riḍwān sought to find other teachers and put questions to each of them, based on the writings of Hippocrates and Galen, which they displayed on shelves in their private libraries. He concluded that they merely knew the titles of books but were ignorant of their contents. He pondered over traveling to Iraq for further education, but financial difficulties prevented his going there. He decided on self-education at the tender age of 15. From perusing Galen's *On the Doctrines of Hippocrates and Plato*, he concluded that he should first study geometry and logic. He studied the well-known books on these two subjects, then proceeded to read textbooks on medicine proper. In this way he reached an understanding of the principles of the art of healing.

Ibn Riḍwān worked very hard as a practicing doctor until he reached the age of 32, when he became well known and earned enough money to build his own residential Palace of Candles (*Qaṣr al-Shamʿ*). At the age of 59 he divided his time between practicing medicine, daily physical exercise (*al-riyāḍah*), and reading books on literature, Islamic law, and medicine. His fame reached the Fātimid Caliph al-Mustanṣir (r. AD 1036–1094), who appointed him Chief of Physicians (*Raʾīs al-Aṭibbāʾ*) in Egypt. He was kind-hearted, treated the poor for free, and was always willing to extend a helping hand to the needy.

In old age, Ibn Riḍwān's mind became disturbed (*taghayyar ʿaqluhu*) as a result of being robbed of all his cherished possessions. He had adopted an orphan young girl whom he brought up in his own house. She absconded with all the precious items he had accumulated and 20,000 gold dīnārs which he had kept in the house. An extensive search for the girl was abortive. Ibn Riḍwān died in AD 1067.

Among Ibn Riḍwān's extensive bibliography are his treatise *Fī Dafʿ Maḍārr al-Abdān fī Arḍ Miṣr* (On the Prevention of Bodily Ills in Egypt) and the *Al-Nāfīʿ fī Kayfiyyat Taʿlīm ṣināʿat al-Ṭibb* (Useful Book on the Quality of Medical Education).

In *On the Prevention of Bodily Ills*, he describes the Nile and the Muqaṭṭam Hills on both sides of the river. The hills in the east hold back the "hot and humid" winds, which are most favorable for the temperament (*mizāj*) of animals and which do not reach *al-Fusṭāṭ*. Ibn Riḍwān gives an account of "the six non-natural causes" (*al-asbāb al-sitta al-ḍarūriyya*) which determine health and sickness: the air surrounding the body, food and drink, movement and rest, sleep and wakefulness, retention and evacuation, and psychic events.

Ibn Riḍwān was discourteous in criticizing members of the medical profession. For example, chapter 5 of this treatise is entitled "On the Incorrectness of Most of Ibn al-Jazzār's [d. AD 1009] Reasons for the Unhealthy Air in Egypt." Furthermore, disagreements arose with Ibn Buṭlān of Baghdad. These are well documented by Meyerhof and Schacht (1937).

In his *Useful Book*, Ibn Riḍwān preserved for posterity a unique document, the late Alexandrian medical curriculum (sixth to seventh century AD). In it he attributes the decline of medicine in his time to the popularity of poor-quality compendia (*kanānīsh*) and summaries and commentaries of the books of Hippocrates and Galen, compiled by incompetent physicians. The Alexandrian curriculum specifies the titles of textbooks of logic, medicine proper, and mathematics (including astronomy). It consists of preparatory (introductory) courses and main courses. The preparatory courses contain optional subjects, including language and grammar, and compulsory subjects: physics, arithmetic, numerals, measurement, geometry, the compounding of drugs, astrology, and ethics.

The main courses include logic and medicine proper. Sixteen of Galen's books were to be studied in seven grades: Grade 1 included Galen's *On Sects*, *On the Art of Physics*, *On the Pulse*, *To Teuthras*, and *To Glaucon on Therapy*. In the final and seventh grade, students studied Galen's *On the Method of the Preservation of Health*.

See also: ►Ibn Buṭlān

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Ibn Rushd (Averroës)

Albert Z. Iskandar

Abu'l-Walīd Muḥammad ibn Aḥmad ibn Muḥammad ibn Rushd (Averroës, AD 1126–1198), a native of Cordoba, Spain, was the namesake of his famous grandfather. Later, to avoid any confusion, he was nicknamed *al-ḥafīd* (grandson). Like his father and grandfather, he was a well-known jurist. By profession, following in the footsteps of his father, he became a *qāḍī* (judge), who specialized in religious matters, and at one time was the Imam of the great mosque of Cordoba. He adhered to the Mālikī sect, one of the four great sects of Islam, and wrote *Kitāb al-Muqaddimāt al-Mumahhidāt* (A Book of Introductions that Pave the Way), for the followers of the sect.

At his father's insistence, Ibn Rushd studied Islamic law (*Sharīʿa*) under the teacher, al-Ḥāfiẓ Abū Muḥammad Ibn Rizq. Ibn Rushd also studied the science of Tradition (*Ḥadīth*), but he is known to have been more interested in Islamic law. He memorized the *Muwaṭṭaʾ* of Imam Mālik and was also greatly impressed by the Ashʿarite science of *Kalām* (Theology). Later, he turned against the Ashʿarī school of thought and attacked its proponent, the Imam al-Ghazālī (d. AD 1111). Ibn Rushd was also acquainted with the doctrines of the Muʿtazila theology.

His teachers of medicine were Abū Marwān Ibn Jurrayūl, a first-class practitioner, and Abū Jaʿfar Hārūn al-Tarjālī, a well-known physician philosopher in Seville, who was knowledgeable about Aristotelian philosophy, as well as the medical writings of the Ancients. Al-Tarjālī was employed by the Almohad (*al-Muwaḥḥid*) ruler Abū Yaʿqūb Yūsuf (r. AD 1163–1184). Abū Yūsuf Yaʿqūb al-Manṣūr (r. AD 1184–1199), before succeeding his father, attended meetings in Seville, to which notable philosophers, physicians, and poets were invited. Abū Bakr Ibn Ṭufayl (Abubacer), Ibn Zuhr (Avenzoar), and Ibn Rushd were regular attendants at these meetings. Ibn Rushd's education under al-Tarjālī qualified him as a physician-philosopher; his studies in religious law, under al-Ḥāfiẓ, entitled him to be considered a jurist (*faqīh*).

In 1153, when he was in Marrakech (Morocco), Ibn Rushd supported the Almohad ruler ʿAbd al-Muʾmin (d. AD 1163) in furthering education by founding colleges. From his commentary on Aristotle's *De Caelo*, one learns that Ibn Rushd conducted astronomical observations when in Marrakech, and in his commentary on the *Metaphysics*, he mentions his yearning for his early studies in astronomy. Ibn Rushd studied the writings of Arabic-speaking astronomers and expressed his own opinion regarding the three kinds of planetary motions: those that can be detected by the naked eye, those that can be seen by instruments of observation (remarking that some occurred over long periods of time that exceeded the lifetime of observers), and those planetary movements whose existence can only be surmised by reasoning. Between AD 1169 and 1179, Ibn Rushd visited many places in the Almohad realm. He was actively researching matters pertaining to astronomy when he met Ibn Ṭufayl, a philosopher and astronomer in his own right. Ibn Ṭufayl enhanced Ibn Rushd's career by introducing him to Abū Yaʿqūb Yūsuf, who appointed Ibn Rushd as *qāḍī* of Seville in AD 1169. Ibn Rushd returned to Cordoba in AD 1171, at which time he was still holding the office of *qāḍī*. In AD 1182, he succeeded Ibn Ṭufayl as a personal doctor to Abū Yaʿqūb Yūsuf, and was elevated to the office of grand *qāḍī* of Cordoba.

For 10 years Ibn Rushd enjoyed the patronage of Abū Yaʿqūb Yūsuf. Out of jealousy, jurists (*al-fuqahāʾ*) of the Mālikī sect, whose influence had grown as a result of their religious zeal during the period of the Crusades, successfully conspired against him for his free-minded views. He was summoned to appear in court, and his philosophical writings were deemed contrary to the teachings of Islam. Ibn Rushd fell from grace in AD 1195 and was banished to Lucena, a province of Cordoba.

Very little is known about Ibn Rushd as a teacher of medicine. Nevertheless, the names of two of his students are known: ʿAbd Allāh al-Nadrūlī and ʿĪsā ibn Aḥmad ibn Muḥammad ibn Qādir. The latter transcribed the whole text of Ibn Rushd's book *Al-Kulliyyāt* (Generalities) from the author's own autograph, during his lifetime, and with his approval.

Kitāb al-Kulliyyāt (Latin, *Colliget*) consists of seven books: *Tashrīḥ al-Aʿḍāʾ* (The Anatomy of Organs), *al-Ṣiḥḥa* (Health), *al-Maraḍ* (Disease), *al-ʿAlāmāt* (Symptoms), *al-Adwiya wa'l-Aghdhiya* (Drugs and Foods), *Hif ẓ-al-ṣiḥḥa* (Hygiene), and *Shifāʾ al-Amrāḍ* (Recovery from Disease). The purpose of the book, according to the author, is to provide medical men with an introduction to concise accounts of the different parts of medicine (*ajzāʾ al-ṭibb*).

Scientific collaboration existed between the eminent practitioner Ibn Zuhr (Avenzoar, d. AD 1162) and Ibn Rushd. Ibn Rushd asked Ibn Zuhr to write a book on therapy, which he did. It was called *al-Taysīr fi'l-mudāwāt wa'l-tadbīr* (An Aid to Therapy and Regimen). *Al-Taysīr* and the *Kulliyyāt* together were meant to cover the whole science of medicine, possibly instead of Ibn Sīnā's (Avicenna, d. AD 1037) *Kitāb al-Qānūn fi'l-Ṭibb* (Canon of Medicine), which Ibn Zuhr severely criticized.

A merchant from Baghdad presented Ibn Zuhr with a beautifully transcribed and ornamented copy of Ibn Sīnā's *Kitāb al-Qānūn*. After reading it for the first time, Ibn Zuhr condemned the book and kept tearing off the margins of its leaves, which he used for jotting down prescriptions for his patients. It took almost a century before a copy of *Kitāb al-Qānūn*, completed by its author in Hamadan (Persia), actually reached Cordoba, Ibn Rushd's home town.

See also: ►Ibn Ṭufayl, ►Ibn Sīnā

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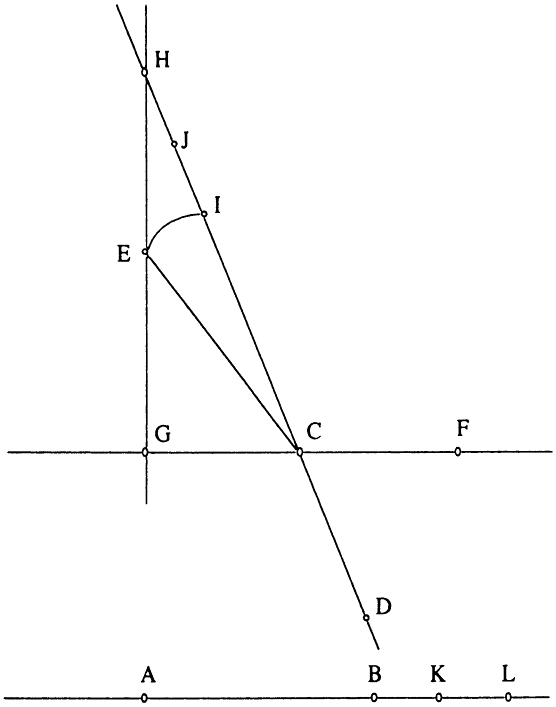
Ibn Sahl

Roshdi Rashed

Ibn Sahl, Abū Saʿd al-ʿAlāʾ, was a first-class mathematician. From his correspondence as well as from diverse information transmitted by mathematicians of the second half of the tenth century, we can deduce that he flourished under the Buwayhid Dynasty, and probably in Baghdād, between 970 and 990. Many of Ibn Sahl's important writings have been lost, namely two treatises, *On the Measurement of the Parabola* and *On the Centers of Gravity*, and a kind of anthology of problems about which we have no direct information. His book *Fī al-Ḥarrāqāt* (On Burning Instruments) was also on the point of being lost. This book, written in Baghdād around 984, is the first known contribution on the geometric theory of lenses.

Let us begin with the contribution of Ibn Sahl to optics. He wrote a memoir on the transparency of the celestial sphere, which was commented on by Ibn al-Haytham. The memoir and the commentary have come down to us. In this, composed in the course of his reading of Book V of Ptolemy's *Optics*, Ibn Sahl takes up not only the rules of refraction set out by his predecessor, but also demonstrates that every medium, including the celestial sphere, is invested with a certain opacity which defines it. Ibn al-Haytham had already captured this idea perfectly when, on reading this same memoir of Ibn Sahl, he wrote that his predecessor wanted to demonstrate that "there is no limit to transparency, and, for each transparent body, another always exists which is more so." That is to say that the mathematician better understands the notion of a medium and its definition by a certain characteristic opacity.

But Ibn Sahl's real discovery takes place when he poses the still unthought-of question of burning by refraction. He no longer defines the medium by a certain opacity, but characterizes it by a constant ratio. It is this concept of constant ratio distinguishing the medium which is the masterpiece of his study of refraction in lenses. This ratio, postulated by Ibn Sahl but never calculated, is nothing but the inverse of the refraction index *n* of the medium in relation to air. It therefore deals with Snellius' law of refraction, its formulation being very close to Snellius' own formulation some six centuries later. Let us look again at *On Burning Instruments* (Fig. 1).



Ibn Sahl. Fig. 1 Refraction in lenses.

At the beginning of the study of refraction in lenses, Ibn Sahl considers a plane surface GF limiting a piece of crystal. He considers the straight line DC following which light propagates in the crystal, the straight line CE according to which it refracts in the air, and the perpendicular at G to the surface GF which cuts the straight line CD at H and the refracted ray at E.

Here Ibn Sahl clearly applies the law by which the ray CD in the crystal, the ray CE in the air, and the perpendicular GE to the surface plane of the crystal, are all on the same plane. As usual, with no conceptual comment, he writes:

> The straight line CE is therefore smaller than CH. We separate from the straight line CH the straight line CI equal to the straight line CE; we divide HI in half at point J; we set the ratio of the straight line AK to the straight line AB equal to the ratio of the straight line CI to the straight line CJ; we extend the straight line BL along AB and set it equal to the straight line BK.

In these sentences, Ibn Sahl concludes that CE/CH is less than 1, which he will use throughout his research on lenses constructed in the same crystal. He will not fail to give this same ratio again, nor to reproduce this same figure, each time he discusses refraction in the crystal.

This ratio is nothing but the inverse of the index of refraction in the crystal in relation to air. In fact, let us consider i_1 and i_2, the angles formed, respectively, by CD and CE with the perpendicular GH. One has

$$\frac{1}{n} = \frac{\sin i_1}{\sin i_2} = \frac{CG}{CH}\frac{CE}{CG} = \frac{CE}{CH}.$$

Ibn Sahl takes on segment CH point I such that CI = CE, and point J at the middle of IH. One has

$$\frac{CI}{CH} = \frac{1}{n}.$$

The division CIJH henceforth characterizes the crystal for all refraction.

Ibn Sahl made innovations not only in optics, but also in mathematics. Among his mathematical inventions, I shall mention only one paper, set down as a follow-up to his contemporary, the mathematician al-Qūhī: his study of the method of projection of the sphere. Al-Qūhī is, in fact, the author of a treatise on *The Art of the Astrolabe by Demonstration*. This treatise is composed of two books, of which the first opens with an introductory chapter on the theory of projections. The propositions which al-Qūhī set forth seemed "difficult to understand" to one of his contemporaries, who turned to Ibn Sahl for clarification of the notions found therein and for the proof by synthesis of what al-Qūhī showed by analysis. We have here a situation of privileged history: we are witness to the elaboration of a new chapter of geometry by two contemporary mathematicians.

In conclusion, I remark upon the emergence of Ibn Sahl, a figure until recently almost unknown, and two chapters: anaclastics and the study of projection of the sphere. Ibn Sahl also made a substantial contribution in infinitesimal mathematics as well as in construction problems – the regular heptagon, for instance.

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Ibn Sarabi (Serapion)

E. Ruth Harvey

There are two different Arab authors known to the medieval Latin west as "Serapion," and the confusion between them in all of the authorities seems inextricable. The elder of the two authors was a Syrian, Yuḥannā ibn Sarabiyun, who lived in the ninth century. He wrote two books in Syriac, which were translated into Arabic: they are called the *Large Kunnāsh* (it was in twelve parts) and the *Small Kunnāsh* (in seven parts). Manuscript copies of the Arabic versions exist in European libraries; what sounds like a whole copy of the *Large Kunnāsh* is in Istanbul. Both works deal with medicine and diet, but not surgery; al-Rāzī (Razes), who may have been a younger contemporary, cites Serapion, naming the *Kunnāsh*, and ʿAlī ibn ʿAbbās al-Majūsī (d. 994) criticizes Serapion for ignoring surgery. The *Small Kunnāsh* was translated into Latin by Gerard of Cremona (d. 1187) and entitled *Practica Joannis Serapionis dicta Breviarium*. There are many manuscript copies of this version and some early printed texts. Moses ben Mazliach translated Gerard's version into Hebrew, and a manuscript of this translation still survives.

The younger Serapion is an even more obscure figure. He was the author of a treatise on drugs called *Kitāb al-adwiya al-mufrada*, which was translated into Latin as *Liber de medicamentis simplicibus* by Simon de Cordo of Genoa and Abraham of Tortosa in about 1290. The younger Serapion cannot have lived earlier than the eleventh century, because he cites among his authorities not only al-Rāzī, but also Ibn al-Wāfid (997–1075). There are many manuscript copies of the Latin translation, and several early prints. Usually the works of both Serapions appear together. In the Latin text, the author explains that he intends to collect and reconcile the views of Dioscorides and Galen on a wide variety of medicinal substances, and then to add in the opinions of others. In his chapter on pearls, for instance, he describes the generally accepted power of pearls to strengthen the heart; he then goes on to cite four Arab authorities on the effects of pearls on the eyesight, the blood, the nerves, melancholia, and as a dentifrice.

See also: ►al-Rāzī, ►al-Majūsī

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Ibn Sīnā (Avicenna)

Mehdi Aminrazavi

Abū ʿAlī al-Ḥusain ibn ʿAbdallāh ibn Sīnā (980–1037), also known as Avicenna, was born in the city of Būkhārā in the Eastern part of Persia into an Ismaʾili family. He demonstrated an incredible genius for learning, and having mastered the *Quʾrān* and the sciences of his time, became a physician at age 16. Ibn Sīnā gained favor with the Sāmānid dynasty for having cured Prince Nūḥ ibn Manṣūr and was thus allowed to use the royal library. He mastered other sciences such as psychology, astronomy, chemistry, and pharmacology by age 18, and toward the end of his life said he had learned everything he knew by then.

Ibn Sīnā lived in a tumultuous time when different princes were engaged in a power struggle, resulting in his traveling from city to city. He first went to Gorgān, an area close to the Caspian Sea, crossing the desert on foot, and after a while traveled to Khorāsān, Rayy, and Qazwīn, until he finally settled in Hamadān at the request of prince Shams al-Dawlah. In 1022, following the death of the prince, Ibn Sīnā went to Iṣfahān where he found the peace and serenity that the intellectual life demands. In 1037 while traveling with ʿAlāʾ al-Dawlah he became ill and died as the result of colic. He is buried in Hamedan.

Ibn Sīnā gained the title of *Shaykh al-Raʾīs* (Master of the Wise) because he composed numerous treatises, 276 of which have been alluded to by his commentators. It is noteworthy that he wrote a great number of these works on horseback while fleeing from one city to another.

Ibn Sīnā's most extensive and elaborate work is *Kitāb al-shifāʾ* (The Book of Healing) which itself consists of four segments: *al-Manṭiq* (Logic), *Tabīʿiyyāt* (Natural Philosophy), *Riyāḍāyāt* (Mathematics), and *Ilāhāyyāt* (Metaphysics). To this monumental work should be added *Kitāb al-nijāt* (The Book of Deliverance), a synopsis of the *Shifāʾ*, and his last major work *al-Ishārāt wa'l-tanbīhāt* (The Book of Directives and Treatments). Among his other philosophical works are *ʿUyūn al-ḥikmah* (Fountain of Wisdom), *Kitāb al-hidāyah* (The Book of Guidance), *al-Mabdaʾ wa'l-maʿād* (The Book of Origin and End), and the first major work written in Persian for ʿAlāʾ al-Dawlah, *Dānishnāmah-yi ʿAlāʾī* (The Book of Knowledge). Finally, there are a few works which are mystical and visionary, such as *Ḥayy ibn Yaqẓān* (Son of the Living Awake), and *Risālat al-ṭaīr* (Treatise of the Bird).

Ibn Sīnā was a great synthesizer in that he not only incorporated the ideas of some of his predecessors such as al-Kindī and al-Fārābī, but also made extensive use of Greek philosophy, in particular Neoplatonism, Plato and Aristotle. From Plotinus he adopted the emanation scheme, from Plato his theory of archetypes, and from Aristotle his logic, physics, and psychology. The genius of Ibn Sīnā was in interpreting these different thoughts within the unitary matrix of Islam.

Ibn Sīnā has been called "philosopher of being" for he brought the question of being and the study of ontology to the forefront of philosophical debates and thereby corrected a deficiency that he saw in Greek philosophy, in particular in Aristotle. Ibn Sīnā divided all beings into three categories: necessary, contingent, and impossible. Furthermore, he argued that existent beings were made up of an essence and existence. This distinction became the central theme of medieval ontological discussions as well as of the subsequent debates within the Islamic philosophical tradition.

Ibn Sīnā, who had studied the Ptolemaic and Aristotelian systems, adopted the Islamic astronomical view based on the nine spheres and interpreted them within the scheme of the emanation of intellects. Each order of intellect accordingly corresponds to one of the heavens. For example, the second intellect corresponds to the highest heaven which is located above the fixed stars, and the tenth intellect corresponds to the moon below which the corporeal domain of our world is located.

Medicine

Ibn Sīnā was in the tradition of such grand Muslim physicians as al-Rāzī and al-Majūsī. By the age of 20, he had already become an accomplished physician and gained the respect of the court for having cured several members of the royal family. Eventually he came to be known as the "prince of physicians". He is the author of the *Qānūn al-Ṭibb* (The Canon of Medicine), which became a standard text both in the Christian West and the Islamic world. In addition to his *magnum opus*, Ibn Sīnā wrote a number of treatises on medicine both in Arabic and Persian some of which deal with particular diseases. He also wrote a book in which principles of medicine are written as poetry in order to facilitate their memorization by medical students.

In medicine, Ibn Sīnā was in many ways a follower of Greek ideas on medicine. However, he made the following revisions:

1. Unified the central principles of Greek medicine and interpreted them within an Islamic framework.
2. Made the theoretical and practical aspects of medicine represent a unified whole.

3. Documented the effects of medications on the body and commented on the necessity of a methodology in the study of pharmacological issues.
4. Introduced a number of medications and treatments for illnesses unknown to Greeks.

Ibn Sīnā believed that the science of medicine was divided into two categories, theoretical and practical. Illnesses were brought about either by internal or external causes. Internal illnesses were caused by an imbalance of temperament in the human body. These causes could also be the result of psychological elements.

Ibn Sīnā is known to have prescribed a variety of treatments for ailments, ranging from psychotherapy and diet to exercising. In the first volume of the *Canon of Medicine*, he states that medicine is the science of knowing the structure of the human body, and he goes on to discuss the fundamental principles necessary to maintain human health. He discusses surgery as an independent branch of medicine and elaborates on the science of anatomy. In the second volume, Ibn Sīnā explains various healing properties of simple and compound drugs and their various applications. In the third and fourth volumes, he presents his diagnosis of a variety of illnesses known to him, ranging from meningitis and cancer to tuberculosis and gastrointestinal illnesses. In the fifth volume of this work, Ibn Sīnā offers an extensive discussion of pharmacology, providing a detailed description of the effects of medications on body.

Some of his observations are extraordinarily advanced for his time. For example, he attributed the cause of plague to mice, commented on a number of contagious diseases, used single hair lines of horses for stitching after surgery, experimented with various drugs as anesthetics when operating on patients, described surgical processes for many operations such as gall bladder, used spices to stop bleeding after surgery, and understood the relationship between temperature and the spread of diseases. He even experimented on animals using different drugs.

Ibn Sīnā's treatment of the subject of psychology as a science which is both independent and part of the field of medicine is extensive. He first argues for the existence of a soul which is rather similar to the Aristotelian *psyche* and then shows how this incorporeal part of man interacts with his corporeal dimension. Ibn Sīnā then goes on to say that the health of the body to a large extent depends on the health of the soul and he offers much elaboration on that point throughout his works.

Perhaps one of the most important contributions of Ibn Sīnā to the field of medicine is the technical medical terminology which he introduced and which is still used by physicians in the Islamic countries.

Psychology

In *The Book of Healing*, Ibn Sīnā treats the subject of the "three kingdoms" (minerals, plants, and animals). He extends the hierarchy of the incorporeal world to the material world, concluding that whereas each domain has its soul it is only in humans that these souls reach their completeness. Ibn Sīnā's treatment of the human soul, its relationship with the body and the active intellect, is extensive. He introduces five internal senses and their equivalent five external senses.

The scope of Ibn Sīnā's writings on sciences includes such topics as motion, the process of sedimentation, and classification of minerals in the *Shifāʾ*, which came to be known in the West as *De mineralibus*. In a famous debate with al-Bīrūnī, Ibn Sīnā responded to ten questions on Aristotle's *De Caelo* and eight other questions such as how vision is possible, the relationship between water and light, the nature of a vacuum, heat, cooling, and how it is that ice floats on water.

Ibn Sīnā's philosophy remained the dominant philosophical school in the medieval west where he became known through translations of his works in Islamic Spain by Avendeuth, who was a Jewish philosopher and Gerard of Cremona. The Sicillian school also benefited much from Ibn Sīnā who was translated by Michael Scot. Ibn Sīnā's works continued to be translated through the sixteenth century influencing such western philosophers as the Augustinian Gundisalvo, Alberttus Magnus, William of Auvergne, Alexander of Hales, Roger Bacon, and Duns Scotus.

Ibn Sīnā left an indelible mark on the history of science, medicine, and philosophy.

See also: ►al-Kindī

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Ibn Ṭāwūs

Zeina Matar

Raḍī al-Dīn Abū-l-Qāsim ᶜAlī ibn Mūsā ibn Jaᶜfar ibn Muḥammad ibn Aḥmad ibn Muḥammad ibn Ṭāwūs was a religious scholar, historian, and astrologer. He was born in al-Ḥilla (Iraq) on 15 Muḥarram 589/21 January 1193. He belonged to a distinguished family of scholars, the Banū Ṭāwūs, whose ancestry can be traced back to ᶜAlī ibn Abī Ṭālib.

Ibn Ṭāwūs grew up in the town of al-Ḥilla, which had been established by the famous scholar Abū Jaᶜfar al-Ṭūsī (385–458/995–1066) as a center of learning boasting five *madrasas* (institutions for the study of the Islamic sciences). Ibn Ṭāwūs spent his formative years in his native town, and in Baghdad where he lived for 15 years. He made pilgrimages to the holy Shīᶜī shrines of Najaf, Kerbela, and al-Kazimayan. He had a reputation for saintly powers, and concerned himself extensively with popular religious practices.

Ibn Ṭāwūs concentrated mainly on devotional literature, but he also wrote in the fields of history and astrology (see the listing of primary sources in the bibliography). In AH 650/AD 1252, he owned over 1,500 volumes in his private library. Professor E. Kohlberg of the Hebrew University of Jerusalem has contributed a superb reconstruction of this library and a detailed critical analysis of the works it contained.

Ibn Ṭāwūs was one of the most prolific medieval Shīᶜī scholars, who aimed at providing the believer with a set of guiding moral and ethical principles. The sources stress his "erudition, knowledge, asceticism, devoutness, trustworthiness, understanding of *fiqh* (science, or knowledge), loftiness and godfearingness [along with his talents as] poet, man of letters, writer, and eloquent speaker" (Āghā Buzurg Tihrānī 1983). A man of deep faith, concerned with religious matters, Ibn Ṭāwūs could also display wisdom in sensitive political situations, as in this apocryphal story:

> When Sultan Hulagu conquered Baghdad in 656/1258, he ordered that the scholars give an opinion on which was preferable: the unbelieving but just sultan, or the Muslim despotic one. The scholars were then gathered in al-Mustanṣiriyya for this purpose. They refrained from answering. Raḍī al-Dīn ᶜAlī Ibn Ṭāwūs was present at this Council. When he saw their hesitation, he took the *futya* (*fatwa*, legal opinion), and wrote that the unbelieving but just ruler was preferable to a Muslim despot.

Although Ibn Ṭāwūs declined the office of Naqābat al-Ashrāf under the Caliph al-Mustanṣir (d. 640/1242), he apparently changed his mind during the Mongol Period, and received the title from Naṣīr al-Dīn al-Ṭūsī (d. 672/1273). This important office, which had originated under the Buwayhids (also Buyids, a dynasty in Persia and Iraq, 320–454/932–1062), enabled the Sayyid families to represent their community in political, religious, and scholarly matters.

The date on which Ibn Ṭāwūs died in Baghdad is generally accepted as 5 Dhū-l-qa ᶜda 664/9 August 1266, and he was probably buried in Najaf.

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Ibn Tibbon

Emilia Calvo

Ibn Tibbon, Jacob Ben Machir, is known as Profeit in Romance languages and as Prophatius Judaeus in Latin. These names come from the translation of *mehir* (prophet) into the languages of Southern France.

Ibn Tibbon was probably born in Marseille ca. 1236. His family was originally from Granada and, for four generations, had been devoted to the translation of Arabic religious, philosophical, and scientific texts. Through these translations, Arabic learning and therefore Greek scientific traditions were made available to the scholars of medieval Europe. Ibn Tibbon studied medicine at Montpellier and probably lived in Gerona, Spain between AD 1266 and 1267. He spent most of his life in Lunel, where his great-grandfather had established and practiced medicine at the beginning of the twelfth century, and Montpellier where he died in AD 1305.

Ibn Tibbon translated works by Autolycus of Pitane, Euclid, Menelaus of Alexandria, Qusṭā ibn Luqa, Ibn al-Haytham, Ibn al-Ṣaffīr, Ibn al-Zarqāllu, al-Ghazālī, Jābir ibn Aflaḥ, and Ibn Rushd from Arabic into Hebrew.

He is also the author of some works dealing with astronomy:

> *Robaᶜ Yisrael* (Quadrant of Israel), written between AD 1288 and 1293, in which an astronomical instrument, called the *quadrans novus*, is described. It consists of a simplification of the face of the astrolabe. Some examples of this instrument have been preserved.
>
> The *Almanac*, calculated for Montpellier and dated 1 March 1300. It is based on Ibn al-Zarqāllu's reelaboration of Awmātiyūs' almanac, although the author says that he has used the Toledan Tables, which is incorrect.

Ibn Tibbon is also the author of the Prologue to Abraham bar Hiyya's *Sefer Hesbon Mahlekot ha-Kokabim* (Calculation of the Courses of the Stars).

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Ibn Ṭufayl

E. Ruth Harvey

Abū Bakr Muḥammad ibn ᶜAbd al-Malik ibn Muḥammad ibn Muḥammad ibn Ṭufayl al-Qaisi was an Arab physician famous for his encyclopedic learning. He was born at Guadix in Granada (modern Spain) in the first decade of the twelfth century. He served local rulers as physician and diplomat, and eventually became the court physician to Abū Yaᶜqūb Yūsuf, the Almohad prince who became the most powerful Muslim ruler of his day. Ibn Ṭufayl enjoyed a close friendship with Abū Yaᶜqūb until the latter's death in 1184; he was esteemed and cherished by Abū Yaᶜqūb's successor, Abū Yūsuf Yaᶜqūb, until his own death in 1185–1186.

Ibn Ṭufayl's importance for history is twofold: the influence of his unique work, *Ḥayy ibn Yaqẓān*, and his patronage of one of the most important Muslim philosophers of the Middle Ages, Ibn Rushd (known to the west as Averroes). The medieval Arab historian, ʿAbd al-Wāḥid al-Marrākushi, recorded that Ibn Ṭufayl would bring all sorts of learned men to his sovereign's notice. It was in this way that Ibn Rushd was given audience with Abū Yaʿqūb Yūsuf, and there was led on by the praise and encouragement of Ibn Ṭufayl to demonstrate his familiarity with Aristotelian philosophical traditions. The Sultan himself joined in the discussion, and Ibn Rushd was commissioned to compose his great commentaries. It was through the mediation of Ibn Rushd's works that Aristotle was reintroduced to the Latin West. The astronomer al-Bīṭrūjī (known in the West as Alpetragius) was a disciple and friend of Ibn Ṭufayl; he mentions Ibn Ṭufayl's criticisms of the traditional astronomical theories on epicycles and eccentrics.

Ibn Ṭufayl was said to have written poetry as well as works on medicine and astronomy, but nothing seems to survive except *Ḥayy ibn Yaqẓān* and (possibly) a poem on medicine recently rediscovered (see Russell 1986). The highly unusual *Ḥayy ibn Yaqẓān* (Life, Son of Awareness) is a philosophical tale in the form of a table: it tells how Ḥayy, cast up as a baby or spontaneously generated on an island, is fostered by a doe and grows to adulthood without any human contact whatsoever. Ibn Ṭufayl's interest lies in positing the natural unfolding of the human reason from the blank of infancy to the highest possible intellectual development; Ḥayy reaches the summit of human possibility in a mystical experience of the godhead. Eventually Ḥayy meets another human being who is so filled with awe at Ḥayy's intellectual and spiritual attainments that he persuades him to make an attempt to convert human society to wisdom. Humanity proves to be unworthy of Ḥayy's teaching, and Ḥayy and his new-found friend retreat back to the island again to spend the rest of their lives in contemplation.

Ḥayy ibn Yaqẓān draws on the philosophy of Ibn Sīnā. It was edited as early as 1671 by Edward Pocock, who provided a Latin translation, thus inserting Ibn Ṭufayl's ideas into the mainstream of European culture. The *Philosophus Autodidactus*, as Pocock named it, was sent to Huygens, Locke, and Leibniz; it was possibly an influence on Defoe's *Robinson Crusoe*, and almost certainly one on Rousseau's *Emile*. English translations have been appearing since 1686; there are Dutch, German, French, Catalan, Hebrew, Persian, and Russian versions. It is still stirring up scholarly debate and controversy.

See also: ►Ibn Rushd, ►Ibn Sīnā

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Ibn Wāfid

EMILIA CALVO

Ibn Wāfid Abū'l-Muṭarrif ʿAbd al-Raḥmān ibn Muḥammad was a pharmacologist and physicist who lived and worked in Toledo during the first half of the eleventh century (ca. 1008–1075). He studied the works of Aristotle, Dioscorides, and Galen in Cordoba but then he moved to Toledo where he planted a botanical garden for the king of this city, al-Maʾmūn.

Ibn Wāfid is the author of a book entitled *Kitāb fī-l-adwiya al-mufrada* (Book on the Simple Medicines) which is a synthesis of Dioscorides and Galen. It is an extensive work to which the author devoted 20 years. It was abridged and translated into Latin by Gerard of Cremona. Translations into Catalan and Hebrew are also extant.

Ibn Wāfid is also the author of a pharmacopeia and manual of therapeutics entitled *Kitāb al-wisād fī ʻl-ṭibb* (Book of the Pillow on Medicine) which, according to Juan Vernet, could be a misreading of the Arabic title *Kitāb al-rashshād fī'l-ṭibb* (Guide to Medicine). This work can be considered complementary to the preceding one because Ibn Wāfid describes compound medicines in it, and it is a practical book: the information given is based on experience. Ibn Abī Uṣaybiʿa attributes to Ibn Wāfid a work entitled *Mujarrabāt fī-l-ṭibb* (Medical Experiences) which could probably be identified with this Book of the Pillow.

Ibn Wāfid is also the author of two works entitled *Tadqīq al-naẓar fī ʿilal ḥāssat al-baṣar* (Observations on the Treatment of Illness of the Eyes) and *Kitāb al-Mughīth* (Book on Assistance) which are not preserved, and of a treatise on balneology which is preserved in a Latin version entitled *De balneis sermo* (Venice 1553).

Ibn al-Abbār attributes to Ibn Wāfid a book entitled *Majmuʿ al-Filāḥa* (Compendium of Agriculture) although his authorship is now being questioned.

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Ibn Yūnus

David A. King

Ibn Yūnus, Abu'l-Ḥasan ʿAlī ibn ʿAbd al-Raḥmān ibn Aḥmad ibn Yūnus al-Ṣadafī was one of the greatest astronomers of medieval Islam. Unfortunately nothing of consequence is known about his early life or education. As a young man he witnessed the Fatimid conquest of Egypt and the founding of Cairo in 969. In the period up to the reign of Caliph al-ʿAzīz (975–996), he made astronomical observations that were renewed by order of the Caliph al-Ḥākim, who succeeded al-ʿAzīz in 996 at the age of eleven and was much interested in astrology. Ibn Yūnus' recorded observations continued until 1003.

Ibn Yūnus' major work was a monumental *zīj* or astronomical handbook with tables. The *Ḥākimī Zīj*, dedicated to the Caliph, is distinguished from all other extant *zījes* by beginning with a list of observations made by Ibn Yūnus and others made by some of his predecessors. Despite his critical attitude toward these earlier scholars and his careful recording of their observations and some of his own, he completely neglects to describe the observations that he used in establishing his own planetary parameters – nor does he indicate whether he used any instruments for these observations. Indeed, the *Ḥākimī Zīj* is a poor source of information about the instruments he used. In view of the paucity of this information, it is remarkable that the statement that Ibn Yūnus worked in a "well-equipped observatory" is often found in popular accounts of Islamic astronomy. Sayili has shown how this notion gained acceptance in Western literature.

Ibn Yūnus' *Zīj* was intended to replace the *Mumtaḥan Zīj* of Yaḥyā ibn Abī Mansūr, prepared for the Abbasid Caliph al-Maʾmūn in Baghdad almost 200 year earlier. When reporting his own observations, Ibn Yūnus often compared what he observed with what he had computed using the *Mumtaḥan* tables.

The observations he described are of conjunctions of planets with each other and with Regulus, solar and lunar eclipses, and equinoxes; he also records measurements of the obliquity of the ecliptic (Chap. 11) and of the maximum lunar latitude (Chap. 38).

In spherical astronomy (Chaps. 12–54) Ibn Yūnus reached a very high level of sophistication. Although none of the several hundred formulae that he presents is explained, it seems probable that most of them were derived by means of orthogonal projections and analemma constructions, rather than by the application of the rules of spherical trigonometry that were being developed by Muslim scholars in Iraq and Iran.

The chapters of the *Zīj* dealing with astrological calculations (77–81), although partially extant in the anonymous abridgment of the work, have never been studied. Ibn Yūnus was famous as an astrologer and, according to his biographers, devoted much time to making astrological predictions.

Ibn Yūnus' second major work was part of the corpus of spherical astronomical tables for timekeeping used in Cairo until the nineteenth century. It is difficult to ascertain precisely how many tables in this corpus were actually computed by Ibn Yūnus. Some appear to have been added in the thirteenth and fourteenth centuries. The corpus exists in numerous manuscript sources, each containing different arrangements of the tables or only selected sets of tables. In its entirety the corpus consists of about 200 pages of tables, most of which contain 180 entries each. The tables are generally rather accurately computed and are all based on Ibn Yūnus' values of 30°0′ for the latitude of Cairo and 23°35′ for the obliquity of the ecliptic. The main tables in the corpus display the time since sunrise, the time remaining to midday, and the solar azimuth as functions of the solar altitude and solar longitude. Entries are tabulated for each degree of both arguments, and each of the three sets contains over 10,000 entries. The remaining tables in the corpus are of spherical astronomical functions, some of which relate to the determination of the five daily prayers of Islam. The impressive developments in astronomical timekeeping in fourteenth-century Syria, particularly the tables of al-Khalīlī for Damascus, also owe their inspiration to the main Cairo corpus.

It is clear from a contemporary biography of Ibn Yūnus that he was an eccentric, careless, and absent-minded man who dressed shabbily and had a comic appearance. One day in the year 1009, when he was in good health, he predicted his own death in 7 days. He attended to his personal business, locked himself in his house, and washed the ink off his manuscripts. He then recited the *Qurʾān* until he died – on the day he had predicted. According to his biographer, Ibn Yūnus' son was so stupid that he sold his father's papers by the pound in the soap market.

See also: ►Yahyā ibn Abī Manṣūr, ►al-Maʾmūn, ►al-Khalīlī

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Ibn Ẓuhr

Munawar Ahmad Anees

Abū Marwān ʿAbd al-Mālik ibn Ẓuhr (Latin: Avenzoar; 484–557/1092–1162) belonged to the Arabian tribe of Iyād, Banū Ẓuhr. His father, Abū al-ʿAlā ibn Ẓuhr (d. 525/1131), was a respected physician in the courts of the Murābiṭ dynasty (482–541/1090–1147). He trained his son in the art and craft of medicine.

Like his father, Ibn Ẓuhr started his career in the service of the Murābiṭ dynasty and earned a good reputation. During the reign of ʿAli ibn Tashfīn (499–537/1106–1143), he served at the palace in Marrakesh, Morocco, where his life was full of trials and tribulations. In ca. 535/1141, he was stripped of his official position and imprisoned. Although he was pardoned and released, he endured a hard life in prison and the experience left a resentment in his heart against the ruling dynasty.

The beginning of the reign of al-Muwāḥḥidūn proved to be a blessing for Ibn Ẓuhr. He was not only appointed as an official physician but also became a *wazīr* in the court of Abū Muḥammad ʿAbd al-Mūmin (d. 558/1163). During this period, Ibn Ẓuhr transmitted his knowledge and skills to his children with meticulous attention. His son and daughter both became famous physicians. One of Ibn Ẓuhr's treatises, *al-Tadhkirah* (The Remembrance), was dedicated to his son in appreciation of his achievements.

At least nine of Ibn Ẓuhr's works are known, but only a few are extant. He is said to have written two works and dedicated them to ʿAbd alʾ-Mūmin. *Al-Aghdhīyyah* (On Dietetics) is a text on the therapeutic properties of selected foods. *Al-Tiryāq al-Sabʿīnī* is a book of antidotes against poisoning by enemies. This work, perhaps, was Ibn Ẓuhr's way of expressing gratitude to his benevolent patron.

Al-Taysīr fī al-Mudāwāt wa al-Tadbīr (On Preventive Regimen and Treatment), in 30 treatises, is considered to be his monumental work. His friend Ibn Rushd considered it a great source of medical knowledge and therapeutic advice. In its Latin version, *Alteisir scilicet regiminis et medelae*, the treatise remained in wide circulation across Europe for centuries. Both Arabic and Latin copies of this work are extant. True to the medical norms of his days, Ibn Ẓuhr presented in this work a mix of astrology and folklore blended with therapeutics and pharmacology. *Al-Kulliyāt* (The Collection), a general compilation on medical practice, appears as an appendix.

The great historiographer Ibn Abi ʿUṣaybiʿah, in his encyclopedic work *ʿUyūn al-Anbā fī Ṭabaqāt al-Aṭibbā*, listed only seven of Ibn Ẓuhr's works:

I

1. *Fī al-Zīnah* (On Beautification)
2. *Al-Tiryāq al-Sabᶜīnī* (On Antidotes)
3. *Fī ᶜIlāl al-Kilā* (On Diseases of the Kidney)
4. *Fī ᶜIllat al-Baraṣ wa al-ᵓBahaq* (On Leprosy and Vitiligo)
5. *Al-Aghdiyyah* (On Dietetics)
6. *Al-Tadhkirah* (The Remembrance)
7. *Al-Taysīr fī al-Mudāwāt wa al-Tadbīr* (On Preventive Regimen and Treatment)

He does not mention two of his treatises. One of the missing ones is *Al-Iqtiṣād fī Iṣlāḥ al-Anfūs wa al-Ajsād* (Treatment and Healing of the Soul and Body). Addressed to the general reader, it focuses on problems of hygiene and therapeutics. The second is *Jāmiᶜ al-Asrār al-Ṭibb* (Compendium of Medical Wisdom). In addition to a discussion on dietetics, this work describes the physiology of several organs including the spleen, liver, and bladder.

Ibn Ẓuhr was a prolific writer and a highly successful medical practitioner. Some of his work showed the influence of the Hippocratic and Galenic traditions, but his original insights came from a rich family heritage in medical practice. Thus, going against the Greco-Roman medical dictates, Ibn Ẓuhr engaged in experimental work and recorded his observations. His detailed study of the pericardial abscess, pharyngeal paralysis, intestinal and mediastinal tumors, and inflammation of the middle ear were great improvements over the work of his predecessors.

Ibn Ẓuhr was one of the great Muslim clinicians and therapists. Through numerous translations of his works, he remained highly influential in the medical academies of the West. In his later age, he suffered from a malignant tumor that ultimately caused his death. He was buried in Seville, Spain.

See also: ►Ibn Rushd

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Ibrāhīm Ibn Sinān

Roshdi Rashed

Ibrāhīm Ibn Sinān Ibn Thābit Ibn Qurra was born in Baghdad in 296/909 where he died 37 years later in 335/946. Grandson of the famous mathematician Thābit Ibn Qurra, cousin of the famous literary figure Hilāl al-Ṣābiᵓ, son of a great physician and mathematician Sinān Ibn Thābit, he thus belonged to an intellectual aristocracy whose members frequented the corridors of power and the upper levels of the worlds of science and medicine. Ibrāhīm was born into and raised in this world, before being the object of a short-lived persecution to which he makes allusion but explains neither the cause nor the duration. Ibrāhīm Ibn Sinān was not only the "heir" to great tradition, but also a mathematician of genius in his own right who made his own mark on the mathematics of his era.

Ibrāhīm Ibn Sinān was also heir to a historical tradition. He belonged to a privileged generation, the fourth since the Banū Mūsā. The translation of the major mathematical texts had been essentially completed and the great traditions of research had already been well established: that of the algebraists, beginning with al-Khwārizmī and extended by Abū Kāmil; that of the geometers, al-Jawharī, al-Nayrīzī, etc., who followed the work of Euclid; and the tradition of the Banū Mūsā which, thanks to mathematicians like Thābit Ibn Qurra, had already gathered considerable results, developed new methods, and elaborated theories. Ibrāhīm Ibn Sinān was clearly a part of this tradition in which Archimedean geometry, a geometry of measurement, and the geometry of Apollonius, which was concerned with the properties of positions, were all combined. Profiting from scholarly works, especially those of his grandfather Thābit Ibn Qurra, Ibrāhīm Ibn Sinān developed the study of geometric transformations and their applications to conic sections, as well as to the measurement of the area of a portion of a parabola. He extended their work on sundials in developing a theory of a whole class of instruments. Finally the questions posed by his predecessors about analysis and synthesis prompted him to write the first treatise worthy of the name on the subject.

Ibrāhīm Ibn Sinān explained the composition of his work in his own autobiography which happily still exists. He published the autobiography after his 25th year, in 934. According to his own account, he began his research at age 15; at 16 or 17 he had written a first version of his book *Fī Alāt al-aẓlāl* (On Instruments of Shadows), which he revised at the age of 25. A year later he was discussing and criticizing Ptolemy's views on The Determination of the Anomalies of Saturn, Mars, and Jupiter (*Fī istikhrāj ikhtilāfāt Zuḥal wa al-Mirrīkh wa al-Mushtarī*) in a treatise that he completed 6 years later, at the age of 24. In geometry, Ibn Sinān wrote *Fī al-dawā*ˀ*ir al-mutamāssa* (The Tangent Circles), *al-Taḥlīl wa*ˀ*l-Tarkīb* (Analysis and Synthesis), *Fī al-masaā*ˀ*il al-mukhtāra* (Selected Problems), *Fī misāḥat qiṭ*ˀ *al-maḥrūṭ al-mukāfī*ˀ (The Measurement of the Parabola), and the *Fī rasm al-quṭū*ˁ *althalātha* (Drawing of the Three Conic Sections). All these works had been published and revised before Ibn Sinān was 25.

To illustrate the approach of Ibn Sinān let us look briefly at his *Measurement of the Parabola*, beginning with what he wrote about his own studies:

> My grandfather had determined the measurement of this section. But several contemporary geometers led me to understand that a work of al-Māhānī on the same subject, which they presented to me, was easier than my grandfather's. I was not pleased that al-Māhānī's work was more advanced than my grandfather's without there being one among us who surpassed his work. My grandfather had determined his result in twenty propositions. He proceeded from several arithmetic lemmas included in the twenty propositions. The question of the measurement of the section appeared to him clearly through the method of *reductio ad absurdum*. Al-Māhānī also proceeded from arithmetic lemmas. He then demonstrated his demand by the method of *reductio ad absurdum* in five or six propositions, which involved lengthy discussions. I myself then determined the measurement in three geometric propositions without recourse to any arithmetic lemma. I demonstrated the surface area of this same section using the method of direct proof, and I did not need the method of *reductio ad absurdum*.

In addition to expressing pride in his heritage and the certainty of an exceptional scholar, these remarks also reflect the qualities of Ibn Sinān as a mathematician: brevity, ease, and elegance.

Ibn Sinān's approach is the following: in a first proposition, he demonstrates that the affine transformation conserves the ratios of the areas in the case of triangles and polygons; he then demonstrates in a second proposition that it is the same for the ratio of the area of a portion of a parabola to that of an associated triangle.

Ibn Sinān again had recourse to geometric transformations in his *Drawing of the Three Conic Sections*. In this treatise, he constructed an ellipse by transforming the circle by an orthogonal affinity – a process already found in the works of the Banū Mūsā. It was also by means of an affinity that he deduced all the hyperbolas of a particular hyperbola for which the latus rectum is equal to the transverse axis.

The intensity of mathematical activity, the large amount of work done, the new demands of brevity, elegance, and rigor in demonstration, as well as the general interest in geometric transformations, all led Ibn Sinān to take up the theory of analysis and synthesis again. Thus he published the first treatise devoted to this subject. He wrote "I found that the geometers of this time had neglected Apollonius's method of analysis and synthesis, as was the case for the majority of things I brought up, and that they had limited themselves just to analysis, limiting themselves to such a degree that they led analysis to the point of letting people think that this analysis was not the synthesis that they were doing."

In this treatise, Ibn Sinān undertook two tasks at once: one didactic, the other logical. On the one hand, he proposed a method (*ṭarīq*) for geometry students which allowed them to solve geometry problems; on the other hand, he reflected on geometric analysis itself, proposing a classification of geometry problems according to their numbers and the hypothesis that they are to verify, and explaining for each class of problems the respective parts of analysis and synthesis.

There is not enough space here to take up, even very briefly, the works of Ibn Sinān. But the examples discussed above do show how this eminent geometer left his mark on all the fields in which he worked, including mathematics and philosophy. The import of his work can be discovered in the work of Ibn al-Haytham who followed up on the research of Ibn Sinān in his own treatise on analysis and synthesis and in his writings on sundials.

See also: ►Banū Mūsā, ►Thābit Ibn Qurra, ►Sinān Ibn Thābit

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Ikhwān al-Ṣafāʾ

Gregg de Young

The 48 treatises composed by the Ikhwān al-Ṣafāʾ (Brethren of Purity) constitute an encyclopedia of the sciences which has had a long and influential career in Islamic civilization. The collection was prepared by a group of scholars who preferred anonymity. This anonymity has generated considerable debate among historians over their identity. Current scholarship places the date of composition in the last half of the fourth AH/AD tenth century, and the place of composition in Basra. This collection of treatises continues to play an important role in the intellectual milieu of modern Islam, especially among groups influenced by Shiʿite and Ismāʿīlī ideas.

The treatises contain a strong gnostic element, an emphasis on esoteric knowledge that exists within the exoteric or phenomenal features of everyday life but is accessible only to the initiated. This interest in esoteric or inner knowledge does not imply that they were uninterested in the physical world. It is necessary to have a thorough understanding of nature in order to penetrate to the inner truth that it expresses. An appreciation of nature, therefore, is one of the first steps toward union with the Divine Knowledge.

Their gnostic orientation can be seen in the classification of knowledge proposed by the Ikhwān. The student begins with introductory or preparatory (*riyāḍiyy*) topics, advances to religious (*sharʿiyy*) sciences, and finally reaches the highest, or philosophic (*falsafiyy*) sciences. This system is at odds with traditional Islamic discussions of the arrangement of the sciences in that it makes religious sciences subordinate to philosophic or intellectual sciences. In the organization of their treatise, the Ikhwān begin with mathematical sciences, advance to physical sciences, human sciences, and finally to metaphysical and revealed sciences.

The gnostic tendencies of the authors appear in the Neo-Platonic and Neo-Pythagorean descriptions of cosmogony and cosmology embedded within these treatises. God created the universe through a series of emanations from himself. First to appear was Intellect, followed by its Archetypes and the World Soul. (Intellect, the Ikhwān tell us, instructs the World Soul through the Archetypes.) The World Soul, through further emanations, produces individual souls or faculties that individuate, or give form to, prime matter. The first of these individuating emanations were the nine celestial spheres (the invisible *primum mobile*, the sphere of the fixed stars, and the spheres of the seven naked-eye planets: Saturn, Jupiter, Mars, Sun, Venus, Mercury, and the Moon), followed by the four terrestrial elements (fire, air, water, and earth). This represents the farthest separation of soul from God. Drawn by an irresistible desire for union with the unity of God, it commences a return ascent heavenward through a process of purification from the contamination of matter achieved through personal morality and deepening esoteric knowledge of the one.

The treatises contain little scientific information that is new. The treatise on geometry (the second treatise of the collection) reports a few simple results from Euclid: the sum of the interior angles of the triangle is two right angles, an exterior angle is equal to the two opposite interior angles, etc. However, there is no discussion of the demonstrations that validate these facts. Rather, the Ikhwān are interested in facts only when related to other facts so as to provide insight into the deeper, esoteric, meanings of the knowledge. They discuss the relation between sensory and intellectual geometry. This is followed by a discussion of magic squares (numbers placed in geometric arrays) and their almost magical usefulness as talismans. Interspersed with these discussions are meditations on the usefulness of intellectual geometry (because, abstracted from the sensations, it exercises the soul for moving beyond phenomena toward the invisible one) and on the necessity for human cooperation and brotherhood in the effort.

Although the treatises provide little insight into the state of intellectual activity in the sciences, they give an intriguing summary of what the educated non-scientist knew about the results of scientific research as they existed in that time. They also offer a window into what might be called a sub-scientific culture, a culture aware of some of the results of science and mathematics, but adapting these results for non-scientific (in this case, largely social and religious) purposes.

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Ino Tadataka

Nakayama Shigeru

Ino Tadataka, 1745–1818, was a Japanese cartographer and an energetic field observer. A major astronomical and geodetic problem of the time in Japan was finding the length of a meridian by Japanese measure. Since Sino-Jesuit works had set zero longitude at Beijing, that of Japan had to be accurately measured so that, in predicting a solar eclipse, the Sino-Jesuit method could be employed for the Japanese longitude. After making over 2,000 measurements of latitude, Ino calculated the length of a meridian which agreed (within several tenths of a second of a degree) with the figure given in the Dutch translation of Lalande's *Astronomie* which had been imported into Japan.

He did not excel in devising new methods or new theories in either astronomy or geodesy. While he was active, knowledge of Western astronomy was available through Dutch translations and Sino-Jesuit works and after, through the works of Lalande. But Ino had no knowledge of Dutch or dynamics and little understanding of astronomical theories. When calculating the length of the meridian, he considered the earth as a perfect sphere rather than a spheroid. Moreover, when observing the position of fixed stars, he did not take into account the effects of refraction, parallax, or nutation.

In his surveying, Ino did not use modern triangulation but relied upon the old traverse method. His mapmaking approach resembled the Sanson–Flamsteed method (it is presumed that his method was developed independently), which is appropriate only for small areas. Ino none the less used the method for an area as large as all of Japan. Despite Ino's scientific failings, his map of Japan, based upon surveys covering the length and breadth of the land, has an important place in geographical history.

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Most of Ino's works, consisting mainly of maps, observations, records of his surveys, field notes, and diaries are preserved in the Ino Memorial Hall in Sahara City.

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Inoculation

Subhash Kak

The first reliable account of inoculation is found in the eighteenth-century reports by British doctors concerning the Indian treatment of smallpox. In the method, believed to have been discovered sometime before AD 1000 in India (Henderson and Moss 1999), one deliberately inoculated, either into the skin or by nasal insufflation, scabs, or pustular material from lesions of patients. This resulted in an infection that was usually less severe than an infection acquired naturally. From India, the practice spread to China, western Asia, and Africa and finally, in the early eighteenth century, to Europe and North America.

It appears that the idea of inoculation derived from both *agada-tantra*, one of the eight branches of traditional Āyurveda (Indian medicine) that deals with poisons and toxins in small dosages, and from the application of specific concoctions to punctures in the skin for treatment of certain skin diseases (*Suśruta Samhitā* in *Cikitsāsthāna* 9.10). The *Caraka Samhitā* speaks of how deadly poisons can be converted into excellent medicine and how two toxins can be antagonistic to each other. The Samhitas speak of organisms that circulate in the blood, mucus, and phlegm. In particular, the organisms in the blood that cause disease are said to be invisible.

The *Suśruta Samhitā*, Chap. 54 of *Uttaratantra* or *Kāyacikitsātantra* (General Medicine), suggests a treatment regimen that includes avoidance of fatty foods and sweets. In the *Nidānasthāna* (Diagnosis), Chap. 5, it is indicated that physical contact and sharing the same air can cause such diseases to spread. Later, in Chap. 13, there is mention of the eruptive boils of the disease *masūrikā*. It appears that originally it meant chicken pox, but by the twelfth century the term was also being used for smallpox, as in the case of the commentator Dalhana.

The best source concerning the Indian method of treatment of smallpox is a report by Dr. John Z. Holwell in 1767 for the College of Physicians in London. This report is an excellent source for understanding the mind of the Ayurvedic doctor of the eighteenth century.

Holwell says that inoculators

> are delegated for this service from the different Colleges of Bindoobund [Vrindavan], Eleabas [Allahabad], Banaras, &c. over all the distant provinces; dividing themselves into small parties, of three or four each, they plan their traveling circuits in such wise as to arrive at the places of their respective destination some weeks before the usual return of the disease (Holwell 1971: 150–151).

One would presume that they were Ayurvedic vaidyas or their assistants.

> They inoculate indifferently on any part, but if left to their choice, they prefer the outside of the arm, midway between the wrist and the elbow, for the males; and the same between the elbow and the shoulder for the females. Previous to the operation the Operator takes a piece of cloth in his hand, (which becomes his perquisite if the family is opulent) and with it gives a dry friction upon the part intended for inoculation, for the space of eight or ten minutes, then with a small instrument he wounds, by many slight touches, about the compass of a silver groat, just making the smallest appearance of blood, then opening a linen double rag (which he always keeps in a cloth round his waist) takes from thence a small pledget of cotton charged with the variolous [smallpox] matter, which he moistens with two or three drops of the Ganges water, and applies it on the wound, fixing it on with a slight bandage, and ordering it to remain on for six hours without being moved, then the bandage to be taken off, and the pledget to remain until it falls off itself… *The cotton which he preserves in a double callico rag, is saturated with matter from the inoculated pustules of the preceding year, for they never inoculate with fresh matter, nor with matter from the disease caught in the natural way, however distinct and mild the species*.

The patient was to abstain from fish, milk, and ghee before and after inoculation for a period of 1 month. Holwell claimed that when the inoculation regime was strictly followed, it is next to a miracle to hear that it "failed in one in a million." He added that since

> this practice of the East has been followed without variation, and with uniform success from the remotest known times, it is but justice to conclude, it must have been originally founded on the basis of rational principles and experiment.

This is how Holwell described the explanations offered to him by Ayurvedic vaidyas:

> The *immediate* (or instant) cause of the smallpox exists in the mortal part of every human or *animal* form; that the *mediate* (or second) *acting* cause, which stirs up the first, and throws it into a state of fermentation, is multitudes of *imperceptible animalculae* [microorganisms] floating in the atmosphere; that these are the cause of all epidemical diseases, but more particularly of the smallpox; that they return at particular seasons in greater or lesser numbers… That these animalculae touch and adhere to every thing, in greater or lesser proportions, according to the nature of the surfaces they encounter; that they pass and repass in and out of the bodies of all animals in the act of respiration, without injury to themselves… smallpox is more or less epidemical, more mild or malignant, in proportion as the air is charged with the animalculae, and the quantity of them received with the food (Holwell 1767: 155–156).

Holwell understood the idea behind inoculation in this manner:

> That when once this *peculiar* ferment, which produces the smallpox, is raised in the blood, the *immediate (instant) cause* of the disease is totally expelled in the eruptions, or by other channels; and hence it is, that the blood is not susceptible of a second fermentation of the same kind.

In other words, he believed that when the disease in its natural form or when introduced in its weak form by the inoculation had run its course, the patient was safe. The difference between these two forms was that in its natural course it is often fatal, whereas when introduced through inoculation, it was only an inconvenience.

It is significant that the spread of disease was taken to be caused by the imperceptible animalculae (microorganisms). This old insight of the *Āyurvedic Samhitās* was a forerunner to the germ theory of disease that arose in the nineteenth century.

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Iron Pillar at Delhi

R. Balasubramaniam

The Delhi iron pillar (Fig. 1) is testimony to the high level of skill achieved by the ancient Indian ironsmiths in the extraction and processing of iron. Hadfield (1912) undertook the first systematic scientific study of the Delhi iron pillar. Results of scientific studies conducted in 1961 were summarized in a special issue of the *NML Technical Journal* (vol. 5, 1963). A review of its corrosion resistance appeared in 1970 (Wranglen 1970). While Anantharaman (1997) has reviewed the known scientific facts about the Delhi iron pillar, Balasubramaniam (2002, 2005) has compiled several new insights into the historical, scientific, and technical aspects of the Delhi iron pillar.

The history of the pillar is revealed in the die-struck three-stanza six-line Sanskrit inscription at a level of about 7 feet from the stone platform (Balasubramaniam 2000a). King *Chandra*, mentioned in the inscription as the royal donor of this *standarc* for Vishnu, is probably identical with Chandragupta II Vikramaditya (AD 375–414), as was also suggested by the use of the name "*Chandra*" on that king's Archer-Type gold coins (Balasubramaniam 2000a). The original erection site of this pillar was Vishnupadagiri (literally "hill of the footprint of Vishnu") as mentioned in the inscription. Vishnupadagiri is most probably identified with Udayagiri in central India, in the close vicinity of Besnagar, Vidisha, and Sanchi (Balasubramaniam 2000a; Dass 2001). The astronomical significance of its erection site has been understood (Balasubramaniam and Dass 2004). The pillar was positioned so that the early morning shadow of the pillar fell in the direction of one of the important bas-reliefs at Udayagiri, i.e., the *Anantaśāyin* Vishnu panel in Cave 13, in the period around the summer solstice. The *chakra* image that originally crowned the iron pillar capital additionally served to highlight its astronomical significance (Balasubramaniam et al. 2004). The Delhi iron pillar was relocated to its current location in New Delhi in the courtyard of the Quwwat-ul-Islam mosque (near the Qutub Minar) around 1233 AD by Iltutmish (Dass 2001; Balasubramaniam 2002) (Fig. 2).

Iron Pillar at Delhi. Fig. 1 Delhi iron pillar located in the Quwwat-ul-Islam mosque in the Qutub Complex at New Delhi.

Engineering Design

The current burial level of the pillar was not the original burial level of the pillar when it was erected at Udayagiri. Hammer-marked cavities are still visible on the surface of the pillar in the rough region just below the smooth surface-finish region (Fig. 3). The rough portion of the pillar was originally buried in the ground and later left exposed outside when the iron pillar was relocated at Delhi around 1333 AD. Beglar, an assistant of Alexander Cunningham, constructed the stone platform around the base of the iron pillar in 1871.

A critical analysis of the dimensions of the main body of the pillar allows an appreciation of the pillar's symmetrical design (Balasubramaniam 1997a). The rough surface occupies one-fourth (60U) and the smooth surface three-fourths (180U) of the pillar main body length, excluding the decorative top (Fig. 4). The decorative bell capital (Balasubramaniam 1998a) is again a symmetrical object. A *chakra* (circular discus) image was originally located atop the capital (Balasubramaniam et al. 2004) and this would have been approximately 20U in length thereby making the total length of the

Iron Pillar at Delhi. Fig. 2 Well-preserved Sanskrit inscription on the iron pillar. This is the oldest inscription on the pillar.

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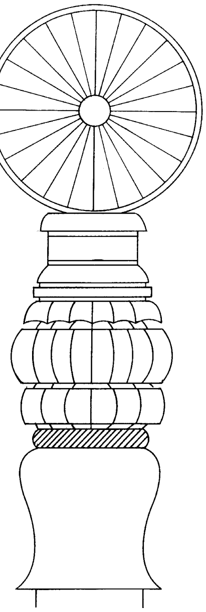
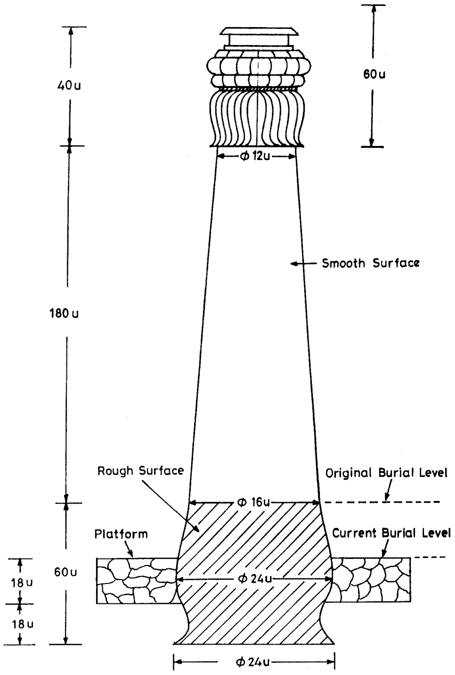
Iron Pillar at Delhi. Fig. 3 Hammer marked cavities are still visible on the surface of the pillar in the rough region. The rough region was originally buried under the ground when the pillar was located at Udayagiri.



Iron Pillar at Delhi. Fig. 5 The Delhi iron pillar decorative capital showing the discus image (*chakra*) that was originally located at the top of the capital.



Iron Pillar at Delhi. Fig. 4 Relative dimensions of the Delhi iron pillar. The unit U measures 1 modern inch.

decorative top 60U (Fig. 5). Therefore, the depth of burial below ground level was equal to the height of the decorative capital, indicative of the engineering design of the pillar. The unit U is equal to 1 modern inch.

Iron of Delhi Pillar

Several analyses of the Delhi pillar iron's composition are available (Table 1). The variation in the published compositions and the high phosphorus content of the Delhi pillar iron must be noted. Compositional analysis near the surface regions of a sample from the iron pillar revealed that the composition of copper (0.05%), nickel (0.05%), manganese (0.07%), and chromium (Nil) was uniform through several millimetres into the sample from the surface (Bardgett and Stanners 1963).

The presence of phosphorus is crucial to the atmospheric corrosion resistance of the Delhi iron pillar. The Delhi pillar iron contains a relatively large amount of phosphorus compared to modern-day iron (produced in the blast furnaces). The relatively higher phosphorus content in ancient Indian irons is related to the kind of slag that was created in the extraction process (solid-state reduction). Lime was not added in the ancient Indian furnaces. The absence of calcium oxide in the slags leads to a lower efficiency for removal of phosphorus from the metal, which invariably resulted in higher phosphorus contents in ancient Indian irons. Thermodynamic analysis of phosphorus removal from iron in the absence of calcium oxide in the slag also provides the same answer (Vikas Kumar and Balasubramaniam 2002).

Some aspects of the microstructure of the Delhi pillar iron are also known. All the available published microstructures have been described in Balasubramaniam (2003). It possesses a nonuniform grain structure and slag inclusions are irregularly distributed. Medium

Iron Pillar at Delhi. Table 1 Published composition analyses of Delhi pillar iron

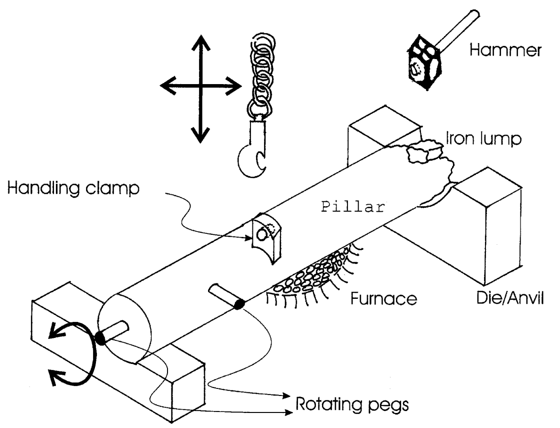
	Hadfield (1912)	Ghosh (1963) Above	Ghosh (1963) Under	Lahiri et al. (1963)	Lal (1996)
C – carbon	0.08	0.23	0.03	0.26	0.90
Si – silicone	0.046	0.026	0.004	0.056	0.048
S – sulfur	0.006	Trace	0.008	0.003	0.007
P – phosphorus	0.114	0.280	0.436–0.48	0.155	0.174
Mn – manganese	Nil	Nil	Nil	Nil	Nil
N – nitrogen	–	0.0065			
Fe – iron	99.720	Diff			99.67
Others	0.246				0.011
Specific gravity	7.81	7.672–7.747		7.5	

to coarse polyhedral grains of ferrite with slip bands were revealed in some grains near the surface. The surface regions were free from pearlite that seemed to increase toward the interior. The absence of a uniform distribution of pearlite is indicative of the segregation of phosphorus because, in such areas of phosphorus segregation, carbon diffuses out and the material becomes poorer in carbon content. The interior portions were comparatively rich in carbon. Therefore, the Delhi pillar iron exhibits a wide variation in structure and this is also a characteristic feature of ancient Indian iron.

The pillar is a solid body with moderate mechanical strength (yield strength of 23.5 tons per sq. in., ultimate tensile strength of 23.9 tons per sq. in. and 5% elongation (Ghosh 1963)). The similarity of yield strength and ultimate tensile strength are indicative of the composite structure of the pillar iron. In fact, a cannonball fired at the Delhi iron pillar in the eighteenth century (either by Nadir Shah in 1739 or Ghulam Quadir in 1787) failed to break the pillar.

Manufacturing Methodology

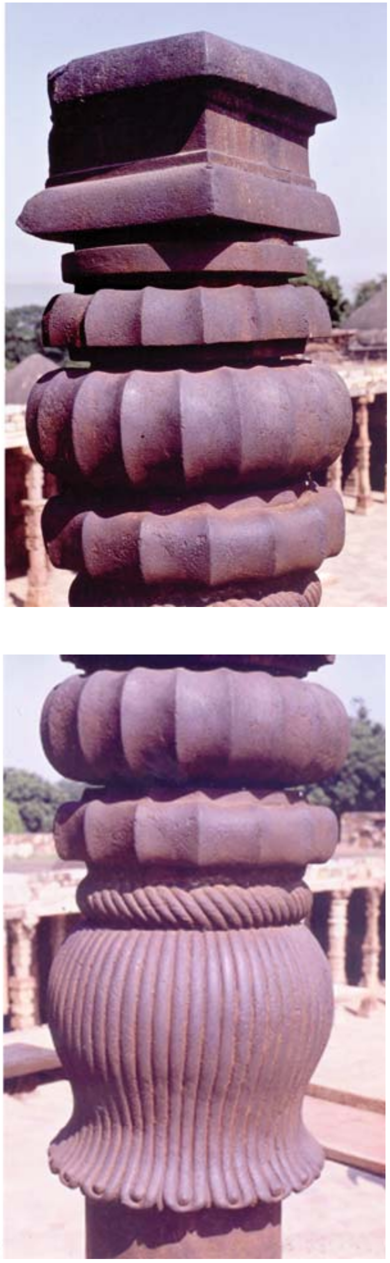
The pillar was manufactured using iron lumps and the method used to fuse the lumps together was forge welding. The individual iron lumps were extracted in bloomery furnaces. The likely manufacturing method has been deduced based on a critical analysis of various aspects concerning the manufacturing methodology like the hammering method, heating method, forging method, use of inserts, use of dies and ease of handling (Balasubramaniam 1999a). The heated iron lumps were placed on the side surface of the pillar and hammered on to the same by the use of hand-held hammers (Fig. 6). The addition of metal would have been sideways with the pillar in the horizontal direction. The pillar's vertical and horizontal movements would have been aided by handling clamps provided on the surface of the pillar, the protruding portion of which must have been chiseled away during the surface finishing operations.



Iron Pillar at Delhi. Fig. 6 Horizontal forge welding technique for manufacture of the main body of the pillar.

Visual proof for the presence of these clamps has been discussed in detail elsewhere (Balasubramaniam 1999a).

The decorative bell capital of the Delhi iron pillar has been described in great detail elsewhere (Balasubramaniam 1998a). The decorative bell capital consists of seven distinct parts, excluding the circular discus that was originally atop the capital (Fig. 7). There are several evidences at the joints between members to indicate that lead solders were utilized for joining the pieces together (Balasubramaniam 1998b, 1999b). The bottom-most part is the reeded bell structure, which has been manufactured by utilizing iron rods of uniform diameter. Atop this comes the slanted rod structure. The next three members are rounded structures, with the top one being only half rounded because when the pillar is viewed from the bottom, this part would appear curved when viewed in perspective from the bottom. A round disc comes above this and finally the box pedestal is placed on the top of the capital. The box capital contains holes that are empty at the four corners. The top of the pillar presently contains a hollow slot (Fig. 8), in which a



a

b

Iron Pillar at Delhi. Fig. 7 The (a) top and (b) bottom portions of the decorative bell capital.

chakra image was originally fit (Balasubramaniam et al. 2004). As regards the fitting methodology, the seven components of the capital were shrunk fit around a hollow cylinder, and this was joined to the main body of the pillar by means of a metallic insert (Balasubramaniam 1998a).

Corrosion Resistance

Several theories that have been proposed to explain the superior corrosion resistance of the pillar can be broadly classified into two categories: the environmental and material theories. These theories have been critically reviewed elsewhere (Wranglen 1970; Balasubramaniam 1997b, 2000b). The proponents of the environment theory state that the mild climate of Delhi is responsible for the corrosion resistance of the Delhi iron pillar, as the relative humidity at Delhi does not exceed 70% for significant periods of time in the year. It is known that atmospheric rusting of iron is not significant for humidity levels less than 70%. On the other hand, several investigators have stressed the importance of the material of construction as the primary cause for its corrosion resistance. The ideas proposed in this regard are the relatively pure composition of the iron used, the presence of phosphorus and absence of sulfur/manganese in the iron, its slag enveloped metal grain structure, passivity enhancement in the presence of slag particles and formation of phosphate film. Other theories to explain the corrosion resistance are also to be found in the literature. They include the mass metal effect, initial exposure to an alkaline and ammonical environment, residual stresses resulting from the surface finishing (hammering) operation, freedom from sulfur contamination both in the metal and in the air, presence of layers of cinder in the metal which do not allow corrosion to proceed beyond the layer (cinder theory) and surface coatings provided to the pillar after manufacture (treating the surface with steam and slag coating) and during use (coating with clarified butter).

Iron Pillar at Delhi. Fig. 8 The top surface of the pillar capital presently contains a hollow slot.

That the material of construction may be the important factor in determining the corrosion resistance of ancient Indian iron is attested by the presence of ancient massive iron objects located in areas where the relative humidity is high for significant periods in the year (for example, the iron beams in the Surya temple at Konarak in coastal Orissa (Graves 1912) and the iron pillar at Kodachadri Hills on the western coast (Anantharaman 1999)). Moreover, a freshly exposed cut surface of the pillar acquires the color of the rest of the pillar in a relatively short period of time (Balasubramaniam 2001), thereby implying that surface coatings were not intentionally applied.

Sanyal and Preston (1952) proposed that the large mass of the pillar implies a large heat capacity for the iron. In that case, the pillar would heat or cool faster than the surroundings. The role of the Delhi environment on the wetting and drying of the pillar has been mathematically modeled (Halder et al. 2004) and the benign role of the large mass of the pillar was noted.

Rust samples obtained from the region just below the decorative bell capital were characterized by X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, and Mössbauer spectroscopy (Balasubramaniam and Ramesh Kumar 2000). The XRD analysis proved the existence of crystalline iron hydrogen phosphate hydrate, FTIR and Mössbauer spectroscopy proved the presence of magnetite and several oxyhydroxides in the amorphous form.

The process of protective film formation during alternate wetting and drying cycles of the Delhi iron pillar has been outlined (Balasubramaniam 2000b) based on rust characterization results. Initially, the corrosion of the matrix is relatively fast due to the presence of second phase particles in the microstructure. The usual corrosion products that are observed in the case of mild steels exposed to atmosphere are generated: α-FeOOH (goethite), γ-FeOOH (lepidocrocite), $Fe_{3-x}O_4$ (magnetite) and X-ray amorphous matter. The initial enhanced corrosion of the matrix leads to the enrichment of phosphorus concentration at the metal-scale interface, which results in the formation of a compact layer of amorphous δ-FeOOH layer next to the metal-scale interface. The formation of this layer confers the initial corrosion resistance to the pillar iron. Conversion of amorphous δ-FeOOH to nanocrystalline goethite is possible on longer exposure times (Yamashita et al. 1994). The enrichment of phosphorus in rust continues with prolonged exposure as observed in P-containing weathering steels (Misawa et al. 1974). Enrichment of phosphorus follows the mesoscopic variation of phosphorus in the matrix (Dillmann et al. 2002). This enrichment should be responsible for the precipitation of the insoluble phosphate, identified by XRD. The formation of this phase at the metal-scale interface provides further corrosion resistance.

A kinetic model for the growth of rust on the Delhi iron pillar has been proposed (Balasubramaniam 2002), based on the known nature and structure of the rust on the Delhi iron pillar and other corrosion resistant ancient Indian irons. According to this model, the initial fast rate of corrosion is followed by a period where the corrosion rate is reduced drastically. Growth rates have been roughly estimated for these two regions based on available Delhi iron pillar rust thickness measurements (Balasubramaniam 2002).

The Delhi iron pillar is a marvel of ancient Indian metallurgical skills. I have explained the engineering design of the pillar followed by a description of the manufacturing methodology for the main body of the pillar. The characteristics of iron of the pillar and the possible reason for its high phosphorus content have been discussed. The theories of corrosion resistance of the pillar have been reviewed and the importance of the protective passive film mechanism has been highlighted. The nature of this protective passive film has been addressed based on a detailed characterization of its rust. The corrosion resistance of the Delhi iron pillar is due to both Delhi (with the environment providing alternate wetting and drying conditions) and iron (with its high phosphorus content conferring protection by the formation of a protective passive film).

I

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Irrigation in India and Sri Lanka

Claude Alvares

Assessments by historians of Asia's irrigation systems and irrigation-related civil engineering techniques have been based on the scantiest of historical or empirical data. Naturally, they have ranged from one extreme to the other. Of these, the one most easily recognized and debated was provided by Karl Wittfogel whose theories led to the idea of "hydraulic civilizations".

A diametrically opposite assessment has been provided by some Indian historians who have concluded that there was no significant irrigation technology in use at all. Symbolic of this view is R. Majumdar and H. C. Raychaudhuri's *An Advanced History of India*, in which the authors make a categorical statement on the "comparative absence of artificial irrigation" in eighteenth century India.

However both views – fairly representative of the historiographical terrain – have had to be revised considerably because of the emergence of new historical materials and investigations. These are reflected in new literature specifically devoted to the subject. Illustrative of these materials is the report of Alexander Walker, an English specialist who toured India in the eighteenth century. Walker produced an elaborate treatise on Indian agriculture in which he drew the conclusion that:

> the practice of watering and irrigation is not peculiar to the husbandry of India, but it has probably been carried there to a greater extent, and more laborious ingenuity displayed in it than in any other country.

This display of ingenuity, however, is not restricted to eighteenth century India and has indeed found expression in a plethora of irrigation systems in Asia each designed to appropriate its own specific ecosystem potential. There is evidence of large-scale irrigation works in several Asian countries including China and Sri Lanka. The systems studied on the subcontinent include gigantic artificial lakes, large-scale and small-scale embankments, and diversion channels. They include schemes for taking water up a hill against gravity, elaborate canal distribution networks, innovations like the *khazans* on the west coast of India, where unmanned wooden sluice gates control the sway of salt and sweet water in low-lying paddy fields adjoining the coastal or tidal rivers, and storage tanks with a bewildering variety of names.

"The irrigation history of Indian has been studied only in fragments" (Sengupta 1993). But even this admittedly fragmentary picture that is emerging is far more fascinating than the simplistic or impressionistic scenarios of Wittfogel or later historians like Raychaudhuri and Majumdar. The most fundamental aspect of irrigation technology and civil engineering works to be noted is that almost all of them are related to monsoon precipitation in one way or another. Over 90% of the annual runoff in the peninsular rivers and 80% in the Himalayan rivers occur during the 4 months of the monsoon. Thus, unlike the case of temperate ecosystems, irrigation becomes extremely crucial: in the wet season which stretches approximately 4 months, in several places less, there can be too much precipitation over intense bursts. This is followed by a dry season during which there is no precipitation at all. The result is predictable: periods of excess water followed by drought.

In this context, the basic design of irrigation technology is intimately related to precipitation: how to save it, store it, and divert it, so that spatially it reaches areas where there is no water (diversion techniques) or temporally makes it available during the dry months (storage techniques). Thus, rain-fed rivers are diverted into channels, or river basins are interconnected. Or the rainfall is directly collected in huge storage facilities on the land.

If this is the scenario (and it is as valid today as it was in 3000 BCE), one would normally expect a much richer history of irrigation techniques in Asian conditions – where rice is a basic crop adapted to growing largely in water – than in any other part of the planet, particularly the temperate zones. It would also follow that the irrigation designs evolved for coping with such situations would not readily be available in other ecosystems. For this reason, it has taken some time for engineers and historians trained in other culture areas to appreciate their worth and function.

The irrigation experience of China is documented in Joseph Needham's *magnum opus*, *Science and Civilisation in China*, and will not concern us here. We shall restrict ourselves in this essay to a consideration of the irrigation and civil engineering techniques that arose in the Indian subcontinent including Sri Lanka and which were the result of a close interaction and adaptation between overall environmental situations and human ingenuity.

Irrigation Technologies

In the circumstances related above, it stands to reason that the primary design objective of irrigation engineers would be predominantly in the direction of a water storage system. The following listing is given by Shankari and Shah.

There were storage systems designed purely for drinking water: *nadi*, tanks, *bowari*, *jhalara*, and *pokhar*. Some were reserved only for human beings; others were for human beings and animals. These we shall ignore here.

The second category of storage technologies relates to irrigation, and there is considerable evidence of the spread of such technologies through the length and breadth of the subcontinent. Though the structures here were all designed for irrigation, they also provided other useful functions of soil conservation and ground water percolation and recharge.

Irrigation water stored in such storages was conveyed through two methods: first, under the force of gravity, or gravity irrigation, and second, through extractive or lift techniques or devices of some kind, including for instance the Persian wheel.

There were three main classes of such irrigation-related storage systems. The first comprised tank and pond irrigation systems. These in turn were of two types: *above surface* storage works, where a reservoir was created above the ground through a fairly long embankment. The corresponding structures were called *Keri*, *Eri*, *Cheruvu*, *Kalvai*, and *Kunta* in South India and *Ahar* in Bihar (northern areas). The second category involved *below surface* storage works, which included dug ponds from which water was lifted by some means manual or mechanical: *pokhar*, *talab*, *jhil*, *beel*, and *sagar*.

The second class of irrigation systems comprised land inundation systems: the land was flooded and saturated before cultivation and then drained off prior to planting (another term used is flood irrigation). These were primarily above surface types or referred to (in India) as submergence tanks. Important variations of these are the *khadin* and the *johad* in Rajasthan and the *bundhies* of Madhya Pradesh.

The *bundhies* were built generally in a series and therefore captured every possible drop of rainwater that fell. If there were a surplus, a waste weir was provided. There was generally a sluice at the deepest part of the storage reservoir. A *stambh* or pillar would indicate the location of the sluice. Sluices could be of different types: pipe sluices or sluices made of masonry for the larger tanks. (Some sluices open, as in the *khazans*, with the pressure of the incoming tides and discharge water automatically when the tide has fallen; these are made from wood.) The crop which was grown in the *bundhies* after the water was drained did not require any irrigation until harvest.

The third class comprised in situ techniques through which storage facilities were created to retain precipitation and ground water infiltration. The difference between classes 2 and 3 was that in the former, cultivation followed drainage; in the latter it occurred simultaneously.

The sizes of these storage tanks varied and the tanks themselves were generally known from the command areas they irrigated: the smallest ones irrigated around 50 acres, the medium ones about 100, and the major ones 500 and above. The large tanks were clearly impressive in scale. The Veeranam Tank in Tamil Nadu has a bund (embankment) 16 km in length. The Gangaikonda Cholapuram tank, also in Tamil Nadu, was constructed by a Chola king from AD 1012 to 1044 and survives even today with a 25 km embankment.

The construction of tanks was a widely dispersed skill. To create a tank reservoir, an earthen embankment, usually curved, was erected in a concave form across the flow of water. The water was retained in the belly of the curve from where it was drawn and directed through channels to irrigate plots at lower levels through gravity irrigation. After the tank was emptied, the tank bed itself could be used temporarily for raising a crop utilizing residual moisture. Many of the tanks in an area were interlinked and functioned as parts of an integrated system. The tank at the higher level released its surplus water as runoff to tanks at a lower level and the next in turn. These were called *chain tanks*. There were also tanks which were fed by canals from a river. Chain tanks were generally created in the upper reaches of the river basin and river-fed tanks in the lower reaches. Their construction would have required detailed cooperation among several communities in the region.

In Mysore in 1866 Major R. H. Sankey, Chief Engineer, wrote:

> Of the 27,269 square miles covered by Mysore, nearly 60% has, by the patient industry of its inhabitants been brought under the tank system. Unless under exceptional circumstances, none of the drainage of these 16,287 square miles is allowed to escape. To such an extent the principle of storage has been followed, that it would now require some ingenuity to discover a site within this great area suitable for a new tank.

The profusion of such tanks was not a feature of Karnataka alone. Experience was similar in Tamil Nadu, Goa, or Bihar. The area north of the Vindhya mountain range in middle India for instance had more than 8,000 submergence tanks. In one district of Rajasthan alone, there were more than 500 *khadins*.

In Sri Lanka, dry areas were populated with what are known as "tank villages". "The one-mile to an inch topographical maps of the island," writes D. L. O. Mendis:

> show nearly 15,000 of these, of which over 8000 are in working condition today. Tradition has it that some 30,000 of these small tanks had been constructed down the ages and there is a reference in the chronicles to 20,000 in the ancient province alone in the 12th century.

Water Conveyance

Apart from the storage works, the subcontinent witnessed the emergence of competent and impressive water conveyance systems designed to divert waters of rivers and flowing streams. Some diversions were accomplished without a check or embankment across the river; in such instances, the flood waters of the river were drained through a natural diversion. The *Kuhls* or *Guls* in the Himalayan areas, the *dongs* of the Northeastern states, and the *pynes* of Bihar all reflect this feature.

The second category involved check dams as a basic feature: the river bed was first raised and the resulting raised water diverted into a channel as was the case with the *band-haras*. Some of these schemes were fairly small, like those in the hilly areas. Others could be extremely large-scale and it is the reports of the latter that probably gave Wittfogel material for his speculations. According to Major T. Greenway, these were works of "truly gigantic magnitude, vast embankments and drainage channels equal to ordinary English rivers in capacity."

Historical Development of Irrigation Techniques

The interesting question that is now being asked is whether one can talk in terms of an evolution of irrigation technologies and civil engineering techniques from the earliest times to the present? The question is important in view of the fact that many of these storage systems, diversion channels, and embankments are largely intact and still in use. There are still parts of the country where Persian wheels are operated. Tanks and storage vessels are once again being made functional and weirs continue to be constructed.

The answer seems obvious: while more complex technological mechanisms did emerge as time passed, the earlier and the later techniques have continued to coexist. The only major new innovation seems to be the idea of dams; these are new in terms of function, since the generation of hydropower was not intended in earlier times. The idea of large dams, once considered the temples of modern India, has taken a severe beating in recent years. They are now considered unsuited to tropical ecosystems, since the reservoirs invariably lead to displacement of large numbers of people, submergence of forests, and destruction of wildlife, and in places like Sri Lanka, submergence of smaller functioning reservoirs.

This being said, it is possible still to identify certain periods as distinct historical events in a possible history of irrigation and civil engineering on the subcontinent. There is archeological evidence of artificial irrigation from pre-Harappan and Harappan times (ca. 5500–3500 BCE): this took the form of a large number of wells. One well found had a brick lining going down 12 m. Post-Harappa, the major irrigation find is Inamgaon on the west coast of India where under the influence of the Jorwa culture (ca. 3400–3000 BCE), one finds evidence of a major diversion scheme reflected in a massive embankment 240 m by 2.2 m wide to divert the river into a channel. The channel itself was 200 m long and 4 m wide.

The first storage tanks in their rudimentary form appear around 2500 BCE – also in Sri Lanka – with the invention of iron tools. Hereafter, there are increasing references in literary works of both Sanskrit and Tamil up to the Gupta (AD 350) period. There are tank-related inscriptions which give details of tank construction, maintenance, sources of funds for maintenance, and so on. The word *eri* also comes into circulation by the seventh century as a term for tanks.

The *anicut* (weir) technique is probably older than the *eri* or tank. The most famous of the *anicuts*, the Kaveri Anicut on the river Kaveri, is linked to a Chola king of the second century AD. It involved a dam on the river Kaveri 300 m long and 12–18 m wide and 5 m deep. There is a dispute about the age of the *anicut*, since the *anicut* technique itself bears a strong resemblance to the Sri Lankan technique of massive stone dams and sluices, a technique which developed, according to Sri Lankan historian R. A. L. H. Gunawardene, only in the seventh century AD.

Sir Arthur Cotton paid eloquent testimony to the engineering talent involved in the large-scale irrigation works. He wrote:

> There are a multitude of old native works in various parts of India… These are noble works, and show both boldness and engineering talent. They have stood for hundreds of years… it was from them that we learnt how to secure a foundation in loose sand of unmeasured depth. In fact, what we learnt from them made the difference between financial success and failure, for the Madras river irrigations executed by our engineers have been from the first the greatest financial successes of any engineering works in the world, solely because we learnt from them… With this lesson about foundations, we built bridges, weirs, aqueducts, and every kind of hydraulic work… we are thus deeply indebted to the native engineers…

Social Arrangements/Religious Sanction

A significant feature of these irrigation works related to their construction and maintenance. Since water availability could be problematic with monsoon failure, those associated with the emergence of these works could gain religious merit for their deed. Though large systems were often sponsored by the state – to include kings, queens, local chieftains, *zamindars* (landowners) – village communities, temples, and even individuals are associated with their construction. Thus a public park in Pondicherry bears an inscription recording a tank built by a *dasi* – a temple dancer/courtesan – while another inscription in Karnataka (AD 1100) records a tank and shrine constructed by a village watchman.

All the major dynasties including the Mauryas (Sudarshan Lake near Kathiawar), the Cholas, the Hoysalas, and the Vijayanagar Kings and Muslim Sultans were associated with irrigation works. Of these, the most impressive schemes are associated with the Cholas. However, these kings depended upon a cadre of skilled hydraulic engineers. Dikshit records the performance of one such engineer in the fourteenth century:

> The Kalludi (Gauribidanur taluk) inscription of 1388 AD is well known. According to it, when Vira Harihara Raya's son Sri Pratapa Bukkaraya was in Penugonda city in order that all the subjects might be in happiness – water being the life of the living beings – Bukkaraya in open court gave an order to the master of ten sciences, the hydraulic engineer (Jalasutra) Singayya Bhatta that he must bring the Henne (Pennar) river to Penugonda. Accordingly Singayya Bhatta conducted a channel to the Siruvara tank and gave the channel the name Pratapa Bukka Raya Mandalanda Kaluve.

The day-to-day operation and maintenance of both large and small works were mostly in the hands of local communities and of special professionals like the *nirkattis* of Tamil Nadu. In many areas, production from certain lands was set aside specifically to meet the maintenance costs of tanks. During the installation of the colonial regime, these revenues were appropriated by the colonial power and consequently the maintenance of such irrigation works fell into bad times leading to declines in efficiency.

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Irrigation in the Islamic World

Lucie Bolens

From Andalusia to the Far East, from the Sudan to Afghanistan, irrigation in Islamic countries is the basis of all agriculture and the source of all life. After the Roman empire, the classical Islamic empires relied on the great cities like Damascus, Baghdad, Cairo, Cordoba, and Fez. In the countryside, all the small villages, made up of groups of rush huts or houses of stone, wood, or concrete were organized around a water source: a mountain fed by a living spring, a cistern of rain water, or wells bringing water up to the surface from deep beds. The Arabic word for water, *Mā*ʾ, is also the word for center. The water for religious ablutions at the center of the courtyard facing every mosque is the symbolic echo of a physical fact.

Islamic irrigation recovered pre-Islamic purviews while at the same time developing and expanding them. The historical record describes a vast network of canals from hot climatic zones to cold, rainy ones. The first were developed in the river valleys of semiarid and arid regions. The Nile, the Tigris and Euphrates, and the Guadalquivir have offered rural and urban communities from earliest times both water and silt, a means of providing refreshment and nourishment.

Where no great rivers existed, human societies dug wells and prospected deep lying aquifer beds, in the south of the Arabian peninsula, in Yemen, and in Hadramawt, as well as in the Sudan. There, where the effects of Indian monsoons are often felt, a tropical agriculture (coffee trees, date palms, banana, and tamarind trees) served as a point of departure for those tropical plant species to Mediterranean regions.

Lastly, on the borders of agricultural zones stretched vast steppes with winter rainfalls varying from 50 to 150 mm per year, seminomadic lands which had been used for thousands of years. Animal husbandry and intensive agriculture at oasis sites have for centuries contributed to the economic base of Yemenites and Maghreb tribes. This association between seminomadic grazing and intensive irrigated agriculture is a distinctive characteristic of Islamic irrigation, a system of a complementary nature between field, pasture, and natural resources in the environment.

For classical Islam, written documentation is inseparable from the latest results of rural archeology; all of the *Kitāb-al-Filāḥat* (Books of Agriculture) – Maghrebian, Andalusian, Egyptian, Iraqi, Persian, or Yemenite – insist meticulously on the deployment of equipment and on the control of water. What are examined are the means of water distribution, following the season and the species being cultivated. A Tribunal of Waters looks at legal cases, and that of the Islamic writer Valence has lasted from the time of the Christian *Reconquista* in 1248 until today. Irrigation was linked to a social time, following necessities of nature but also following the social rank of the users.

In the current state of research, one of the oldest calendars of irrigation was found in the *Filāḥat al-Nabaṭiyyah* (Nabataean Agriculture, by Ibn Waḥ shiyyah), which in the 1000s gave information on pre-Islamic Mesopotamia and Abbasidian Iraq. For western Islam, jurisprudence provided historians with precise details of daily life and ecological behavior, and explained the elements relating to the history of that environment, such as torrential rains in the autumn and the spring, the shifting of waterholes, and complaints from the owners of cultivated estates which had been deprived of water from one day to another. The *fiqh* Islamic juris, had to regulate any unexpected events from case to case. The joint purchase of land and water, inherent to the *fiqh*, confronted the fact of the capriciousness of nature: the agrarian weather of microclimates really was the final law. In Islamic law ownership of land is always linked to ownership of waters.

Lastly, financial writings integrate the agrarian dependence on water into the framework of the whole political and social evolution of Islamic history. Irrigation is the crucial element of agriculture in Islamic lands.

The rains follow two dominant climatological patterns: one Mediterranean, the other tropical and subtropical. The Mediterranean basin, along with southern Africa and California, has the only climate which has rain in the winter and maximum heat in the summer. The vegetation there needs a hot, humid season in its tillage phase. In other respects, the torrential spring and autumn rains create a major risk for the thin, mountainous soil which is predominant in the Mediterranean basin. A negative quality can thus indeed have positive effects.

This link between the climate and the soil in Andalusia entailed three inseparable factors: an extremely fragile ecology at risk of erosion, a highly organized and detailed system of irrigation which was adapted to regional conditions, and a stable political and administrative system (except in time of war).

In certain historical cases, like that of Andalusia, in spite of the fluctuating tides of conquest and reconquest, there existed a true ecological pattern which lasted for several centuries and which served as a real ecological laboratory for eastern and western Islamic statutes, based on a high level of natural science, climatology, and botany. The extensive spread of theoretical and technical knowledge made of the Andalusian model a precedent which could be applied to all societies, ethnic, and religious differences aside, which were trying to understand the environment in its historical dimension.

It was water which governed the classification of land types. The rich agronomical and administrative literature of Arabic Islam divided cultivatable land into rainy land and irrigated land. The former were those lands which received enough winter rain to permit the cultivation of olive trees, grape vines, and citrus trees, the Mediterranean trilogy. Irrigated plantings used water stored in deep beds; the surface of the land was hot and irrigated and was worked in squares irrigated by ditches or *acequias*. The device which allowed the flowing of water into the ditches across fields, squares, or gardens was a wheel of variable dimension called a *noria*. More simply, on river banks and along the shore a system of scales and counterweights called *shaduf* was used.

The plan of irrigated water brought about a kind of intensive horticulture comparable to that achieved in the great Asiatic deltas. In the development of the countryside irrigation allowed plant species which became the basis of the popular diet – e.g., rice and legumes rich in protein – to become acclimated to the Muslim west. In Andalusia, sugar cane, rice, and cotton were cultivated.

In plateau regions (Meseta, Morocco, Iran) where aquifer beds were deep, the most profitable procedure was the traditional system of *qanats*. The *qanats* were deep drainage tunnels which directed water to springs or artesian wells. Some were over 16 km long, and their deep tunnel was dug from the outlet up to the mother-well. The gradient incline of the aquifer bed can range from almost zero to very steep. Well sites were marked and were used for ventilation and disposition of debris from land clearing. The science of the *qanats*, traditionally, was based on empirical knowledge and was passed down by gesture or through oral tradition. The earliest descriptions are Iranian. Later they were developed on the Castilian Meseta (Madrid) and in Morocco (in Marrakesh). Today, one can see them in Central America; they are the oil-qanats.

In between the canals of flowing water and the system of *qanats* the Islamic world watered its gardens and fields, its city courtyards and domestic patios, and its mosques, with water from wells whose volume was increased through a process described by Ibn al-ʿAwwām in the *Kitāb al-Filāṭḥat* and in *Nabatean Agriculture.* Chapters relevant to finding the underground water level and sinking wells are followed by considerations on ways to increase the volume of water stored, ways to raise water from wells that are too deep, and ways to modify the taste of brackish or salty water.

The detailed observation of the earth or of its vegetation, in order to identify the presence of water, as well as the empirical nature of the investigation to sample the earth, in order to define various qualities of water, such as neutral, salty, or brackish and bitter, systematically mobilized the senses. Empiricism was able to bring about the creation of an irrigated, productive agriculture area. This success was built on the very controlled work of the *fellahs*, a political encouragement of individual appropriation, and on a high level of applied knowledge.

This multisecular, integrated system was the reason behind the development of numerous plant species crucial to the existence of civilization.

See also: ►Technology in the Islamic World, ►Agriculture in the Islamic World, ►*Qanat*, ►Dams in Arabia

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Irrigation in South America

Gray Graffam

Large-scale irrigation systems (canal irrigation) went hand-in-hand with the rise of cities and truly complex societies on the coast of Peru during pre-Hispanic times. Such systems delivered water to hundreds of hectares of potentially fertile land along a dry desert coast. Relatively late in prehistory, from 300 BCE onward, a number of well-known urban cultures (e.g., Moche, Lima) undertook the construction and expansion of irrigation works, which supported dense populations. This process culminated around AD 1000 in the construction of exceptionally large and sophisticated works by the Chimu, including an intervalley canal of impressive proportions from the Rio Chicama. These works made it possible for a population of some 25,000 to reside at the capital city of Chan Chan. Irrigation agriculture played a primary role in sustaining urban communities near the coast, where large irrigable plains of potentially fertile land were brought into production.

Similar irrigation systems in the Andean highlands are also of note. Some researchers, such as Michael Moseley, believe that irrigation agriculture developed here, as an extension of hunter–gatherer practices. Because of the steep slope, short canals would have been sufficient to water desired areas, and over the course of a millennium or more, a sophisticated irrigation technology developed. By AD 600, canal irrigation brought hundreds of hectares of otherwise unusable land into production in the Ayacucho valley of south-central Peru. These networks helped support a population of some 20,000 or more at the urban site of Huari, which is situated at an elevation of some 3,000 m, above any substantial acreage of arable land.

Other agricultural systems are also known for the Andes, and for elsewhere in South America. These include (a) sunken gardens on the desert coast, where plots of land were dug down to the water table and then planted, (b) terraces along the highland slopes, which served to retain moisture and enhance production, and (c) raised or drained fields along lake margins and in the Amazon basin, which served to reclaim inundated wetland. Aspects of irrigation technology theoretically come into play with each. Upland irrigation tends to create a higher water table downslope, which can make sunken fields possible in otherwise very dry areas. Slope irrigation can deliver a supply of water to terraced fields, and such systems are documented for the Inca. During the dry season, spring water can be run into the swales of raised field systems, which can allow for double cropping in some settings, e.g., Lake Titicaca. Irrigation plays a role in other agricultural systems of the Andes. All of these agricultural systems were geared toward intensive production, as a means for dense human adaptation to the Andean environment.

In general, the construction and maintenance of irrigation systems are portrayed in the archaeological literature as a powerful force leading to the rise of civilization and urban life. This theory is based upon the view expressed by Karl Wittfogel, and subsequently anthropologists such as Julian Steward, that water management plays a key role in crystallizing political authority; it is also referred to as the "Hydraulic Hypothesis." According to this theory, highland peoples came to control a scarce resource of high value – water – which led to a hierarchical system for its management and distribution. Such a scenario is thought to have led inevitably to the formation of stratified society and subsequently state bureaucracy. Political power is seen as a direct outgrowth of the struggle for water, from which centralized authority and state-level government emerge. Not everyone agrees, and some scholars, such as Robert Adams, have argued forcefully that irrigation is the consequence of political power, rather than its cause.

The Peruvian data do not support the "Hydraulic Hypothesis" of civilization's emergence. A strong maritime economy typified subsistence strategy along the coast during preceramic times, and large agglutinated settlements that housed hundreds of people were built along the coast between 2500 and 1800 BCE, e.g., Huaca Prieta, El Paraiso, Rio Seco, Playa Culebras, and others. There is an active debate on the role that crops, including maize, had in this developmental process, but it seems quite clear that irrigation agriculture played little part and certainly not to the scale of later times. According to Michael Moseley, the sociopolitical organization that accompanied these settlements was highly evolved, incorporating the management of labor mobilization (a form of taxation) on a regional basis. Irrigation agriculture took hold around 1800–900 BCE in the prehistoric sequence for Peruvian cultures. By this time, authority figures and labor taxation systems had already emerged. Irrigation technology did not bring them about, but vice versa.

Still, the matter of irrigation's impact on society is a topic of central concern. For the north coast of Peru, it has been argued that irrigation technology went hand-in-hand with hierarchical social organization during late pre-Hispanic times. According to Patricia Netherly, water was a valuable commodity, and groups benefited from a hierarchically organized social structure, capable of resolving conflict when it occurred. Michael Moseley adds the perspective that large-scale irrigation projects were designed and engineered by rulers in these settings. Together both views provide a clear understanding of how irrigation was carried out, on the one hand through kinship organization, and on the other through government intervention in labor-intensive projects. Irrigation may not have given rise to civilization and urban life in the Andes, but it clearly evolved within the power structure of subsequent developments.

Today, systems of native irrigation management are under study, as are the impacts of modern attempts to improve them (Mitchell 1991; Bolin 1990). It is noted that highland communities often attempt to maintain their rights to water use and management, although in Peru such rights no longer exist in the legal sense. All water belongs to the Peruvian state, and there are national laws and regulations that govern its use. Highlanders, especially those who regard themselves as

"Owners of the Water," fall into conflict with people in the lowland valleys. According to Bolin, there is a great need for agricultural and government agencies to investigate the indigenous patterns of water use, and the competition between and within villages for access to irrigation water. As revealed by Mitchell and Netherly, such patterns of water rights are likely to be deeply embedded within kinship organization and indigenous social structure.

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Isa Tarjaman

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During the Yuan dynasty (1271–1368) the Arabs played a role in Chinese science and technology similar to that of the Indians in the Tang, bringing in stimulating outside influences which were then incorporated and synthesized into Chinese mathematics, astronomy, and medicine. Isa Tarjaman (1227–1308) or Aixue in Chinese, was a remarkable example. Isa Tarjaman, sometimes called Isa the Interpreter or Isa the Mongol, was a Nestorian Arab from Syria. He was skilled as a mathematician and astronomer as well as in medicine and pharmacy. He came to China in about 1247, then worked for the Mongol Khans till his death in 1308. In 1263 Kublai Khan appointed Isa the director of the Muslim Astronomical Bureau and Medical and Pharmaceutical Bureau. During this time he suggested that Kublai prepare a new calendar in the Arabian style which he finished in 1267 in cooperation with a Persian astronomer Zhama Ludin or Jamāl al-Dīn, who was working in China too. This was called the *Wan-nian* (ten thousand years) calendar. Meanwhile, they made seven kinds of Arabian astronomical instruments for the Huihui (Muslim) Observatory. All of these exerted some influence on the Chinese astronomer Guo Shoujing (1231–1316) and his work.

From 1283 to 1286, Isa was sent to Il-khan as a member of a delegation. There he visited the famous Maraghā Observatory and worked together with some Arabian and even Chinese astronomers who were working there for a time. Then he brought some of these astronomical and mathematical works back to China. These were studied by staff members at the Muslim Astronomical Bureau in Beijing.

As the director of the Medical and Pharmaceutical Bureau, Isa Tarjaman established a Capital Hospital to introduce Arabian medicine to China; his wife Sara also worked there. An important Arabian medical work entitled *Huihui Yaofang* (Collection of Muslim Prescriptions) was compiled under his leadership. It is interesting that some of the contents of this work were taken from Ibn Sīnā's *Canon*. Therefore, Isa made a great contribution to the history of the Sino-Arabian scientific exchange, and he thus was praised by the Mongol Khans. After returning from Il-Khan he rose to be a Hanlin Academician, then the minister of State in 1297. After his death the Mongol court made him the Fuolin Prince. He was the only Arab to attain such a high official position in China.

See also: ►Guo Shoujing, ►Maraghā

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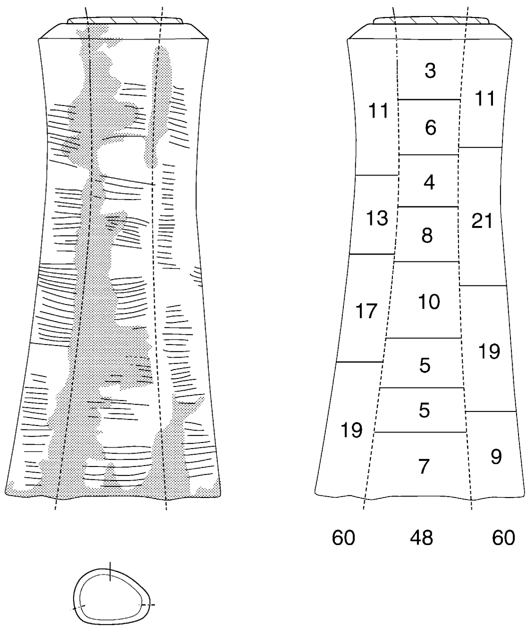
Ishango Bone

Anne Hauzeur

The engraved bone drew international attention as soon as it was described by J. de Heinzelin in 1957. Its uniqueness, as well as its geographical and chronological position, were astonishing.

Ishango is located on the top of a fossil terrace of the Semliki River, at the mouth of Lake Edward/Rutanzige,

Ishango Bone. Fig. 1 The engraved bone from Ishango, with a quartz at the tip (photo and ©RBINS).



Ishango Bone. Fig. 2 Uurolled sketch of the Ishango bone, and number in each group of notches (after de Heinzelin, 1957).

in the Democratic Republic of Congo. There were several prehistoric occupations from 20,000 till 5000 BC, when the volcano Katwe erupted. The different levels of human occupation are characterised either by a great amount of small-sized tools in a translucent white quartz, but most of all by numerous bone harpoons. Those latter evolved from a one-barbed sided to a two-barbed sided type. The settlement of Ishango would illustrate an old step of this harpoon production, whose pattern would have been widespread from the Great Lakes region towards Western Africa and the North in Sudan and Egypt. Rainfall was increasing during this time, so that the way of life was more devoted to fishing. This fishing tradition went on after sedentarisation and the introduction of animal breeding.

The engraved bone has several points of interest. It is the only piece among the whole artefacts assemblage to have a series of notches engraved in a very ordered rhythm (Fig. 1). As with the other tools, it was made on the settlement. A diaphysis [the mid-section of a long bone] from an unidentified animal was prepared and worked. At one end a little piece of white quartz was shafted to be used as a tool. Without any archaeological evidence the function is unknown; perhaps it was used to incise or engrave. The "shaft wears" groups of notches, displayed in three rows on its periphery. When adding all the groups of each row, the sum is 48 or 60, a multiple of 12 (Fig. 2). Each group of notches sums either prime numbers between 10 and 20, or numbers multiplied by 2, or 10 ± 1. It could illustrate a numerical converter system of base 10/base 12. In such a case, the Ishango bone could be considered as the oldest computing machine, used during the times of the hunter-gatherer nomads. It would be the oldest transcribed testimony of the mathematical intelligence of our ancestors, right in Central Africa, some 20,000 years ago. Originally, the antiquity of the piece was questioned, but new dating has proved its age.

Archaeological facts demonstrate the wide spread of the harpoon tradition, i.e., from Central Africa to the Nile basin. Traditional scholars teached that the first mathematics came from the Ptolemaic period and the Golden Age of Alexandria.

See also: ▶Mathematics in Africa

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Isḥāq Ibn Ḥunayn

Gregg De Young

Isḥāq ibn Ḥunayn (215–298 AH/AD 830–910) is best known for his role in the translation of Greek texts, both philosophical and mathematical, into Arabic. In addition to his work in the translation institute founded for his father, Ḥunayn ibn Isḥāq (193–263 AH/AD 809–877), he served as a physician to the court under caliphs al-Muʿatamid and al-Muʿatadid. Although Ḥunayn was a Nestorian Christian, some sources imply that Isḥāq converted to Islam.

As a translator, Isḥāq followed the scientific approach developed and applied by his father with such success to the Galenic corpus. Rather than translate mechanically word-by-word, he attempted to capture the meaning of each Greek thought unit in an appropriate form in the target language. (Both Isḥāq and his father are said to have preferred to translate first from Greek into their native Syriac, only later producing an Arabic version based on the Syriac. Assuming such reports to be true, the paucity of Syriac translations among extant manuscripts remains puzzling to historians.)

Isḥāq's greatest contributions lay in his translations of Greek philosophical texts, especially the works of Aristotle. He produced Syriac versions of a part of the *Prior Analytics* and all of the *Posterior Analytics* and the *Topics*. He also rendered the *Categories*, *On Interpretation*, *Physics*, *On Generation and Corruption*, *On the Soul*, parts of the *Metaphysics*, and the *Nichomachean Ethics* into Arabic. He may also have translated the *Rhetoric* and the *Poetics*. In addition to Aristotle's works, he translated Galen's *Number of the Syllogism* and part of his *On Demonstration*, as well as some logical and philosophical works by Alexander of Aphrodias, Porphyry, Themistius, and Proclus.

Isḥāq was also instrumental in translating several important Greek mathematical treatises into Arabic. These include Euclid's *Elements*, *Optics*, and *Data*, as well as the *Almagest* of Claudius Ptolemy, *On the Sphere and Cylinder* by Archimedes, the *Spherics* of Menelaus, and minor works by Autolycus and Hypsicles. It is reported that Isḥāq's translations of Euclid and Ptolemy were revised by the mathematician, Thābit ibn Qurra. Apparently, Thābit compared the Arabic version with additional Greek manuscripts which he had at his disposal and noted differences between the Arabic and Greek versions. Whether any other editing was involved, we do not yet know. All extant Arabic manuscript copies of Euclid seem to reflect some aspects of this editing process, although no manuscript contains the complete set of known comments attributed to Thābit. The relationship of Isḥāq's version of Euclid to the earlier transmission attributed to al-Ḥajjāj ibn Yūsuf ibn Maṭar is difficult to establish because the earlier version has disappeared. In the case of the *Almagest*, however, both Arabic versions appear to be extant, allowing some conjectures to be made concerning the translation principles applied by both men.

Isḥāq also produced a number of original works on medicine. Unfortunately, these seem not to have survived. His *Tārīkh al-Aṭṭibāʾ* (History of Physicians), an extended version of a Greek book of the same title by John Philoponus, does survive. Isḥāq has added the names of philosophers active during the lifetime of each physician mentioned. This work has been helpful to historians of both medicine and philosophy.

See also: ►Ḥunayn ibn Isḥāq, ►*Almagest*, ►Thābit ibn Qurra, al-Ḥajjāj

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I

Jābir Ibn Aflaḥ

Richard P. Lorch

Almost nothing is known of Jābir's life, but remarks by Maimonides (d. 1204), e.g., that he knew Jābir's son, place Jābir probably in the first half of the twelfth century, and the name "al-Ishbīlī" establishes a connection with Seville. Indeed, legend associates his name (wrongly) with the building of the Torre del Oro and of the tower now belonging to the cathedral in Seville. Jābirs' principal work was a commentary (or correction, *iṣlāḥ*) on Ptolemy's *Almagest*, the standard textbook on mathematical astronomy, which he had seen in two translations from the Greek. In this treatise he not only simplified the mathematics and separated theory from calculation (there are no tables in the book), but also indulged in violent criticisms of Ptolemy. The introduction to the commentary contains a list of Ptolemy's "errors", which are considered in detail in the body of the book. His best known astronomical claim of this kind was his assertion, against Ptolemy, that Venus and Mercury must lie above the Sun because of their lack of parallax.

Jābir's lasting contribution was his statement of the requisite theorems in trigonometry. The essence of his plane trigonometry is to be found in the *Almagest* itself, but his clear enunciations of his results for triangles obviated the need for construction lines that cluttered so many diagrams. Again, his theorems on spherical triangles, which replaced Ptolemy's theorems involving six quantities by proportions involving four, were clearly taken over from a group of scholars, such as Abū 'l-Wafāʾ and Abū Naṣr ibn ʿIrāq, who worked in Baghdad and elsewhere in the eastern provinces of Islam about AD 1000. Curiously, Jābir quotes no Arabic author in his work, not even Ibn Muʿādh, who had lived and worked in eleventh-century Seville.

The text of the *Iṣlāḥal-majisṭī*, at least in the trigonometrical part, was revised, perhaps by the author. Ibn Rushd (*ḍ*. 1198) and al-Biṭrūjī in Spain were both influenced by the work. It was also known in the East, for al-Shīrāzī (d. 1311), one of the Marāghā astronomers, made a compendium of it. There were two translations into Hebrew, by Moses ben Tibbon (1274) and by Jakob ben Makhir (revised by Samuel ben Yehuda of Marseilles, 1335), and Jābir appears to have had considerable influence in Hebrew astronomy. But the most lasting influence of the work was through the translation into Latin by Gerard of Cremona (d. 1187). For the Latins not only was "Geber" a vigorous critic of Ptolemaic astronomy, but his treatise established trigonometry in the West. This can be seen in an anonymous commentary, in an anonymous compilation of the plane trigonometry, *De tribus notis* (On Three Known [quantities]), and in the works of Simon Bredon, Richard of Wallingford (both fourteenth century), and others. Finally, "Geber" was the source of much of Regiomontanus' *De triangulis* (On Triangles), perhaps the source for the trigonometrical section of Copernicus' *De revolutionibus* (On the Revolutions [of the Heavenly Spheres]).

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Jābir Ibn Ḥayyān

S. Nomanul Haq

Abū Mūsā/Abū ʿAbd Allāh Jābir ibn Ḥayyān, for a long time the reigning alchemical authority both in Islam and the Latin West, is at the same time among the most important and most enigmatic figures of the history of Islamic science. Doubts already existed in the medieval Arabic tradition as to whether the large corpus of alchemical, philosophical, and religious texts attributed to Jābir were authentic. Scholars of modern times have shared these doubts, and some have gone as far as to conclude that Jābir may never have existed at all, and that contrary to the received view, the Jābirian corpus is not the work of a disciple of the sixth Shīʿī Imām Jaʿfar al-Ṣādiq (d. 765); rather, it was produced piecemeal by several generations of Ismāʿīlī authors, the oldest of whom lived no earlier than the second half of the ninth century.

This essentially is the widely accepted position of Paul Kraus who still remains the greatest Jābirian scholar of modern times. Some historians have disagreed with this position, and others have tended to revise it. At this juncture, then, very little about Jābir can be claimed with certainty. It might be safe to say on the basis of the most recent evidence that Jābir was a historical Muslim figure of the eighth century, that there was a small authentic core of Jābirian writings, and that out of this core developed the largely apocryphal and grand Jābirian corpus as we know it today.

Jābir is generally referred to as an alchemist. But if turning base metals into gold is the essential preoccupation of alchemy, then Jābir is hardly an alchemist, for transmutation of metals was only a minor part of his concerns. He was concerned, rather, with developing an all-embracing metaphysical and natural scientific system based upon immutable universal principles. It is this search for universal principles that led him to the study of language, music, and numbers. The Pythagoreans said that things are numbers; Jābir says that things are the names that designate them. An analysis of the name of a thing is for Jābir an analysis of the thing itself; this daring ontological claim of an equivalence between language and reality sounds more metaphysical than alchemical.

Jābir did write extensively about chemical processes and techniques, and in this field he made some highly original and historic contributions. For example we find in his treatises the theory that all metals are composed of sulfur and mercury existing in various proportions. It was this idea that led to the phlogiston theory of modern chemistry. Another Jābirian contribution is the introduction of sal ammoniac in the repertoire of chemistry. Two varieties of sal ammoniac were distinguished: natural (ammonium chloride) called *al-ḥajar*, and derived (ammonium carbonate) called *al-mustanbaṭ*. The latter was obtained by the dry distillation of hair and other animal substances. Again, the use of organic materials, both plant and animal, in addition to the inorganic, is a monumental Jābirian innovation.

Jābir's chemical processes are never carried out in a theoretical vacuum; we find in his writings both a developed theory of matter and a sophisticated cosmology. He believed that matter was ultimately composed of four "natures" – hot, cold, moist, and dry. But unlike the familiar Aristotelian qualities, Jābir's natures were not abstractions; rather, they were real, material, and independently existing entities; hot, cold, moist, and dry were the "first elements" out of which were born the "second elements": air, water, earth, and fire. The former were simple, the latter were compound; the former were primary, the latter were derived; the second elements could be resolved into natures, but natures were immutable. Jābirian natures were, then, the ultimate building blocks of the world.

A striking aspect of Jābir's cosmology is his parallel idea of the "first creation" and the "second creation." The former was an act of God, the latter an act of man. The difference between these two is that God acts in a timeless fashion, whereas man effects his creation in a temporal domain. Thus man can imitate God's work, but he requires time to accomplish it. From this emerges the Jābirian idea of artificial generation. Birds, for example, are found in nature, but these creatures can also be produced over a period of time in a laboratory; so can human babies. Through a manipulation of natures man can generate even such living beings as are not found to exist naturally – monsters, dwarfs, giants, freaks, and so on. Indeed, Jābir's idea of artificial generation sometimes strikes one as thoroughly modern.

If Jābir is the first alchemist of Islam, then he is the pioneer of all that is important and characteristic of Islamic alchemy: the sulfur–mercury theory, the introduction of sal ammoniac, the use of organic substances, the idea of artificial generation of life, the production (though not recognition) of mineral acids, and the conceptual distinction between heat and temperature. He was widely known in Medieval Europe, and at least three of his treatises were translated into Latin.

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Jagannātha Samrāṭ

K. V. Sarma

Paṇḍita Jagannātha (1652–1744), who bore the title "Samrāṭ", writer on astronomy and mathematics, and designer of astronomical instruments, was the religious preceptor and collaborator in astronomical pursuits of Jai Singh Sawai (1688–1744), the astronomer-prince of Jaipur in Rajasthan. Born into a Vedic family, the son of Gaṇeśa, Jagannātha was attached to the court of Jai Singh from an early age and assisted his patron in all his social, religious, and scientific activities.

At Jai Singh's behest, Jagannātha mastered Arabic and Persian, the two foreign languages prevalent in the Mughal court, which he utilized in the study of Islamic astronomy and put to beneficial use translating into Sanskrit texts in those languages for his patron. In this way, Jagannātha produced his *Rekhāgaṇita* and *Siddhāntasārakaustubha*, which are translations of Euclid's *Elements of Geometry* and Ptolemy's *Almagest*, respectively, from their Arabic versions by Naṣīr al-Dīn al-Ṭūsī. It is interesting that in the case of *Rekhāgaṇita*, Jagannātha himself coined more than a hundred Sanskrit equivalents of technical terms.

In his original work *Siddhānta-samrāṭ*, composed at the behest of Jai Singh, Jagannātha described the construction and application of a number of astronomical instruments. He also mentioned the reasons that his patron, who was obsessed with metallic instruments like the astrolabe for making celestial observations and reading out the results, later opted for huge outdoor observatories with stone and mortar. The reason was that Jai Singh found that the metallic instruments did not give minute readings, and were also susceptible to wear and tear, and to climatic conditions, which brick observatories were not. His *Yantraprakāra* is a more elaborate work on the subject of astronomical instruments, which includes descriptions of some more instruments, computations, a number of tables, and allied data.

Jagannāha's *Siddhānta-samrāṭ* and *Yantraprakāra* carry a number of recordings of celestial observations of different types, for periods short or long, which demonstrate how the instruments designed, and observatories constructed, as above, had been put to use for correcting parameters, preparing almanacs and the like. The part played by Jagannātha in these endeavors was considerable and significant.

See also: ►Jai Singh, ►*Almagest*, ►Naṣīr-al-Dīn Ṭūsī, ►*Elements*, ►Astronomical Instruments in India, ►Observatories in India

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Jai Singh

Virendra Nath Sharma

Jai Singh, or Jai Singh Sawai (Jaya Siṃha Savā'ī), the eighteenth century statesman–astronomer of India, was born on November 3, 1688 to the royal house of Amber, in the present state of Rajasthan, India. His ancestors were semiautonomous rulers of their princely state under the Mughals and occupied important posts at the Mughal court. Jai Singh lived his life during one of the most troubled, uncertain, and critical periods of Indian history, and he was involved directly or indirectly in just about every political or military conflict of his time. With his diplomacy and political maneuverings, he acquired a great deal of authority and influence throughout the Mughal empire. Making full use of his prestige and power, Jai Singh embarked upon a program of reviving astronomy in his country.

Jai Singh displayed an early inclination toward astronomy and mathematics and soon acquired mastery over these two subjects. He realized that the astronomical predictions based on the Hindu, Islamic, or European books (which were available to him) did not agree with actual observations. He reasoned that the disagreements between predictions and observations were primarily due to the outdated parameters found in the astronomical books, and would not be alleviated until new parameters based on careful observations were made available. Consequently, he decided to obtain new parameters.

With the blessings of the reigning emperor, Muḥammad Shāh, Jai Singh initiated a multifaceted program in astronomy. He designed instruments, built observatories, compiled an excellent library, assembled competent astronomers of different scientific backgrounds, and sent a fact-finding scientific mission to Europe. His scientific career lasted for more than 20 years. He died in 1743, at the age of 54.

Jai Singh started out first with traditional instruments of brass built according to the designs given in the texts of the Islamic school of astronomy. However, the metal instruments did not measure up to his expectations; he discovered with disappointment that the instruments gave inaccurate results once their axes wore down, displacing their centers. The instruments were also unsteady during observing because of their portable nature. He discarded these instruments, therefore, in favor of the instruments of masonry and stone of his own design and tried to achieve the desired precision from their large sizes and steadiness from relatively inflexible structures. His instruments range anywhere from 1 to 25 m in height.

Jai Singh built five observatories in cities of north India, at Delhi, Jaipur, Varanasi, Ujjain, and Mathura, and equipped them with instruments of his own design. His observatory in Delhi was completed in 1724 and the others within a decade. His observatories, all except that of Mathura, are still extant in good to fair states of preservation. His observatory at Jaipur has the largest number of instruments and is in the best preserved state. The observatories of Delhi and Jaipur are big tourist attractions these days and visited by hundreds of thousands of people each year.

An inventory of Jai Singh's major instruments of stone and masonry is presented in Table 1.

The Samrāṭ, Ṣaṣthāṃs'a, and Dakṣinottara Bhitti are Jai Singh's high precision instruments. With these instruments, he extended precision to the very limit of naked eye observing, i.e., 1′of arc.

Although the telescope had become common with European astronomers and had acquired refinements such as the micrometer and crosshair, there is no evidence that Jai Singh benefited from it. His instruments do not use a telescopic sight, and with all their ingenuity of concept and design are no more than what may be called "naked eye tools" somewhat in the tradition of the medieval astronomers such as Ulugh Beg of Samarkand. It is reasonable to believe that the invention of the telescopic sight, which had come into vogue with European astronomers only a few decades earlier, did not come to his attention early enough. It should be pointed out, however, that Jai Singh was familiar with the telescope and had observed with it. His personal library inventory lists a telescope bought for him at a cost of 100 rupees.

Jai Singh's early training as an astronomer had been under Hindu *pundits*, and they remained the mainstay of his program until the very end. At one time there were at least 22 astronomers working at the observatory of Jaipur alone. Jagannātha Samrāṭ, Kevalarāma, and Nayanasukhopādhyāya were his principal astronomers. These astronomers constructed instruments, collected data, translated books, and compiled original works in astronomy. The translated works included Ptolemy's *Almagest*, Euclid's *Elements*, and De La Hire's *Tabulae Astronomicae*.

Jai Singh was equally interested in the Islamic and the European traditions of astronomy. He collected astronomical works in Persian and Arabic, and patronized Muslim astronomers of the Persian–Arabic school. The Muslim astronomers included Muḥammad Ābid, Sheikh Asad Ullah, Sheikh Muḥammad Shafī, and Dayānat Khān. These astronomers procured astronomical books for the royal library, constructed instruments, helped with the translations, collected data at the observatories of Delhi and Jaipur, and traveled to distant lands at the command of their patron (Fig. 1).

By 1725, the involvement of the Muslim *nujūmīs* or astronomers in Jai Singh's astronomical program began to taper off and, in its place, the involvement of Europeans, primarily Jesuit priests, increased. The European astronomers included De Bois, Figuerado, Boudier, Gabelsberger, and Strobl. The Europeans played the role of conveyors of European knowledge to

Jai Singh. Table 1 Major instruments of masonry and stone of Jai Singh

1	Jaya Prakāśa (Hemispherical dial I)	2	Delhi, Jaipur
2	Samrāṭ yantra (Equinoctial sundial)	6	Delhi, Jaipur, Ujjain, Varanasi
3	Rāma yantra (Cylindrical dial)	2	Delhi, Jaipur
4	Rāśi valaya (Ecliptic dial)	12	Jaipur
5	Ṣaṣthāṃs'a yantra (60° instrument)	5	Delhi, Jaipur
6	Dakṣinottara Bhitti (Meridian dial)	6	Delhi, Jaipur, Ujjain, Varanasi, Mathura
7	Digaṃs'a yantra (Azimuth circles)	3	Jaipur, Ujjain, Varanasi
8	Nāḍīvalaya (Equinoctial dial)	5	Jaipur, Ujjain, Varanasi, Mathura
9	Kapāla A (Hemispherical dial II)	1	Jaipur
10	Kapāla B (Hemispherical dial III)	1	Jaipur

Jai Singh. Fig. 1 Sawai Jai Singh (1688–1743). Courtesy of the Sawai Man Singh II Museum, Jaipur (used with permission of the author).

the Raja. Accordingly, they led a delegation to Europe, procured texts and instruments, translated De La Hire's tables, and carried out mathematical computations. However, the knowledge these Europeans brought to Jai Singh and his astronomers had already become outdated in Europe, for it did not include the theories of Galileo, Kepler, or Newton; nor did it include observational techniques such as those employed by Flamsteed in England.

In 1727, Jai Singh dispatched a scientific delegation to Europe after learning that "the business of the observatory was being carried out there." The delegation, first of its kind from the East, was led by Figuerado, and it reached Portugal in January 1729. The delegation stayed on in Portugal for over a year. It did not travel to Paris or London, however, where the most advanced work in astronomy was being done. In 1730, the delegation returned to Jaipur, the capital of Jai Singh's state at the time, with some instruments, books on mathematics, and the tables of De La Hire. The delegation did not bring any books elaborating the heliocentric world view, such as proposed by Newton, Kepler, or Copernicus, since these publications were prohibited by the Catholic Church.

After collecting data for nearly a decade, Jai Singh succeeded in obtaining new astronomical parameters. With these parameters, he prepared a set of astronomical tables called a *Zīj*. The *Zīj*, completed sometime between 1731 and 1732, was dedicated to the reigning monarch, Muḥammad Shāh and is, therefore, called *Zīj-i Muḥammad Shāhī*. *Zīj-i Muḥammad Shāhī* is a 400-page long traditional work of astronomy similar to the *Zij-i Sulṭānī* of Ulugh Beg. *Zīj-i Muḥammad Shāhī* may be considered Jai Singh's most important contribution to the astronomy of India. The *Zīj* remained a valuable resource for traditional astronomers of the country for nearly 150 years.

For the sake of rejuvenating astronomy in his country, Jai Singh expended a great deal of energy as well as his personal fortune, but he failed to initiate the new age of astronomy in India. He himself remained unaware of the Copernican revolution that had swept the intellectual circles of Europe. Lack of good communication systems, and a complex interaction of intellectual stagnation, religious taboos, theological beliefs, national rivalries, and the simple human failings of his associates share the blame for it. Jai Singh's scientific accomplishments were medieval in retrospect, but his scientific outlook was quite modern.

See also: ►Jagannātha Samrāṭ, ►*Zīj*, ►Observatories in India, ►Astronomical instruments in India

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Jamu

Christine Tuschinsky

Jamu is the Indonesian and Malay term for indigenous pharmaceuticals made from fresh or dried medicinal herbs. These medicines are popular among the ethnic Malays in the whole Malayan Archipelago (Malaysia, Singapore, Brunei Darussalam, and Indonesia). It is assumed that *jamu* originates from the Javanese principal courts. On the other hand there are different local recipes and ways of preparation with an old tradition, which contribute to the idea of a common popular knowledge.

Jamu can be an infusion of herbs, a mixture of fresh, dried or dried and powdered medicinal plants, and even an extract of herbs. It can be made of a single plant, but mostly it is a composition of up to 40 different ones. Today *jamu* is sold in the form of powder, tablets, pills, tonics, and capsules for internal use; and in the form of ointments, oils, tonics, or compresses for external use. The powdered *jamu* are packed in individual portions, which are then sold in nearly every small shop across Indonesia. Today these *jamu* as well as pills and capsules are available in Malaysian and Singaporean supermarkets, too.

In the traditional way, *jamu* is produced at home. An experienced family member provides friends and relatives with the homemade version of the product. To supplement family income, female family members sell the surplus to neighbors or villagers. These "*jamu* women" are still a familiar sight in Indonesia, even in the big cities. As a kind of peddlar, the *jamu* woman wanders through villages or capital streets, offering the contents of her *jamu gendong* (*jamu* being carried on the back) to a regular clientele.

Indonesia was, and is, the trendsetter in the production, development, and marketing of *jamu*. At the beginning of the twentieth century her *jamu* production reached a turning point. Some innovative entrepreneurs began to produce homemade *jamu* for their sale, thereby founding a flourishing cottage industry. The profits which accrued in this fashion kicked off a process which led to the modern *jamu* industry, in which more than 350 factories are registered in Indonesia. Their product is exported to several countries, the largest consumers being Malaysia and Singapore. The industrialization of *jamu* manufacture had severe consequences. It altered the outer appearance of *jamu*, and demanded more and more modernizing and profitable sale strategies. It was necessary to change the image from an old fashioned herbal remedy to a proudly promoted "ancestral heritage," which fit better into the Western back-to-nature trend.

Jamu concentrates on aspects and interrelationships which Western medicine does not take as seriously. The *jamu* idea of medication is based on a broad conception of body, health, and sickness; the notion of care and therapy, for example, tend to be kept less separate. *Jamu* is more than a pharmaceutical in the Western sense; it is food supplement, prophylaxis, and specific remedy all at once. Keeping healthy also necessitates staying beautiful and attractive as long as possible. Cosmetics, general tonics, and, above all, aphrodisiacs are very popular, and have considerable stature in *jamu* medicine.

Culturally different world views and concepts of knowledge find their expression in all aspects of culture, including the "hardware" of medicine, the pharmaceuticals. If we characterize the Western world view roughly as individualistic, bound to linear thinking, the ideas of cause and effect and the explanation of isolated phenomena on a microlevel, the Malay world view can be seen as sociocentric, bound to the mutual dependency of microcosmos and macrocosmos, and to the maintenance of balance and harmony on all levels of existence.

Medicines reflect these different aspects. Western pharmaceuticals consist of molecular defined substances or mixtures of substances, which are considered to be active. Any function of inactive substances is denied. The number of ingredients tends to be kept low in order to avoid synergistic effects. In contrast *jamu* are preparations of dozens of entire plants, with all active, inactive, and unknown substances plus the fibrous material. *Jamu* is a whole cosmos of ingredients, in which each part is supposed to play its proper role. *Jamu* has to be taken regularly for some weeks or months, and helps, in a long run, to balance the state of health between the poles of hot and cold.

Jamu cannot be completely analyzed. Pharmacologists are able to screen only some of the active ingredients, not to mention those which are called *inactive*. Synergistic effects are a matter of course and are considered to be of special importance in the efficacy and safety of *jamu*. The discussion of synergism and risk reduction started in 1976, when the Indonesian scientist Sutrisno formulated his SEES (side effect eliminating/secondary effectiveness enhancing substance) theory which postulates fewer side effects and a well-balanced total efficacy of entire plant extracts. Western science considered the SEES theory not sufficiently proven. Much research has been carried out to prove that some of the active *jamu* ingredients have curative value. This is an attempt to translate a non-Western medical concept into a Western one, which soon reaches methodological limits.

These facts are not perceived as contradictions by the Malay – or, in a melting pot like Singapore also Indian and Chinese – clients. As a vivid element of Malay culture *jamu* is consumed in any form, in tiny villages and big capital cities, and plays a constant role in everyday health care.

See also: ►Medicine in the Malay Peninsula

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Jayadeva

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Ācārya Jayadeva is an early Indian mathematician, known only through a long aphoristic (*Sūtra*) quotation in 20 verses from an unknown work of his. In this passage, Jayadeva sets out, step by step, an ingenious method for solving the indeterminate equation of the form $Nx^2 \pm C = y^2$. This quotation was extracted by Udayadivākara, an astronomer of Kerala, in his commentary called *Sundarī* on the *Laghu-bhāskārīya* of Bhāskara I (b. 629). Udayadivākara flourished about AD 1073. This means that Jayadeva lived before that date.

The above extract was made in the context of an astronomical problem involving two simultaneous equations (1) $7y^2 + 1 = z^2$ and (2) $8x + 1 = y^2$. Here, Udayadivākara states that the value of y in the first equation can be found by an ingenious method called *varga-prakṛti* (lit. "square-nature") enunciated by Ācārya Jayadeva, and the value of x in the second equation by the method of inversion.

The extract from Jayadeva forms an account of *varga-prakṛti* as he conceives it and solves problems through it. First he defines the term: "When (in an equation of the type $Ax^2 \pm C = y^2$) the square of an optional number is multiplied by a given number and then the product is increased or decreased by another number, and the result is in the nature of a square, such an equation is called *varga-prakṛti*." He then goes on to explain the technical terms which would be used in the course of his exposition, such as *Kaniṣṭha-mūlam* (lesser root), *jyeṣṭha-mūlam* (greater root), *kṣepa* (interpolator), *bhāvanā* (visualization), and its two forms, *samāsa-bhāvanā*, and *viśesa-bhāvanā* or *tulya-bhāvanā* and *atultya-bhāvanā*, all of which form the step by step processes for the solution of the indeterminate equation envisaged. Working through these processes is called the *cakravāla* (cyclic method) through which any number of solutions can be found. The actual method of solving the equation is given in the last five verses, toward the close of which Jayadeva quips, "Thus have we identified a very ingenious method for solving the problem which is as difficult as it is for a flea to fly against the wind." Jayadeva is perhaps justified in making such a comparison, for his cyclic method was set out later by other authors like Bhāskara II (b. 1114) and Nārāyaṇa (1356). The historian of mathematics Hermann Hankel has remarked: "It is above all praise; it is certainly the finest thing which was achieved in the theory of numbers before Lagrange."

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Jia Xian

Ang Tian Se

Little is known of Jia Xian's life except that he served as a minor functionary during the reign of Emperor Renzong of Northern Song dynasty in the first half of the eleventh century. He learnt mathematics from Chu Yan, a famous astronomer and mathematician (fl. AD 1022–1054). Jia Xian was said to have written two books, *Huangdi Jiuzhang Suanjing Xicao* (Detailed Workings of the Nine Chapters on Mathematical Art), and *Suanfa Xuegu Ji* (A Collection of Ancient Mathematical Rules). While the latter was irretrievably lost, the former was largely found in Yang Hui's *Xiangjie Jiuzhang Suanfa* (A Detailed Analysis of the Mathematical Rules in the Nine Chapters) of AD 1261 preserved in Ms. form in chapter 16,344 of the *Yonglo Dadian* encyclopedia compiled by Xie Jin in 1407 during the Ming dynasty. In his preface, Yang Hui explicitly stated that his text was an attempt to expound and preserve the works of his predecessors, notably those of Jia Xian.

Jia Xian's main contribution to mathematics lies in his innovative method for the solution of numerical equations of higher degrees. The processes for square and cube root extractions began with *Jiuzhang Suanshu* (Nine Chapters on the Mathematical Art) at the beginning of the Christian era, and continued to appear in all later mathematical books without many improvements. It was Jia Xian who came out with a method called *Zengchang Kaifang* (Method of Multiplying and Adding for Root Extractions) which could be extended to the solution of numerical higher equations for approximate values of roots. This method is similar to that developed by Ruffini (1765–1822) and Horner (1786–1837) in 1802 and 1819, respectively.

Accompanying the method was an array of binomial coefficients up to the sixth power tabulated in the form of a triangle similar to that by Blaise Pascal (1623–1662) in 1665, now commonly known as the Pascal Triangle. This triangle of binomial coefficients was subsequently copied and expanded by Zhu Shijie in the thirteenth century. Thus, Jia Xian's mathematical knowledge to some extent laid the foundation for the rapid development of mathematics during the twelfth and thirteenth centuries.

See also: ▶Liu Hui and the *Jiuzhang Suanshu*—Gou-gu Theorem

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Jiuzhang Suanshu

Karine Chemla

The Nine Chapters on Mathematical Procedures (*Jiuzhang suanshu* 九章算術, hereafter abbreviated to *The Nine Chapters*) is the oldest Chinese book devoted to mathematics that has been handed down through a written tradition. Mainly composed of problems, answers to them, and algorithms solving them, the book was probably compiled in the first century after the Common Era. The earliest piece of evidence bearing witness to its existence is the mention of its title in the inscriptions borne by a standard measuring vessel enacted by the Chamberlain for the National Treasury (*Dasinong* 大司農) in 179.

The main reason why *The Nine Chapters* survived may well be that, soon after its completion, it became a "Canon" (*jing* 經). This is the term which the first commentator whose comments on it came down to us, Liu Hui 劉徽, uses for it. Consequently, several commentaries were composed on it, two of which were selected by the tradition to be handed down with the Canon: Liu Hui's commentary, completed in 263, and the commentary composed by a group under the supervision of Li Chunfeng 李淳風, and presented to the throne in 656. In fact, there is no surviving edition of *The Nine Chapters* that does not contain these commentaries. Liu Hui's and Li Chunfeng's commentaries mention the works of other scholars: Zhang Heng 張衡 (78–142), Zu Chongzhi 祖沖之 (429–500), and his son Zu Geng (or Zu Gengzhi), attesting to a tradition of research on the topics dealt with in *The Nine Chapters* that historical evidence confirms. The Song dynasty testified to a keen interest in *The Nine Chapters*. The Department of the Imperial Library printed it in 1084, the reprint of this edition by Bao Huanzhi 鮑澣之 in 1213 being today the earliest extant edition. Moreover, new commentaries were composed, such as: Jia Xian 賈憲's *Detailed Procedures of Huangdi's Canon of The Nine Chapters on Mathematics* (*Huangdi jiuzhang suanjing xicao* 黃帝九章算法細草), in the first half of the eleventh century, and Yang Hui 楊輝's *Detailed Explanations of The Nine Chapters on Mathematical Methods* (*Xiangjie jiuzhang suanfa* 詳解九章算法) in 1261.

During the Song dynasty, the status of *The Nine Chapters* as a "Canon" was regularly and forcefully emphasized. Hence, in one of his prefaces, Yang Hui, quoting the preface composed by Rong Qi when he had Jia Xian's commentary printed in 1148, states:

> When the government instituted the examinations in mathematics to select officials, they chose *The Nine Chapters* to be the most important of the mathematical Canons, since, indeed, it is like the six Canons of the Confucians, the (*Canon of*) *Difficulties* and the (*Grand*) *Simplicity* of the medical schools, the *Book of Master Sun* of military art!

The matching of the book with the Confucian Canons expresses the immense value bestowed on it, echoing with the fact that it was then believed to have been written by some mythical Emperor or some Sage of Antiquity. In any case, all the practitioners of mathematics of the Song–Yuan period whose writings came down to us, Qin Jiushao, Li Ye (or Li Zhi), Yang Hui, and Zhu Shijie, drew inspiration from it, taking this Canon as a key reference work. This testifies to the significance of the book for the mathematical traditions that developed in China from the beginning of the Common Era up until the golden age of the Song–Yuan period and beyond.

The nine chapters of the Canon embody a traditional organization of mathematical knowledge in ancient China in “nine parts of mathematics (*jiushu* 九數).” According to the *Rites of Zhou* (*Zhouli* 周禮), the education of the children of the high dignitaries included the teaching of six arts, the last of which consisted in “the nine parts of mathematics” or “the nine procedures.” Quoting on this point the Chamberlain for the National Treasury (*Dasinong* 大司農) Zheng Zhong 鄭眾 (?–83), the scholar and commentator Zheng Xuan 鄭玄 (127–200) interpreted these as branches of mathematics that, for the main part, gave their names, and hence corresponded, to the various sections of *The Nine Chapters*. Probably the process of “recovery” of the damaged Canon included the identification of what the *Rites of Zhou* meant by the “nine parts of mathematics” or the “nine procedures.” Let us review briefly how *The Nine Chapters* provides an interpretation of this organization of mathematics.

Chapter 1: “Rectangular field” (*fangtian* 方田)

This chapter describes algorithms to carry out the basic computations on fractions, on the basis of numerators and denominators. It also contains algorithms to compute the areas of the fundamental figures or “fields”: the rectangle, the triangle, the circle, the annulus, the spherical sector, etc.

Chapter 2: “Millet and husked grains” (*sumi* 粟米)

This chapter is devoted to the rule of three and some of its applications. There, the rule is mainly used for computing equivalence between grains, according to official rates enacted by the National Treasury and relating to the payment of taxes in kind.

Chapter 3: “Parts weighted according to degree” (*cuifen* 衰分)

The algorithm for dividing a given whole into unequal parts defined by given coefficients constitutes the main topic of this section. The main field of reference for the algorithm consists in sharing gratification between officials having different status in the bureaucracy.

Chapter 4: “Small length” (*shaoguang* 少廣)

The chapter gathers together various sorts of “division”: divisions with fractionary numbers and root extractions, which were conceived of as divisions: square root and cube root extraction, as well as “circular” and “spherical” root extraction. In it, irrational numbers of the type “square root of 2” are introduced.

Chapter 5: “Discussing works” (*shanggong* 商功)

Mainly devoted to the organization of civil works, this chapter describes algorithms to compute the volume of fundamental solids: the parallelepiped and the cylinder, the trapezoidal prism, the pyramid and the truncated pyramid with squared basis, the tetrahedron, the cone and the truncated cone, etc.

Chapter 6: “Paying taxes in a fair way according to transportation” (*junshu* 均輸)

The title of the chapter refers to the topic of the first problems, devoted to a fair distribution of taxes or corvée (labor exacted by a local authority for little or no pay or instead of taxes) among various administrative units. The various problems gathered usually require combining rules of three or unequal sharing.

Chapter 7: “Excess and deficit” (*ying buzu* 盈不足)

The chapter is devoted to the rules that in the Latin West were to be called of false double position.

Chapter 8: “Measures in square” (*fangcheng* 方程)

An algorithm for solving the systems of n linear equations with n unknowns is described and progressively extended throughout the chapter. It is equivalent to what is today called the “Gauss elimination method.” In order to carry out this algorithm in all cases or to use it with full generality, positive, negative, and zero coefficients are introduced.

Chapter 9: “Base and height” (*gougu* 句股)

These are the two technical terms for designating the sides of a right-angled triangle, the treatment of which is the topic of this section. An algorithm corresponding to the so-called “Pythagorean theorem” opens the chapter. The following problems lead to solving some of the fundamental problems linked to the right-angled theorem. In this chapter, one of the problems is solved by using a quadratic equation.

The Nine Chapters displays mathematical knowledge in the form of algorithms. The book attests to specific ways of carrying out research on algorithms and manifests some of the theoretical trends guiding this research. In particular, the algorithms contained in *The Nine Chapters* are general. This feature relates to the fact that generality was one of the main theoretical values prized by the practitioners of mathematics in ancient China. This key fact accounts for properties that algorithms contained in *The Nine Chapters* regularly exhibit. They make use of assignment of variables, conditionals, and iterations. Furthermore, with the help of these techniques, the algorithms of the Canon can cover distinct cases that a given problem may present. They can also integrate distinct procedures and hence allow solving various types of problems. All these features contribute to shaping algorithms that are as general as possible. Such is the Canon that, in mathematics like in any other field of inquiry, commentators set out to expound.

Two kinds of evidence shed light on the historical process that led to its composition. As a canon, *The Nine Chapters* is not ascribed to any "author." Liu Hui's preface to his commentary mentions two scholars who contributed to its "edition." According to him, the Canon took shape in high antiquity and was damaged by the process of transmission. Later on, Zhang Cang 張蒼 (ca. 250–152 BCE) and Geng Shouchang 耿壽昌 (fl. 50 BCE) successively strove to restore the book, as it had been composed in antiquity. This indicates that, early enough, the process that produced *The Nine Chapters* was understood to have extended over centuries, and probably Liu Hui thought he was carrying it out further. In addition, a mathematical book was recently unearthed from a tomb sealed around 186 BCE: the *Book of Mathematical Procedures* (*Suanshushu* 算數書). This piece of evidence is extremely important for two reasons. On the one hand, it provides us with the first known mathematical writing preceding the compilation of *The Nine Chapters*. On the other hand, it is a book that was not handed down by the written tradition, but arrives to us in exactly the shape it had at the beginning of the second century before the Common Era. It shares many algorithms with *The Nine Chapters*, which indicates that the Canon had much in common with documents of that type. Furthermore, by comparison, it appears that the Canon contains algorithms obtained from other algorithms attested to in the *Book of Mathematical Procedures* by abstraction. What is even more interesting is that, when Liu Hui comments on the abstract algorithms of the Canon, he interprets them concretely along the lines of algorithms found in the *Book of Mathematical Procedures*. This piece of evidence thus also casts light on the process of composition of the commentaries.

The earliest exegete whose commentary was handed down, Liu Hui, appears today as being the most important of them all. However, almost nothing is known concerning his biography, except that he composed a commentary on *The Nine Chapters* as well as a small treatise, originally conceived as restoring a missing part of the Canon and devoted to geometrical methods of surveying: the *Mathematical Canon of the Sea Island* (*Haidao suanjing* 海島算經).

The significance of Liu Hui's commentary for the history of mathematics cannot be underestimated.

First, in contrast to *The Nine Chapters*, which consists mainly of problems and algorithms solving them, the exegetes systematically established that the algorithms provided by the Canon were correct. This implies that, in contrast to Euclid's *Elements*, the proofs of which establish that theorems are true, the commentaries' goal is to prove the correctness of algorithms. Moreover, to do so, they seem to follow stable patterns of reasoning, which indicates that proofs were conducted according to procedures that were normalized. Liu Hui's commentary hence bears witness to the earliest known practice of mathematical proof in China. How should this branch of the history of mathematical proof be integrated in a world history of proof? As far as I know, this question has not yet been addressed.

Furthermore, Liu Hui's commentary provides evidence showing how he read *The Nine Chapters*. On the one hand, his testimony sheds light on actual mathematical practices in ancient China. On the other hand, it discloses his expectations with respect to, and his approach of, a book of the kind of a Canon. In both respects, the evidence he provides is essential for recovering the details of mathematical activity and intellectual pursuit in ancient China.

Last, but not least, Liu Hui quotes several philosophical texts, thereby pointing to a relationship between mathematics and philosophy in ancient China. In addition, he stresses, and comments on, theoretical aspects of the mathematics he is dealing with. He thereby gives essential clues regarding the theoretical dimensions of mathematical activity as it developed in China.

See also: ►Mathematics in China, ►Gougu Theorem, ►Qin Jiushao, ►Yang Hui, ►Zhu Shijie

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Kamalākara

K. V. Sarma

Kamalākara was one of the most erudite and forward-looking Indian astronomers who flourished in Varanasi during the seventeenth century. Belonging to Maharashtrian stock, and born in about 1610, Kamalākara came from a long unbroken line of astronomers, originally settled at the village of Godā on the northern banks of the river Godāvarī. Towards AD 1500, the family migrated to Varanasi and came to be regarded as reputed astronomers and astrologers. Kamalākara studied traditional Hindu astronomy under his elder brother Divākara, but extended the range of his studies to Islamic astronomy, particularly to the school of Ulugh Beg of Samarkand. He also studied Greek astronomy in Arabic and Persian translations, particularly with reference to the elements of physics from Aristotle, geometry from Euclid, and astronomy from Ptolemy. He wrote both original treatises and commentaries on his own works and those of others.

Kamalākara's most important work is the *Siddhānta-Tattvaviveka*, written in AD 1658. The work which is divided into 15 chapters and contains over 3,000 verses, faithfully follows the *Sūryasiddhānta* in the matter of parameters, general theories, and astronomical computation. However, in certain matters Kamalākara made original contributions and offered new ideas. Though he accepted the planetary parameters of *Sūryasiddhānta*, he agreed with Ptolemaic notions in the matter of the planetary system. He presented geometrical optics, and was perhaps the only traditional author to do so. He described the quadrant and its application. He proposed a new Prime Meridian, which is the longitude passing through an imaginary city called Khalādātta, and provided a table of latitudes and longitudes for 20 important cities, in and outside India, on this basis. Kamalākara was an ardent advocate of the precession of the equinoxes and argued that the pole star also does not remain fixed, on account of precession. Kamalākara wrote two other works related to the *Siddhānta-Tattvaviveka,* one a regular commentary on the work, called *Tattvavivekodāharaṇa*, and the other a supplement to that work, called *Śeṣāvasanā*, in which he supplied elucidations and new material for a proper understanding of his main work. He held the *Sūryasiddhānta* in great esteem and also wrote a commentary on that work.

Kamalākara was a critic of Bhāskara and his *Siddhāntaśiromaṇi*, and an arch-rival of Munīśvara, a close follower of Bhāskara. This rivalry erupted into bitter critiques on the astronomical front. Thus Ranganātha, younger brother of Kamalākara, wrote, at the insistence of the latter, a critique on Munīśvara's *Bhaṅgī* method (winding method) of true planets, entitled *Bhaṅgī-vibhaṅgī* (Defacement of the *Bhaṅgi*), to which Munīśvara replied with a *Khaṅḍana* (Counter). Munīśvara attacked the theory of precession advocated by Kamalākara, and Ranganātha refuted the criticisms of his brother in his *Loha-gola-khaṇḍana* (Counter to the Iron Sphere). That in turn was refuted by Munīśvara's cousin Gadādhara in his *Loha-gola-samarthana* (Justification of the Iron Sphere). These kinds of astronomical and intellectual battles were typical of the philosophical and religious disputes which were common in ancient India.

See also: ►Astronomy in India, ►Ulugh Beg, ►Astronomy in the Islamic World, ►*Sūryasiddhāntha*, ►Precession of the Equinoxes ►Bhāskara, ►Munīśvara

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Kerala School of Astronomy and Mathematics

M. S. Sriram

After Bhāskara II (b. AD 1114), the most significant contributions to mathematics and astronomy in India came from Kerala, in the southwestern part of India. Kerala has had a continuous tradition of astronomy and mathematics from much earlier times. Sarma has listed nearly 750 independent works on astronomy, astrology and mathematics including minor works by 110 authors in the Kerala tradition.

Vararuci (date unconfirmed), who is credited with the authorship of 248 *Candravākyas* (sentences for computation of the moon's longitude) by the manuscript tradition, is considered to be the father figure in the astronomical tradition of Kerala. *Āryabhaṭīya* (ca. AD 499) of Āryabhaṭa which set the tone for all further work on mathematical astronomy in India, appears to have become popular in Kerala soon after its composition. In fact, out of the 20 or so available commentaries on *Āryabhaṭīya*, as many as 12 are from Kerala. The astronomical parameters in *Āryabhaṭīya* were revised by a group of astronomers who had gathered in the religio-educational centre of Tirunavay in northern Kerala in AD 683–684. Haridatta in his *Grahacāranibandhana* enunciated the revised system called *Parahita-gaṇita*. Many later works refer to the *Parahita* system.

Laghubhāskarīya and *Mahābhāskarīya* of Bhāskara I, which expounded the Āryabhaṭan school in detail, were also popular in Kerala. Govindasvāmin (AD 800–850) wrote an elaborate commentary on *Mahābhāskarīya* and his student Śaṅkaranārāyaṇa (AD 825–900) wrote one on *Laghubhāskarīya.* Udayadivākara (eleventh century), who wrote a detailed commentary titled *Sundarī* on *Laghubhāskarīya,* also probably hailed from Kerala. This work contains a method for solving quadratic indeterminate equations or *Varga – prakṛti* and ascribes it to Jayadeva. It is in fact the same as the famous *Cakravāla* algorithm, expounded in detail later by Bhāskara II in his *Bījagaṇita.* Suryadeva Yajvan (AD 1191–1250) wrote detailed commentaries on both *Āryabhaṭīya* and *Laghumānasa* of Manjulācarya.

The Kerala tradition entered a new phase with Mādhava of Saṅgamagrāma (AD 1340–1425). His *Venvāroha* and *Sphuṭacandrāpti* both contain an efficient computational procedure to calculate the true longitude of the Moon every 36 min. Those books and *Agaṇitagrahacāra* are conceptually not major works. However all the later astronomer–mathematicians from Kerala attribute the path-breaking results in the infinite series for the inverse-tangent, sine and cosine functions and many innovations in astronomical calculations to him. He is also hailed as *Golavid* (master of Spherics). Parameśvara of Vatasseri (AD 1360–1455), a student of Mādhava, was a prolific writer, authoring about 30 works. Emphasising the need for revising the planetary parameters through observations, he thoroughly revised the *Parahita* system and introduced the *Dṛggaṇita* system. Apart from *Dṛggaṇita,* the other important works of Parameśvara are *Goladīpikā* in three parts, *Bhaṭadīpika*, a commentary on *Āryabhaṭīya*, *Mahābhāskarīyabhasya* and *Siddhānta-dīpikā*, a super-commentary on Govindaswamin's *Mahābhāskarīyabhāṣya*, and *Grahaṇamaṇdana* on eclipses. He was one of the astronomers to discuss in detail the geometrical model of planetary motion implied in the conventional calculational procedures in Indian astronomy in his *Siddhāntadīpikā* and *Goladīpikā.*

No full-fledged work of Dāmodara, son and disciple of Parameśvara is known, but he is quoted at several places by his famous pupil, Nīlakaṇṭha Somayāji or Somasutvan (AD 1445–1545) of Tṛkkaṇṭiyur. Nīlakaṇṭha's *Tantrasaṅgraha* ranks along with *Āryabhaṭīya* of Āryabhaṭa and *Siddhāntaśiromaṇi* of Bhākaracārya as one of the major works which significantly influenced all further work on astronomy in India. In *Tantrasaṅgraha,* Nīlakaṇṭha introduced a major revision of the traditional Indian planetary model. There are also important innovations in mathematical techniques especially related to the series expansion of the trigonometric functions and systematic and exact treatment of spherical astronomy problems.

In addition to *Tantrasaṅgraha*, Nīlakaṇṭha composed many other works. *Āryabhaṭīyabhāṣya,* composed late in his life, is perhaps the most elaborate commentary on *Āryabhaṭīya.* He himself calls it a *Mahābhāṣya* (from *mahā*, great and *bhāṣya*, commentary), which is amply justified considering the wealth of information in it. Apart from the detailed explanation of mathematical results and procedures, it discuses the geometrical model of planetary motion, eclipses, and even some "physical" concepts like the planets' being illuminated by the Sun. Some of his other major works are *Golasāra* on spherical astronomy, *Siddhānta-darpaṇa,* in which he presents the planetary parameters as verified through his own observations, *Candracchāyā-gaṇita* on 'shadow' problems, and *Grahaṇanirṇaya* on lunar and solar eclipses. *Jyotīrmīmāmsā* of Nīlakaṇṭha has a unique place in the history of Indian astronomy, as it is the only work which focuses on epistemological issues concerning the science of astronomy and mathematics. It falsifies the claim of many scholars that Indian astronomy, in contrast to the Greek tradition, did not have a scientific methodology worth the name. It strongly emphasises the role of observations and experimentation in revising astronomical parameters. Sundararāja, a contemporary of Nīlakaṇṭha hailing from Tamilnadu, sought clarifications on many topics in astronomy from Nīlakaṇṭha, the answers to which formed the work *Sundararāja-praśnottara,* as stated by Sundarāja himself in his *Vākyakaraṇa*. Clearly, it is a work different in nature from texts and commentaries. The manuscripts pertaining to this work have yet to be traced.

Jyeśṭhadeva (ca. AD 1500–1610) of the *Parakroda* or *Paroṇṇoṭṭu* family, was also initially a pupil of Dāmodara and received instructions from Nīlakaṇṭha Somayāji later. In his *Gaṇita-Yuktibhāṣā* (Rationale of Mathematics and Astronomy), popularly known as *Yuktibhāṣā* composed around AD 1530, we see an elaborate and systematic exposition of the rationale of mathematics in Part I and of astronomy in Part II. Though it claims to explain the contents of *Tantrasaṅgraha* and provide the rationale for the calculational procedures in it, it is really an independent work (especially part I). It is a unique work in Indian astronomy/mathematics for two reasons (1) it is exclusively devoted to proofs and demonstrations, including the infinite series for π and trigonometric functions, and explanations for all astronomical calculational procedures current at that time and (2) it is written in Malayalam, the local language of Kerala. Perhaps this is one of the reasons for the title of the book, *Yuktibhāṣā* (the language which is spoken is called *Bhāṣā*). A Sanskrit version of the text is also available, but it is clearly a rough translation into Sanskrit of the Malayalam original. Śaṅkara Vārier of Trikkutaveli (AD 1500–1560) was a disciple of Nīlakaṇṭha Somayāji, and as he himself stated, was also deeply influenced by Jyeśṭhadeva. He is the author of two commentaries on *Tantrasaṅgraha*, namely *Laghuvivritti* (in prose), and a far more elaborate *Yuktidīpikā* (in verse). He is also the author of a major portion of the commentary on *Līlāvatī* called *Kriyākramakarī* which was completed by Mahisamangalam Nārāyaṇa. *Yuktidīpikā* and *Kriyākramakarī* are also devoted to proofs and demonstrations, and there are similarities between the treatment of various topics in them and in *Yuktibhāṣā*.

Citrabhānu (AD 1475–1550), the author of *Karaṇāmrta* was also a disciple of Nīlakaṇṭha, whereas Acyuta Piśaraṭi (AD 1550–1621) of Trkkaṇṭiyūr was a student of Jyeśṭhadeva. It was Acyuta who discussed the "Reduction to ecliptic" in detail in his *Sphutanirṇayatantra* and *Rāśigolasphutāniti.* Putumana Somayāji's (AD 1660–1740) *Karaṇapaddhati* provides rationale for astronomical algorithms. *Sadratnamālā* of Prince Śaṅkara Varman (AD 1800–1838) is a compendium of the Kerala school of mathematics and astronomy. The tradition continued up to modern times with works incorporating some of the results of modern positional astronomy.

Apart from these major works, there are several short texts which interpret and discuss specific formulae and procedures associated with specific topics. These texts have the words *Yukti* or *nyāya* (rationale) attached to their titles. Examples are *Grahaṇa-nyāya-dīpikā* on the computation of eclipses by Parameśvara and *Gaṇita-yuktayaḥ* by an anonymous author. There are also a large number of works devoted to astrology. Many of them are in the Kerala tradition but by non-Keralite authors.

There is great emphasis on observation in the Kerala school. In his *Siddhāntadīpikā,* Parameśvara refers to the numerous eclipses observed by him over a long period. In his *Āryabhaṭīyabhāṣya,* Nîlakaṇṭha observes that Parameśvara revised the planetary parameters in his *Dṛggaṇita* after observing eclipses and planetary occultations for 55 years. In his *Jyotirmīmāmsā* he argues:

> One has to realise that the five *siddhāntas* had been correct at a particular time. Therefore, one should search for a *siddhānta* that does not show discord with actual observations (at the present time). Such accordance with observation has to be ascertained by (astronomical) observers during times of eclipses etc. When *siddhāntas* show discord, that is, when an earlier *siddhānta* is in discord, observations should be made of revolutions etc. (which would give results in accord with actual observations) and a new *siddhānta* enunciated.

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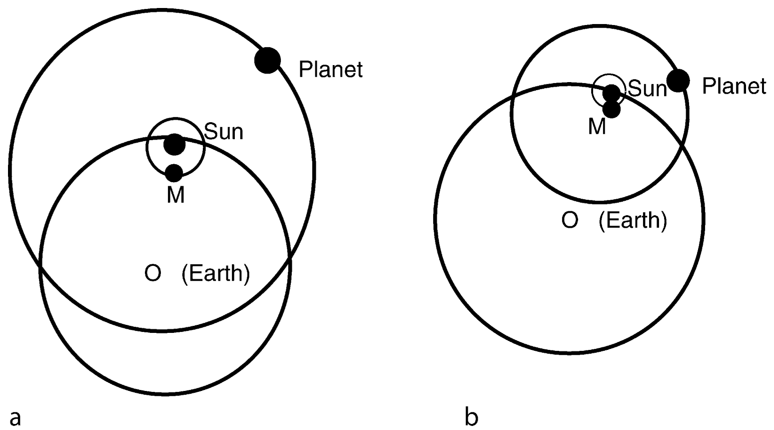
Major Contributions

Astronomy

In his *Tantrasaṅgraha*, Nīlakaṇṭha introduced a major revision of the traditional Indian planetary model. He arrived at a unified theory of planetary latitudes and a better formulation of the equation of centre for interior planets (Mercury and Venus) than was available, either in the earlier Indian works, or in the Islamic or European traditions of astronomy until the work of Kepler. In his other works *Golasāra, Siddhāntadarpaṇa* and *Āryabhaṭīya bhāṣya*, Nīlakaṇṭha outlined the geometrical picture of planetary motion that follows from his model. According to this picture, the five planets Mercury, Venus, Mars, Jupiter and Saturn move in eccentric orbits inclined to the ecliptic around the mean Sun, which in turn goes around the earth. This is similar to the model of Tycho Brahe (AD 1583). Nīlakaṇṭha's



Kerala School of Astronomy and Mathematics. Fig. 1 Nīlakaṇṭha's geometrical model of planetary motion for (a) an exterior planet, and (b) an interior planet. In each case, *M*, which is in the direction of the aphelion (the point in the orbit of a planet, comet or other celestial body that is farthest from the Sun), is the centre of the eccentric orbit.

"heliocentric" planetary model is depicted in the accompanying figure (Fig. 1).

The discussion on physical distances of planets in the last chapter of *Tantrasaṅgraha* indicates that Nīlakaṇṭha meant it to be a physical model. Parameśvara anticipated many of the ideas of Nīlakaṇṭha regarding the geometrical picture of planetary motion in some of his works. The model is discussed in detail in *Yuktibhāṣā* also.

In *Tantrasaṅgraha,* we have a discussion of the instantaneous velocities of planets, including the correct expression for the derivative of the inverse – sine function. There is a systematic treatment of spherical astronomy problems with exact spherical trigonometry formulae and with applications to the determination of time from the shadow, *Lagna* (orient ecliptic point), eclipses, exact angular separation between the centres of the solar and lunar disks, and elevation of lunar cusps. There is emphasis on methods rather than mere computational algorithms, in contrast with the other *Tantra* texts in Indian astronomy. All the spherical astronomy results are proved in detail in *Yuktibhāṣā*.

The Moon moves in an orbit inclined to the ecliptic, and as noted earlier, Acyuta Piśaraṭi provided the expression for the correction to the orbital longitude of the Moon to reduce it to the ecliptic. Interestingly, Tycho Brahe (AD 1546–1601) who discussed the "reduction to the ecliptic" for the first time in the European tradition, was a contemporary of Acyuta.

Mathematics

The crowning achievements of the Kerala school in mathematics are the infinite series expansion of the inverse-tangent function (*Yuktibhāṣā, Yuktidīpikā* and *Kniyākramakarī*), and the sine and cosine functions (*Yuktibhāṣā, Yuktidīpikā*). In modern terminology:

$$\mathrm{Tan}^{-1}\, x = x - \frac{x^3}{3} + \frac{x^5}{5} - + \cdots,$$

$$\mathrm{Sin}\,\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - + \cdots,$$

$$\mathrm{Cos}\,\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - + \cdots.$$

As noted earlier, these are all ascribed to Mādhava. Geometrical proofs for the above are to be found in *Yuktibhāṣā*. When $x = 1$, the inverse tangent series reduces to

$$\frac{C}{4D} = \frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \cdots,$$

where C and D are the circumference and diameter of a circle.

Earlier, Nīlakaṇṭha had noted the irrational character of π in his *Āryabhaṭīya bhāṣya.*

The above series for π is slowly convergent. A systematic procedure to calculate π with a finite number of terms and a suitable "remainder" or "correction" term is discussed in *Yuktibhāṣā* with the final result:

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \cdots + (-1)^{n-1}\frac{1}{2n-1} + (-1)^n \frac{n^2+1}{(4n^3+5n)}.$$

When $n = 50$, this leads to a value of π correct to 11 decimal places. In *Sadratnamālā* (AD 1823) of Śaṅkara Varma, the value of π is given as 3.14159265358979324, which is correct to 17 decimal places. This value was probably obtained using the same procedure, with the correction term evaluated to a higher degree of accuracy.

It is possible to obtain a fast convergent series for π by incorporating the correction terms from the beginning itself. Two of the fast convergent series for π mentioned in *Yuktibhāṣā* in this context are

$$\frac{\pi}{16} = \frac{1}{1^5 + 4.1} - \frac{1}{3^5 + 4.3} + \frac{1}{5^5 + 4.5} - \frac{1}{7^5 + 4.7} + \cdots,$$

$$\frac{\pi}{4} = \frac{3}{4} + \frac{1}{3^3 - 3} - \frac{1}{5^3 - 5} + \frac{1}{7^3 - 7} - \cdots.$$

Use of the sine-series to compute the sine of an arbitrary angle to a high degree of accuracy with the aid of simple mnemonics is found in *Yuktdīpikā.*

The differential of the sine (cosine) function is proportional to the cosine (sine) function. These differentials are used with confidence in various applications to problems in astronomy in *Tantrasaṅgraha* and *Yuktibhāṣā.* The correct expression for the differential of the ratio of two functions involving sine/cosine functions is given in Acyuta's *Sphutanirṇayatantra.* Integration procedures to calculate the area and volume of a sphere are also given in *Yuktibhāṣā*. The area and circumradius of a cyclic quadrilateral in terms of the sides are some of the other topics discussed in *Yuktibhāṣā*.

Another characteristic feature of Kerala mathematics is the geometrical demonstration of many algebraic and arithmetical results. Multiplication, division, squaring, etc. are all illustrated geometrically in *Yuktibhāṣā.* An advanced example is the geometrical proof of

$$1^3 + 2^3 + \cdots + n^3 = \frac{n^2(n+1)^2}{4}$$

in Nilakaṇṭha's *Āryabhaṭīyabhāṣya*.

See also: ►Nyāya

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Kitora Burial Mound

Simon Potter

Inside the Kitora Burial Mound at Asuka, Nara prefecture, in Japan is a tomb that dates to ca. AD 700 and has a celestial map and murals of cosmological significance. Both the map and the murals bear evidence of scientific and artistic diffusion from China to Japan via the Korean peninsula, but the map has the added significance of being the oldest extant celestial map that is currently known to be scientific in spirit and, more or less, complete. Since research on the map and murals is still in progress and might yield changes in details, readers are directed to the asterisked websites in the references for photographs, taken from small cameras which were inserted into the tomb, and related illustrations.

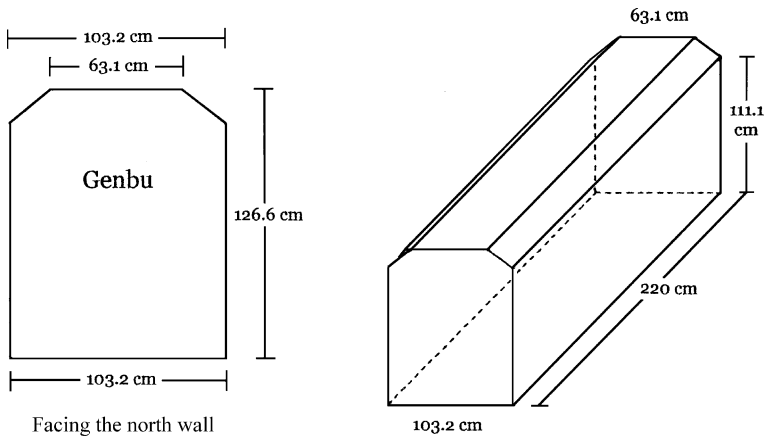
The Mound and the Tomb

Kitora's date of ca. 700 makes it a rather late burial mound since most of those in Japan were constructed during the fourth, fifth, and sixth centuries AD. Although it had been replaced by nearby Fujiwara in 694 (until 710), Asuka had served as the capital city throughout the seventh century, and Kitora seems to have been built in the aftermath of a period of significant Korean influence on higher learning and its applications in Japan. It is not yet clear who was buried in the Kitora tomb, but it might reasonably be assumed that he or she was from a family of importance during or toward the end of Asuka's primacy.

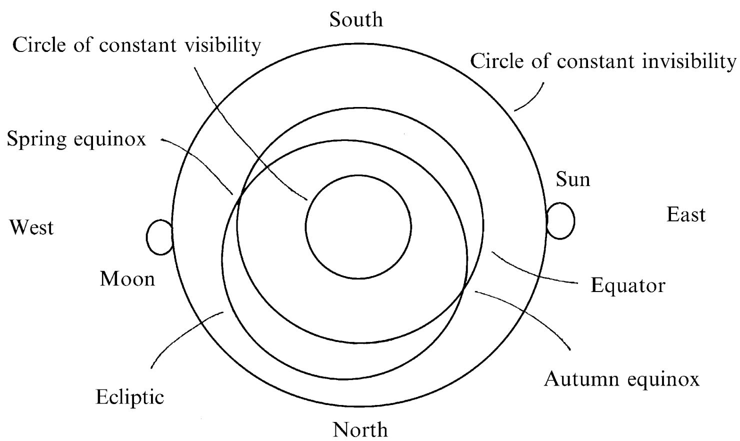
The burial mound stands 3-m high, is conical in shape, and archeologically is classified as a circular mound with its diameter at the base being 14 m. Inside it is an essentially rectangular stone tomb that measures approximately 220 × 103.2 × 126.6 cm, with the ceiling disrupting the geometry by having a centered flat part of 63.1-cm width that is flanked on either side by small slopes that make the walls along the length of the tomb stand at 111.1-cm high (Fig. 1). Other than the celestial map and murals which are discussed subsequently, the chamber is devoid of any artifacts and apparently was raided centuries ago.

The Celestial Map

Volume 2, Book 2 (1994) of *The History of Cartography* series demonstrates that East Asia has a rich heritage in celestial cartography, and the foundations for this regional or "Chinese" tradition were laid centuries before Kitora was constructed. Chinese astronomy involved the likes of observing celestial phenomena, compiling catalogs of stars, and making diagrams of the night sky, all of which contributed to improvements in scientific knowledge that was applied in such fields as calendar-making, government, and prognostication. Important cartographic features included the celestial equator, the plane of the ecliptic, the line of constant visibility (within which were the circumpolar stars, i.e., those which could always be seen), the line of constant invisibility (beyond which no stars could ever be seen), the 28 lunar lodges that tracked the path of the moon through its monthly cycle, and other constellations which were not directly associated with the moon. Although the earliest celestial maps cannot be tracked down, it is known that astronomy and other sciences such as medicine spread to the Korean peninsula and, from there during a period of peninsular instability from the mid-sixth century, to the western part of



Kitora Burial Mound. Fig. 1 The dimensions of the chamber containing the star map and murals inside the Kitora Burial Mound (drawing by the author).



Kitora Burial Mound. Fig. 2 The main circles of the Kitora star map (drawing by the author).

the Japanese archipelago. The route of diffusion was southward from the northern kingdom of Koguryŏ to Paekche, the weakest of the three independent Korean kingdoms, which transmitted knowledge to Japan through specialists and books in a time of political trouble. This background is useful for establishing an intellectual premise to argue that the celestial map inside Kitora was not a product of independent innovation in Japan, something which may also be said of its murals as well.

The Kitora map includes the four circles mentioned above as well as constellations which may be traced to China. Both the circles and the stars were formed by chiseling into the stone, with the grooves of the circles having been filled with cinnabar and the holes for the stars evidently with gold leaf, and the disposition of the circles and stars suggests that an azimuthal or zenithal equidistant projection was employed. The diameters of the three concentric circles have been estimated from photographs to be 18 cm (constant visibility), 42.5 cm (equator), and 64 cm (constant invisibility), while the offset ecliptic is also about 42.5 cm. Outside the western and eastern edges of the circle of constant invisibility, but just touching it, are, respectively, an orb for the moon and another for the sun (Fig. 2).

Two of the circles have significant errors, both of which might be explained by the circumstances faced by the craftsmen. One is that the circle of constant invisibility is smaller than it ought to be (about 67 cm) based on the radii of the circle of constant visibility and the equator, and this probably was due to an attempt to fit all of the map within the 63.1 cm, flat part of the ceiling since only a part of the outer circle and the entire lunar and solar orbs are on the slanting parts. The ecliptic has two errors, one being that it is circular rather than an oblate circle slightly larger than the equator as it should be on the zenithal equidistant projection (and therefore does not correctly display the equinoxes), and the other being that it is offset toward the northwest rather than toward the northeast. Whereas the first is most likely attributable to a drawing compass having been used, the latter could be adduced to the workmen having confused the cardinal directions while transferring the model diagram to the ceiling.

If the circle of constant invisibility had been drawn in correct proportion to the other concentric circles, it would be possible to derive a reasonably accurate estimate for the terrestrial latitude of observation of the sky shown in the Kitora map. Despite this and other problems regarding the placement of the stars, a less reliable estimate based on the radii of the circle of constant visibility and the equator was calculated to be about 38°24′ north, which might be simplified to between 38° and 39°. For the Japanese archipelago, these latitudes lie in central Tōhoku and suggest that the Kitora map shows the sky as it might have been viewed from present-day Yamagata and Miyagi prefectures, a frontier region of Japanese rural settlement around 1,300 years ago. For comparison, Asuka itself lies at 34°30′ north, yielding a difference of about 4° or 450 km in latitude.

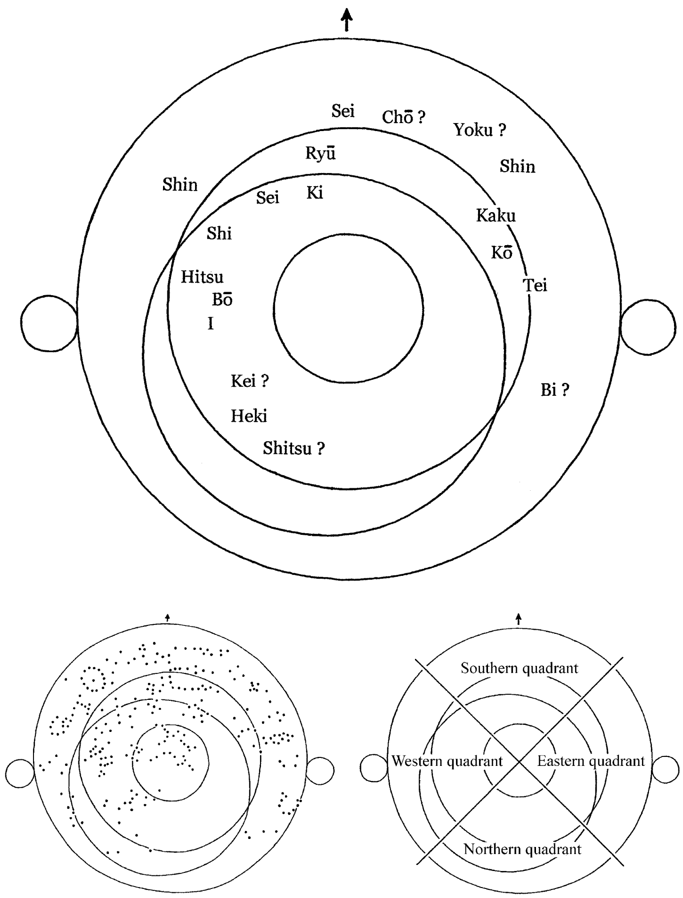
Because 38°–39° is considerably to the north of the Japanese cultural hearth in the Nara Basin and corresponds to an area within the archipelago that hardly interested the Japanese at the time, it would seem that the Kitora map was based on observations made elsewhere and, therefore, on an imported star map that served as its model. The ancient major Chinese centers of Cháng'ān (now at Xī'ān) and Luòyáng lie between 34° and 35° north, the same as the Nara Basin, and Dūnhuáng and Āsītǎnā which have Táng dynasty (AD 618–907) celestial diagrams or maps inside archeological sites are, respectively, at about 40° and 43° north, while a capital city prior to 510, Píngchéng at present-day Dàtòng, was also at approximately 40° north. On the Korean peninsula, the only cultural center north of 36° at the time was P'yŏngyang, which at 39° north had served as the capital of Koguryŏ from AD 427 until its absorption by Silla in 668. It is therefore suspected that the original map from which that inside the Kitora tomb was derived aimed or pretended to show the sky at or near P'yŏngyang.[1]

Although the Kitora enterprise has been dated to ca. 700, dating the celestial map which served as its model has been difficult to do. One of two estimates places the date of observation in the latter half of the fifth century, when P'yŏngyang was a capital city, yet there is little confidence in this mainly because the celestial north pole does not coincide with the center of the concentric circles. The other estimate, derived by considering the positions of the stars according to their right ascensions, suggests ca. 65 BCE as a possibility, but is not reliable because of insufficient data, differing values according to which stars are used, and errors that can be attributed to the workmanship and/or the photographs used for study. Despite their roughness, these estimates could be pointing at a synthetic map in which a graticule for the P'yŏngyang area was superimposed on a distribution of stars according to a Chinese catalog or survey from the first century BCE, the inconsistencies having been of little or no concern to the compiler(s).

Such a synthetic, incorrectly layered map could conceivably have been put together in the heyday of P'yŏngyang, and the best evidence which might be cited to support this idea is a verbal reference on a late fourteenth-century circular star map to its own alleged model, a stone engraving which was sunk in the Taedong River in AD 670 when Koguryŏ fell to Silla. At least one rubbing of the map had been made before the stele was sunk because the inscription on the *Ch'ŏnsang Yŏlch'a Punya ji Do* (Map of the Sphere with Images in the Heavens and the Line of Lodges), another stele made in 1395–1396 and reengraved approximately 300 years later, relates this history. Other documentary evidence supports this as well as the idea that celestial diagrams in general had existed in Koguryŏ, and calculations from the engravings of the *Ch'ŏnsang Yŏlch'a Punya ji Do* indicate that it could have been based on an original with stars surveyed roughly 2,000 years ago, that is possibly around the same time as the suspected model for the Kitora map. The biggest problem in linking the Kitora map with the *Ch'ŏnsang Yolch'a Punya ji Do*, however, is that a detailed comparison reveals that they differ considerably from each other, perhaps to the point that they used different models.

Detailed star maps such as the *Ch'ŏnsang Yŏlch'a Punya ji Do* and a Chinese circular map at Sūzhōu that was engraved in stone in AD 1247 have been useful for identifying the lunar lodges and other constellations, many of which are given away by the red lines that connect stars. Although a complete picture cannot be derived because of damage to the ceiling over time, the reasonably good assessment of the southern half of the map that has been made argues that the map was engraved with an appreciation of scientific detail and an intention to get the important stellar information reasonably correct. Notable is the distribution of the

[1] The calculations in previous research have assumed that the ratio of the radii of the circle of constant visibility and the equator is correct. Another line of reasoning might be that the circle of constant invisibility is in correct proportion to one of the other circles, and the calculations for latitude would yield approximately 39°30′ if it were correct vis-à-vis the circle of constant visibility (meaning that the equator would be slightly too large) or approximately 44°30′ if it were correct vis-à-vis the equator. Although the latter calculation would put the latitude for the circles in the Gobi or in northernmost Koguryŏ, the former helps support the hypothesis of the P'yŏngyang area having been meant by the circles.



Kitora Burial Mound. Fig. 3 The distribution of the identified and possibly identified lunar lodges in the Kitora star map. Of the two smaller diagrams, that on the left shows the distribution of the stars according to the photographs taken and that on the right divides the sky into quadrants, within each of which are supposed to be seven lunar lodges (drawing by the author).

identified and possibly identified lunar lodges, which demonstrates that they were positioned within their proper directional quadrants, seven to each, with all seven of the south having been identified despite the possibility of two of them having been switched (Fig. 3). Other constellations such as Gunshi (Army Town), Bunshō (Written Prosperity), Taibien (Big Faint Fence), and Hokutoshichisei (Seven Stars of the Northern Ladle) have also been identified by the patterns created by the lines that connect their stars, and their placement is correct in a relative context. Analysis of the lunar lodges and other constellations has also revealed that they and, vis-à-vis the geometry of the constellations, their stars are larger than usual, while the errors made in positioning them were greater than those on the *Ch'ŏnsang Yolch'a Punya ji Do* and other celestial maps that were used for comparison.

The Murals

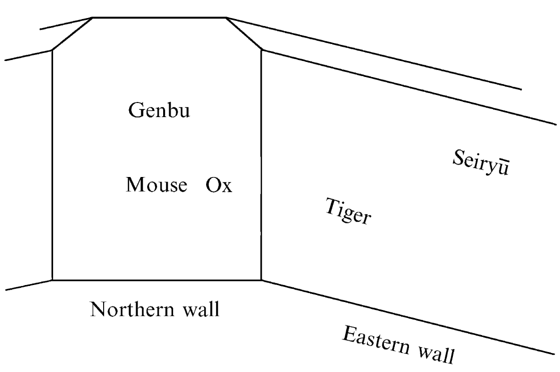
Two sets of illustrations have been discerned on the walls inside the Kitora tomb, and both are easily traced to Chinese cosmology. One set in particular, that of the four spirit-beasts which originated in China, is useful evidence of the diffusion of continental art into a Japanese cultural hearth and, in terms of esthetics, can be used to argue for a high probability of Korean immigrants and/or their descendants having worked on the Kitora project.

The four spirit-beasts – a term derived from the Chinese characters that comprise the Japanese word *shinjū* – are also known as the four spirits (*shijin*) which are often described as tutelary or protective deities of the north, east, south, and west. Their Japanese names are, respectively, Genbu (Black Warrior; actually a turtle and snake entwined), Seiryū or Seiryō (Blue Dragon), Suzaku or Shujaku (Red Bird), and Byakko (White Tiger), and all four still exist on the appropriate walls inside the Kitora tomb. Three had previously been found inside the Takamatsuzuka Burial Mound, about 1 km north of and contemporaneous with Kitora, but because its southern wall had been damaged by a break-in, it could only be surmised that Suzaku must have been painted on that wall to complete the set. The discovery of

Suzaku inside Kitora supports this idea; it generated a fair amount of excitement within the community of art historians and others interested in ancient culture because it was the first time that the complete set of spirit-beasts had been found inside a Japanese tomb.

Perhaps the more interesting set of murals appears to have been 12 smaller creatures drawn in threes on the four walls below the spirit-beasts. Because of deterioration of the walls, this set is no longer complete and educated guesses have been made from examining photographs of remnants of the murals based on their location. The first to have been examined is on the eastern wall, not far from the northern, and appears to be a person with the head of an animal that has been inferred to be a tiger. Other markings have been observed, notably two along the northern wall that occupy positions which suggest that the heads would have been those of a mouse and an ox (Fig. 4). An interesting point about what remains of these illustrations is that this is the first time that the 12-animal set has been found to have been painted on tomb walls anywhere.

These animals belong to the 12-animal Chinese zodiac which popularly gets linked to a cycle of 12 years, but they also have directional and temporal equivalents which are of greater importance here. Along the northern wall of the tomb the boar or pig (north–north–west), mouse (north), and ox or cow (north–north–east) would be expected to be shown; along the eastern would be the tiger (east–north–east), rabbit (east), and dragon (east–south–east); along the southern would be the snake (south–south–east), horse (south), and sheep (south–south–west); and along the western would be the monkey (west–south–west), cockerel or bird (west), and dog (west–north–west). Each of these animals, in the same sequence, corresponds with a 2-h block of time which makes sense in a geographical context so that, for example, the animals along the northern wall



Kitora Burial Mound. Fig. 4 The location of three markings which were probably murals of figures with heads of animals that symbolize geographical direction and 2-h blocks of time (drawing by the author).

correspond with night (the sun never entered the northernmost sky in the Chinese world), the hours for the rabbit are 5–7 a.m. when the sun comes up in the eastern sky, the horse overlaps midday from 11 a.m. to 1 p.m. when the sun is due south and at its highest, and the cockerel or bird symbolizes sunset in the west between 5 and 7 p.m.

Korean Provenance

Both the science and the art with scientific implications inside Kitora may be traced ultimately to ancient China, yet the evidence argues not only for one or more countries on the Korean peninsula as the agent for cultural transmission, but also for the strong probability that migrants from the peninsula and/or their descendants were directly involved in the Kitora project. The estimated latitude for stellar observation, mentioned previously, contributed to this line of thinking and surmising that the star map might be related to that noted in the inscription for the *Ch'ŏnsang Yŏlch'a Punya ji Do* as having been lost during the seventh-century turmoil between the Korean kingdoms. Examination of the murals, however, has provided more depth to argue for Korean provenance, as the following briefly notes.

An important lead in the early investigations was the fact that both a celestial diagram and murals of the four spirit-beasts were found inside the tomb, something that was far more common in Koguryŏ than in the Chinese or even the other Korean states. Although there is no known celestial map with the scientific spirit of that inside Kitora that either predates or is contemporaneous with it, that on the ceiling of the Takamatsuzuka tomb having been a square diagram without any of the scientific circles, archeological evidence from contemporary and later tombs suggests that there was no specific model for such celestial diagrams. In the case of the murals of the four spirit-beasts, though, there were similar drawings inside earlier tombs in Koguryŏ as well as inside Takamatsuzuka at Asuka to use for artistic comparison. When those and other murals inside Takamatsuzuka were discovered in 1972 – 11 years before Genbu, 26 before Byakko and Seiryū, and 29 before Suzaku were discovered inside Kitora – experts from northern and southern Korea were quickly invited to examine them, and the reasonable probability of Korean influence on them cannot be discounted, which may also be said to be true for the spirit-beasts inside Kitora because of the similarities between the three that are found in both tombs at Asuka. Further suggestive evidence of a Korean provenance for the murals inside Kitora is that influential artists of seventh-century Japan were settlers from the Korean peninsula, who most likely brought models which could have been used for the murals, and their descendants. Speculation has notably focused on an artist known as Kibumi and his school.

See also: ►Astronomy in Japan, ►Time in China, ►Time in Korea

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Knowledge Systems in China

Yang Di-Sheng

The science and technology developed in China often led the world before the fifteenth century. Statistics of significant discoveries in the world from the sixth century BCE to the nineteenth century AD show that before the year 1500, discoveries made in China comprised more than half of the total (Guo Jianrong and Guo Guangyin 1987). Then, the percentage dropped rapidly, and in the nineteenth century it became less than 1%.

The mode of development of science in China is, roughly speaking, a slowly progressed "mode of accumulation." It is not full of ups and downs like the Western saddle-shaped "mode of revolution".

In contrast to the West, Chinese scientific and technological achievements mainly belonged to the technical and empirical type. The Chinese were less inclined to use theoretical and experimental methods. The four best known inventions – compass, gunpowder, paper, and printing – when they came to Europe, exerted a great influence on the West.

The most developed sciences in ancient China were astronomy, mathematics, medicine, agronomy, and other related branches. This was determined by the needs of the agricultural Chinese society.

The characteristics of the development of science and technology in China were formed by factors that existed before the Christian era. At that time Chinese culture was already very different from Greek culture. There were both a different value orientation and a different way of thinking, which had long-term influences over the directions of the development of Chinese society and Chinese science and technology.

In regard to value orientation, the highest goal for Chinese ancient thinkers was in searching for the harmony and balance in one's mind, and in the relationship between Man and Man, Man and Society, and Man and Nature. The core of the Confucian thought is *ren* (loving people). Therefore, the only important criterion for learning is usefulness for humanity's purpose; other factors do not matter at all. In this regard, it is very different from ancient Greece, where study was for knowledge's sake only and without any practical intention.

Huishi was the only exception among Chinese ancient thinkers. But thinkers from all the other schools such as Confucians, Daoists, Mohists, and Legalists uniformly criticized him, and they suppressed him. This contributed to the fact that the ancient Chinese were strong in technological achievements and relatively weak in theoretical ones. Even though the Mohists discussed almost all the problems contained in classical logic, they never made a single step toward formalization or axiomization. Therefore, they never came up with their own axiomatic system. The main reason for this was that logic, at that time, did not seem to have any practical use.

The Chinese also developed mathematics to a very high level. For example, in the *Shushu Jiuzhang* (Mathematical Treatise in Nine Sections) compiled by Qin Jiushao in 1247, there was a method of solving high degree equations. However, the Chinese never developed axiomatic systems similar to Euclidean geometry. Therefore, despite the fact that China had the most complete, most systematic astronomical records in the world at that time, and that she was rich in cosmological constructions, such as the *gaitian* (hemispherical dome), the *huntian* (celestial sphere), and the *xuan ye* (infinite empty space) hypotheses, she never produced any geometric cosmological models similar to Ptolemy's or Copernicus'. Chinese mathematics characteristically took practical use as its aim and centered around calculation. Its earliest representative work is *Jiuzhang Suanshu* (Nine Chapters on the Mathematical Arts) written in the Western Han dynasty. Ancient Western mathematics was mainly geometry; ancient Chinese mathematics was mainly algebra. Today, when computing technique once again is the primary concern of so many mathematicians, the practical value of ancient Chinese mathematical inclination becomes more and more obvious.

The development of modern science and technology makes people realize that it is a double-edged sword; it can bring benefits as well as destruction. Therefore, its development must be controlled ethically and politically, under strict management and control. In this respect, Chinese value orientation is a very significant model.

In regard to ways of thinking, Chinese traditional philosophy has always inclined to an organismic view of nature. Chinese philosophers regarded heaven, earth, and man as a united whole. This was fundamentally different from other ways of thinking, as there was no distinction between Object and Self. French thinker L. Levi-Bruhl (1857–1939) misunderstood when he considered the chinese way of thinking primitive. The Chinese idea of the unification of heaven and man mainly emphasizes that humans are only a part of heaven (nature); the Way of Heaven and the Way of Man are one and the same. Humans should be in a harmonious existence with nature, and these two should not be opposed to each other.

Chinese philosophy also claims that heaven, earth, and everything else are constituted by a pair of contradictions. Chinese philosophers use two symbols, *yin* and *yang*, to represent this pair of contradictions. *Yinyang* is a unity of contradictions. There is an antagonistic as well as a complementary and containing relationship between them. There is *yang* in *yin* and there is *yin* in *yang*. They can convert to each other under certain conditions. Therefore, in order to achieve harmony in nature, the stability of a society, and a long rule with eternal peace, as well as the health of individuals, "the doctrine of the mean" has to be applied to keep a dynamic balance between *yin* and *yang*. The philosophy advocates that nothing should be overdone, and all actions should be done appropriately. This way of thinking is different from the dichotomy in two-valued logic (A or $\tilde{A}$), in which every proposition is either true or false. Its symbolic representation is the *yinyang* fish *taiji* pattern (Fig. 1).

A mechanistic mode of thought has never been dominant throughout Chinese history. This organismic way of thinking affected the development of Chinese science to a very large degree. It can be found in ancient

Knowledge Systems in China. Fig. 1 Two-valued logic and the *yinyang* fish *taiji* pattern.

Chinese cosmology, astronomy, medicine, agronomy, and social theories. It contributed tremendously to keeping peace and stability during the Middle Ages. However, at the same time it restrained the growth of capitalism, and served as one of the most important reasons that prevented China from having a scientific revolution.

According to the Chinese traditional view, the origin of the universe is the result of the changes of *yin* and *yang*. Imbalances of *yinyang* caused natural disasters like earthquakes, as well as social disturbance. The *yinyang* theory is also the theoretical foundation of Chinese medicine. It considers the human body as a whole. If a body loses its balance of *yin* and *yang*, the person becomes sick. The task of a medical doctor is to use every method to help the patient to resume this organismic dynamic balance. However, Chinese medicine is not a two-value system; it is a multiple-value system, totally different from the Western medical system. But these two can go hand in hand and complement each other, thereby enriching the treasury of our medical knowledge.

The Chinese traditional way of thinking is an organismic one which emphasizes integrity and perceivability, and allows fuzziness. It is, relatively speaking, weak at analytical thinking and it does not value axiomatic systems. Generally it is not good for macrocosmic descriptions in the area of physics, especially mechanics. However, it is closer to the microcosmic world of modern science, such as the area of quantum mechanics, or to descriptions of cosmological, artificial intelligence, and social systems. The return from accuracy back to fuzziness is one of the main indications of contemporary science. Nowadays many scientists realize that this Chinese way of thinking could indeed bring helpful inspirations to the progress of modern science.

See also: ►Mathematics in China, ►Algebra in China, ►*Yinyang*, ►Medicine in China, ►Calculation: Chinese Counting Rods, ►Liu Hui and the *Jiuzhang Suanshu*, ►Environment and Nature in Chinese Thought, ►Qin Jiushao, ►Acupuncture

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Knowledge Systems of Aboriginal Australians: Questions and Answers Arising in a Databasing Project

Helen Verran

Why Use a Databasing Project to Tell About an 'Other' Knowledge Tradition like that of Aboriginal Australians?

There are many reasons for being interested in 'other' peoples and their knowledge. A general or removed interest about 'others' often arises out of curiosity. Satisfying that curiosity can put into perspective our selves, our times and places, our cultures and accepted ways of going on. There are many different ways of knowing. Recognising some differences and similarities between knowledge traditions helps to see the strengths and limitations of our own ways.

Sometimes there are more specific reasons for learning and puzzling about other knowledge traditions. In this article I consider knowledge traditions of Aboriginal Australians comparatively, by referring to a particular contemporary way of 'doing knowledge'. The aim of the project I write out of is to devise some specific forms of databasing that might be useful for Aboriginal people. You can find out more about this project at ►http://www.cdu.edu.au/centres/ik/. This contribution takes the form of questions and answers that are frequently asked about Aboriginal Australian knowledge traditions in the context of such projects.

The databasing project involves the intersection of two quite different knowledge traditions. The intersection 'reveals' both technoscientific knowledge traditions and Aboriginal Australian knowledge traditions.

Engagements of various sorts must occur in an Aboriginal digital databasing project, and studying that process is helpful from the point of view of comparatively learning about Aboriginal Australian knowledge traditions.

How Can Asking About Knowledge in the Context of a Databasing Project Help in Understanding Aboriginal Australian Knowledge Traditions in General?

Many Aboriginal communities in northern Australia are interested in using digitising technologies – computers, video and still cameras, audio recorders, and written texts – to generate digital items that can contribute to the various forms of collective memory in Aboriginal communities. Just as in the sciences, collective memory in its various guises is important in using and making knowledge in Aboriginal knowledge traditions.

When it comes to actually doing the work of assembling a collection of digital objects that might be useful to an Aboriginal community however, several aspects of how to do it immediately become problematic. For example, what sorts of things digital objects *are* in an Aboriginal context of knowing turns out to be surprisingly puzzling and difficult to predict. How a database might be organised so that it could be useful to Aboriginal people as they do their knowledge in their own ways, using their own forms and structures, is likewise not at all clear in the beginning. Needing to think through those questions helps to understand knowledge traditions generally, and Aboriginal Australian and technoscientific knowledge traditions in particular.

Why Use the Term 'Knowledge Traditions' Rather than 'Knowledge Systems' When Discussing Databasing of Aboriginal Knowledge?

Both 'systems' and 'traditions' are metaphors, working images of how we understand knowledge using and knowledge making. 'Tradition' comes from the Latin word *tradere*, 'to give'. Traditions emphasises human communities 'doing' their knowledge, giving across generations and to other knowledge communities. 'Systems' come from the ancient Greek term *systēma* meaning 'set'. Systems imply a concern with boundaries and focus on framings and separations. It emphasises the structures of knowledge.

In using traditions I am not denying the importance of structure in knowledge. The practical difficulties that can arise in working disparate knowledge traditions together are often caused by differences in the ways things are framed and structured. In using 'knowledge traditions' I mean to draw attention to the fact that all human communities have complex and varied ways of dealing with such issues in their practices of knowledge using and making. The ways that framings and re-framings are managed when knowledge traditions work together is part of what is at stake in a project like Aboriginal databasing. When we want to compare and contrast knowledge traditions we need to think about and discuss the various sorts of re-framings we need to do so that we can usefully juxtapose knowledge traditions.

What Are the Terms We Can Use in Discussing the Various Sorts of Re-Framing We Need to Do so that We Might Compare and Contrast Knowledge Traditions?

In using and making knowledge there are some framings that people are very aware of. There are others that are deeply hidden. For example all knowledge traditions have experts in various fields and disciplines. Access to expert knowledge must be managed. There is 'outer', 'inner' and 'secret' knowledge, and institutional ways of managing access to those levels. The institutional arrangements involved in using and making knowledge express theories about what knowledge is in that knowledge tradition. The social arrangements involved in working a knowledge tradition embody the ways that knowledge is justified as true. 'Epistemic' is the general term we use to name this aspect of knowledge. Discussing and considering the management of these institutionalised structurings and re-framings is epistemology. These terms come from the Greek word for knowledge, *epistēme*. The *-ology* bit of the term means 'to study'.

There are also divisions and definitions that knowledge users and makers are far less aware of. Becoming sensitive to this level of difference can be crucial in successful working together of disparate knowledge traditions. These structural differences are embedded in language use and in the ordinary generalising we do when we use numbers. Here people are working at the level of assumption; things are usually just taken for granted as people go on together. In working disparate knowledge traditions together people must bring these assumptions and what they take for granted out into the open. Often, especially in the beginning, that is not comfortable. Philosophers name this profound level of framing the ontic (referring to the existing reality) level. Ontology is the study of what there is. 'Ontic' and 'ontology' come from the ancient Greek term *onto-* a form of the verb form *eimi* or 'am' in English, part of the verb 'to be'.

How Do Epistemic Differences Arise When People Try to Work Technosciences and Aboriginal Knowledge Traditions Together?

One of the many reasons for researching Aboriginal databasing is the need to manage epistemic differences that emerge when environmental scientists and Aboriginal land owners try to work together to conserve biodiversity. In northern Australia perhaps the most valuable tool for ecological management is firing the bush. By maintaining a sophisticated regime of firings, a complex mosaic of dynamic ecological successions is achieved. Aborigines have been doing this in Australia for millennia. Science, which has been working with Australian nature for only a little over 200 years, seems to be much less successful at achieving complex dynamic mosaics. And besides, much of the land in northern Australia is owned by Aboriginal Australians who have a right to work their lands according to the standards of their own knowledge traditions.

A firing is judged as a valid and efficacious instance of the knowledge tradition of Aboriginal Australians in several ways. These are epistemic concerns. Theories of knowledge determine the forms of witnessing and evaluating any instance of applying and engaging knowledge. In Aboriginal knowledge traditions it is most important that particular knowledge authorities participate in specific roles in the planning and execution of the firing. Expressions of knowledge are not valid unless this condition is met.

Firing of any particular place must always begin in a specific spot and proceed in certain ways, through a series of contiguous particular named spots in the landscape. The names of a series of contiguous spots in the landscape must be publicly and collectively recited before a firing begins. The knowledge authorities are those who know which spots are where, and the directions in which the various sequences of names move across the land. In addition it is important that particular items of food are gathered in the process of firing and distributed to appropriate persons in the correct relative amounts. This distribution of various foods collected from the multiple micro-ecological zones that constitute the area fired expands the number of people who can attest a firing episode as legitimate. A particular firing will imply that people are moving through places where it is recognised that particular foods are found. Being able to present the appropriate food items to others is a form of proof that the firing was valid. These institutionalised forms of proof and witness go along with epistemology which sees that true knowledge can only be performed and enacted in place.

These forms of Aboriginal witnessing and evaluating an episode of firing are very different from the ways epistemic concerns are institutionalised in environmental science. There, scientists plan their firings with maps that allow areas to be delineated. They collect observations on the fire and its effects on vegetation and assemble the results in scientific papers that are published, reports that other environmental scientists might read. These reports attest and witness the efficacy of the firing. These forms express an epistemology which understands knowledge as representing an 'out-there' reality.

Nowadays when it comes to managing Australia's northern savannas to promote a robust biodiversity through firing, there are two incommensurable standards. There are no possibilities for an Aboriginal way of judging a firing to be a valid expression of knowledge to have salience in science. In the same way it is literally inconceivable that scientific validation could legitimate in Aboriginal traditions. The epistemic differences are unresolvable as such.

Yet perhaps digitising technologies can help us get around this problem. It is possible to imagine assembling digital objects during planning, execution and evaluation of firing. Audio files can capture what is said, and still images, movies, and spoken commentaries might also be gathered, along with the foodstuffs, and/or the measurements, as Aborigines and scientists go about their tasks of planning, execution, and witnessing firing episodes.

Imagine storing these digital items in a structure free digital matrix. In databasing terms this implies that there is no distinction between data and metadata. If we want to go further we could imagine two quite differently configured interfaces by which the set of digitised objects might be interrogated. One interface can express the epistemic concerns of science, the other can be configured in a way that embeds the epistemic concerns of Aboriginal Australian knowledge traditions. To do this of course the two sets of epistemic standards must be translated into digital interfaces. In each case, in becoming database interfaces, the epistemic standards take up new forms of institutionalisation. In actuality of course, those sorts of translations require a lot of work and resources.

How Do Ontic Differences Arise When People Try to Work Technosciences and Aboriginal Knowledge Traditions Together?

Different knowledge traditions make very different assumptions about what there is. One set of clues we can get about this level of difference lies in the grammars of different languages. Grammars are deeply embedded in and express the ontic. Another set of clues can be winnowed out by considering the everyday forms of generalising we find working in a knowledge tradition. We can look at what is involved in using numbers for example. In the case of Aboriginal Australian communities we need to consider the generalising that makes up their very different form of mathematics. You can read about this in my other entry in this encyclopaedia 'The Mathematics of Aboriginal Australia'. Yet another set of clues can be found in the stories that peoples tell about the origins of the worlds they know and the things that comprise it. This is generally called the metaphysics of a knowledge tradition. That is the subject of my next question.

Imagine a scientist watching an old Aboriginal man demonstrating the process of making fire by rubbing two sticks together. The old man has chosen sticks from bushes that look very different. He uses one as a base and cuts a notch in the middle. He uses the other stick like a drill bit. Seating it in the notch he twirls it very fast between his palms. Gradually a pile of hot sawdust accumulates and when it is smoking he tips this smouldering pellet into a nest of shredded bark which when blown on breaks into flame.

Enthusiastic and interested, the scientist asks the names of the two bushes from which the fire making sticks were plucked. It is quite clear to him that the plants are very different – they belong to different biological families. He is genuinely shocked when the old man insists that they are *really* the same. While the old man accepts that the plants might look different, he insists that what is important is that *logically* they are 'the same one'. The old man and the scientist have been confronted with an ontic difference.

Is this ontic difference resolvable? Yes, but only by opportunistically assuming the existence of a third translating domain. This move involves an ontology that is both and neither Aboriginal and scientific. But this is not a meta-ontology. It is not an ontic domain which supervenes and contains the other two. On the contrary, it is an infra-ontology, an inside connection. It takes enough of what matters ontologically to Aborigines when they are dealing with firings, and enough of what matters to scientists when they are engaged in doing their prescribed burns. Learning how to do this in on-the-ground situations is not easy because it involves working with contradictions in disciplined ways. Particularly for scientists it is difficult, because contradiction is usually outlawed in science.

'Same and different' are constituted through different framings in science and Aboriginal knowledge traditions. It often shocks people when they experience this form of difference. Another similar sort of experience is often associated with differences around 'whole and part'. Recognition of this sort of difference can also emerge when Aborigines and scientists try to learn each others' firing regimes.

Scientists assume that a thing like a habitat is an entity found in nature. While there may be many attributes and characteristics which could be the subject of quite different scientific disciplines – pedology, botany, hydrology – the habitat itself is just a single given object. Many different representations of this given, whole thing might be made, and they tell of the various parts of a single whole thing. The differences between the experiences of the separate groups of scientists are downplayed and backgrounded. This being so, when scientists report their burning of an area, they tell their activities in accordance with the assumption that they are about a single entity. They go to great pains in the introduction and conclusion of their reports to show that all the separate experiences of the scientists really relate to one thing – the habitat under observation.

But when Aborigines report their episodes of burning, they completely fail to attend to the place as a whole. They emphasise and recognise only the diverse involvements of the groups who have variable interests at stake in a collective episode like a firing. The singularity achieved in different kin groups working together in a single purposeful episode is taken for granted background in any reporting. Aborigines do not assume that places exist in the here-and-now as single whole things. Places might achieve a form of ephemeral singularity when a firing or some other such collective activity occurs – if all the correct people are present and things are done in a correct manner. Those ephemeral unities of actual existence are achieved re-enactments of an originary act of creation by spiritual ancestors.

As scientists see things, reports of firings given by Aborigines fail to attend to the place as a whole. In contrast Aborigines feel that scientists fail to credit properly the multiplicities that inhere in place. This is another instance of ontic difference. It too, with care and caution, can be worked around well enough for Aborigines and scientists to feel confident in going on together.

How Are Aboriginal Accounts of the Origins of Knowledge Different to Technoscientific Understandings of Origins of Knowledge?

As well as issues of epistemology, such as theories of knowledge and truth, and issues of ontology, commitments to particular sorts of things being in the world and issues of metaphysics, such as originary stories, are involved in working disparate knowledge traditions together. The metaphysics of Aboriginal Australian knowledge traditions is very different to that of the technosciences. They have very different accounts of the origins of knowledge.

In Aboriginal Australian traditions knowledge is taken as already always in the land. However, knowledge needs the correct circumstances for true expression. In Aboriginal Australian knowing, there is no given or a priori separation of places and persons who belong to that place. Knowledge is in the land and in people by virtue of their belonging to the land.

The origin of knowledge/place/persons is often named in English as 'The Dreaming'. This is a transcendental time parallel to the secular time of the ordinary here-and-now. From The Dreaming the creative impulse for the world arose and continues to arise. This creative impulse of The Dreaming emerges from the complex collective lives of a multiplicity of beings, both human-like and non-human in form. Entities that can be known in Aboriginal Australian knowledge are framed primarily as here-now expressions of The Dreaming. Knowledge and the spiritual life of religion are not separate in Aboriginal traditions, so all things have an intrinsic spiritual dimension.

As well as an ultimate division between the eternal Dreaming and the secular here-and-now world of everyday individual experience, there is a subsidiary division between the world's two sides. There is exhaustive division of both the secular domain and The Dreaming, into formal opposites. Amongst the Yolngu Aboriginal clans in northeast Arnhem Land for example, these two sides or moieties are named *Yirritja* and *Dhuwa*. Everything is either Dhuwa or Yirritja.

Knowledge in the ordinary world of the secular is the outcome of *Dhuwa* Dreaming knowledge and *Yirritja* Dreaming knowledge working together to generate true expressions of The Dreaming. Knowledge in the here-and-now is justified as a true expression of The Dreaming if relevant knowledge authorities of the opposed moieties with interests in the particular set of issues at hand, witness and attest a particular expression of The Dreaming as valid.

In the technosciences, while many practitioners might profess religious belief, Islamic, Buddhist, or Christian for example, these spiritual commitments are not embedded in the forms of technoscientific knowledge. The entities of technoscience do not possess an intrinsic transcendental element. Knowledge of the world is taken as distinct from the world itself. Knowledge is a representation. Knowledge is about the world and the origin of knowledge is the human mind which knows the world. There is some disagreement over whether the ultimate structure of knowledge reflects the structure of the human mind, or the structure of the world. Most philosophers agree that it is some form of combination of both.

In the sciences there is a fundamental division of people as knowers and things (including places) as known about. Things known are matter that extends in space and time and is situated in an empty space–time frame. In a secondary or derived way abstract things like numbers are understood by analogy to primary material things. True knowledge about those material and abstract things is taken as accumulating through the application of proper scientific method. Knowledge is justified as true if it can be shown to have been produced in valid ways.

Aboriginal Knowledge is Taken as in the Land Itself. How Can Knowledge be Stored in the Land and in Databases Too?

How can we understand Aboriginal people when they say 'knowledge is in the land?' How can science learn how to take that claim seriously? The land is a set of sites with meaning embedded, with information there in place. But those meanings, necessarily organised in some way, are accessible only to those who have been sensitised and trained in the right traditions.

One way to think about databasing in an Aboriginal context is to understand a computer as a simplistic and 'outside' version of one of those meaning full sites in land. 'Doing databasing' can contribute to the remembering/forgetting that is inherent in community life, as can 'doing ceremony' which mobilises information embedded in the land.

Databasing can be understood as a way of doing outside collective memory with digitised materials. Images made with digital cameras – video and still, audio files, and written texts typed up on a computer can record something that might be re-presented later in another forum in such a way as to help those involved in some endeavour to remember in a helpful way. Seeing things this way reminds us of the importance of developing some protocols around generation of digital objects.

What Are the Knowledge-Making Sites in Aboriginal Australian Knowledge Traditions? How Are They Similar to or Different from Knowledge-Making Sites in the Technosciences?

Aboriginal knowledge-making centres around ceremonies, some of which might involve firing episodes. In much the same way technoscientific knowledge-making pivots around the workings of laboratories and field sites. Just as there are many and varied types of laboratories, so too there are many different sorts of ceremonies in Aboriginal life. These are religious ceremonies, but they are not repeated rituals. No two ceremonies are identical in Aboriginal life. Each is concerned with spiritual practice and knowledge making with respect to particular times and places and groups of people.

We can describe scientific knowledge making in laboratories and field sites through elaborating the specific sorts of social institutions involved, the material routines that are crucial in knowledge making, and the literary texts and literacies involved. But to give a complete picture we need also to include the paradigms, theories, or imaginaries in which these processes make sense. These same headings can be used to describe the workings of Aboriginal ceremony and the knowledge making that occurs in them. Just as the entities that emerge from laboratories and field sites remake their worlds, so do the entities that emerge from the ceremonies of Aboriginal Australian life.

Ritual and Ceremony Are Parts of Aboriginal Knowledge. How Can You Recognise the Role of Ritual and Ceremony When Knowledge is Stored in Databases?

In ritual and ceremony Aboriginal knowledge authorities use many diverse sources of information. In ceremony, dance, painting, song and story need to be performed correctly and under the right auspices to become knowledge making.

Often people see databases as 'archives'. But in this project we are *not* seeing them as tiny digitised museums. We are asking if databasing can become a useful additional experience. Can digitised information feed into, complement and extend the already well-developed ways that information is handled and managed in Aboriginal communities to support Aboriginal people in doing their knowledge? Under what conditions might databasing become a useful form of managing information? These are empirical questions and Aboriginal people are the ones who must drive the process to come up with answers.

Aborigines Have Local Knowledge But Databases Are Universal. How Is Local Knowledge Consistent with Having Databases?

The notion of databases as somehow universal knowledge assumes two things. First it takes for granted the existence of 'facts' – little pieces of knowledge referring to a single reality. And second it assumes that if you could only get enough of them together in one place, facts would eventually link up into one complete system of knowledge. In many traditions of Indigenous knowledge (and in many sciences) both assumptions are seen as wrong.

Anyone who thinks about the notion of universality for very long will see that facts are always generated and 'made solid' in specific places and times by particular groups of people. Knowledge is always done in specific ways. It is a commonplace that it is actually very difficult to get things to link up. It is sometimes very difficult actually to link working databases – for example those that have been assembled in doing biodiversity. Data are just as diverse as biological organisms are.

We found this when we started searching for databases in northern Australia that included 'indigenous knowledge'. A database *is* a form of local knowledge. It is a collection in digitised form of data items that have been generated using very specific local methods.

Of course Aborigines have local knowledge. All knowledge is local. It remains true that sometimes with prodigious collective effort some, or even many, local knowledges can be linked. Sciences often are good at linking up their local knowledges, although sometimes it is very difficult to get different sciences to work together. Sometimes and in some places scientific knowledge and Aboriginal knowledge can be usefully linked.

How Could Elements of Traditional Culture be Strengthened by Encouraging Aboriginal People to Use Digitising Technologies?

A problem arises if we think of traditional Aboriginal knowledge as 'anti-modern', the opposite of modern culture. Then we will begin to think of traditional cultures as stuck in the past and want to put them in a museum and close the exhibit case. Understanding 'traditional' in that way, we think of it as somehow inconsistent, perhaps even incompatible, with computers.

Traditional cultures are contemporary forms of life just as modern cultures are. They are rich in modes of innovation as well as having ways for preservation of cultural forms. We can understand traditional cultures as involving non-modern forms of identity. They have ontologies that make modern assumptions about knowledge and knowing look strange. Digitised information arranged in ways that make sense and are useable by those working within non-modern cultures can surely be devised. As long as we do not make assumptions based on modern ways of using digital objects, if we proceed in open ways, empirically researching how indigenous people actually use digitising technologies, there is the possibility of strengthening traditional forms of cultural innovation with computers.

Traditional forms of passing knowledge from an older generation to a younger one often involves young and old being in the same place at the same time doing things together, talking about it. It involves a process of re-imagining it together, finding new forms in which to express the understandings in sharing them.

We often find that indigenous communities want to assemble collections of digitised items for specific reasons. They want to be able to intervene in a specific context in a particular way. Assembling digitised items in these projects becomes a site, a time and place where young and old, with their varying competencies work together. Databasing can become an impetus for young and old to work together in ways that can empower and educate the young while recognising older people as knowledge authorities.

What About Protecting Intellectual Property? Can Databases Not Easily Lead to Indigenous Peoples Losing Control over the Natural and Cultural Resources Their Groups Own?

Protecting collective intellectual property is important in all 'closed' knowledge economies. Aboriginal societies are no different from American corporations in this. The issue is one of controlling who knows and how much they know. Strategic revealing and hiding is involved.

Modern companies protect their intellectual property with patent laws, by various technical means, and by selectively authorising and commissioning various knowers. Aboriginal clans have equally effective means of managing the strategic revealing and hiding of intellectual resources.

There are two rather separate elements that need to be considered in thinking about intellectual property and indigenous knowledge with respect to collections of digitised items that point to natural and cultural resources.

The first relates to forms of management for these collections that express indigenous ways of doing intellectual property. Workable ways of respecting different clan ownership of various elements, and recognising differential individual access need to be found. Our stance at this point is to restrict our research to secular contexts. We avoid engaging with knowledge that is sacred and religious. Second, maintaining collections of digitised material in ways that protect the collections appropriately to avoid piracy from outside interests is important.

Can We Articulate Some General Principles for Thinking About Engaging Disparate Knowledge Traditions?

Genuine recognition of difference can be painful. It involves beginning to doubt our own knowledge traditions as sources of absolute certainty and see them as having limits. Accepting that every knowledge tradition is inherently and systematically partial is challenging. It is sometimes difficult to accept the profound significance of difference and at the same time persevere in learning about 'the other' and in considering how our familiar ways of knowing might engage with other ways of knowing. Very often we approach other knowledge traditions thinking that they are just an odd or unusual version of the ways we know. That is a form of inauthenticity.

The odd aspect of seriously engaging with the other is that in order to recognise difference in knowledge traditions we need to 'make strange' our own. In part that is what I have tried to do in these questions and answers, telling of some of the issues that arise when Aborigines and scientists work together. Beginning to explore how digitising technologies might contribute, I engaged in a process of 'strangification'. I 'made strange' the epistemological assumptions of science, revealing them by setting them alongside another way of 'witnessing' valid expressions of knowledge associated with an alternative account of truth. To make strange our own knowledge traditions we must begin to open up questions of metaphysics.

Eventually we must find ways to do a form of 'experimental metaphysics'. This way we make both sides strange with respect to each other. An experimental metaphysics is a framing of issues of difference that takes elements of both metaphysical systems to develop what we might call an ad hoc hybrid translation borderland. This can help us begin to accept the limits of our own ways of being certain about what we know – our own types of epistemic standards. It can also provide a way to imagine how we might connect in partial, strategic, and opportunistic ways. Some entities that might be usefully linked in partial ways – like Aboriginal firings and the prescribed burns of science can be identified. The on-the-ground activities that enable strategic linking can be identified. Each firing can begin to make some sense in the other knowledge tradition through the use of a metaphysically explicit translating zone.

See also: ►Environment and Nature

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Knowledge Systems of the Incas

R. Tom Zuidema

On the fourteenth of November, 1533, Francisco Pizarro and a small Spanish army entered the town of Cajamarca. On the next day they took Atahuallpa, the last Inca king, prisoner after he had come to their encounter with a large army. It was the first and the last time that the Spaniards received a glimpse of the independent Inca state which had conquered an empire into southern Colombia and northern Argentina and Chile. Perhaps the empire had already been weakened by the civil war that Atahuallpa had won over his brother Huascar, the crowned king. While in prison, Atahuallpa had Huascar killed, and after some months in Cajamarca the Spaniards executed Atahuallpa. But more than these events, it was the possession of superior arms, including horses, and the help of native troops choosing their side, that allowed the Spanish army to cross the country almost without resistance and to enter the capital of Cuzco a year later. Here they set up Manco Inca as a puppet king. Less than two years later Manco Inca fled Cuzco and withdrew to the eastern slopes of the Andean mountains where heavy forest made it difficult to defeat him and his successors. In 1572, thirty-six years later, the last Inca king, Tupac Amaru, was captured and executed in Cuzco. It was the end of Inca resistance, and the viceroy Francisco de Toledo could consolidate a colonial government that ruled until the early nineteenth century when the Andean countries of Colombia, Ecuador, Peru, Bolivia, Argentina, and Chile declared their independence.

Some of the first Spaniards that described their participation in the conquest of the Inca empire included in their accounts valuable information about its people. But only after some 20 years did the first chronicles appear, by Juan de Betanzos [1551],[1]one of the first Spaniards to learn the Inca language of Quechua well, and Pedro Cieza de Leon [1551]. These give an integrated view of Inca culture, referring to aspects of history, social and political organization, agriculture and husbandry, and religion. Although much of this information derived from the memory of Inca nobles in Cuzco, it was not based on direct observation of a thriving culture with all its rituals and feasts. Moreover, Andean civilization never developed a system of writing, recognized by the chroniclers as such, through which we would be able to hear the independent voices of its peoples on what they thought about their cosmos, their gods and goddesses, and their myths and rituals, without being directed by the questions of representatives (administrators, lawyers, priests) of Spanish domination. Almost all the documentation needed for Inca administration was recorded on knotted cords with numerical information organized in bundles, called *quipus*. Hundreds of these *quipus* have been found in graves on the desert coast of Peru. Most are from Inca times but some are from the earlier Wari culture, demonstrating a different system of knots and chords. We can study the sophistication of Inca mathematics, analyze some of the information, mostly on bureaucratic and economic but also on ritual matters, as released by *quipu* specialists through Spanish prodding, and be aware of additional information on the Inca past and culture memorized by the specialists. But most of this research is still in its infancy (Ascher 1981).

Other promising sources of information on Inca culture are the many textiles that survived in coastal graves, were conserved in heirlooms from colonial times, and were represented in colonial art. The Incas inherited sophisticated techniques of weaving from earlier cultures, but the style of their art was very much their own. Certain types of male tunics show highly standardized geometric patterns. Others include a wide variety of square designs, *tucapus* that in their distribution as possible signs with meaning are reminiscent of a writing system, although only for a few *tucapus* are there clues to their interpretation. None the less, a careful comparison with written sources on the use and iconography of Inca textiles can help us to establish this art as an independent, pre-Hispanic source of documents on aspects of Inca culture.

The colonial chroniclers provide us with the only written knowledge of Andean culture at the time of the Spanish conquest. Beginning with Betanzos and Cieza, they organize their material in a historical framework. Thus they tell how Manco Capac, the first Inca king, came out of a cave some 50 km south of Cuzco with three brothers and four sisters and founded the future capital. At the time of his writing, the conquered people in the valley of Cuzco still remembered their pre-Inca past. From here the Incas first conquered surrounding valleys and gave their kingdom an administrative structure recognizing the old local lords as lower-ranked members of their own nobility. This nobility consisted of different ranks defined according to criteria of kinship to the reigning king and queen; thus the local lords were defined by the chroniclers as "Incas by privilege". Like the Inca nobility, they themselves were exempt from contributing labor to Cuzco but their subjects were not. Moreover, they and their subjects participated in the ritual organization of the town. From this base the empire was conquered.

When the Spaniards were still in Cajamarca, they had some inkling about the enormous extent of the Inca empire but no idea how it was obtained and who had been the successive conquerors. On their arrival in Cuzco, they reconstructed the last two royal successions before the Spanish conquest. Twenty years later a certain consensus was arrived at of the earlier dynasty. But as this list of kings was not based on historical records, its reconstruction conformed more to a pattern of western than of indigenous ideas about royalty, succession, conquest, and history. One of the most arduous tasks of research deals therefore with the questions of evaluating how the Spaniards reconstructed the conquest of the Inca empire, how their Inca informants presented this conquest to them, and how the conquered peoples, especially those outside the original kingdom, understood how this Inca domination had occurred.

Betanzos, Cieza, and others after them, especially Pedro Sarmiento de Gamboa [1572], placed as the central person in the epic of Inca conquests the ninth king, called Pachacuti Inca. Cuzco had been attacked by the kingdom of the Chancas during the reign of his father, Viracocha Inca. As the latter fled from town, Pachacuti Inca defeated the enemies and was crowned king even though he had not been designated as crown

[1] Square brackets after the name of an old author indicate the date of writing or of first publication.

prince. He rebuilt the city, reorganized the people who lived in its valley, elevating in rank those who had helped him in the defense and lowering others, and he established different institutions of government. Thus he divided the valley into districts based on the system of agricultural irrigation; he organized a system of worship of those ancestral mummies that he decided to recognize as such; he assigned administrative posts to relatives and other nobles; and he established the calendar of state celebrations.

The story of Pachacuti Inca has all the characteristics of a foundation myth and with its help we can get an understanding of how the histories of the Incas before and after this king were constructed in colonial times. Memories of earlier times were organized according to the ancestral system, wherein a ranking order of mummies was used to establish a dynastic order. But the dynastic sequence after Pachacuti Inca cannot be taken without critical examination either. The many conquests of the Inca empire toward Colombia and Chile and Argentina were said to be accomplished mostly by Pachacuti Inca's son, Tupa Yupanqui, and grandson, Huayna Capac. (The latter died some seven years before the Spaniards arrived). But the Inca informants to Spanish questioning recognized that some rulers after Pachacuti Inca had been suppressed from the official list of kings. Thus it is very possible that the history of Inca conquest was not as short as suggested. Here the memories of the conquered peoples can help us to arrive at a more realistic picture of Andean history.

Intensive documentary research beginning some 50 years ago on various local kingdoms integrated into the Inca empire allows us to get some idea of their cultural and institutional differences and their ties to earlier peoples whose art and archaeology we study. Perhaps the most important kingdoms that the Incas conquered were those of the Chimu on the north coast of Peru and around Lake Titicaca. All had had a prestigious history of their own. The Chimu had built a kingdom along the coast from about the valley of Lima to near the present-day border of Peru with Ecuador. Their capital of Chanchan had been the largest city in South America. They were the descendants of the Mochica people (ca. AD 0–700) whose pottery with realistic painted scenes established one of the high points of Andean arts. The Chimu are the only kingdom on which we have some dynastic information from before the Spanish and even Incaic conquests. Recently, much work has been accomplished reconstructing their culture and political organization (Moseley and Cordy-Collins 1990).

Around Lake Titicaca the cultures of Pucara (ca. 200 BCE–AD 400), north of the lake, and Tiahuanaco (ca. AD 200–900) south of it once flourished. The impressive stone ruins of their ceremonial centers played an important role in Inca mythology. Chroniclers constructed the myth of a creator god coming from Lake Titicaca or Tiahuanaco, called Tunupa, around the lake and Viracocha in Cuzco. In the sixteenth century three different languages were spoken: Aymara that extended to the west of Cuzco and near Lima, Puquina, and Uru. Puquina was probably the most important language at the time of Tiahuanaco, and Uru may have been there and in the high plains of Bolivia even earlier. But since colonial times Uru was retained mostly by people with a fishing and hunting economy, and Puquina died out. Today, Aymara is mostly spoken by people living south and east of Lake Titicaca.

Most of our historical information on Aymara culture derives from colonial administrative documents. Among these are, however, two of the most important ones for research on local government and economic organization in the Andes at the time of Spanish conquest. The first, from 1567, describes the former kingdom of the Lupaca south of Lake Titicaca. Its economy was based not only on highland crops grown there but also on crops from distant valleys down on the Pacific coast. Instead of obtaining these lowland crops through trade it had sent its own people to grow them. The second document, from 1568–1570, concerns a former kingdom north of the lake; here cultivation of coca in the lower valleys east of the Andes had been important.

In conquering Chimu and Lake Titicaca, the Incas had concentrated their rule near former centers of power. In other cases they established new provincial capitals away from such centers. The most important and best researched example of this kind is the city of Huanucopampa in central Peru near the eastern slopes of the Andes. It formed part of a chain of provincial capitals going north from Cuzco, including Vilcas Huaman, Bombon, Huanucopampa, Cajamarca, Tumibamba (present day Cuenca in Ecuador) and Quito. Huanucopampa was perhaps the largest of all. It is also best preserved, as its location on a high plateau did not attract later Spanish settlement. Huanucopampa expresses in an admirable way the basic ideas of Inca town planning. Around a huge rectangular plaza the four quarters of town were organized, each with its own pattern of social activities. In the center of the plaza stood the Ushnu. Chroniclers describe the Ushnu in the plaza of Inca towns as a platform or pyramid near a small round structure of stone where offerings of corn beer were pledged to the Sun god, the ancestors, and the forces of the underworld. Cuzco had such a ritual complex but the platform was probably a temporary structure used only during special feasts. But in Huanucopampa the large platform was built of stone and could have served also during military parades. On the east side of the plaza and aligned with the Ushnu stood the palace of the Inca governor. The king probably resided here when passing through town. It contained three courtyards, as one chronicler also describes for a royal palace in Cuzco. Thus we can assume that Inca and non-Inca subjects could enter the first and largest courtyard, that only nobility entered the second courtyard, and that the family of the governor or the king had exclusive access to the third and smallest courtyard to which were attached their living quarters. There was a straight road leading from the plaza to the inner court and the various gates through which visitors had to pass still stand, each crowned by two stone lions facing one another like on the lion gate of Mycenae. Above the town, on its outskirts, can still be seen the hundreds of storehouses for the tribute brought by the people of the province of Huanucopampa. Two extensive documents from 1562 describe in detail the demographic composition of this province and the contributions that its villages had to make to the state. Huanucopampa and its province have provided us with the best opportunity for research on the organization of an Inca province and its economy.

Many documents now being studied allow us to reconstruct the local sociopolitical situations in Inca times. Regular forms of organization, like those consisting of moieties and of three or four local groups, reveal patterns of regional variation which have survived in many places. Although the social functions of these organizations may have changed after almost half a millennium, they retain their ritual importance. A form of state organization that could be combined with the ones already mentioned consisted of bringing together families in numbers of 10, 50, 100, 500, 1,000, 5,000, 10,000, and finally 40,000, the latter number expressing an ideal way of organizing an Inca province. In a similar way, the population of Cuzco itself consisted of ten *panacas* and ten *ayllus,* the first referring to the relatives of the king who administered these groups. *Panacas* and *ayllus* played a crucial role in the calendrical rituals of the capital.

With the Inca conquests of the empire, the administrative model of Cuzco was replicated in the organization of the whole empire. For instance, the four quarters of town, the *suyus,* were extended into the four provinces of the empire. Inca nobles and lords of the Incas-by-privilege became imperial administrators (*tucricuc*) supervising local lords (*curacas*) who themselves governed their territories like the king in Cuzco. But *curacas,* or their representatives or sons, also had to visit Cuzco. Periods of four months' or a year's residence in town are mentioned, but we do not known how regularly they were repeated. A specially important time for such visits was after harvest, when lords came with their tribute and presents for the Inca king. He consulted with them about their governments and discovered who did not want to comply with his obligations. Presents that the king received from one province were awarded by him to the lords of another.

Of particular interest is the imperial (re-)organization of the *acllas,* the "chosen ones." Girls were selected in local organizations according to set criteria of beauty and assigned tasks, like weaving and making corn beer, in houses built for that purpose. From there they could be reselected and sent to provincial capitals and even to Cuzco. Their organization touched on almost all aspects of Inca culture. Ranking was expressed in an idiom of age-classes, and these applied also to men from their time of initiation and marriage to the time that they turned over their social obligations to their sons. Some *acllas* were married off by their *curaca,* an Inca governor or the king, either as a principal or as a secondary wife, or were dedicated to a role in Inca religion. When, with the Spanish conquest this organization fell apart, one way *acllas* were dealt with was by converting them to nuns. But their roles were not really comparable to those of nuns, because this female organization with the queen at its head in most respects paralleled the male hierarchy. The concept of *aclla* also played a central role in the imperial organization of sacrifice, the *capac hucha,* as this practice had grown out of the calendrical organization of local rituals in Cuzco. Children were selected as *acllas* and dedicated to various but always specifically recorded purposes. Thus they were sacrificed, including couples of a boy and a girl. In their own locality, sacrifice might be for the purpose for obtaining good pottery clay. In far-away places sacrifices commemorated important events, such as winning a battle. In Cuzco it was part of a great state ritual, either for the time of planting, of the December solstice or of the harvest. *Aclla* sacrifice was the culminating act in an organization of rituals that crystallized the cosmological values of Inca government.

Inca religion forms an integral part of Andean religion in general as observed in various parts of the empire. Because of the importance of Cuzco as imperial capital and the intellectual interest of the Spanish in its history, we are also well-informed about Inca religion. However, for reasons of colonial history we also have extensive accounts of myths, rituals, and religion in the mountain provinces of Huarochiri and Cajatambo, central Peru, where in the early seventeenth century the Spaniards believed they observed a resurgence of indigenous beliefs that they tried to eradicate. While the original belief systems in Cuzco and the two other provinces may not have been that wide apart, the circumstances of their recording were very different. Chroniclers in Cuzco, among whom there were well-educated people, came to the Inca past through their own curiosity and were informed by Inca nobles. Initially, both parties may have looked for a common intellectual basis. However, the religious expressions in Huarochiri and Cajatambo were seen as a rebellious return to pagan beliefs in villages after more than 80 years of teaching that Christianity was the only true religion. I will deal here with the problem of studying Inca religion, although many myths and rituals may have been recorded in Huarochiri and Cajatambo in a form closer to pre-Hispanic reality.

Unlike the situation of extensive pantheons in Aztec and Maya religions and of illustrations of gods, goddesses, and priests dressed as such in pre-Hispanic and early colonial codices and chronicles, the Spaniards described only a few gods and goddesses for the Incas, and even those were not visualized in any way in Inca art. Nevertheless, documents and chronicles are replete with names of sacred places in the form of mountains and rocks, lakes and springs, and all other kinds of natural and man-made objects with ritual significance. Foremost were three male gods, the Sun, the Thunder, and Viracocha and one female god, Pachamama, the "mother earth." The ruling king was considered to be the son of the Sun, but from Cuzco we have no mythical description of the latter's actions. The Thunder god was seen in various parts of the country as an active mountain god, but in Cuzco only indirect references to his deeds occur. The god Viracocha seems to have corresponded to a type of mythical figure, known elsewhere in the Andes under various names. The myth of the god Coniraya in Huarochiri, there compared to Viracocha, has perhaps best preserved this pre-Hispanic image. He pursues a woman along a river down to the Pacific Ocean. Here she escapes as he cannot follow her any further. Along the way and through various acts that present him as a trickster, he defines the interests of people in their land for cultivation, water for irrigation, and wild animals for use in rituals. An original way of representing Viracocha in Cuzco, although found in a late chronicle, is as a force of nature, a giant, who during a month of heavy rain comes down the Villcanota river near Cuzco, flowing from the southeast to the northwest, threatening to destroy it. But Betanzos and Cieza describe Viracocha as a god who brought forth from the island of Titicaca (the rock of the cat), in the lake of the same name southeast of Cuzco, the sun, the moon and the ancestors of different peoples. Viracocha sends these underground to their local places of origin, from where they reemerge to establish local government. Viracocha himself also travels northwest, following the Villcanota river near Cuzco, but continues until he arrives at the sea in Ecuador. There he disappears, not into the sea but over it toward the horizon. This version of the myth was well adapted to the imperial interests of the Incas and may have also received a colonial reinterpretation because of the Spanish interests of including Peru in a universal empire. Soon the exploits of Viracocha were also phrased in terms of those of two early apostles, Saint Bartholomew or Saint Thomas, who had been said to have traveled through the country bringing Christianity long before the Spaniards did. According to this colonial reinterpretation, Viracocha was the creator god of the Incas. But his mythology became embedded also, in fragmentary form like that of other gods, in the legendary history of kings. Stories were told of the eighth king, Viracocha Inca, that were more fitting for his namesake the god Viracocha, and in a similar vein his son Pachacuti Inca was associated with the Thunder god. In fact, one chronicler recognizes these relationships as such when he says that each king took as his name of nobility that of his god. Pachamama was the great goddess of the earth, but again no stories of her exploits are told. The myths of some Inca queens are more interesting, considered in their roles as ancestral deities. Probably, the attention to Pachamama was mostly developed in early colonial times.

Of more immediate interest for the study of Andean religion are the numerous sacred places, the huacas, mentioned in various local documents. Sometimes myths are told about them as actors like humans. Two indigenous chroniclers from the early seventeenth century give us extensive hierarchies of huacas of more than local importance, although our sources tell us little about their possible organization. In about 1560, however, the Spaniards had become aware that in Cuzco the cult of the huacas was organized according to a highly sophisticated scheme of directions as seen from the temple of the Sun in the town. Families each took care of the cult of a particular huaca and larger social groups were associated with the huacas along one direction, the ceque, or with groups of ceques. The organization of the ceques served various social purposes. For instance, the topographical description of the valley was of interest for land distribution in agriculture, irrigation, husbandry, and mining, especially in terms of quarries of stone used for building purposes. Through the ceque system a formal description can be given of Cuzco's political organization including its calendrical organization of state rituals as defined in terms of its system of astronomical observation. Polo de Ondegardo, the chronicler who discovered the ceque system in Cuzco, mentions that other villages, towns, and provinces of southern Peru and Bolivia also had their ceque systems. Some interregional ceques are described, of use in the imperial system of capac hucha sacrifice that suggests a hierarchy and network of ceque systems. Ceque systems were recorded on quipus. They supported an Andean way of reflecting in an abstract way on cultural values.

Andean civilization did not direct its interests toward the use of writing like Mesoamerican civilization did. Thus the intellectual aspects of Inca culture are difficult to grasp. But so much can still be studied of early Andean practices through those of their descendants, as in techniques of agriculture and weaving that it will become possible to define the originality of Andean civilization.

See also: ►*Quipu*, ►Textiles, ►Mummies, ►Calendar, ►City Planning, ►Stonemasonry, ►Irrigation, ►Time

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Knowledge Systems in India

A. V. Balasubramanian

Traditionally all knowledge in India has been traced to the Vedas. The Vedas are considered to be divine revelation. They were organized into four major branches: *Ṛgveda*, *Yajurveda*, *Sāmaveda*, and the *Atharvaveda*. Various other branches of knowledge grew up as auxiliaries that were to be developed in order to interpret and put to practical use the material of the Vedas.

There were a total of 14 *Śāstras* or branches of knowledge: the four Vedas, the four Upavedas (auxiliary Vedas), and the six Vedāṅgas (parts of the Vedas). The four Upavedas were (1) *Āyurveda*, literally "The Science of Life," which constituted the medical system; (2) *Arthaśāstra*, which constituted state craft and political theory; (3) *Dhanurveda*, literally, archery, but practically constituting the art of warfare in its varied aspects, and (4) *Gāndharvaveda*, constituting music, drama, and the fine arts.

Similarly, the knowledge systems required for understanding, interpreting, and applying the Vedas were organized into six branches called *Vedāṅgas*, literally "the limbs of the Vedas," with the Vedas personified in a human form. The six *Vedāṅgas* are *Vyākarana* (Grammar), *Chandas* (Metrics), *Śikṣā* (Phonetics), *Nirukṭa* (Etymology), *Kalpa* (Ritual), and *Jyotiṣa* (Astronomy and Mathematics).

These *Vedāṅgas* were essential, since the Vedas had to be understood correctly (needing etymology and grammar), pronounced and chanted accurately (needing metrics and phonetics), and used properly in various contexts (needing ritual), and the times for these performances had to be computed correctly, requiring the knowledge of computation of the flow of time and of planetary movements (needing astronomy and mathematics). Even though the *Śāstras* originally evolved in the context of the Vedas, they also developed an independent identity and their own corpus of literature and applications that extended well outside the originally formulated requirements of the Vedic context.

In later periods the list of *Śāstras* became much larger and the area covered was much wider. For example, in his famous text *Kámasūtra*, the author Vātsyāyana provides a list of 64 arts with which any scholar should be familiar.

Since the various branches of Indian knowledge systems are extremely diverse, we will focus upon a few that can best illustrate some characteristic different features. These are (1) the fact that linguistics occupied a seminal place even for exact sciences (unlike Western knowledge systems); (2) the nature of theorization and theory building in Indian tradition; (3) the algorithmic nature of Indian computation, and (4) the sociology of organization of knowledge –the "classical" and the "folk" streams and their interrelation.

In any scientific discourse it is essential to achieve precision and rigor. In the Western tradition, the geometry of Euclid is considered the paradigm of an ideal theory, and various other branches of knowledge tried to emulate Euclid by setting out their knowledge on the basis of a formal axiomatic system. In contrast, in Indian tradition, an attempt was made to use natural language and to refine and sharpen its potential by technical operations so that precise discourse was possible even in natural language. This is so, particularly in Sanskrit, where we find that even the most abstract and metaphysical discussions regarding grammar, mathematics, or logic are still written in natural language. In Indian knowledge systems, it is the science of linguistics that occupied the central place which, in the West, was occupied by mathematics.

Linguistics

Linguistics is the earliest of Indian sciences to have been rigorously systematized. This set an example for all the other Indian sciences. Linguistics is systematized in *Aṣṭādhyāyī* – the text of Sanskrit grammar by Pāṇini. The date of this text is yet to be settled with any certainty. However, it is not later than 500 BCE. (The dates mentioned here are those based on Western scholarship. An indigenous Indian dating and chronology in this matter have yet to be established.) In the *Aṣṭādhyāyī*, Pāṇini achieves a complete characterization of the Sanskrit language as spoken at his time, and also manages to specify the way it deviated from the Sanskrit of the Vedas. Given a list of the root words of the Sanskrit language (*dhātupatha*) and using the aphorisms of Pāṇini, it is possible to generate all the possible correct utterances in Sanskrit. This is the main thrust of the generative grammars of today that seek to achieve a purely grammatical description of language through a formalized set of derivational strings. It is understandable that until such attempts were made in the West in the recent past, to the Western scholars the Paninian aphorisms (*sūtras*) looked like nothing but some artificial and abstruse formulations with little content.

Science in India seems to start with the assumption that truth resides in the real world with all of its diversity and complexity. Thus for the linguist what is ultimately true is the language as spoken by the people. As Patañjali, a famous grammarian who wrote a commentary on Pāṇini's *Grammar* emphasizes, valid utterances are not manufactured by the linguist, but are already established by practice in the world. Nobody goes to a linguist asking for valid utterances, the way one goes to a potter asking for pots. Linguists do make generalizations about language as spoken in the world, but these are not the truth behind or above the reality. They are not the idealization according to which reality is tailored. On the other hand, what is ideal is real, and some part of the real always escapes our idealization of it. It is the business of the scientist to formulate these generalizations, but also at the same time to be attuned to the reality, to be conscious of the exceptional nature of each specific instance. This attitude seems to permeate all Indian science and makes it an exercise quite different from the scientific enterprise of the West.

Astronomy and Mathematics

Indian mathematics finds its beginning in the *Śulbasūtras* of the Vedic times. Purportedly written to facilitate the accurate construction of various types of sacrificial altars of the Vedic ritual, these *sūtras* lay down the basic geometrical properties of plane figures like the triangle, the rectangle, the rhombus, and the circle. Basic categories of the Indian astronomical tradition were also established in the various *Vedāṇga Jyotiṣa* texts.

Rigorous systemization of Indian astronomy begins with Āryabhaṭa (b. AD 476). His work *Āryabhaṭīya* is a concise text of 121 aphoristic verses containing separate sections on basic astronomical definitions and parameters; basic mathematical procedures in arithmetic, geometry, algebra, and trigonometry; methods of determining the mean and true positions of the planets at any given time; and descriptions of the motions of the sun, moon, and planets along with computation of the solar and lunar eclipses. After Āryabhaṭa there followed a long series of illustrious astronomers with their equally illustrious texts, many of which gave rise to a host of commentaries and refinements by later astronomers and became the cornerstones for flourishing schools of astronomy and mathematics. Some of the well-known names belonging to the Indian tradition are Varāhamihira (d. AD 578), Brahmagupta (b. AD 598), Bhāskara I (b. AD 629), Lalla (eighth century AD), Muñjāla (AD 932), Śrīpati (AD 1039), Bhāskara II (b. AD 1115), Mādhava (fourteenth century AD), Parameśvara (ca. AD 1380), Nīlakaṇṭa (ca. AD 1444), Jyeṣṭhadeva (sixteenth century AD), Gaṇeśa, and Daivajña (sixteenth century AD). The tradition continued right up to the late eighteenth century, and in regions like Kerala, original work continued to appear until much later.

The most striking feature of this tradition is the efficacy with which the Indians handled and solved rather complicated problems. Thus the *Śulbasūtras* contain all the basic theorems of plane geometry. Around this time Indians also developed a sophisticated theory of numbers including the concepts of zero and negative numbers. They also arrived at simple algorithms for basic arithmetical operations by using the place-value notation. The reason for the success of the Indian mathematician lies perhaps in the explicitly algorithmic and computational nature of Indian mathematics. The objective of the Indian mathematician was not to find "ultimate axiomatic truths" in mathematics, but to find methods of solving specific problems that might arise in astronomical or other contexts. The Indian mathematicians were prepared to set up algorithms that might give only approximate solutions to the problems at hand, and to evolve theories of error and recursive procedures so that the approximations might be kept in check. This algorithmic methodology persisted in the Indian mathematical consciousness until recently, so that Ramanujan in the twentieth century might have made his impressive mathematical discoveries through its use.

Āyurveda: The Science of Life

The third major science of the classical tradition is *Āyurveda*, the science of life. Like linguistics and astronomy this finds its early expression in the Vedas, especially the *Atharvaveda*, in which a large amount of early medicinal lore is collected. Systemization of *Āyurveda* takes place during the period from the fifth century BCE to the fifth century AD in the *Caraka Saṃhitā*, *Suśruta Saṃhitā* and the *Aṣṭāṇga Saṇgraha*, the so-called *Bṛhat-trayee* texts which are still popular today. This is followed by a long period of intense activity during which attempts are made to refine the theory and practice of medicine. This process of accretion of information and refinement of practice continued right up to the beginning of the nineteenth century.

Folk and Classical Traditions

There exists a vast amount of knowledge which represents the wisdom of thousands of years of observation and experience. While in any given area (such as medicine) there may be a body of experts or learned professionals, knowledge also prevails in more diffuse or scattered forms. In Indian tradition, it seems to be a general principle running through all types of learning that knowledge can and does prevail in various forms and also gets communicated in many ways.

The general picture that emerges seems to be that the "classical texts" in any area of learning may set out broad general principles as well as their application in a given context, say a particular region of the country. But in various different contexts or regions, knowledge gets expressed based on the given situation, and the generalities get adopted, modified, or even overridden sometimes based on the specificity. This can perhaps best be illustrated in the case of medicine, where classical medical texts themselves deal with this issue. A classical text of *Āyurveda* such as *Caraka Samḥitā* expounds general principles of drug action on the six factors: *Dravya*, *guṇa*, *Rasa*, *Vīrya*, *Vipāka*, and *Prabhava*. It also discusses remedies for several diseases and lists specific drugs. These may get modified to suit local conditions. In any recipe for a drug, one can substitute a nonprincipal component with an equivalent, which may be listed in the text or selected on the basis of the principle of *Rasa, Vīrya*, etc. From time to time traditional physicians produce texts and manuals which set out prescriptions for drugs in any given area based on what is available and suitable to the requirements of that area. For example, the text *Rājamṛgaṇka* lists 129 recipes, and in his foreword the editor states that it is a compilation that must have been made by a *vaidya* (physician) from Tamil Nadu, since it contains recipes based on herbs readily available in Tamil Nadu. Such recipes are not only easier to formulate, but they are also more suited to the area, in accordance with Caraka's dictum, "For a person who belongs to a particular country or a region, herbs from the same region are most wholesome."

The fact that it is the particularity of the context that is the overriding consideration and that Sastric (i.e., scientific) principles are to be considered as precepts and guidelines and not applied in a mechanical or legalistic manner is clearly stated in many classical texts. "A Vaidya who comprehends the principles of *Rasa*, etc. would discard treatment if not wholesome to the patient in a given situation, even if it is prescribed in the texts; on the contrary he would adopt treatments that are helpful to the patient, even if they do not find a mention in the texts."

It is also interesting to note what the texts of *Āyurveda* say about folk knowledge. The *Caraka Saṃhitā* states that "the goatherds, shepherds, cowherds and other forest dwellers know the drugs by name and form." Similarly, the *Suśruta Saṃhitā* states "one can know about the drugs from the cowherds, tapasvis, hunters, those who live in the forest and those who live by eating roots and tubers."

This is an overview of Indian knowledge systems and does not go into the details of achievement in a variety of areas, particularly those pertaining to material sciences. Our attempt is to highlight basic characteristics of these knowledge systems, particularly in those respects where they differ from their modern counterparts.

See also: ►Mathematics in India, ►Astronomy in India

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Knowledge Systems of Indigenous America

LAURELYN WHITT

First Words

> "Knowledge is inherent in all things" (Luther Standing Bear 1933).

Luther Standing Bear's observation that knowledge inheres in all things openly expresses what many indigenous knowledge systems presuppose, and what, by being presupposed, shapes several of their distinctive features. The inherency of knowledge, and the inclusiveness of its scope, are reflected in what is taken to be primary or fundamental – in what knowledge is held to be knowledge *of*. They are also reflected in a web of prescriptions and proscriptions that guide the process of knowing. In both respects, indigenous knowledge systems stand in contrast to their counterparts originating within the West (a location more ideological than geographic).

We can only begin with our own assumptions, with what is taken for granted in what follows. And that is that knowledge systems are diverse and their value is contextual. Oppressive relations of power, however, have shaped their histories and continue to inflict the present, in ways that obscure or override this diversity. As a result, the existence and value of indigenous knowledge systems, in the Americas and elsewhere, has been systematically denied. In the origin stories of the dominant culture, indigenous peoples have superstitions, myths, or belief systems based on ignorance. They do not have knowledge systems.

These stories no longer have the force they once did. There are two reasons for this. The first is that the dominant knowledge system has begun to falter in ways that are obvious even within the West. While some have seen this as a matter of inadequacy or incompleteness, others believe the problem lies deeper. The second is that indigenous peoples across the planet are presently engaged in various and vigorous projects of recovery: of language and land, of law and sovereignty, and of knowledge and value systems. We will touch only lightly on the first two of these, but linger on the third. Indigenous peoples, in the Americas and elsewhere, are intent on restoring and protecting their knowledge systems. And they are using many different approaches and every means available to do this. This story of resistance and recovery is essential to understanding not only the politics of indigenous knowledge systems, but also their substance, and their vital role in the world.

It is a story we attempt to relate here by drawing on as many different voices as possible, mindful that "writing things up gives authority to a particular view and a particular writer… writers are insulated from the discipline imposed on purveyors of knowledge in an oral culture – from the collective analysis and judgment of a community, each of whose members share equal authority to interpret reality" (Castellano 2000).

Relatedness and the Inherency of Knowledge

> "In each place they lived, they learned the subtle, but all important, language of relationship" (Cajete 2000).

If knowledge inheres in all things, it can only properly be educed or drawn forth. So coming to know another entity or process is best approached as an eductive process that turns on establishing certain relations with it. Coming to know it well involves strengthening and sustaining those relations. So knowledge within indigenous knowledge systems is always knowledge of relations; it is not individual entities or processes which are primary or basic, but the relations that hold between and among them. Indigenous knowledge, Battiste and Henderson (2000) note, is "the expression of the vibrant relationships between the people, their ecosystems, and the other living beings and spirits that share their lands." Relatedness, or affiliation, is best understood in its primary – genealogical – context. One of its clearest and simplest expressions is in the Lakota invocation *mitakuye oyasin* ("I am related to all that is"). It is reflected as well in the Andean concept of an *ayllu* – a group of related persons, human, and nonhuman, who live in a particular place: "*Ayllu* refers not only to relationships between human beings but to the relationship between all members of the *Pacha*… they are all relatives and are at once children, parents, and siblings" (Rivera 1995).

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Those seeking knowledge must first elicit, or solicit, then sustain relations with whatever it is they hope to know. As Deloria (1992) states, the "principle of relatedness always remained the critical interpretive method of understanding phenomena." Because knowledge is a matter of establishing connections with other entities, or of recognizing bonds that already exist, the process of knowing is dynamic, interactive. Both parties are actively engaged in knowing as well as in being known. Since most things are held to be animate, rather than inanimate, they are fully capable of engaging in relationships, of entering into relations with human beings. Knowledge of them is not, as the dominant knowledge system would tend to have it, a unilateral process, the result of an active knowing subject working upon a passive object that is known. Within indigenous knowledge systems, coming to know other entities is always a bilateral, and most often a multilateral, process. This involves and encourages an awareness of interdependency: "Only through interdependence could the human beings survive. Families belonged to clans, and it was by clan that the human being joined with the animal and plant world. Life on the high, arid plateau became viable when the human beings were able to imagine themselves as sisters and brothers to the badger, antelope, clay, yucca, and sun. Not until they could find a viable relationship to the terrain – the physical landscape they found themselves in – could they *emerge*" (Silko 1996).

Another implication of Standing Bear's comment that knowledge inheres in all things is that knowledge is not an exclusively human project. Other than human entities are capable of knowing, of making and maintaining relations; if they were not, we would not be able to know them. Moreover, if alternative ways of knowing the world were not possible for us, the scope of human knowledge would be severely constrained. Indigenous knowledge systems place considerable value and significance on gaining access to the perspective of the other than human. By expanding "our understanding of the sense of being relatives," Deloria (1992) observes, "We discover that plants, birds, and animals often gave specific information to people."

Indigenous accounts of knowledge as a process of relating and of acknowledging relatedness, of making connections and sustaining bonds with other entities, allow great latitude in what can be known and how one comes to know. They embrace "the relational potentiality of all peoples and all creation" (Williams 1997). Their commitments to epistemological pluralism and nonanthropocentrism, to coming to know the world through perspectives that are diverse and not restricted to that of the human, run counter to those of the dominant knowledge system. They are at odds too with the idea that knowledge requires separating the knower from the known in order to capture the one way the world really is, independently of the human beings who know it. As Momaday (1976) comments, nature is not something apart from the human, but the element in which the human exists.

If human beings are in fact inextricably bound up in relations – to one another and to the entities and processes in the natural world – what is vital is understanding those relations, knowing how our behavior threatens them and how we can best sustain them. Indigenous knowledge systems do not purport to offer knowledge in the sense of universal truth, or of accurate accounts of the one way the world really is independently of us. Their virtue is that they enable survival, by helping us realize relatedness, the role and contribution which all entities make, and how those roles may best be preserved and continued.

Sovereignty, Responsibility, and Respect

> Yet within the Aboriginal community a paradox seemingly exists. In no other place did the individual have more integrity or receive more honour than in the Aboriginal community. The individual's ability as a unique entity in the group to become what she or he is ultimately meant to be, was explicitly recognized. There was explicit recognition of the individual's right in the collective to experience his or her own life. No one could dictate the path that must be followed (Ermine 1995).

Indigenous construing of knowledge as relatedness, as a matter of appreciating how we are bound to other entities and processes, makes integration with them possible, desirable and necessary for survival. Our fates and futures are understood to be conjoined with theirs. Knowing them commits us to cohering and cohabiting with them. Indigenous knowledge systems enable such coherence, such holding and living together. To acknowledge affiliational ties with other entities in the natural and social worlds is to acknowledge that and how our lives are linked together with theirs. Connection or affiliation with them makes survival possible, and because we are so connected our survival can only be mutual. We are allied and responsible for one another.

This leads to an understanding of sovereignty that diverges markedly from those that have prevailed within the West. Sovereignty is held to be relational, rather than absolute; it is conditioned by responsibility and respect. It is also applicable to all entities, human or not. Relations of domination and assimilation have no place within such a concept of sovereignty; self-determination is held to be compatible with, and constrained by, mutual interdependence. The *Gus-Wen-Tah*, the Two Row Wampum Treaty Belt hat the Iroquois presented to the United Nations, visually expresses this view of relational sovereignty. According to it, differing peoples may be allied and interdependent, yet retain their full distinctiveness and ability to live according to their own laws, customs and ways: "We shall each travel the river together, side by side, but in our own boat. Neither of us will steer the other's vessel" (Penner 1983). The same vision of a relational sovereignty in which power and agency are constrained by responsibility and respect, was expressed by a delegate to the United Nations Working Group on Indigenous Populations: "We need to begin to think of self-determination in terms of peoples existing in relationship with each other…[T]he right of a people to self-determination is not a right for peoples to determine their status without consideration of the rights of other peoples with whom they are presently connected and with whom they will continue to be connected in the future. For we must realize that peoples, no less than individuals, exist and thrive only in dialogue with each other. Self-determination necessarily involves engagement with and responsibility to others…" (Scott 1996). Sovereignty, so construed, is accountable. It enables and endorses collective survival but is inconsistent with domination and assimilation.

Human power and agency are thus limited in fundamental ways by the relationships that bind us to other entities, as Coffey and Tsosie (2001) suggest. Knowledge of other beings involves acknowledgement of them, that is, respect for their role in and responsibilities to the alliances that bind us together. In other words, to know is to value. The processes of knowing and valuing are integrated in indigenous knowledge systems; they mutually inform, and are informed by, one another. This is evident in the fact that one of the primary virtues within indigenous value systems, respect, is as much a cognitive virtue as an ethical one. Knowledge that is not conditioned by respect cannot be had, nor can there be respect in the absence of understanding. Among the Iroquois, respect, or the "wish-to-be-appreciated," is the "fundamental shared perception – the first principle – of existence. As long as everything is appreciated for what it does and what it shares to sustain the cycles of Creation, the world will be in balance and life will continue" (Barriero 1992). The Anishinabe concept of *minobimaatisiiwin* (the good life) expresses a similar notion. "Implicit in minobimaatisiiwin," LaDuke (1992) notes, "is a continuous habitation of place, an intimate understanding of the relationship between humans and the ecosystem and of the need to maintain this balance." It describes, "how you live your life according to natural law, how you behave as an individual in relationship with other individuals and in relationship with the land and all the things which are animate on the land" (LaDuke 1997). In this manner, indigenous knowledge systems offer accounts of knowledge "intended to incite humans to act in such ways as to ensure the protection and reproduction of all creatures in the universe" (Holmes 2000).

Story: Experience and Imagination in Indigenous Knowledge Systems

> "There is a story connected with every place, every object in the landscape" (Silko 1996).

Since knowing other entities involves sustaining relations with them that acknowledge mutual responsibilities and respect, knowledge is so intimately tied to experience and imagination as to be inconceivable without them. Stories are acts of the imagination that enable us to enact and re-enact experience. They do so, typically, by focusing on characters who establish relations with one another, and respond to one another in various ways. One source of their richness as pedagogical vehicles is their facility in demonstrating how knowing and valuing implicate, and are implicated in, one another. Another is that they permit us some access to the perspectives of other beings, often those very different from ourselves. We come to know them by relating ourselves to them, by imaging what it is like to be them, and to experience the world – including ourselves – through them.

Stories have long figured as indispensable aspects of indigenous legal and political knowledge practice. As Williams (1997) observes, "Indian diplomats recognized that making connections with others was a most difficult process. Successful treaty-making required the use of great acts of the imagination so that the two sides could come to see themselves as related in their needs and sufferings as fellow human beings… this is why a treaty was told as a special kind of story, a way of imagining a world of human solidarity where we regard others as relatives." The integrative power of stories, the way they help us initiate and maintain relations with others who may appear different from us, is especially needed to guide human interaction with the other than human world. Stories are related to convey the behavioral constraints that should guide us if we are to act responsibly, if we are to understand and respect the role of other entities and their unique contribution to the natural world we share. Many different peoples have many different stories about what happens when someone, human or otherwise, violates these constraints.

The significance of stories within indigenous knowledge systems lies as much in the telling as in what is told. The intergenerational transmission of knowledge from elders is both a responsibility and a gift. Stories are only told in the context of particular relationships and are a means of maintaining and nurturing those relationships. Part of the responsibility of telling stories lies in determining when and to whom they should be told.

> Elders often decline to have their words printed or to be videotaped because they insist that what they have to say must be communicated in person. Aboriginal people know that knowledge is power and that power can be used for good or evil. In passing on knowledge the teacher has an obligation to consider whether the learner is ready to use knowledge responsibly.…Teachers who allow these things relinquish the possibility of adjusting their teaching to the maturity of the learner and thereby influencing the ethical use of knowledge (Castellano 2000).

As vehicles of experience, stories relate empirical knowledge about the relations that connect us to the world and to one another, and about how those relations can be well or adversely affected. Such knowledge is the product of careful observations, spanning generations, of how entities in particular places are interrelated and of the complex dynamics of their relationships. While it is temporally "deep" or historically replete, it is also spatially located or endemic knowledge – intimately bound to the land, to specific places and the entities located there. It is, thus, presentational rather than representational knowledge: its continuation, its transmission, its possibility turn vitally upon the presence of the natural world and on the kind of experiences that world offers.

> The need to walk on the land in order to know it is a different approach to knowledge than the one-dimensional, literate approach to knowing. Persons schooled in a literate culture are accustomed to having all the context they need to understand a communication embedded in the text before them… Persons taught to use all their senses – to absorb every clue to interpreting a complex dynamic reality – may well smile at the illusion that words alone, stripped of complementary sound and colour and texture, can convey meaning adequately (Castellano 2000).

It is in this sense that knowledge inheres in the world; it is caught up in experience and cannot be extracted from its context. The value of knowledge, so construed, the ultimate test of its validity, "is whether it enhances the capacity of the people to live well" (Castellano 2000).

The Politics of Knowledge: Resistance and Recovery

> "If we do not resist, we will not survive. Our resistance will guarantee our children a future" (LaDuke 1997).

Knowledge has not become politicized; it always has been so. Indigenous knowledge systems explicitly recognize this by their responsiveness to the normative aspects of knowledge, to how human power and agency must be constrained if relations of affiliation with other entities are to be acknowledged and maintained – relations that enable our mutual, and multigenerational, survival. Yet the ideology of Western science, wedded as it is to the thesis of value-neutrality, insists that issues of power do not enter into knowledge making, or shape the dynamics of knowledge systems. The relations of domination and assimilation that characterize imperialism – whether in its historical or contemporary variants – are thus neither acknowledged nor acknowledgeable.

And so the endangered status of indigenous knowledge systems is recognized, but responsibility for it, complicity in it, is denied.

> Critical analysis of *why* Indigenous Knowledge is threatened rarely moves beyond simplistic assertions that 'Elders are dying' or the assumption that IK systems are more vulnerable… because they are oral… The answers to how and why our knowledge has become threatened lie embedded in the crux of the colonial infrastructure (Simpson 2004).

With the aid of such depoliticization, and often under the guise of humanitarian concern, powerful Western institutions – corporate, academic, and legal – have joined together to "save" indigenous knowledges by documenting them before they disappear. The disappearance of indigenous peoples, their cultures, and languages, by contrast, is assumed to be inevitable. Thus are the rich contexts that constitute living indigenous knowledges reduced to texts. "Documenting and digitizing Indigenous Knowledge is a seemingly benign way of appearing to recover Traditional Indigenous Knowledge while at the same increasing access to the knowledge and vastly increasing the potential for its exploitation" (Simpson 2004).

It is a process that is both extractive and assimilative. What is held to be of value is removed and processed, made over in the image of knowledge as formulated within the dominant knowledge system, by methods which "seek to remove knowledge from the person, its proper place (location), and the process from which it is embedded… its context" (McGregor 2004). Indigenous agricultural and medicinal knowledge, along with traditional medicines, plant genetic resources and the cell-lines of the peoples themselves, are "discovered," processed in laboratories, legally transformed into private intellectual property, rendered as commodities and placed for sale. A pattern that began with indigenous land and tangible resources, continues now with indigenous knowledge. The response to these developments from indigenous communities, elders, activists, and scholars has been twofold: (1) a fierce resistance to and critique of such ongoing imperialism coupled with (2) a wide-ranging effort to recover and preserve indigenous knowledge systems and all that they inhere in – language, land, and culture.

The resistance begins with an insistence that this contemporary phase of colonization be recognized for what it is. Since the way in which knowledge is conceived has ethical and political implications, knowledge systems must be assessed in those terms. The tendency to abstract, isolate, and immunize the various "extractive" projects of the dominant knowledge system has been subjected to vigorous critique. Indigenists have insisted on contextualizing recent research initiatives like the Human Genome Diversity Project and the Genographic Project, both historically in terms of the impact of earlier comparable research as well as currently in terms of how such research is situated within powerful social alignments that perpetuate inequities. They have mounted strong advocacy internationally, within both political and legal fora, for the inclusion of broader human rights standards in scientific research. Individual tribes and tribal members have initiated lawsuits to protect genetic materials and resources. Throughout these struggles, extraordinarily effective use has been made of modern communication technologies to exchange information, to generate solidarity and to ensure publicity and exposure. Organizations like the Indigenous Peoples Council on Biocolonialism (IPCB) is representative of these efforts by indigenous peoples across the globe. The IPCB provides educational and technical support "to assist indigenous peoples in the protection of their genetic resources, indigenous knowledge, cultural and human rights from the negative effects of biotechnology" (►www.ipcb.org).

Resistance has spawned numerous projects of recovery. In article after article, indigenous scholars and activists speak of "an Indigenous renaissance," of how native peoples are "taking control of their destiny," of the "revitalization of aboriginal societies." Evidence for this is plentiful and promising. It includes a range of initiatives to take control of education through curricular development and the creation of tribally controlled programs and schools. These consist of various measures to restore indigenous languages, such as language immersion programs and internet classes. The connection between language preservation and knowledge preservation is often underscored.

> Our native language embodies a value system about how we ought to live and relate to each other… It gives a name to relations among kin, to roles and responsibilities among family members, to ties with the broader clan group… There are no English words for these relationships… if you destroy our languages you not only break down these relationships, but you also destroy other aspects of our Indian way of life and culture, especially those that describe man's connection with nature, the Great Spirit and the order of things" (Taylor 1992).

Efforts are also underway to revive spiritual ceremonies and protect the land and ecosystems that sustain indigenous peoples themselves. "The ecologies in which we live are more to us than settings or places; they…do not surround Indigenous peoples; we are an integral part of them and we inherently belong to them" (Battiste and Henderson 2000).

What is at stake in all of this is more than continued physical existence. "Survival for Indigenous peoples… is an issue of preserving Indigenous knowledge systems in the face of cognitive imperialism. It is a global issue of maintaining Indigenous worldviews, languages and environments…a matter of sustaining spiritual links with the land" (Battiste and Henderson 2000). Determined to replace the politics of disappearance with the politics of debate and dialogue, indigenous people, and communities worldwide are pursuing these and other strategies of resistance and recovery (Shiva 1993). "Disappeared" knowledge systems are political acts, ones of omission as much as commission, and assumptions that the disappearance of indigenous knowledge systems, languages and peoples are somehow inevitable often lie behind both. The indigenous response has been that nothing in this is foreordained. It is in our power to prevent further loss. "It was not inevitable that Western knowledge would conquer Indigenous knowledge, or that our ways of life had to end. At any point in history we could have worked jointly toward conditions that would facilitate the return of Indigenous ways of being while appreciating the knowledge that supported those ways. Even now this is not an impossible task" (Wilson 2004).

Extra 1: Indigenous American Knowledge Transmission

Native American societies have utilized various forms and technologies of representation and achievement in order to execute, preserve, and transmit knowledge of many kinds across time and space. Knowledge-bearing objects, from the near and distant past, are still found embedded in the landscapes of the Americas. Knowledge as embodied in objects, texts, images, and practices may also be found in great abundance in museum collections of material culture and, most importantly, in the modern lives of Native American peoples, sometimes openly shared with the world and sometimes confined to the kiva or other sacred tribal spaces.

Some workers in Indigenous Studies have followed the lead of other disciplines (such as Cultural Studies), broadening the theoretical notion of the "text" to include any "object of study" which has a semiotic or tacit component. This is a recognition that indigenous knowledge may be found in any cultural artifact capable of communicating meaning or of transmitting knowledge and culture, whether through language, image, implicit relationship, structure, procedure or performance. Thus, in its most broadly inclusive sense, the term "knowledge bearing text" may refer to story, dance, calendar, map, architecture, textiles, hunting and farming practice, rock art, trails, spaces, stone placement or any other form in which knowledge may be fixed, discerned or performed.

One important dimension of this approach is the assumption that indigenous knowledge traditions cannot be subsumed in particular language texts, whether written or spoken, or in single objects, such as a maps and quipus, or in environments, altered and constructed, or in performance, such as agricultural practice or dance. Rather, knowledge is only fully apprehended by exploring connection, relationship, kinship, and reciprocity. In Indigenous America, all knowledge is ecological – a multiplicity of narratives, local practices, artifacts, and ontologies taken together with their intersections and interactions, physical and cultural.

Extra 2: International Resolutions and Declarations

Over the last quarter century, there has been no shortage of documents, issued by a range of international organizations and conferences, which recognize the intellectual stature and continuing social validity of indigenous modes of thought. These reports, resolutions and declarations usually emphasize the integrity and value of traditional knowledge while also attempting to bring indigenous knowledge and modern science into a more productive, and at the same time more socially equitable, working relationship.

Efforts to achieve such a reconciliation are manifest across a broad spectrum of social practices, such as agriculture, health care, and environmental and resource management, raising important and difficult issues in relation to sustainable development, equity in resource governance, knowledge access and control, intellectual property rights, the maintenance of biological and cultural diversity, and more.

Such matters have remained a major concern of UNESCO, which has commissioned, over a period of time, a number of reports on knowledge, culture and development, all of which have taken strong positions opposing past policies of cultural assimilation, policies which have been viewed, almost universally by indigenous peoples, as culturally destructive and even genocidal. The rhetoric and content of these reports can be seen in the brief extracts given below from two major UNESCO documents appearing in 1981 and 1995.

More recent UNESCO declarations have explored forging new links between indigenous knowledge systems and Western techno-scientific knowledge. In a 1999 Declaration adopted by the World Conference on Science in Budapest (jointly sponsored by UNESCO and the International Council for Science (ICSU), this position was developed in some detail. (See extract below)

Such initiatives as that taken at the Budapest conference, while widely welcomed, have generated serious tensions on both sides of the knowledge divide. For example, when the ICSU General Assembly was asked to ratify the above Declaration, major doubts were voiced, suggesting that unqualified approbation of indigenous knowledge was likely to encourage the advocates of pseudosciences, like astrology and intelligent design. The GA resolutions then "reaffirmed its support for the values and methods of verifiable science" while recognizing that the "relation between traditional knowledge and modern science is both important and a highly complex political and sociological question that cannot be addressed in a few lines of a wide ranging document."

These developments led the ICSU to set up a Study Group to prepare a report giving the question more thorough examination. The Study Group report was issued in 2002 in two different formats both of which strongly reassert the original thrust of the Budapest Declaration, while providing guidelines for distinguishing between indigenous knowledge and the pseudosciences. The Study Group report also gives limited recognition to the importance of reversing the trend for the "gradual weakening and disappearance of traditional knowledge." (See below for links to both of these documents.)

Finally, it is must be noted that these Resolutions and Declarations have brought few significant benefits to indigenous cultures around the world. Indeed, some scholars have taken the position that such documents, however well intentioned, have simply expedited the exploitation of these peoples.

UNESCO: Report on Endogenous Development and the Transfer of Knowledge Extracts from: *Domination or Sharing?* (1981)

What sort of transfer of knowledge would it be that had as its purpose or consequence the stifling of the culture of such groups or peoples, that sought to impose uniformity upon them by forcing them to adopt a model or systems devised and developed by an elite or a dominant nation?

This was the failing of colonialism. The danger is the same today… we introduce them to ways of life, techniques and economic imperatives which have the effect of destroying their traditions, imprisoning them in a new state of dependence, preventing them from making their own distinctive contribution.

Thought should be given to the desirability for each country to determine the models, the systems of representations and values and the technical knowledge that have been supplanted by those imposed from abroad. Some ancient practices… are proving essential to further progress. Evidence of this is to be found in such different fields as agriculture, physical education, medicine, art and philosophy…. Everywhere the curtain is being lifted on civilizations which, only yesterday, were still despised by the West…. The objective is not merely to preserve the national heritage but… the rehabilitation of traditional forms of knowledge and, above all, of the potentialities which have been stifled by the pressure of the dominant countries or groups.

What is the possible starting point for this innovative effort?… On the one hand, traditional education transmits knowledge and systems of representations and values that are peculiar to a society or group but does not prepare the ground satisfactorily for the receipt of knowledge from abroad. On the other hand, models of education imported from dominant countries detract, deliberately or otherwise, from everything that has its origin in the basic culture, while encouraging those dominated to seek the particular type of education which, in their eyes, is the only avenue to advancement in the new society. If the transfer of knowledge is to offer any opportunity for endogenous creative activity, it must be fed with resources from within.

UNESCO: World Commission on Culture and Development Extracts from: *Our Creative Diversity* (1995)

Cultural ethnocide is the process whereby a culturally distinct people loses its identity… as the use of its language and social and political institutions, as well as its traditions, art forms, religious practices and cultural values, is restricted… The challenge today for nations committed to cultural pluralism and political democracy, is to develop a setting that ensures that development is integrative… and inclusive. This means respect for value systems, for the traditional knowledge that indigenous people have of their society and environment, and for their institutions in which culture is grounded.

If the communities of the world are to improve their human development options they must first be empowered to define their futures in terms of who they have been, what they are today and what they ultimately want to be. Every community has its roots, its physical and spiritual affiliations reaching back symbolically to the dawn of time, and it must be in a position to honor them. It is crucial that a people's understanding of its values, beliefs, and other cultural patterns be developed – in the first place by the people directly concerned.

Through centuries of living close to nature, indigenous peoples throughout the world have acquired detailed knowledge of their environment and its natural resources…. Equally, ecological concerns are embedded in their very struggles for survival, identity, autonomy, and in many cases democratic rights and governance. Who decides the fate of tribal culture and nature?

UNESCO: World Conference on Science – Budapest Extracts from: *The Declaration on Science and the Use of Scientific Knowledge*

Version adopted by the Conference (1 July 1999)

26. That traditional and local knowledge systems as dynamic expressions of perceiving and understanding the world, can make and historically have made, a valuable contribution to science and technology, and that there is a need to preserve, protect, research, and promote this cultural heritage and empirical knowledge,

38. There is also a need to further develop appropriate national legal frameworks to accommodate the specific requirements of developing countries and traditional knowledge, sources, and products, to ensure their recognition and adequate protection on the basis of the informed consent of the customary or traditional owners of this knowledge.

Extracts from *Science Agenda-Framework for Action*

Version adopted by the Conference (1 July 1999)

2.2 Science, environment and sustainable development.

32. Modern scientific knowledge and traditional knowledge should be brought closer together in interdisciplinary projects dealing with the links between culture, environment and development in such areas as the conservation of biological diversity, management of natural resources, understanding of natural hazards and mitigation of their impact. Local communities and other relevant players should be involved in these projects.

33. Governments, in co-operation with universities and higher education institutions, and with the help of relevant United Nations organizations, should extend and improve education, training and facilities for human resources development in environment-related sciences, utilizing also traditional and local knowledge. Special efforts in this respect are required in developing countries with the co-operation of the international community.

3.4 Modern science and other systems of knowledge

83. Governments are called upon to formulate national policies that allow a wider use of the applications of traditional forms of learning and knowledge, while at the same time ensuring that its commercialization is properly rewarded.

84. Enhanced support for activities at the national and international levels on traditional and local knowledge systems should be considered.

85. Countries should promote better understanding and use of traditional knowledge systems, instead of focusing only on extracting elements for their perceived utility to the S&T system. Knowledge should flow simultaneously to and from rural communities.

86. Governmental and nongovernmental organizations should sustain traditional knowledge systems through active support to the societies that are keepers and developers of this knowledge, their ways of life, their languages, their social organization and the environments in which they live, and fully recognize the contribution of women as repositories of a large part of traditional knowledge.

87. Governments should support cooperation between holders of traditional knowledge and scientists to explore the relationships between different knowledge systems and to foster interlinkages of mutual benefit.

See Figs. 1–5.

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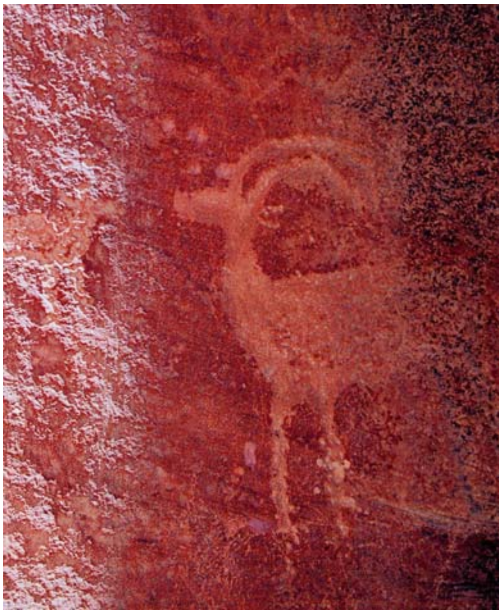
Knowledge Systems of Indigenous America. Fig. 1 Geometric Figures, Tsankawi Cave Dwellings, Bandelier National Monument, New Mexico (Photo by Wade Chambers).

Knowledge Systems of Indigenous America. Fig. 2 Human and Elk at Chevlon Canyon, Arizona, USA (Photo by Christopher Angeloni).

Knowledge Systems of Indigenous America. Fig. 3 Cosmological Panel petroglyph on sandstone, central Utah, USA (Photo by Christopher Angeloni).



Knowledge Systems of Indigenous America. Fig. 4 Bighorn at Capitol Reef National Monument, Utah, USA (Photo by Christopher Angeloni).

Knowledge Systems of Indigenous America. Fig. 5 Hunting panel on sandstone at Nine Mile Canyon, Utah, USA (Photo by Christopher Angeloni).

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Links to Relevant Websites

American Indian IKS Internet Resource Index: ►http://www.hanksville.org/NAresources/indices/NAknowledge.html
Alaska Native Knowledge Network: ►http://www.ankn.uaf.edu/ ►http://www.ankn.uaf.edu/publications/handbook/integrating.html
AAAS: Handbook on Intellectual Property and TEK: ►http://shr.aaas.org/tek/handbook/
Indigenous Peoples' Restoration Network: ►http://www.ser.org/iprn/default.asp
Indigenous Environmental Network: ►http://www.ienearth.org/
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Seventh Generation Fund: ►http://www.7genfund.org/index.html
Indigenous Knowledge Listserv: ►http://www.africa.upenn.edu/Listserv/Indigenous_Knowledge_13238.html
Native Tech Internet Resource: ►http://www.nativetech.org/
Infography: Indigenous Peoples' Knowledge Systems: ►http://www.infography.com/content/620138698080.html
Native Eyes Indigenous Studies: ►http://www.iaia.edu/nep2/index.php
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Science and Development Network – Indigenous Knowledge: ►http://www.scidev.net/dossiers/index.cfm?fuseaction=dossierfulltext&Dossier=7
Science and Development Network – Intellectual Property: ►http://www.scidev.net/dossiers/index.cfm?fuseaction=dossierItem&Dossier=8
Indigenous People's Biodiversity Network: Declaration on Biodiversity: ►http://www.ecouncil.ac.cr/rio/focus/report/english/ipbn.htm
Indigenous Peoples Council on Biocolonialism: ►http://www.ipcb.org/ ►http://www.ipcb.org/publications/other_art/bsinabs.html
Development Gateway: ►http://topics.developmentgateway.org/indigenous?goo=1744
Original ICSU Study Group Report: ►http://www.icsu.org/2_resourcecentre/RESOURCE_list_base.php4?rub=7
Joint ICSU & UNESCO version of Study Group Report: ►http://www.icsu.org/Gestion/img/ICSU_DOC_DOWNLOAD/65_DD_FILE_Vol4.pdf
UNESCO: 1999 Budapest Declaration: ►http://www.unesco.org/science/wcs/eng/declaration_e.htm
UNESCO: Science-Agenda Framework for Action: ►http://www.unesco.org/science/wcs/eng/framework.htm

UNESCO: Local and Indigenous Knowledge Systems: ►http://portal.unesco.org/sc_nat/ev.php?URL_ID=1945&URL_DO=DO_TOPIC&URL_SECTION=201

Columbia University CIESIN Agriculture IKS: ►http://www.ciesin.org/TG/AG/iksys.html

UNESCO: Indigenous Knowledge: Best Practice: ►http://www.unesco.org/most/bpikpub.htm#ik

Knowledge Systems: Indigenous Knowledge of Trees and Forests

Klaus Seeland, Mihir K. Jena

Trees and forests act as indicators of cultural phenomena when interpreted in the context of a society. Their sociocultural interpretation indicates specific social needs and cultural values, while stimulating culturally distinct economic and technological processes. Methodologically, it is difficult to understand what *trees and forests* mean in a particular culture, as they are descriptive terms, not analytic ones. They invoke aesthetic and religious perceptions, botanical and silvicultural classifications, and economic valuations. The indigenous perspective is always an amalgamation of these perceptions and valuations, which characterizes the development of the local culture (Harrison 1993; Bahuchet 1993) and even culture in general.

Forests represent a legacy and are a testimony to the evolution or migration of biological species, flora and fauna, in various societies. Forests, trees, and their products are managed by indigenous people, who are knowledgeable about local consumption, in largely self-sustained rural communities often located in remote areas. To make use of these resources and manage them, indigenous knowledge of trees and forests encompasses locally available renewable natural resources and social and spiritual energies. At the same time, scientifically based commercial forestry has a specialized professional knowledge of how to manage forest resources, predominantly the production of timber for a market economy. The dilemma in dealing with forests and their products is that the commercial and indigenous approaches each serve different interests of people living in different social worlds. What "forest" and "knowledge of forests" mean to members of any culture are reflections of their worldview and traditions, which vary according to their different stages of economic and technological development. This knowledge goes beyond technical (i.e. botanical) knowledge, hunting skills, wood harvesting know-how, or non-timber forest product usage.

More than two decades ago, indigenous technical knowledge became an important topic in the debate over the economically and culturally sound development of communities, based on self-sustained agriculture in Third World countries (Brokensha et al. 1980). Ever since then, it has predominantly been discussed with regard to the development of appropriate new agricultural techniques, rather than the application of existing traditional ones that were once part and parcel of a self-sustaining mode of production (Warren et al. 1995). "Indigenousness" refers to something that originates locally in natural surroundings and is performed by a native community. It emerges in the form of an ethnic community's perceptions and experiences within their environment and continues as a process of observation and interpretation in relation to the locally acknowledged everyday rationalities and transcendental powers. Indigenousness constitutes a context of local social performance that makes sense between people who share a common rural habitat, language, and knowledge, be it exoteric (open to all) or esoteric (secret knowledge). Indigenous knowledge of trees and forests is a very important part of human life experience in a distinct and unique local setting. The local context is perceived as the universal framework in which knowledge matters, and is an authentic representation of being. This context is comprised physical facts and social interactions among people in the surroundings they perceive as their material world, and it combines with spiritual beliefs. Indigenous knowledge of trees and forests is not taught formally, but is an inherited or individually acquired configuration of knowledge, skills, know-how, and practical experience that grows inside this encapsulated world. It is bound to the environmental context and is acquired from and makes use of the local surroundings. The acquisition of indigenous knowledge is generally guided by utilitarian considerations. It is neither shared equally among all of the inhabitants of a locality nor is it a standardized and comprehensive account of *what is known*; it varies, sometimes tremendously. Often gender-specific knowledge separates what is known among people of the same area into different worlds. Indigenous knowledge is applied at the level of human senses – such as seeing, touching, and feeling – as well as by remembering natural phenomena. To our knowledge, there is no published record of indigenous people being interested in the traditional or local knowledge of another forest dwelling community. Knowledge for the sake of knowledge mostly does not exist in an indigenous community; curiosity – about flora, fauna, or other natural phenomena that do not have any practical value – is rare.

There is always a fundamental basis of inherited knowledge in every community, representative of the society in its typical geographical and climatic surroundings, that is individually interpreted, modified, and passed on for generations. The experience and knowledge of a people's ancestors are generally passed down orally to the younger generations, but increasingly often this transmission is limited by cultural change. Indigenous knowledge of trees and forests consists of a rather solid fund of knowledge, although the pace at which environmental conditions change may vary, becoming slower or quicker in the wake of social and cultural evolution. Devaluation of indigenous knowledge can have many causes: intruding alternative lifestyles, new modes of production, and degradation of important natural resources, as well as forest dwellers' being displaced into territories unknown to them or their world's being affected by laws and modernisation from outside.

The world of a forest dwelling community is an encompassing natural and social entity, a configuration of related natural and spiritual phenomena that gives cultural meaning to a particular location (Ballée 1994; Descola 1994; Jena et al. 2002). These entities are linked, for example, by language, using identical terms as metaphors for the same objects or symbols. Employing certain plants or animals or natural phenomena to represent supernatural, religious phenomena make up a common context or a sacred landscape.

A tree or forest is – in any society, and particularly in traditional non-Western societies – a matter of definition based on cultural values and perceptions. For instance, trees are venerated and deified as sacred phenomena in animistic cults. Or they are worshipped as representations of deities in more complex religions based on Holy Scriptures and an extensive iconography, as, for example, in Hinduism, where tulsi (*Ocimum basilicum* L.) is considered a sacred "tree" in which the Hindu god, Vishnu, resides. In other cultures, they are perceived as beautifying elements in a landscape or garden or simply as biomass or an economic commodity. In still other cultures, trees are predominantly viewed in terms of their functions, such as providing shade or shelter. In many forest dwellers' cultures there is kinship among humans, plants, and animals, either in the form of clan totems that regulate the social structure of a community or of symbolic marriages between humans and plants or animals. Rituals in which forest plants and animals play a significant role are based on the nature-based cosmogony of a forest dwelling community. Forests can be hunting grounds, wild gardens or swidden patches amidst the primeval forest, foraging grounds, sacred groves or some combinations of uses for indigenous communities.

The following example involves the Kuttia Kondh (Jena et al. 2006), a forest dwelling tribe in Orissa (India). The Kuttia Kondh perception of the life cycle of a tree is quite close to that of natural science.

The Kuttia Kondh are aware of the life cycle of a tree, because of the different changes that occur during its growth, described as a sequential process. At the time of birth, unlike human beings and animals, plants do not have a distinct shape and they are virtually indistinguishable from one another. During the later stages of growth, however, new structures (organs) evolve. Animals and human beings, in contrast, have structural (organ) limitations, and over time their organs age but do not change. In short, at birth the plants are all alike, but at later stages of growth they develop different characteristics and thus become distinct plants. The phenomenon of the birth of plants is known as *sate* (emerging from the earth) and the birth of animals and human beings is *pdite* (coming out of genital organs).

The changes observed in the lifespan of plants are described in the Kui language. Planting or dibbling a seed in the earth is known as *penka mete*, when the germinating seed breaks through the upper soil layers it is known as *tana genjite*, and when it emerges from the soil it is known as *kana aate*. The stage when foliage appears is termed *aaku gate*. The growth of shoots is *peda late*, and the emergence of inflorescence, a tree's floral axis, *tula parite*. The flowering stage is called *punga pute*, while the shedding of petals is known as *punge dumbite*. *Padasi kadgai ate* refers to the early fruiting stage. *Padasi juri ate* refers to the fruit maturation stage. Finally, the fruit drying stage is known as *padasi bachite*, and the bursting of fruit to scatter seeds is known as *penka ate*.

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The Kuttia Kondh claim that the different stages from *penka mete* to *penka ate* describe the life cycle of a plant/tree, from the pre-germination to the post-germination phase. Trees are bound to a certain locality and, therefore, appear to be constant. The Kuttia people believe that trees are formed more than once within their life cycle, however, and that consequently what distinguishes plants from animals/humans is that, relative to a specific locality, the former are believed to go through a sequence of lives, while the latter live only one life from birth to death.

The life cycle of a plant is dependent upon water. According to the Kuttia Kondh, water is the most fundamental element necessary for a plant's survival. The skin (*palla*) and the plant's internal water transportation system (*lenja*) keep the water in the plant. If *lenja* is not working, *palla* can still absorb water; but if *palla* is absent, the water absorbed by *lenja* evaporates. The Kuttia Kondh believe that any abnormality occurring in the plant is due to a failure of the water transport system; for example, the drying up of a tree or parts of a tree comes from inadequate water absorption. *Paskadi* is a disease caused by the irregular swelling of parts of a plant as a result of a blockage in the water supply to the affected areas. *Bachine* refers to the drying up of a plant due to the lack of a water supply from the roots. *Kita bachine* is the drying of one part of the plant, and *pakodake bachine pakodake silali* refers to the drying of one lateral half of it while the other part remains alive.

Their understanding of the relationship between water and *palla* is demonstrated by a technique known as "girdling", which is used by the tribe to kill a tree. The Kuttia do not fell large trees. Instead, they use a labour-saving technique that involves the removal of a ring of bark at the tree base. The tree dies after a few days. The death of trees and plants following the removal of the *palla* is known as *mara grudu sate*, literally meaning "tree full dead". *Eju* (water), *daki* (the root base), and *palla* give plants and trees *jella* (life force). *Eju* is a metaphor for *jella*, which is believed to move up and down in the infant stage of plants. *Eju* is thought to become stationary at *daki* when the plants attain maturity. It is thus considered that *palla* and *jella* are mutually supportive and cannot survive without each other. The tree survives or perishes according to the relationship between *jella* and *palla*.

Now let us look at how the same community classifies its forest world. The type of natural vegetation growing on the hilltops has a particular significance for the Kuttia Kondh. They regard their hill god (*Soru penu*) as being solely responsible for the distribution of such vegetation. They believe that the god of the forest, usually named after a hill, bases his decision about the type of tree species that will grow there on the locality. It is claimed that he favours a tall tree on a hilltop for his abode, where he can enjoy the first touch of virgin rain. This provides an excellent vantage point for observing the lives of the villagers living at the foot of the hill. He uses the network of tree creepers to move from one place to another inside the forest, meeting the other *penus* and discussing the welfare of the Kuttia Kondh. He allows the growth of the grass at the base of the trees to make the forest floor softer so that divine beings can roam around freely.

Bati

The term *bati* has several meanings. *Bati* is the most common name for the forest, yet the term also refers to bushy vegetation, including undergrowth, shrubs, creepers, and herbs that lie between the foothills and hill slope areas. The Kuttia Kondh consider this to be forest in its primeval state. They also believe that the spreading branches of the trees (*kena*) inside the *bati* provide space for small plants to flourish (*ningine*). Their perception of the *bati* is that its vegetation grows quickly in soft soil (*dea vira*) that has an abundant water supply (a supply which is greater than that of the *kambani*, as its rainfall is supplemented by water runoff from the hilltop). The fertility of the *bati* is also enhanced by the many fast growing species which, after atrophying, add to the fertility of the soil.

The enormously varied fauna inside of the *bati* includes snake (*rachu*), such as the python (*masi*), monitor lizard (*boda*), porcupine (*saju*), pangolin (*jerandi*), many different varieties of bird, jungle fowl, peacock, rabbit, deer (*kateri*), and the occasional bear. The Kuttia Kondh believe that the larger snakes favour the coolness of the *bati*. The snakes feed on mice and fowl. The pangolin and porcupine are known to create underground burrows.

Umda (Grove)

This term is used to describe a patch of forest surrounded by rocky or barren land. *Umda* is commonly found on hilltops noted for their rocky, stony ground. The vegetation in such surroundings generally is comprised *Ficus benghalensis*, *Ficus religiosa*, and *Ficus scandens* (which are naturally dominant) along with *Terminalia tomentosa*, *Buchanania lanzan*, *Shorea robusta*, *Pterocarpus marsupium*, and *Acacia pinnata*. The term *umda*, however, is not restricted to this particular territory. Other small patches of forest found in non-rocky areas containing a wide variety of small trees and plant species (*ladenga*) at the centre of an open space are also called *umda*.

Tuleni (Burial Ground)

The term *tuleni* refers to an area of forest used by the Kuttia Kondh as a burial ground. A remote patch of land is chosen as a suitable site, as it is not clear whether the spirits of the dead roaming the *tuleni* will be malevolent or benevolent, and all forms of human interference should be limited. As a result, visitors to the *tuleni* are rare. Among the different plant species growing here, the sal tree (*Shorea robusta*) is given special status, as it is believed to be the abode of the *Dukeli penu* (god of ancestral spirits), the god most closely associated with the *tuleni*. Because firewood collection, tree felling, and the harvest of resins and edible products are activities that have traditionally been, and still are, prohibited within these areas, the sal trees have remained virtually undisturbed. The dead are considered to be forest dwellers (*kambanate*) and taking anything from the *tuleni* is considered to be synonymous with depriving the ancestral spirits of the food on which they subsist. The Kuttia Kondh are aware that so much as picking a leaf or snapping a twig inside the *tuleni* is taboo. There are three exceptions to this general rule. First of all, certain medicinal plants that are considered highly effective remedies for particular diseases are rarely collected in the *tuleni* by anyone other than the medicine man (*Kutaka*), who has the Dukeli penu's permission to use certain herbs and roots. Secondly, the funeral rites conducted by the village priest (*Jani*) involve breaking a brush stick to offer to the dead person; then with permission from the dead person's spirit, others can break brush sticks. Thirdly, the wood used for cremation is collected inside the *tuleni*, because wood from other areas is forbidden inside the *tuleni*. These taboos are believed to have existed since the times of the earliest settlements, and gradually certain myths have evolved concerning these lone virgin patches of wilderness. The fear felt by the Kuttia Kondh has ensured that such restrictions are upheld, which in turn guarantees the preservation of vegetation inside the *tuleni*.

A large variety of animals roam in this forest, such as deer, mouse deer, porcupine, sambar (*Cervus unicolor*), and boar. Yet hunting inside the *tuleni*, although not prohibited, is rare. On these occasions, the Kuttia Kondh hunt during daylight hours and as a group, rather than individually, for fear that ghosts and spirits may infect them with a fatal illness. During burial or cremation ceremonies, the village attendants pray to *Dukeli penu* so that he will provide them with sufficient game, even on a hunting expedition that takes place during the mourning period (*Dasah*) between the third and seventh day after a death. If *Dukeli penu* is satisfied with their prayer, the hunt is a success.

The villagers rarely move the location of the *tuleni*, for they believe that by doing so they disturb the spirits of their ancestors. The few circumstances that force them to abandon a site include an outbreak of a plant disease, the spread of certain parasite creepers (*Gachchi*), and forest fire (to which the sal species is especially susceptible). The leasing of forest patches by government departments to outsiders is also another reason for their abandonment of the *tuleni*. The Kuttia Kondh are required to ask permission from the *Dukeli penu* before deserting the site. The *tuleni* is not associated with any particular location, although it must be situated on a hill or in a forest and kept at a reasonable distance from any settlement.

Katani (Hill Forest)

In Kui, the language of the Kuttia Kondh, the term “wild” (*boti ne ajine*) has a number of definitions in reference to a description of the forest. In general, however, the wilder a forest, the greater the growth of vegetation and the presence of animals. According to the Kuttia Kondh’s definition, a forest is particularly wild when the concentration of trees is dense enough to prevent the penetration of sunlight (*ujada*). They also believe that trees compete among themselves as to who can grow closest to the sky (*wani*). The term *Katani* also means “wild”, and here it refers to wild vegetation, rather than to the presence of certain species of plants or animals. The *Katani* is a “four storied forest”. The ground cover consists of wild grass (*randa*) and herbs, the second storey is comprises bushes, and the third and fourth floors are or have *bati* and *kambani*, respectively.

What seems to be the most relevant appeal of indigenous knowledge of trees and forests emerging out of the principles of a local subsistence economy is a certain amount of political independence. The use of local indigenous knowledge of trees and forests spares forest dwellers from being turned into clients of the state administration, at least not the elder ones; right or wrong, they stick to their own traditions and customs (Seeland and Schmithüsen 2000). In periods of deregulation and decreased administrative capacity, an independent, self-sufficient social performance is very important.

The recent history of the expropriation of tribal societies by post-colonial nations is, in most cases, a depressing account of environmental colonialism, where ethnic sections of young developing nations are pauperized and expelled from their territories. They often vanish with the forests they used to live in. The knowledge of forest dwellers and poor peasants thus becomes the legacy of a cultural heritage and tradition that shaped the face of the forests. It is from here that some of today’s cultures originate.

The attempt at integrating indigenous knowledge of trees and forests into the development process of a society in transition would be naïve the society not to recognize the massive political obstacles confronting it. Contemporary environmental problems attempt to find solutions which are an up-to-date match to them (Seeland and Schmithüsen 2003). Although it may sound odd to some people, the traditional indigenous knowledge of past generations can be a valid match for today’s problems. Not only does it contain environmental knowledge in a technical sense, it also holds the accumulated wisdom of cultural traditions that have messages for those who are ready to listen to them. Although they lack the political bargaining power essential today, indigenous resource users and their knowledge may survive and be helpful in times of administrative deregulation and facilitate responsible management of resources in the regions where they live.

See also: ►Timber in Japan

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Selected Websites for Further Reading and References

► http://www.iifm.org/databank/ef/ethnoforestry.html
► http://lucy.ukc.ac.uk/rainforest/malon.html

Knowledge Systems: Local Knowledge

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The concept of local knowledge has recently come to the fore in the field of the sociology of scientific knowledge, where it is a common empirical finding that knowledge production is an essentially local process. Knowledge claims are not adjudicated by absolute standards; rather their authority is established through the workings of *local* negotiations and judgments in particular contexts. This focus on the localness of knowledge production provides the condition for the possibility for a fully fledged comparison between the ways in which understandings of the natural world have been produced by different cultures and at different times. Such crosscultural comparisons of knowledge production systems have hitherto been largely absent from the sociology of science. A necessary condition for fully equitable comparisons is that Western contemporary technosciences, rather than being taken as definitional of knowledge, rationality, or objectivity, should be treated as varieties of such knowledge systems. Though knowledge systems may differ in their epistemologies, methodologies, logics, cognitive structures, or in their socioeconomic contexts, a characteristic that they all share is their localness. Hence, in so far as they are collective bodies of knowledge, many of their small but significant differences lie in the work involved in creating assemblages from the "motley" of differing practices, instrumentation, theories, and people (Hacking 1992). Much of that work can be seen as strategies and techniques for creating the equivalences and connections whereby otherwise heterogeneous and isolated knowledges are enabled to move in space and time from the local site and moment of their production and application to other places and times.

In this view, all knowledge systems from whatever culture or time, including the contemporary technosciences, are based on local knowledge. However within the master narrative of modernism, local knowledge is an oxymoron. Exploring this contradiction and the manifold meanings of local requires a brief excursion into postmodernism as well as some of the arguments underpinning the sociology of scientific knowledge.

Though postmodernism eludes definition and is more likely a stage of modernism than a marked epistemological break, there has been a recent coalescence of strands of thought in a wide variety of areas that have questioned the assumptions underlying modernism. Postmodernism is most frequently equated with the collapse of the concepts of rationality and progress held to accompany the emergence of the postindustrial society and is consequently concerned with the rejection of universal explanations and totalizing theories. But perhaps the strand that is most truly pervasive in the constellation of reformulated approaches to understanding the human condition is the emphasis on the local.

In physics, ecology, history, feminist theory, literary theory, anthropology, geography, economics, politics, and sociology of science, the focus of attention has become the specific, the contingent, the particular. This is the case whether it is a text, a reading, a culture, a population, a site, a region, an electron, or a laboratory. Within this diversity of uses of local there seem to be two broad and rather different senses being used. On the one hand there is the notion of a voice or a reading. The voice may be purely individual and subjective or may be a collection of voices belonging to a group, class, gender, or culture, but in all cases the notion captures one of the basic characteristic elements of postmodernism, courtesy of deconstruction, that all texts or cultures are multivocal and polysemous. That is they have a multiplicity of meanings, readings and voices and are hence subject to "interpretive flexibility" (Collins 1985). On the other hand, local is used both in the more explicitly geopolitical sense of place and in the experiential sense of contextual, embodied, partial, or individual. A range of disciplines from meteorology to medicine now recognize the necessity of focusing on the particular conditions at specific sites and times rather than losing that specificity in unlocalized generalizations.

The sociology of scientific knowledge is one of the most classically post of all modernisms and is therefore an area in which the local is also a thematic presence which is only now coming into focus. Some philosophers of science have come to re-evaluate the role of theory and argue that scientists practicing in the real world do not deduce their explanations from universal laws but rather make do with rules of thumb derived from the way the phenomena present themselves in the operation of instruments and devices. Similarly philosophers and sociologists of science alike have recognized for some time the lack of absolute standards and the role of tacit knowledge in technoscientific practice, and have sought to display the context in which the practice of science is manifested as craft skills and collective work. However the recognition of the social and material embodiment of skills and work in the cultural practice of individuals and groups has only recently coalesced into the general claim that all knowledge is local. Knowledge, from this constructivist perspective can be local in a range of different senses. “It is knowledge produced and reproduced in *mutual interaction* that relies on the *presence* of other human beings on a direct, face-to-face basis” (Thrift 1985). It is knowledge that is produced in contingent, site, discipline, or culture specific circumstances (Rouse 1987). It is the product of open systems with heterogeneous and asynchronous inputs “that stand in no necessary relationship to one another” (Pickering 1992). In sum scientific knowledge is “situated knowledge” (Haraway 1991).

Perhaps the most important consequence of the recognition of the localness of scientific knowledge is that it permits a parity in the comparison of the production of contemporary technoscientific knowledge with knowledge production in other cultures. Previously the possibility of a truly equitable comparison was negated by the assumption that indigenous knowledge systems were merely local and were to be evaluated for the extent to which they had scientific characteristics. Localness essentially subsumes many of the supposed limitations of other knowledge systems compared with western science. So-called traditional knowledge systems have frequently been portrayed as closed, pragmatic, utilitarian, value laden, indexical, context dependent, and so on. All of which was held to imply that they cannot have the same authority and credibility as science because their localness restricts them to the social and cultural circumstances of their production. Science by contrast was held to be universal, nonindexical, value free, and as a consequence floating, in some mysterious way, above culture. Treating science as local simultaneously puts all knowledge systems on a par and renders vacuous discussion of their degree of fit with transcendental criteria of scientificity, rationality, and logicality. Now the multidisciplinary approaches to understanding the technosciences which together constitute the sociology of scientific knowledge can be made more fully anthropological by the addition of a new subdiscipline called comparative technoscientific traditions.

Emphasizing the local in this way necessitates a reevaluation of the role of theory which is typically held by philosophers and physicists to provide the main dynamic and rationale of science as well as being the source of its universality. Karl Popper claims that all science is cosmology and Gerald Holton sees physics as “a quest for the Holy Grail,” which is no less than the “mastery of the whole world of experience, by subsuming it under one unified theoretical structure” (Allport 1991). It is this claim to be able to produce universal theory that Western culture has used simultaneously to promote and reinforce its own stability and to justify the dispossession of other peoples. It constitutes part of the ideological justification of scientific objectivity, the “god-trick” as Donna Haraway calls it; the illusion that there can be a positionless vision of everything. The allegiance to mimesis has been severely undermined by analysts like Richard Rorty, but theory has also been found wanting at the level of practice, where analytical and empirical studies have shown it cannot provide the sole guide to experimental research and on occasion has little or no role at all. The conception of grand unified theories guiding research is also incompatible with a key finding in the sociology of science: “consensus is not necessary for cooperation nor for the successful conduct of work.” This sociological perspective is succinctly captured in Leigh Star’s description:

> Scientific theory building is deeply heterogeneous: different viewpoints are constantly being adduced and reconciled… Each actor, site, or node of a scientific community has a viewpoint, a partial truth consisting of local beliefs, local practices, local constants, and resources, none of which are fully verifiable across all sites. The aggregation of all viewpoints is the source of the robustness of science (Star 1989, 46).

Theories from this perspective have the characteristics of what Star calls “boundary objects”; that is they are “objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites.” Thus theorizing is itself an assemblage of heterogeneous local practices.

If knowledge is local we are faced with a problem: how are the universality and connectedness that typify technoscientific knowledges achieved? Given all these discrete knowledge/practices, imbued with their concrete specificities, how can they be assembled into fields or knowledge systems; or in Star’s terms “how is the robustness of findings and decision making achieved?” Ophir and Shapin ask, “How is it, if knowledge is indeed local, that certain forms of it appear global in domain of application?” The answers, considered here, lie

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in a variety of social strategies and technical devices that provide for treating instances of knowledge/practice as similar or equivalent and for making connections, that is in enabling local knowledge/practices to move and to be assembled.

Research fields or bodies of technoscientific knowledge/practice are assemblages whose otherwise disparate elements are rendered equivalent, general, and cohesive through processes that have been called "heterogeneous engineering" (Law 1987). Among the many social strategies that enable the possibility of equivalence are processes of standardization and collective work to produce agreements about what counts as an appropriate form of ordering, what counts as evidence, etc. Technical devices that provide for connections and mobility are also essential. Such devices may be material or conceptual and may include maps, calendars, theories, books, lists, and systems of recursion, but their common function is to enable otherwise incommensurable and isolated knowledges to move in space and time from the local site and moment of their production to other places and times.

Some of these devices have been revealed relatively unproblematically through direct observation. Others are less susceptible to investigation and analysis, being embodied in our forms of life. One way to catch a glimpse of these hidden presuppositions and taken for granted ways of thinking, seeing, and acting, is to misperceive, to be jolted out of our habitual modes of understanding through allowing a process of interrogation between our knowledge system and others. Such an interrogative process of mutual intertranslation can enable us to catch sight of the cultural glasses we wear instead of looking through them as if they were transparent.

This challenging of the totalizing discourses of science by other knowledge systems is what Foucault had in mind when he claimed that we are "witnessing an insurrection of subjugated knowledges" and corresponds to an emphasis on the local that has emerged in anthropology at least since Clifford Geertz's *Interpretation of Cultures*. In his critique of global theories and in his emphasis on "thick description" Geertz pointed out that cultural meanings cannot be understood at the general level because they result from complex organizations of signs in a particular local context and that the way to reveal the structures of power attached to the global discourse is to set the local knowledge in contrast with it.

Equally there is the pervasive recognition characterized as postcolonialism that the West has structured the intellectual agenda and has hidden its own presuppositions from view through the construction of the other. Nowhere is this more acute than in the assumption of science as a foil against which all other knowledge should be contrasted. In the view of Marcus and Fischer we are at an experimental moment where totalizing styles of knowledge have been suspended "in favour of a close consideration of such issues as contextuality, the meaning of social life to those who enact it and the explanation of exceptions and indeterminants." In this emphasis on the local we are postparadigm.

However we should not be too easily seduced by the apparently liberating effects of celebrating the local since it is all too easy to allow the local to become a "new kind of globalizing imperative" (Hayles 1990). In order for all knowledge systems to have a voice and in order to allow for the possibility of intercultural comparison and critique, we have to be able to maintain the local and the global in dialectical opposition to one another. This dilemma is the most profound difficulty facing liberal democracies now that they have lost the convenient foil of communism and the world has Balkanized into special interest groups by genders, race, nationality, or whatever. By moving into a comparatist mode there is a grave danger of the subsumption of the other into the hegemony of western rationality, but conversely unbridled cultural relativism can only lead to the proliferation of ghettos and dogmatic nationalisms. We cannot abandon the strength of generalizations and theories, particularly their capacity for making connections and for providing the possibility of criticism. At the same time we need to recognize reflexively that theory and practice are not distinct. Theorizing is also a local practice. If we do not recognize this joint dialectic of theory and practice, the local and the global, we will not be able to understand and establish the conditions for the possibility of directing the circulation and structure of power in knowledge systems. It is in the light of this recognition that I want to consider the ways in which the movement of local knowledge is accomplished in different knowledge systems and their consequent effects on the ways in which people and objects are constituted and linked together; that is their effects on power. The essential strength of the sociology of scientific knowledge is its claim to show that what we accept as science and technology could be other than it is. The great weakness of the sociology of scientific knowledge is the general failure to grasp the political nature of the enterprise and to work toward change. With some exceptions it has had a quietist tendency to adopt the neutral analyst's stance that it devotes so much time to criticizing in scientists. One way of capitalizing on the sociology of science's strength and avoiding the reflexive dilemma is to devise ways in which alternative knowledge systems can be made to interrogate each other.

Considerable advances in understanding the movement of local knowledge have been made possible through Bruno Latour's insightful analysis. For Latour the most successful devices in the agonistic struggle are those which are mobile and also "immutable, presentable, readable, and combinable with one another." These immutable mobiles are the kinds of texts and images that the printing press and distant point perspective have made possible. These small and unexpected differences in the technology of representation are on his account the causes of the large and powerful effects of science. That which was previously completely indexical, having meaning only in the context of the site of production, and having no means of moving beyond that site, is standardized and made commensurable and representable within the common framework provided by distant point perspective. Hence that which has been observed, created, or recorded at one site can be moved without distortion to another site. At centers of calculation such mobile representations can be accumulated, analyzed, and iterated in a cascade of subsequent calculations and analyses.

Latour's account has been augmented by the work of Steven Shapin and Simon Schaffer in the *Leviathan and The Air Pump* (1985). They have shown that experimental practice in science is sustained by a range of social, literary, and technical devices and spaces that we take for granted but which had to be created deliberately to overcome the fundamentally local and hence defeasible character of experimentally derived knowledge claims. In the seventeenth century, the problem for Robert Boyle, one of the earliest experimentalists, was to counter the arguments of his opponent Thomas Hobbes about the grounding of true and certain knowledge which they both agreed was essential in a country riven by dissent and conflicting opinion. Reliable knowledge of the world, for Hobbes, was to be derived from self-evident first principles, and anything that was produced experimentally was inevitably doomed to reflect its artifactual nature and the contingencies of its production; its localness would deny it the status of fact or law. Boyle recognized the cogency of these arguments and set out to create the forms of life within which the knowledge created at one site could be relayed to and replicated at other sites. In order for an empirical fact to be accepted as such it had to be witnessable by all, but the very nature of an experimental laboratory restricted the audience of witnesses to a very few. Boyle, therefore, had to create the technology of what Shapin calls virtual witnessing. For this to be possible three general sorts of devices or technologies had to be developed. Socially groups of reliable witnesses had to be formed. Naturally in the seventeenth century they were gentlemen. These gentlemen witnesses had to be able to communicate their observations to other groups of gentlemen so that they too might witness the phenomena. This required the establishment of journals using clear and unadorned prose that could carry the immutable mobiles, experimental accounts, and diagrams. The apparatus had to be made technically reliable and reproducible, but perhaps most importantly the physical space for such empirical knowledge had to be created.

Hobbes, of course, was right: experimental knowledge is artifactual. It is the product of human labor, of craft and skill, and necessarily reflects the contingencies of the circumstances. It is because craft or tacit knowledge is such a fundamental component of knowledge production that accounts of its generation, transmission, acceptance, and application cannot be given solely in terms of texts and inscriptions. A vital component of local knowledge is moved by people in their heads and hands. Harry Collins, a sociologist of science, has argued that this ineradicable craft component in science is ultimately what makes science a social practice. Because knowledge claims about the world are based on the skilled performance of experiments their acceptance is a judgment of competence not of truth. An example of the centrality of craft skill is the TEA laser, invented in Canada by Bob Harrison in the late sixties, which British scientists attempted to replicate in the early seventies. "No scientist succeeded in building a laser using only information found in published or other written sources" and furthermore the people who did succeed in building one were only able to do so after extended personal contact with somebody who had himself built one. Now TEA lasers are blackboxed and their production is routine and algorithmic. But in order to become routinized, Harrison's local knowledge had to be moved literally by hand.

Joseph Rouse (1987, 72) in considering the contemporary production process of scientific knowledge has summarized the implications of this understanding of science:

> Science is first and foremost knowing one's way about in the laboratory (or clinic, field site etc.). Such knowledge is of course transferable outside the laboratory site into a variety of other situations. But the transfer is not to be understood in terms of the instantiation of universally applied knowledge claims in different particular settings by applying bridge principles and plugging in particular local values for theoretical variables. It must be understood in terms of the adaptation of one local knowledge to create another. We go from one local knowledge to another rather than from universal theories to their particular instantiations.

According to the historian of science Thomas Kuhn the way a scientist learns to solve problems is not by applying theory deductively but by learning to apply theory through recognizing situations as similar. Hence theories are models or tools whose application results from situations being conceived as or actually being made equivalent. This point is implicit in the recognition that knowledge produced in a laboratory does not simply reflect nature because nature as such is seldom available in a form that can be considered directly in the lab. Specially simplified and purified artifacts are the typical subject of instrumental analysis in scientific laboratories. For the results of such an artificial process to have any efficacy in the world beyond the lab, the world itself has to be modified to conform with the rigors of science. A wide variety of institutional structures have to be put in place to achieve the equivalences needed between the microworld created inside the lab and the macroworld outside in order for the knowledge to be transmittable. The largest and most expensive example of this is the Bureau of Standards, a massive bureaucracy costing six times the R&D budget. Without such social institutions the results of scientific research are mere artifacts. They gain their truth, efficacy, and accuracy not through a passive mirroring of reality but through an active social process that brings our understandings and reality into conformity with each other.

The result of the work of Latour, Collins, Shapin, Star, Hacking, Rouse, and others has been to show that the kind of knowledge system we call Western science depends on a variety of social, technical, and literary devices and strategies for moving and applying local knowledge. It is having the capacity for movement that enables local knowledge to constitute part of a knowledge system. This mobility requires devices and strategies that enable connectivity and equivalence, that is the linking of disparate or new knowledge and the rendering of knowledge and context sufficiently similar as to make the knowledge applicable. Connectivity and equivalence are prerequisites of a knowledge system but they are not characteristics of knowledge itself. They are produced by collective work and are facilitated by technical devices and social strategies. Differing devices and strategies produce differing assemblages and are the source of the differences in power between knowledge systems.

In conclusion, it has been argued that Western science, like all knowledge in all societies, is inherently local, and furthermore other non-Western societies have developed a variety of social and technical devices for coping with that localness and enabling it to move. Some of them are technical devices of representation like the mason's templates, and the Incan *ceques* and *quipus*. Some of them are abstract cognitive constructs, like the Anasazi and Incan calendars, and the Micronesian navigation system. All of them also require social organization, rituals, and ceremonies. All of them have proved capable of producing complex bodies of knowledge and in many cases have been accompanied by substantial transformations of the environment. The major difference between Western science and other knowledge systems lies in the question of power. Western science has succeeded in transforming the world and our lives in ways that no other system has. The source of the power of science on this account lies not in the nature of scientific knowledge but in its greater ability to move and apply the knowledge it produces beyond the site of its production. However at the end of the twentieth century we can now perceive that there is a high cost to pay for science's hegemony. Much of that cost in terms of environmental degradation and ethnocide is due not so much to the totalizing nature of scientific theories but to the social strategies and technical devices science has developed in eliminating the local.

The task of resisting and criticizing science may now be addressed by reconsidering the causes of its dominating effects. Without the kinds of connections and patterns that theories make possible we will never be able to perceive the interconnectedness of all things. Without the awareness of local differences we will lose the diversity and particularity of the things themselves. Thus, rather than rejecting universalizing explanations what is needed is a new understanding of the dialectical tension between the local and the global. We need to focus on the ways in which science creates and solves problems through its treatment of the local. Science gains its truthlike character through suppressing or denying the circumstances of its production and through the social mechanisms for the transmission and authorization of the knowledge by the scientific community. Both of these devices have the effect of rendering scientific knowledge autonomous, above culture, and hence beyond criticism. Equally problematic is the establishment of the standardization and equivalences required in order that the knowledge produced in the lab works in the world. The joint processes of making the world fit the knowledge instead of the other way round and immunizing scientific knowledge from criticism are best resisted by developing forms of understanding in which the local, the particular, the specific, and the individual are not homogenized but are enabled to talk back.

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Knowledge Systems of the Olmec

Carolyn E. Tate

People in Formative Period Mesoamerica (2000–250 BCE) developed an array of empirical knowledge and technological adaptations that became the foundation for the later great civilizations. These included domesticated plants, skilled ceramic production, lithic technologies, and long-distance travel and trade.

This essay will focus on the little-studied topic of Olmec knowledge of the human body. It uses as evidence the hundreds of Olmec three-dimensional sculptures of the human figure in stone and clay (Fig. 1). Apparently the Olmec recorded their empirical observations about the process of human gestation and about the innate energies of the adult human body in many kinds of sculptures (Fig. 2). The practice of encoding knowledge and lore in sculpture characterizes all Mesoamerican cultures. It is documented for the sixteenth-century Yucatec Maya, whose word "its" refers to art not as a category of objects made to be admired, but the related knowledges of science, art, philosophy, and wisdom.

Between 1000 and 400 BCE, Mesoamericans made small stone figurines that could be transported across linguistic zones to convey the new knowledge. By

Knowledge Systems of the Olmec. Fig. 1 Olmec "Jade" mask from Arroyo Pesquero, University of Veracruz Museum of Anthropology. Author photo.

Knowledge Systems of the Olmec. Fig. 2 Fetus figurine found in a bowl containing cinnabar. Alabaster. Private Collection, drawing by Corey Escoto.

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900 BCE, the subjects of these sculptures and of the incised symbol system were quite consistent in cultures across southern Mesoamerica. Most of the sculptures portrayed human beings, and some of these showed humans in specific stages and states of being. Many sculptures illustrated Olmec knowledge of human gestation, bodily organs, and mental disciplines of the body. Because the sculptures and the knowledge they encoded were linked to ritual practice, we might consider the sculptures as illustrations of spiritual technologies. However, Olmec knowledge of gestation and the disciplines of the human body also informed agriculture, and calendrics, and was part of a long-distance trade technology.

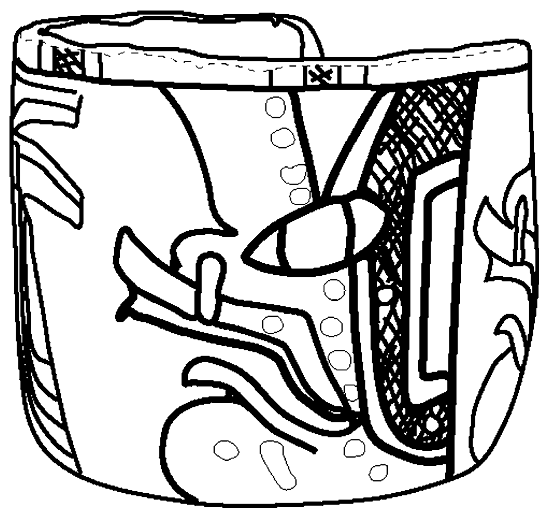
The name "Olmec" was given in the early twentieth century to the inhabitants of ancient Mexican Gulf Coast civic centers such as La Venta and Tres Zapotes. At that time, little evidence of the Formative Period existed, and many scholars assumed that most early culture traits originated in the Gulf Coast region. Since then archaeologists have shown that nascent civilizations in Central Mexico, Highland Oaxaca, the Pacific Coast, Guerrero, and the Gulf Coast all contributed to an ideological system that coalesced by the Middle Formative. This article follows the (debatable) convention of referring to all the groups who participated to some extent in this ideological system as "Olmec."

By no means did ALL Olmec sculptures portray these scientific subjects. Many sculptures showed humans as a part of creation stories or engaged in political events (Fig. 3). However, a significant number of monumental and small sculptures displayed Olmec knowledge of life processes, beginning with gestation.

Knowledge Systems of the Olmec. Fig. 3 Monument 1 of San Martin Pajapan. Portrays a ruler in part of creation narrative, in the act of "raising the world tree" (Reilly 1994). On the headdress is an embryo plaque. Drawing by corey Escoto.

The Human Embryo

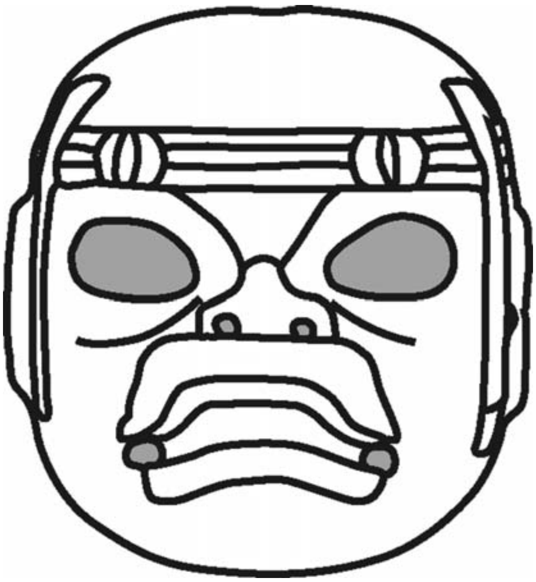
Recent research strongly suggests that a human embryo image formed part of the earliest symbol system of Mesoamerica. A figurine from Oaxaca (made in the Tierras Largas Phase, about 1400 BCE, at the cusp of the appearance of "Olmec" traits in Mesoamerica) portrayed a human female with a fetus enclosed in a cavity in the abdomen (Marcus 1998). In the Basin of Mexico around 1200 BCE, villagers created a stylized image of the human embryo at about 48–56 days of gestation (Fig. 4). Within the next 300 years, many groups throughout Mesoamerica forged, shared, and adapted an ideological system, or a set of interconnected concepts and metaphors. To show alliance to these concepts and the supernatural and meta-environmental powers they indexed, men wore images of the human embryo in greenstone (Fig. 5). This kind of exotic, elite regalia evoked powers of creation, vital energy, and the dawn of life. The "embryo" symbol was one of the most widespread characteristics of the "Olmec" civilization. Earlier in the twentieth century, scholars referred to the symbol as "were-jaguar," "were-snake," or "were-crocodile." The interpretation of it as "embryo" remains controversial (see Extra).



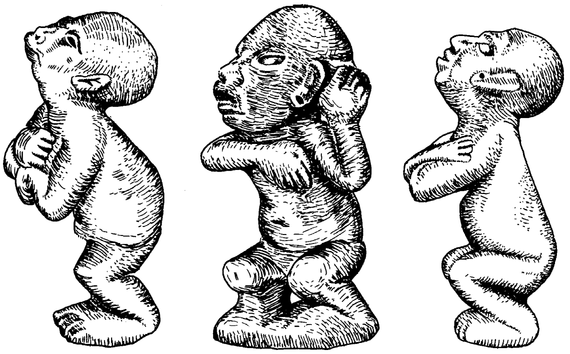
Knowledge Systems of the Olmec. Fig. 4 An early form of the stylized embryo image on a ceramic vessel from Tlapacoya, a village in the Basin of Mexico. About 1200 BCE. Drawing by Corey Escoto.

The Human Fetus

The argument that the Olmec focused on the human embryo as a major symbol of vital spirit is strengthened by the fact that they also made sculptures of the human fetus (Fig. 6). About 50 such sculptures are known, many from the Gulf Coast. One small fetus figurine was excavated, along with an embryo figurine and two of children, from La Venta, which demonstrates that the fetus was a legitimate subject of sculpture (not the invention of modern forgers). Also, three colossal fetus sculptures were found at La Venta in the 1940s and recently installed at the site museum. Fetus sculptures have the disproportionately large head and flexed limbs of a human fetus. They must have been modeled on fetuses that aborted, yet all are portrayed alive. Their meaning is less clear, but I suspect that they were considered to be intermediaries between the world of humans and that of the supernatural life forces.



Knowledge Systems of the Olmec. Fig. 5 A greenstone headdress ornament of the embryo face adorned with a headband. Private collection, drawing by Corey Escoto.



Knowledge Systems of the Olmec. Fig. 6 Olmec sculptures of the human fetus. Author drawing.

The human infant

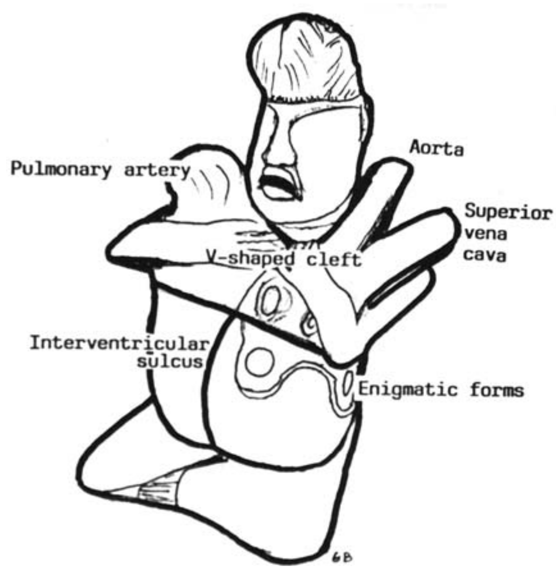
Olmec exploration of the human gestation process continued with representations of infants (Fig. 7). These most often appear in the form of large, sometimes life-sized, hollow ceramic figurines. The proportions and faces of some of these figures seem older than infants, so the significance of the hollow figures seems to vary. Nevertheless, they seem to have celebrated the rapid growth and vitality of infants as well as an acknowledgment of the precariousness of human life in its early years. Just as many communities today carry statues of specific saints into the agricultural fields to bless and promote the fertility of the crops, these hollow babies may have brought their vital energy to ancient crops (Fig. 8).

Human Gestation and the 260-Day Calendar

The ancient focus on human gestation explains the priority of the 260-day calendar in Mesoamerican ideology, and ties ancient knowledge of lunar cycles ($9 \times 29 = 261$) to menstruation and gestation. The 260-day calendar seems to have been established in Oaxaca (where the earliest known figurine of a woman with a fetus in an abdominal cavity occurred), well before the existence of the Long Count. It continued to serve as a divinatory calendar, primarily consulted by female

Knowledge Systems of the Olmec. Fig. 7 Hollow sculptures of human infants, in the National Museum of Anthropology, Mexico. Author photo.

Knowledge Systems of the Olmec. Fig. 8 This embryo sculpture and canoe of "matching" jadeite were found together at Cerro de las Mesas. The excavator, Drucker (1955), noticed that the figurine "fit" into the canoe. On each end of the canoe is an incised embryo symbol. Drawing by Corey Escoto.



Knowledge Systems of the Olmec. Fig. 9 A drawing of a small ceramic vessel representing a seated human with an outsized, but fairly accurate, human heart, Drawing by Gordon Bendersky.

clients, into the sixteenth century and even later. Many Mesoamerican groups considered the life cycle of maize to be 260 days, like the gestation of humans, despite the fact that from the Western point of view, it is shorter. Rituals conducted before the planting of maize and after its harvest extended the life of maize to parallel the period of human gestation. The Maya believed that humans were made of maize. "Humans are maize" was a major operative metaphor of many Mesoamerican cultures.

Olmec Art as Medical Illustration

Not only did the Olmec illustrate the processes of embryogenesis and human infancy, they also explored and illustrated certain organs and congenital anomalies.

One small hollow ceramic vessel illustrates a seated human figure with an exposed heart of exaggerated size (Fig. 9). Gordon Bendersky, MD, a cardiologist, has discussed the relative accuracy of the portrayal, concluding that the image must have been made from direct observation of a heart but that certain features were changed "to display the organ more symmetrically and to facilitate the placement of the head directly on the sulcus" (Bendersky 1997). As with Olmec representations of the human embryo, the representation of the subject in sculpture was modified (or in artistic terms, "stylized") – the actual thing was transformed into a symbol.

Dr. Bendersky (2000) has also made a case that a number of figurines with a normal number of facial features served to illustrate an incidence of congenital defects in the small farming community of Tlatilco, on the shore of Lake Texcoco in highland Mexico. A number of figurines from the site exhibit two heads, or sometimes, double-facedness, with two noses and mouths and three or four eyes (Fig. 10). While these figurines have traditionally been interpreted as mythological beings, Bendersky found a 1:1 correspondence between documented cases of a congenital anomaly called diprosopus and the range of features shown in the Tlatilco figurines.

The case is compelling that Formative Period Mesoamericans were fascinated with the processes of human gestation and physical development. Another class of objects, stone figurines of humans, suggests that they were also interested in the potential of the disciplined body, in what we might call mind-body communication.

Exploring the Spiritual Potential of the Adult Body

Small-scale stone images of the human figure occur across Mesoamerica (except in the Maya area) in the later Formative Period (900–400 BCE). From Guerrero to the Gulf Coast to the Pacific Slope, "Olmec" people made stone figurines in only a few variations: standing figures, seated figures, kneeling or half-kneeling, and lying on the belly with the legs bent backward so the feet touch the head.

Over 100 "standing figures" with an exceptionally consistent posture have been published. The best known of these are the sixteen that constitute a group known as La Venta Offering 4. Each figure is made of a different stone, probably by a different sculptor, yet the poses are nearly identical. The figures neither wear costumes nor hold regalia, so the focus of the piece is

Knowledge Systems of the Olmec. Fig. 10 *Left*: Tlatilco figurines, from about 1100 BCE, exhibit multiple features or heads. Drawing by Gordon Bendersky, used with kind permission. *Right*: Photo of an individual exhibiting a form of diprosopus, courtesy Gordon Bendersky.

on the pose itself (Fig. 11). The figures stand with their weight distributed symmetrically. The knees are flexed and the pelvis is tilted to straighten the spine (Fig. 12). The limbs are loose and muscles are not articulated, providing a sense of focused relaxation. In sum, the figures exhibit a perfectly straight spine with relaxed limbs and a focused gaze. This pose looks comfortable, but it is deceptively difficult to maintain. Flexing the knees demands effort from the quadriceps, the largest muscle in the body. After a minute of standing this way, the heart begins to pound. This posture is common to several physical-spiritual disciplines. In Hatha Yoga, this position is called Tadasana, the Mountain Pose. It is said to teach endurance, steadiness, contentment, and enable a person to experience the flow of energy spiraling up from the feet to the top of the head. In T'ai Chi, the pose is called Hun-Yuan Kung or Beginning Posture. In this position, it is said that the earth is invoked by the rootedness of the feet, the sky by the verticality of the spine, and humanity by the sinking of energy to the Dan T'ien, an energy center below the navel. In both traditions, the pose is used to focus the mind or meditate. However, although both Asian traditions are at least as old as 1000 BCE, no known portrayals of this pose survive from Asia from this era.

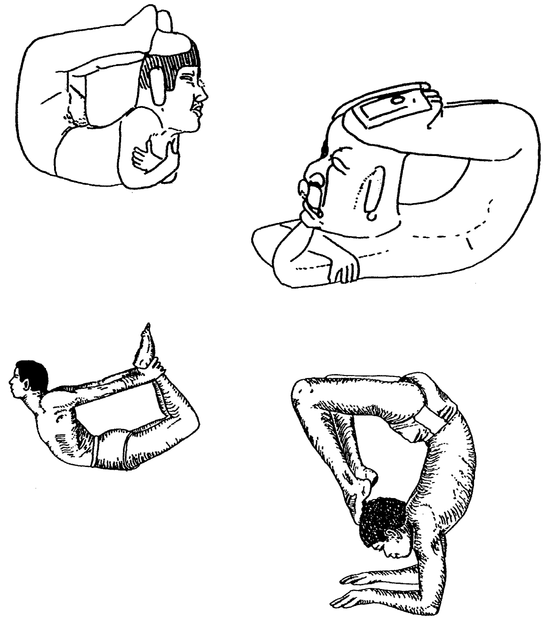
Not all Olmec standing figures portray nude figures in this pose. A few wear clothing and hold weapons or ritual items. Their meaning is distinct from that of the standing meditators.

Seated stone figurines are more rare in the Olmec corpus, but the few that exist (about eight, half of which are from archaeological contexts) also seem to exhibit a disciplined posture (Fig. 13). Each sits cross-legged with a straight spine. In a few, the hands are resting on bent knees. At least two sit in a half-lotus position, with one foot resting on the other knee.

Knowledge Systems of the Olmec. Fig. 11 Standing figures from La Venta Offering 4. Photo by John Verano.

Quite a few Olmec sculptures portray a human in a pose clearly based on a very difficult disciplined posture. The figure reclines on the stomach and bends backward to form a wheel (Fig. 14). The elbows support the elevated chest and head. The back and legs arch so that the feet touch the top of the head. Hatha Yoga includes several such postures. Within the many

Knowledge Systems of the Olmec. Fig. 12 A standing figure from La Venta Offering 4. The profile shows the straight spine and flexed knees. Photo courtesy John Verano.



Knowledge Systems of the Olmec. Fig. 14 *Top:* Figurines in the backward arching pose. Private collection. *Bottom:* Portrayal of an expert Yogi, Swami Vishnudevananda, in similar disciplined poses. Author drawings.

Knowledge Systems of the Olmec. Fig. 13 Seated figures from La Venta Tomb A. from Drucker 1952: Plater 46. Public domain.

systems of yoga, these postures are ascetic disciplines whose practice and attainment involves controlling the body and mind, sometimes with the goal of realizing oneness with the divine consciousness. In the past, these backward arching figures have been called “acrobats” and considered to be “court jesters.”

Another subject of Olmec stone figurines shows a person kneeling or half-kneeling with hands on the knees. In many of these, an animal skin partially covers the human figure. The skin has split and is peeling away, like that of a snake or lizard that sheds its skin. Kent Reilly (1989) has interpreted such figures as humans transforming into an animal alter ego. In light of the focus on the human embryo in Olmec sculpture, symbolic of the rapid transformation of the human “seed” into various animal-like forms and finally into a human form, the fetus, this adult transformation makes sense as a part of larger ideological structures.

In summation, While Formative Period people were domesticating food plants, building early public architecture, engaging in long-distance travel and trade, getting to know their environment, and establishing the ideology that would permeate later Mesoamerican cultures, they were also exploring the human body itself. One major focus was on the mysteries of human development from the stage of the embryo, which appears as much like a tailed animal, bird, or fish as a human, to the fetus, which is clearly human, to infancy. No later Mesoamerican civilization focused to this extent on the early stages of life, the "seed" stages, as did the people in these seminal societies. It is also clear that a guiding metaphor of Mesoamerican civilization, "humans are maize," so clearly expressed in the Maya *Popol Vuh,* originated in the Formative Period. Another major focus of their research, which they expressed in sculpture, was that of the physical-spiritual disciplines of the body. Although later cultures, notably the large central Mexican city of Teotihuacan, made similar standing and seated stone figures, the postures are less specifically "disciplined" and the meaning of these figures seems to have changed in the Classic Period.

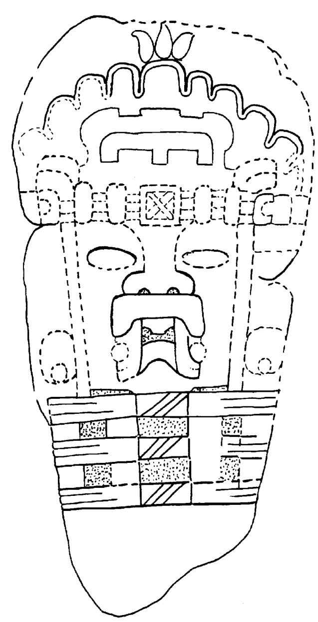
Extra: Human Embryo or Were-Jaguar in Olmec Sculpture?

One of the characteristic features in Olmec art is a symbol that is widely known as a were-jaguar. The symbol appeared as a disembodied head on headdress ornaments, as a whole body in the form of figurines (Fig. 15) and large ritual axes, and on monumental stelae (Figs. 16 and 17). First advanced in 1946, the interpretation of this symbol as a were-jaguar has survived many attempts to replace it with alternatives. All of these have pointed out that the symbol lacks the pointed ears, fangs, claws, whiskers, tail, spots, and body of a jaguar. The only vaguely jaguar-like features are a puffy upper lip, a flat nose, and an open mouth, usually toothless. Newer interpretations contend that the symbol was based on another animal: a crocodile, snake, or a fantastic creature or represents a deity. It was considered a hallmark of Olmec art that the Olmec portrayed "biologically impossible creatures." Very recent research strongly suggests that the symbol IS biologically based and that it represents the human embryo of about 56 days (Fig. 18).

To explore the proposal that this image represents the human embryo, this discussion compares the features of a human embryo

Knowledge Systems of the Olmec. Fig. 15 Figurine representing and Embryo with a pronounced crest on its head. Private collection, drawing by Corey Escoto.

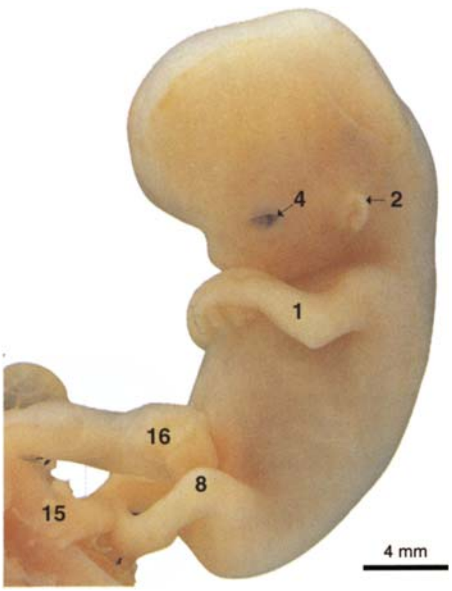
Knowledge Systems of the Olmec. Fig. 16 The Kunz Axe, jadeite, American Museum of Natural History. Represents an embryo or "human seed," Drawing by Corey Escoto.



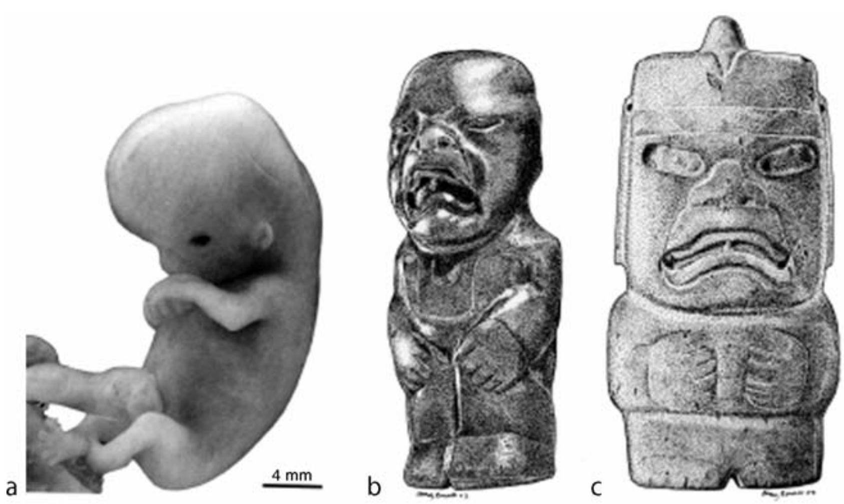
Knowledge Systems of the Olmec. Fig. 17 La Venta monument 25/26 represents a human embryo with a headband, bundled at the bottom, and with a head in the shape of a mountain. Here the embryo symbolizes the vital energy inherent in seeds. Author drawing.

of 56 days to those of two Olmec pieces, a figurine and an "axe" (Fig. 19):

- *Overall proportions*: in each case, the head is very large in proportion to the body. The human embryo's torso from the base of the head to the rump head is about 1.25 times the size of the head. The same is true of the Olmec figurine. On the axe, the head is even larger than the rest of the stylized body.
- *Head*: the embryo's forebrain, midbrain, and hindbrain form bulges that create the shape of the head. Soft bony portions are separated by large sutures called fontanels. The anterior fontanel is diamond-shaped. The Olmec figurine's head shows these typical swelling masses. The stylized forms on the axe give the head a slightly curved, tapering rectangular shape. Both the figurine and the axe show the anterior fontanel. In the figurine it is subtle but present; in the axe it takes the stylized "cleft-head" form. In other examples it is diamond-shaped.
- *Eyes*: lidless oval eyes sit on the sides of the head in the human embryo (Fig. 20). The eyes are still open but eyelids begin to form between days 52 and 57. On the figurine and axe, the eyes are widely spaced and lidless although on the figurine, which seems to show an embryo of about 57–58 days, lids are beginning to close over the eyeball (Fig. 21).
- *Nose and mouth*: at four weeks, the embryo exhibits a single, arching slit where the nose and mouth will soon develop. In the 5th–6th week, buds at the corners of the slit, called maxillary prominences, grow rapidly toward each other to form an upper lip that separates the nostrils from the mouth. The maxillary prominences are just that – prominent or puffy. At this stage, the nose barely projects above a swollen upper lip. This facial development occurs rapidly and at the stage during which the embryo is frequently lost from the womb (this will be explained below). Anyone who had seen several embryos would have noticed the swollen upper lip and shallow nasal pits. The principal feature of the Olmec symbol is its "puffy upper lip" and arching mouth, usually toothless. Above the upper lip are the flat nostrils of a human embryo. Sometimes Formative Period people added the dentition of various animals to the basic image to confer certain mythical associations or animal-like qualities on the symbol (see Fig. 22).
- *Ears*: on an embryo the ears first appear as small arches on the sides of the neck. They do not move up onto the head until Week 10. Similarly, on the figurine, ears are not shown. On this axe, the maker included the cultural symbols of the headband and long earflaps but no ears.
- *Limbs*: in the developing embryo, the arms appear in Week 4, slightly before the legs. Hand plates appear in Week 6 but toe rays only in Week 7. Most of the Olmec images show short arms with poorly differentiated fingers. Both the figurine and axe show arms that are better developed than legs. Apparently the Olmec took care to show the developing stages of the limbs in both naturalistic and conventionalized images.



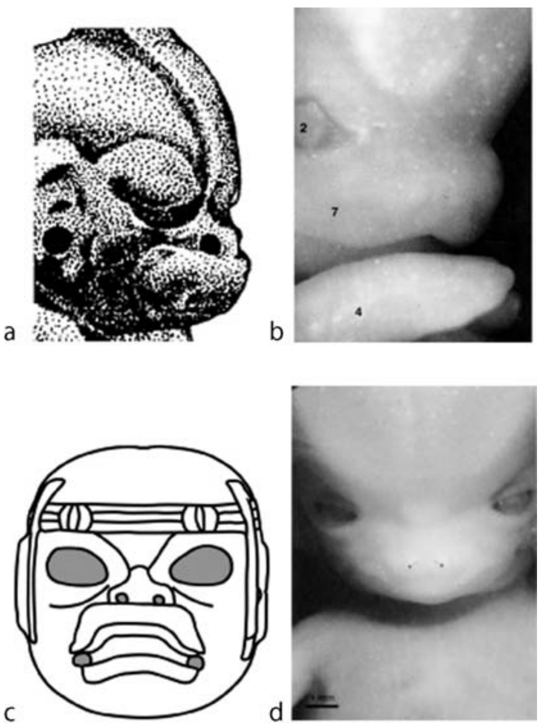
Knowledge Systems of the Olmec. Fig. 18 Photograph of a human embryo of 56 days, from England 1996. Used with kind permission.



Knowledge Systems of the Olmec. Fig. 19 A comparison of a human embryo at 56 days, an Olmec figurine, and an Olmec axe. The figurine is somewhat naturalistic, and the axe is a more stylized representation of the human embryo. Drawings by Corey Escoto.

Knowledge Systems of the Olmec. Fig. 20 The Face of human embryo. Photos courtesy England 1996.

Knowledge Systems of the Olmec. Fig. 22 An Olmec "axe" based on the form of the human embryo, with feline teeth added. Drawing by Corey Escoto.



Knowledge Systems of the Olmec. Fig. 21 A comparison of the faces of actual human embryos with those of Olmec embryo figurines, Photos courtesy England 1996. Drawings by Corey Escoto.

The degree of correspondence between the Olmec symbol and the human embryo is so high that there is little question that the symbol indeed is a stylized representation of an embryo. The use of the embryo as a symbol points to knowledge of the human gestation process. Could this be possible? Access to embryos in the Formative Period was at least as high as it is today. Since about 20% of recognized pregnancies in the modern industrialized societies terminate between 42 and 56 days, (Weeks 6–8) it is also likely that miscarriage was at least that common in the past. The embryo measures from 20 to 30 mm at that stage, and so is quite visible. Human embryos were described in texts from other cultures, such as in the *Garbha Upanishad* (1400 BCE, India), so clearly ancient people did observe them.

Although there are no written texts from the Formative Period to corroborate the notion that the symbol represents an embryo, there are many references by modern indigenous people to embryos, placentas, conception, and gestation. Two modern stories illustrate the survival of this cultural focus. These stories illuminate what the embryo might have meant to the Olmec.

The first story comes from Nahuatl (Aztec) speakers. In a village in Veracruz, people place a cedar box in the shrine of the earth mother, Tonantsij. Her domain includes ruling over her children, known as the seed spirits, who are "…the life force or potential for fertility of each crop" (Sandstrom 1991: 244). These "seed spirits" seem to be a modern version of the ancient embryo symbol. From woman-made paper, villagers form elaborately dressed figures of the seed spirits and place them in the box. These are cleaned, renewed, and redressed annually. Throughout the year they are given offerings of food, so they will not want to return to their mountain-cave home. The most important seed spirits, those of maize, are called 7-Flower and 5-Flower, and are considered to be divine human twin children. Also, the Amatan people make bundles out of bandanas. They call these "elote child" and say they represent spirit and flower of maize. Three ears of corn are tied together, one for its backbone and two for its face. Marigolds, (representing the fiery energy of conception) emerge from the opening at the top and a candle, representative of the phallus, is inserted into this womb-like bundle to bring male energy in the form of fire.

Similarly, the twentieth-century Maya of Santiago Atitlán keep a box representing the womb of one of the three Marias in a shrine. In the box is a bundle called "Heart of the Placenta." It is wrapped in a woven, beribboned cloth decorated with three faces called the corn girls, which a shaman places on the belly of a pregnant woman to give her fetus its face. Hanging from the ribbons, which represent umbilical cords, are two small bags filled with dry corn paste. The Atitecos call these bags "divine twins" – one male, one female – and consider them to be the original placentas that wrap the original seeds of the human race: the "root of children" (Tarn and Prechtel 1986: 175–176).

The ultimate spiritual technology in Olmec ideology seems to have been the evocation of the embryo (seed) spirit as the vital force that animates crops and human life.

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Kūshyār ibn Labbān

Michio Yano

In his book *al-Madkhal fī ṣinā'at aṣkām al-nujūm* (Introduction to the Art of Astrology) the author calls himself Kūshyār ibn Labbān ibn Bāshahrī al-Jīlī. This name indicates that Kūshyār was a son of Labbān who was a son of Bāshahrī and that he hailed from Jīlān, a region of modern Iran south of the Caspian Sea. The date of the book is some time around AD 992, the year for which positions of the fixed stars are given. In the same book he refers to his two earlier books on astronomical tables (*zīj*es), *al-Zīj al-jāmi'* (Comprehensive) and *al-Zīj al-bāligh* (Far-reaching). In some manuscripts "Abū al-ṣasan" (the father of al-ṣasan) is added at the top of his name. No further information is available about his family and life.

One of the most famous of his books is the *Kitāb fī uṣūl ṣisāb al-hind* (Book on the Principles of Hindu Reckoning) which is known as the oldest surviving Arabic book on arithmetic using Hindu numerals. The Arabic text is divided into two parts. In the first section of the first part Indian numerals and the decimal system of notation are introduced. In the following sections are (2) addition, (3) subtraction, (4) multiplication, (5) results of multiplication, (6) division, (7) results of division, (8) square root, and (9) arithmetic checks. The second part comprising sixteen sections is devoted to sexagesimal computations using sexagesimal tables.

According to Kennedy's (1956) classification of the subject matter of Islamic *zīj*es, Kūshyār's *Comprehensive Astronomical Table* covers the following subjects: chronology, trigonometric functions, spherical astronomical functions, equations of time, mean motions, planetary equations, planetary latitudes, stations and retrogradations, parallax, eclipse theory, visibility conditions, geographical locations, star tables, and astrological tables.

Kūshyār's book on astrology seems to have been one of the most popular handbooks on this subject, especially in the eastern half of the Muslim world, as is witnessed by the abundance of surviving Arabic manuscripts and translations into Persian, Turkish, and Chinese. The book consists of four books, following the model of Ptolemy's *Tetrabiblos*. Almost all the chapters in the first book have corresponding ones in the *Tetrabiblos*. The second book deals with so-called judicial astrology where Kūshyār shows his knowledge of topics of Persian and Indian origin. Most of the subjects in the third and fourth books are found in Books III and IV of the *Tetrabiblos*. The last two chapters of the third book are devoted to a subject which was not unknown to Ptolemy but which found a significant development in Persian astrology, namely, the rules for computing the so-called *tasyīr* arc for determining the length of an individual's life.

In the introduction of this book he clearly distinguishes between two branches of the science of stars: astronomy and astrology in modern terms. The former, dealing with spheres of planets, their motion, and the computation of their positions, is more fundamental and is grasped by instruments and observation, and is to be proved by geometry. The latter branch concerns the knowledge of human deeds which is derived from the planets, their power, and their influence upon whatever is below the sphere of the moon. This is grasped by experience and analogy (*qiyās*).

See also: ►Sexagesimal System

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K

Lalla

K. V. Sarma

Lalla, an eighth century Indian astronomer, was an exponent of the school of astronomy founded by Āryabhaṭa (b. AD 476). He was the son of Tāladhvaja and grandson of Sāmba alias Trivikrama, and hailed from Daśapura in Mālava in Western India.

Lalla was a popular astronomer who wrote both on astronomy and astrology. His most important work is the *Śiṣyadhīvṛddhida* (Treatise Which Expands the Intellect of Students), which, as he says, was composed to expatiate astronomy as set out by Āryabhatṭa. He uses the parameters enunciated in the *Āryabhaṭīya*, but propounds corrections to them every 250 years commencing from AD 498, the time of Āryabhaṭa. The first such correction falls in AD 748, which gives an indication of Lalla's date. The *Śiṣyadhīvṛddhida* is in two sections, entitled *Grahādhyāya*, dealing with planetary computations, and *Golādhyāya*, dealing with spherics, and theoretical and cosmological material. The first section, which is comprised of chapters I–XIII, treats of the mean and true planets, the three problems relating to diurnal motion, eclipses, rising and setting of the planets, the moon's cusps, planetary and astral conjunctions, and complementary situations of the sun and the moon. The second section (chapters XIV–XXII), deals with the graphical representation of the motion of the planets, the rationale of the rules enunciated earlier, rejection of popular false notions on astronomy, and astronomical instruments. Another work of Lalla, known from quotations by later authors on astronomy, is *Siddhāntatilaka*.

Lalla wrote a work on natural astrology, entitled *Ratnakośa* which is still in manuscript form. Lalla's verses on mathematical topics are frequently quoted by later writers, but the complete text from which these verses are taken has yet to be found. This provides the justification for Lalla's being referred to in later works as *Tri-skandhavidyākuśalaikamalla*, "the one stalwart versed in all three branches", that is, mathematics, astronomy and astrology.

Though Lalla follows Āryabhaṭa in certain aspects, he follows Brahmagupta (b. AD 598), and Bhāskara I (fl. AD 629), in certain others. It is also interesting that some of his innovations are followed by later astronomers like Śrīpati (tenth century), Vaṭeśvara (ca. AD 900), and Bhāskara II (b. AD 1114). This makes Lalla an important link in Indian astronomical tradition.

See also: ►Astronomy in India, ►Āryabhaṭa, ►Brahmagupta, ►Bhāskara, ►Astronomical Instruments in India, ►Śrīpati

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Leather Work in Ancient Egypt

André J. Veldmeijer, Janet Laidler

Our knowledge of skin and leather products in ancient Egypt is surprisingly scanty and only a few substantive publications have appeared. Three are of special importance for the present work. Forbes (1966) might be slightly outdated (see below) but still provides a good overview. Van Driel-Murray (2000) contains a wealth of information and is the only publication to date that predominantly relies on fieldwork and the study of the leather artefacts themselves. Not only does Van Driel-Murray provide a good overview, she clearly pin points the problems and priorities with leather in ancient Egypt. Schwarz's (2000) book deals not only with the artefacts but also with other aspects of leather and compares it with traditional European and African leather crafts. Furthermore, she incorporates texts and depictions in her study and her book contains many illustrations of leatherwork and related objects, making it an important reference for the present work.

Technology

Skin Processing

The processing of skin into leather[1] is rather universal and described in various handbooks, giving a good picture of the process. The following general summary is largely based on Forbes (1966: 1–21) and Van Driel-Murray (299–306). After flaying the skin, the preservation process was started with removal of the underlying fat. Next, hair was usually (but not always) removed (depilation), using urine, ash or a mixture of flour and salt, rubbed into the haired surface. Curing then took place, arresting the degenerative process (not irreversible in contrast to tanning). Curing in oil seems to have been the preferred method, although mineral curing was probably also practiced, particularly in the predynastic period. After soaking in oil, the skin was pulled back and forth over a beam to make it supple (staking). The remaining oil was worked into the skin using stones, wooden, or leather pounders or tools called "slickers". Finally, the skin was dried on a wooden stretching frame.

Vegetable tanning is the only means of producing chemically stable leather which is imputrescible (not subject to decay), flexible and waterproof. Current scholarly opinion is that this process was unknown in Egypt before the Ptolemaic period and only became common in the Roman period. There may be a number of explanations for this and one might be that the arid conditions rendered this more complex process unnecessary for the ancient Egyptians. These arid conditions are in themselves excellent for preservation and account for the amount of recovered leather items rather than the advanced methods of skin processing. The Romans, however, had experienced wetter environments forcing them to adopt the use of tanned leather.

The Objects

The range of objects made from leather is fairly large and ranges from parts of musical instruments and furniture to clothing, footwear and cordage. Research in progress suggests that the objects were sewn with simple seams and stitches made of flax but mostly leather thongs (and to lesser extent sinew).

Decoration Techniques

Before the New Kingdom (1550–1069 BCE), mineral dyes predominated. A full range of colours is hard to establish as their survival is dependent upon the conditions for preservation and the likelihood is that certain shades are more susceptible to discolouration. Here too, little research has been done, using modern analysis, accounting for our limited knowledge.

According to Van Driel-Murray (2000: 306) "red was achieved with iron and, perhaps, lead compounds and green was created with copper compounds". Favoured curing methods produced a very light leather so white was probably obtained by manipulation of the already pale surface with pastes of chalk mixed with fats such as egg yolk and brains. Blue does not seem to be represented with leather despite the availability of minerals such as cobalt. There is no explanation for this other than blue may be one of the colours which do not survive. After the 18th dynasty vegetable dyes such as madder (red), indigo (blue) and pomegranate (yellow and black) appear and alum is featured as a mordant. Other mordants used would have included urine and vinegar. In dyeing leather, the colour seems to have been generally confined to the grain surface and was applied after curing the complete skins. Staining and gilding came into use as late as the Coptic period.

There are examples of stamped and incised decoration; appliqué (multicoloured) is known, for instance from the funeral tent of Queen Istemkheb dating from the 21st or 22nd dynasty (1069–715 BCE) and examples of openwork by the cutting out of figures are represented in the archaeological record.

Tools[2]

Apart from the large pots for dipping, the trestled beams used for staking and the low stools and platforms upon which much of the cutting and working was carried out, a leather working toolkit seems to have comprised the following items. Needles of bone and probably copper were used for stitching leather from the earliest times. Awls of bone and later of metal were also used for piercing, as were marlin spikes. Horns were used to enlarge the holes.

Most of the leather cutting was carried out using curved, broad or narrow bladed knives which seem to have appeared in the New Kingdom (Stocks 2001: 443). Longer knives, still with curved blades, were used in earlier periods.

Leather was often pricked to facilitate easy penetration with a needle. This was done with awls or a comb-like tool. Stone and leather or wooden pounders for smoothing, depilation, working in oils and fats etc. would also have been widely used. Slickers, blades with triangular anti-clogging holes, could have been used for any of the above mentioned purposes and would have been preceded by the flint scraper (Van Driel-Murray 2000: 303; Davies 1943: 50; Stocks 2001: 443). There

[1] Although we use the term "leather" technically speaking this term only refers to tanned or tawed (converting (skin) into white leather by mineral tanning, as with alum and salt) skins rather than cured skins. In Egypt, tanned or tawed skin did not occur in Pharaonic times.

[2] Schwarz (2000: 78–123) is a particularly important source. Not only are all possible tools discussed and illustrated, she also compares Egyptian with traditional European and African leather working.

would also have been tools for incised decoration and, although it is not clear exactly what form these tools took, there are plenty of examples of pointed tools which could have served this purpose. Stamps would probably have been cast from metal or carved from stone or possibly wood, although no examples were found for inclusion in the present work.

The Importance of Skin Products

Little is known about the status of leather workers, the most well-known source to date being the *Satire of the Trades* which is heavily biased and, therefore, unhelpful (for example Lichtheim 1973). A monetary economy did not exist in dynastic Egypt, but there was an efficient system of exchange in most commodities which were "priced" in terms of their equivalent value in *deben*, a standard weight of copper. The only community from which price lists survive is the New Kingdom workmen's village at Deir el Medina, which is probably not representative of the rest of the country (Janssen 1975: 562). Furthermore, leather is not mentioned in these lists in sufficient detail to be useful (Janssen 1975: 526).

Perhaps the first thing to consider when trying to establish the monetary value of leather is the value of the animals from which skin products were obtained. It is tempting to assume a direct correlation between the value of the animal and its hide/skin. If this is the case, then bovid hide will have been the most expensive as bovidae were the most highly prized animals commonly used for leather.

Because taxes were collected in leather goods in the New Kingdom, and payment for work by the state and the temples was made in things like leather sandals, it can be assumed that leather goods had generally recognised values (Stocks 2001: 283). Furthermore, leather sandals could cost as much as a whole sheep or goat which may imply that the expertise required for the processing of finished leather goods was quite highly prized (Janssen 1975: 525–526).

The importance of leather to ancient Egyptian civilization seems to have differed over time. According to Van Driel-Murray (2000: 307) skin was widely used in the Badarian (5500–4000 BCE) and Amratian (=Naqada I) (4000–3500 BCE) periods and was handled with considerable skill and confidence but was largely superseded in the Gerzean (=Naqada II) period (3500–3100 BCE) by cloth (Petrie 1940: 128). This may have been due to the development of a more settled sedentary lifestyle over time conducive to the large-scale undertaking of craft activities such as weaving (Bard 2000: 61–62). Cow, sheep, goat and gazelle have been identified from predynastic contexts (Van Driel-Murray 2000: 308) and remained the most commonly used skins for leather throughout Pharaonic Egypt. Besides those listed, other animal skins known to have been utilised are lion, panther, cheetah, antelope, leopard, camel, hippopotamus (Reed 1972: 86) and crocodile (own observation).

In the Old and Middle Kingdoms, the use of leather declined in favour of fibre and textiles. Skin seems to have been of secondary importance to the meat at this time (Van Driel-Murray 2000: 300).

The Second Intermediate Period (1650–1550 BCE) represents a continuation of early predynastic traditions in that cattle hides, decorated leather garments, containers and pouches of high quality occur again but these are mainly associated with the "pan-grave" culture which belonged to a semi-nomadic tribe of Nubian cattle herders who entered Egypt during the Middle Kingdom and the Second Intermediate Period (Shaw and Nicholson 1995: 255). During the New Kingdom leather was much more widely used. New weapons technology such as the chariot was partially responsible for this (Van Driel-Murray 2000: 309). Also, the New Kingdom saw a change in slaughterhouse practices with more attention being paid to hides and skins as products in themselves.

It is difficult to say whether the use of leather continued to the same extent into the Third Intermediate Period (1069–747 BCE) because tombs were becoming smaller with a paucity of grave goods. The range of uses was no longer represented among the goods, most of the surviving items from this and the Late period being mummy braces.

The lack of material from the Late and Ptolemaic periods has been partially explained above. However, the leather from the Roman period is much better represented (Bowen 2002; Phillips 1999, 2001; Veldmeijer 2007, Winterbottom 1991, 2001), due to the relatively large number of finds. Then, the use of tanned leather became widespread and a clear increase in the level of technological skill can be seen. According to Forbes (1966: 35) skin products were both imported and exported at this time and the sale of leather goods seems to have been free like that of linens.

Technologically, ancient Egyptian leather working up to the Ptolemaic period remained essentially Neolithic. The idea that it was advanced from the earliest times (Hasanien 1997) is based upon misconception because full vegetable tanning which produces the leather with which we are familiar today was unknown in Egypt until the Ptolemaic period and was not common until the Roman period. In fact, pre-Ptolemaic skin products, many of which are referred to here as "leather", are no more than lightly cured pseudo-tannages which only survive because of Egypt's naturally favourable conditions for preservation.

Dyeing techniques were relatively basic and the properties of alum as a mordant were not appreciated in Egypt until long after her influential neighbour, Mesopotamia, had rendered its use commonplace.

When elaborate and colourful decoration was fashionable, it was achieved by appliqué techniques which were often coarsely executed. Compared to the skill and patience needed to produce the exquisitely fine New Kingdom network loin cloths (which seems to be from Nubian origin) or the skills seen in the Roman material, the Pharaonic leatherwork might be judged as "poor", or perhaps better "pragmatic". As also remarked by Van Driel-Murray, the Nubian material is unequalled in Egypt and leather might have played a much more important role in Nubia than in Egypt (Van Driel-Murray, personal communication).

The extent to which leather was used varied greatly over time with the periods of greatest use being the early predynastic and New Kingdom. It is important to note that this is at least partially due to a bias in archaeological record. For example, the amount of material which survives from the New Kingdom is largely due to the fact that elite burials of this period were generally rich and elaborate with a whole range of material deposited with the body for use in the after life (Spencer 1982: 50–51). Because much of the Pharaonic Egyptian archaeological record is constructed from tomb goods, burial practices are a major contributing factor in terms of what survives. Another example is the fact that little archaeology has been done in true Ptolemaic layers. Finally, many Roman settlements have been excavated, largely accounting for the numerous leather finds. (The fact that much Roman material has been tanned also accounts for this.) It has been claimed that leather was of "marginal importance" in ancient Egypt in all periods (Van Driel-Murray 2000: 299) but considering the amount of surviving material and the range of uses represented, this conclusion should be challenged. Leather goods were used as currency but their actual value is impossible to quantify accurately.

Egyptian leatherwork is still poorly understood and much in need of reassessment which should include, for example, detailed analysis of technology (seams, stitches), shape (especially footwear) and, mentioned by Van Driel-Murray (2000: 300), extensive analyses on well-dated samples for both curing and colouring agents as a framework for future investigation. Fortunately, in recent years interest in leatherwork has increased and variousstudies are currently being executed.

See also: ►Tools, ►Military Technology, ►Dyes, ►Writing

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Leo the African

Thomas F. Glick

Leo the African was born in Islamic Granada as Al-Ḥasan ibn Muḥammad al-Wazzān al-Zayyātī around 1485 and was educated in Fez, where his family settled several years before the conquest of Granada. He is known primarily for his geographical writings based on four trips. The first, from Fez to Constantinople, probably took place in 1507 and 1508. The second, sometime between 1509 and 1511, was his first to Timbuctu following the caravan route south, probably as far as the Niger river. The third trip (1512–1514) took him across the Sahara via Lake Chad to Egypt, providing important information on the Sudan. The fourth trip (1515–1518) took him to Constantinople as ambassador of the Moroccan sultan, Egypt, and Arabia; on his return he was captured by the Italian pirate Pietro Bovadiglia. In Italy he was given as a slave to Pope Leo X whose name he took upon his conversion to Christianity.

Although he wrote an Arabic–Hebrew–Latin vocabulary in 1524, he is best known for his geographical treatise written and published in Italian as *Della descrittione dell'Africa* (Venice, 1550), although it was no doubt based on an Arabic draft. The treatise is divided into nine books, whose principal significance was to provide European cartographers with detailed information about areas of sub-Saharan Africa practically unknown in the West. Leo also made a substantial contribution to natural history. In his description of African plants, animals, and minerals he points out errors made by ancient writers such as Pliny. Leo's *Description* also contains invaluable information on Islamic institutions such as, for example, his description of the *muhtasib*, or market inspector, of Fez. Leo returned to North Africa in 1529, reconverted to Islam, and died in Tunis sometime after 1554.

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Levi Ben Gerson

J. L. Mancha

Levi Ben Gerson (1288–1344), also known as Gersonides or Leo de Balneolis, his Provençal name, was one of the most original Jewish thinkers of the Middle Ages, and he wrote on logic, philosophy, biblical exegesis, mathematics, and astronomy. He lived in Orange, where the de Balneolis family was prominent, and occasionally in Avignon (France). During the last years of his life he maintained relations with the papal court of Clement VI (1342–1352), to whom he dedicated a Latin version of his work on trigonometry and on the Jacob Staff (*Tractatus instrumenti astronomie*, 1342).

On mathematics, his *Maʿaseh Hoshev* (Work of the Computer, 1321) deals with arithmetic, summations of series, algebra, and combinatorial analysis. At the request of the French musical scholar Philippe de Vitry, he composed his *De numeris harmonicis* (On Harmonic Numbers, 1343, extant only in Latin) to demonstrate that numbers belonging to geometrical progressions of ratio

2 or 3 and first term 1, or generated by product of terms in these progressions, differ by a number greater than 1, excepting pairs 1–2, 2–3, 3–4, and 8–9. On geometry, he wrote a commentary on Books I–V of Euclid's *Elements*, a treatise on Euclid's parallel postulate, preserved incomplete, and commentaries apparently lost on Menelaus' *Sphaerica* and Thābit ibn Qurra's *Risāla fī Shakl al-qaṭṭā*ʿ (On the Secant Figure).

Levi's most important scientific achievements are contained in the *Sefer Tekhunah* (Book of Astronomy), in fact, part 1 of the fifth book of his main philosophical work, *Milḥamot Adonai* (Wars of the Lord). Preserved in Hebrew and Latin versions, it is a lengthy work, divided into 136 chapters, which contains planetary observations and research from 1321 to 1340, and is based on a profound understanding of the astronomical tradition as well as on a sound criticism of some of his predecessors, mainly Ptolemy and al-Biṭrūjī. Levi's purpose was to construct a true astronomy, able to satisfy at the same time the requirements of experience, natural philosophy, and metaphysics. The crucial role attributed to observation led him to construct the Jacob Staff (an instrument for determining the angular distance between two stars or planets widely used in navigation until the eighteenth century, whose precision he increased by inventing a transversal scale for linear measurement, later also applied to the astrolabe), and to investigate successfully the theory of the *camera obscura*, which he used for observing eclipses. Levi employed his own observations both for deriving parameters for his new solar and lunar models and for testing them. Of special interest is his lunar model, which avoided the inadequacy of Ptolemy's model at half-moon phase (when it ought to appear twice as large as at opposition) and eliminated the use of the Ptolemaic epicycle (which would allow us to see both sides of the moon, again contrary to appearances). Using his own solar and lunar models, Levi composed ca. 1335 a set of tables and canons for computing eclipses, later partially modified when it was incorporated into the *Sefer Tekhunah*, which includes tables for the sine function, spherical astronomy, and solar and lunar mean motions and corrections. The chapters of the work dealing with planetary models are apparently unfinished, but a measure of Levi's originality is his theory of planetary distances and sizes: although Levi considered as not fully decided the problem of the position of Mercury and Venus with respect to the sun, assuming that these planets were placed above it, he computed the distance of the sphere of the fixed stars to be $159 \times 10^{12} + 6.515 \times 10^{8} + 1.338 \times 10^{4} + 944$ earth radii (instead of Ptolemy's 20,000 earth radii, generally accepted in the Middle Ages).

See also: ►Thābit ibn Qurra, ►al-Biṭrūjī, ►Astrolabe

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L

Li Bing

SUN XIAOLI

Li Bing (fl. 322–247 BCE) is famous in Chinese history as an expert in irrigation works. He had a good knowledge of astronomy and geography as well as of engineering and technology. In 316 BCE Shu (Sichuan province) was conquered by the State of Qin. In order to establish the province as an important base and to harness the Minjiang River floods, King Huizhao (r. 306–2551 BCE) appointed Li Bing governor of Shu.

During 277–250 BCE Li decided to build the large waterworks at Guanxian county, from where the river flows into the plain of Sichuan. The whole project is known as Dujiang Yan. Li decided to divide the river into two great feeder canals, the Neijiang (Inner Canal) on the east and Waijiang (Outer Canal) on the west. This was done by means of piled stones, known as *Yuzui* (Fish Snout). The inner canal was used for irrigation, while the outer one, the mainstream, acted as a flood channel, and also carried some boat traffic. In order to construct the inner canal Li made a great rock cut through the end of a ridge of hills. This is known as the Bapoing Kou (Cornucopia Channel). Between the primary division-head and the rock cutting the channels were separated by the Feisha Yan (Flying Sands Spillway) which was adjusted to regulate the volume of flow into the inner canal.

In order to measure the water level so as to control it, three stone figures were put at three different places at the canal intake. With the help of observing the water level at the inner canal intake the feeding capacity into that canal was controlled by division dams of the Yuzui, Feisha Yan, and Baoping Kou. The whole engineering operation made it possible to supply water for an area of 4.4 million acres to support a population of five million people, most of them engaged in farming, while at the same time remaining free from drought and floods. It can be compared with the ancient works of the Nile, and it is still in use today. Apart from this great contribution, Li also developed the deep-drilling technology for producing well salt and built six bridges near Guangdu (Chengdu). The exploitation of water resources and the manufacture of well salt greatly promoted the development of agriculture, industry, and commerce in the Sichuan area and made it become a famous "Land of Abundance" in China since Li's time.

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Li Chunfeng

JENNIFER W. JAY

Li Chunfeng (602–670) was a Chinese mathematician, astronomer, and early historian of science. A native of Shaanxi province in northwest China and influenced by his Daoist father, Li Chunfeng served as a high-ranking court astronomer and historian for several decades in the early Tang dynasty (618–906). Both Li Chunfeng's son and grandson successively occupied the position of court astronomer.

As a mathematician Li Chunfeng is not considered to be original, but he played a role in indeterminate analysis, or the Chinese remainder theorem. He is credited, along with Zu Chongzhi in the fifth century, with developing the *zhaocha* method of finite or divided differences in mathematical astronomy. Using algebra to deal with the *ping* (floating differences) and *ding* (fixed differences) Li Chunfeng calculated the "angular speed of the sun's apparent motion" (Needham 1959).

Li Chunfeng applied this method of finite differences in designing the Linde (Unicorn Virtue) calendar, which was adopted in 665. The new calendar was an improvement over the previous ones in predicting the movements of the planets and in the placing of the long (30 days) and short months (29 days) as well as the intercalary months. To compensate for the extra days in a solar year of 365.2422 days and a lunar month of 29.5306 days, 1 intercalary month needs to be added every 3 or 4 years.

Li Chunfeng also earned a place in the history of *hunyi* (armillary spheres), predecessor to the telescope. His armillary sphere had three nests of concentric rings: the inner sighting tube ring, the intermediate nest, and the outer stationary nest. Li's innovation lies in the intermediate ring, which improved the observations of celestial bodies and allowed for finer accuracy.

Li Chunfeng wrote the treatises on astronomy, calendar, and portents in the official dynastic histories, the *Jinshu* (History of the Jin Dynasty) and *Suishu* (History of the Sui Dynasty), in addition to authoring another extant work, *Yisizhan* (Omen-taking, 645). Typical of astronomers in his time, Li Chunfeng could not avoid the moral and political responsibility of interpreting omens to the country, and included portent astrology and omen lore in his writings.

Li Chunfeng commented on the ten mathematical manuals that were officially designated for curriculum use both in Tang China and in Korea and Japan. These appear below with translated titles (Ho 1985): *Zhoubi suanjing* (Arithmetical Classic of the Gnomon and the Circular Paths of Heaven), *Jiuzhang suanjing* (Nine Chapters on the Mathematical Art), *Sunzi suanjing* (Mathematical Manual of Sunzi), *Haidao suanjing* (Sea Island Mathematical Manual), *Wucao suanjing* (Mathematical Manual of the Five Government Departments), *Xiahou Yang suanjing* (Mathematical Manual of Xiahou Yang), *Zhuishu* ("Stitching" Method), *Zhang Qiujian suanjing* (Mathematical Manual of Zhang Qiujian), *Wujing suanshu* (Arithmetic in the Five Classics), and *Jigu suanjing* (Continuation of Ancient Mathematics). *Zhuishu* is not extant and was substituted by *Shushu jiyi* (Memoir on Some Traditions of Mathematical Art).

See also: ►Liu Hui, ►Armillary Spheres, ►Zu Chongzhi

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Li Gao

Hong Wuli

Li Gao was born in 1180 in Zhending (now Zhengding County of Hebei Province) and died in 1251. His surname was Mingzhi, and Dongyuan the Old Man was his nickname. He was an exponent of one of the four major schools of the Jin-Yuan period.

After his mother died of an unknown disorder which was treated to no avail by unskilled practitioners, Li made up his mind to pursue medical studies. His tutor Zhang Yuansu, who advocated the revolutionary idea that "modern diseases cannot be cured by ancient prescriptions," taught him to probe for new ideas and prescriptions so as to free himself from the yoke of the ancient art of prescribing. He was conversant in the nature and properties of drugs and in their beneficial potentials. The recipes he formulated were all organized according to the theory of "king, minister, assistant, and attendant," commonly composed of 10 to 20 kinds of herbal drugs. In line with the classical theory, all the ingredients were closely related with both complementary and opposing relationships (Jiang 1963).

He emphasized the role of stomach *qi* during all seasons. *Qi* is the root of all body functions. The spleen and stomach are the roots of growth and metabolism; various disorders arise when their functions are jeopardized. He expounded the etiology and mechanism of disease due to endogenous pathogens (those coming from within), which are different from those caused by exogenous ones, and he stressed the importance of the spleen and stomach in the course of endogenous disorders. He criticized quacks that mix up disorders of different etiology and apply methods for exogenous ailments to tackle the problems of endogenous ones, with ensuing complications. Clinically, he stressed that the spleen and stomach should always be nourished so as to renew the body. He formulated a famous recipe, the *Buzhong Yiqi* (Benefiting-Interior Reinforcing-Qi) decoction, and the *Shengyang Yiwei* (Ascending Yang Replenishing-Stomach) decoction, which are both common remedies still applied today. Due to his emphasis on spleen and stomach, he was given the title of the head of an academic school, the Earth-Replenishing School (Li 1913). He was also a prolific writer. Among his works, the most famous ones include *Nei wai shang bien huo lun* (*Differentiation for Endogenous and Exogenous Disorders*), *Pi wei lun (On Spleen and Stomach), Yi xue fa ming* (Medical Inventions), *Dong yuan shi xiao fang* (*Dongyuan's Trial Effective Formularies*), *Lan shi mi cang* (*Clandestine Collections in Orchid Mansion*), *Huo fa ji yao* (*Essentials of Flexible Methods*), *Yao lei fa xiang* (*Pharmaceutical Normalcy*), *Yong yao xin fa* (*Mastery of Drug Application*), and *Shang han hui yao* (*Collected Essentials of Disease Due to Exogenous Cold*). In his later years, he passed his academic ideas and works on to his disciple Luo Tianyi (Taki 1956).

See also: ►Medicine in China

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Li Shanlan

JEAN-CLAUDE MARTZLOFF

Li Shanlan. Fig. 1 Li Shanlan.

Li Shanlan (1811–1882) was a native of Haining, Zhejiang. Although he belonged to a moderately fortunate family and was given formal training in the classics, he never passed government examinations beyond the first level, and had to give up the dream of entering officialdom. Under difficult circumstances, he took refuge in Shanghai, a city newly opened to foreign trade as a consequence of the Opium War.

From 1852 to 1859, Li went into service with the London Missionary Society who employed him as a co-translator of all sorts of Western scientific works. Missionaries had an insufficient mastery of literary Chinese and for that reason they had to rely on Chinese co-workers, even though these, like Li Shanlan, generally had no knowledge of foreign languages. During this period, Li translated with Alexander Wylie (1815–1887) Joseph Edkins (a Protestant Missionary 1829–1890) and others the part of Euclid's *Elements* not yet translated into Chinese (Books 7–15), Augustus de Morgan's *Elements of Algebra* (1835), Elias Loomis's *Elements of Analytical Geometry and of Differential and Integral Calculus* (1851), John F. W. Herschel's *Outlines of Astronomy* (1849), and other manuals on mechanics and botany. But what made Li famous in the eyes of his contemporaries was not so much the numerous translations he was responsible for but his own mathematical works.

Contrary to what might be expected, Li's works were not based on new Western mathematics but on ancient Chinese conceptions, especially the positional algebra *tianyuan shu* developed five centuries earlier during the Song and Yuan dynasties. Li however did not stick slavishly to the venerable discoveries of his ancestors. Rather he used much ingenuity emulating Westerners and trying to beat them at their own game. Using ancient tools, he thus conducted research of his own into logarithms, infinite series, and combinatorics. In particular, he made extensive use of algebraic computations, analogical reasoning and inductive generalizations built on the knowledge of a few particular cases. But he never relied on hypothetical-deductive reasoning. One of his original results, which may be expressed as follows using modern symbolism, is:

$$\sum_{j=0}^{k} \binom{k}{j}^2 \binom{n+2k-j}{2k} = \binom{n+k}{k}^2,$$

where the $\binom{n}{p}$ represent the usual binomial coefficients occasionally appears in modern books.[1]

Owing to the generosity of Zeng Guofan (1811–1872), a famous general responsible for the suppression of the Taiping revolt, Li Shanlan's collected mathematical works were published in Nanking in 1867 under the title *Zeguxi zhai suanxue* (Mathematics from the Studio "Devoted to the Imitation of the Ancient Chinese Tradition").

The contents of the *Zeguxi zhai suanxue* collection are as follows:

A. Two prefaces
   1. Li Shanlan's preface, dated 1867, where he expresses his deep admiration for ancient Chinese mathematics and refers to himself as "Shanlan": "When ten years old, Shanlan found a copy of the Nine Chapters ....he read it and found that it was so easy that it necessitated no special study. But from this, he fell in love with mathematics *suan* [...] At the occasion of the provincial examinations, he found a copy of (Li Zhi's) *Ceyuan haijing* (Sea Mirror of Calculations Concerning Inscribed and Circumscribed

[1] Very interesting details (translated into English from the Hungarian original paper), about how this formula became known in Europe are stated precisely in Paul Erdos, ed. *Collected Papers of Paul Turan*. Akademiai Kiado, 1990. See Also J.-C. Martzloff. *A History of Chinese Mathematics*. Springer, 1997. 341.

Li Shanlan. Fig. 2 Alexander Wylie.

Circles) and of [Dai Zhen (1724–1777)'s] *Gougu geyuan ji* (Treatise on Cyclotomy by means of Right-Angled Triangles) (1755) [...]"

2. Preface by one of his (now unknown) disciples.

B. Thirteen treatises

1. *Fangyuan chanyou* (The Mysteries of the Square and Circle). The opening sentence starts by a proud assertion of what Li Shanlan considers an erroneous Western conception: "First, we must acknowledge the fact that what the Westerners call 'points', 'straight lines' and 'planes' cannot be dimensionless." Note that this offensive declaration must be taken *cum grano salis* because Li Shanlan was the translator of the *Elements* into Chinese. Then the treatise develops quadratures and developments into infinite series by submitting infinitesimals to all sorts of arithmetical operations and limiting processes. In this way, he obtains, for example, the following result:

$$\pi = 4 - 4\left(\frac{1}{3 \times 2} + \frac{1}{5 \times 4!!} + \frac{3!}{7 \times 6!!} + \frac{5!}{9 \times 8!!} + *\right)$$

where $4!! = 4 \times 2$, $6!! = 2 \times 4 \times 6, \ldots$ and where the factorial has the usual meaning.

2. *Hushi qimi* (The Mysteries of the Arc and Sagitta Unveiled). Developments into infinite series of trigonometric functions (sinus, tangent, secant...).
3. *Duishu tanyuan* (The Origin of Logarithms).
4. *Duoji bilei* (Accumulated "Heaps" Studied from an Analogical Point of View). Generalised Pascal's triangle with all sorts of finite summations. The term "heaps" used here refers to the fact that Li Shanlan visualised binomial and other combinatorial coefficients under the form of geometrical heaps of material objects such as small cubes or spheres analogous to marbles. Li Shanlan's formula occurs here.
5. *Siyuan jie* (An Explanation of the "Four Elements"). An interpretation of the meaning of Zhu Shijie's medieval algebra, developed in the famous *Siyuan yujian* [Mirror of the Four Elements] (1303).
6. *Linde shu jie* (An Explanation of the *Linde* Canon). The treatise contains an elucidation of this extremely difficult technical text and, in particular, of its non-linear interpolation formula. The term *Linde* is the name of a reign-period (664–666) of the Tang Emperor Gaozong. Its literal meaning is "unicorn virtue", a classical Chinese allusion to prosperity and happiness. Generally speaking, *shu* means "methods", "set of mechanical rules" or "algorithms" and *li* "mechanical rules for mathematical astronomy and calendrical calculations", but here they are interchangeable. *Linde shu* or *Linde li* means "*Linde* canon (of astronomical calculations)" and not merely "*Linde* calendrical calculations" as is often (and wrongly) said.
7. *Tuoyuan zhengshu jie* [An Explanation of the True *Shu* (here algorithms) of the Ellipse (lit. "flat circle")].
8. *Tuoyuan xinshu* (New *shu* for the ellipse)
9. *Tuoyuan shiyi* (Remaining Considerations on the Ellipse).
10. *Duishu jiantui bianfa shi* (Explanation of a Modified Method for the Calculation of Logarithms).
11. *Huoqi zhenjue* (True Tricks Concerning Fire Machines). This contains an explanation of the parabola in connection with the trajectory of projectiles.
12. *Jishu huiqiu* (The Reversion of Series). Given an infinite development, $y = f(x)$, find x in terms of y.
13. *Tiansuan huowen* (Queries on Chinese Mathematics).

In 1869, Li was appointed Professor of Mathematics at the newly created Tongwen guan, a college in Beijing devoted to the teaching of foreign languages, technology, and science. He based his lectures partly on Western mathematics and partly on Chinese mathematics, and remained in that post until his death. His works were much admired in China by mathematicians and non-mathematicians alike. They can be considered at the same time the most creative mathematics written

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in China during the whole of the nineteenth century and the swan song of Chinese traditional mathematics.

Unsolved Problems

1. It is customary to refer to the above combinatorial formula as “Li Shanlan’s formula” in the same way as we refer to Pythagoras’ theorem, Bezout’s theorem and the like. Very often, however, these appellations are very loose and do not always adequately reflect historical reality. For example, Pythagoras’ theorem was not a “theorem” at first but rather something like an algorithm, and it was known long before Pythagoras.

   Thus, it may be that Li Shanlan’s formula was buried somewhere in the huge and not wholly explored treasure-house of nineteenth century mathematics, or in Japanese mathematics (*wasan*), where the occurrence of combinatorial formulae in various guises is not so infrequent.

   So we can ask ourselves if we can prove or disprove the statement: the appellation “Li Shanlan’s formula” is not a misnomer.
2. Is it possible to translate the *Zeguxi zhai suanxue* into a Western language?

   It most definitely is. Li Shanlan’s treatise is written in a crystal clear and beautiful sort of classical Chinese. Providing a translation, however, might be difficult, especially in view of the very special technical terminology he relied on. Concerning the importance of specific calculations in this work, the would-be translator would have to avoid any reference to “concrete mathematics” as Knuth would perhaps call these. But programs able to manipulate formal expressions and multi-precision arithmetic, like Maple, would help redoing the calculations mechanically, painlessly and exactly.

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Li Shizhen

Fabrizio Pregadio

The great Chinese naturalist and pharmacologist Li Shizhen was born in 1518 near modern Qichun (Hubei). Born into a family of doctors, he concentrated on the study of medicine at an early age under the guidance of his father. His reputation as a physician soon reached the prince of Chu, who in 1543 entrusted him with medical and administrative responsibilities at his court in Wuchang. From 1544 to 1549 Li practiced at the Imperial Academy of Medicine (Taiyi Yuan) in Beijing. After that, he returned to his native village, where he worked as a doctor until his death in 1593.

The experience as a physician suggested to Li the need of a thorough revision of the traditional repositories of pharmaceutical knowledge (*bencao*). Earlier standard sources such as the work by Tang Shenwei had been made obsolete by the adoption of new drugs and prescriptions, along with errors in the identification and classification of some substances. Li apparently began to conceive the compilation of a definitive pharmacopoeia around 1552, and worked on this project for more than 25 years. He spent much of that time reviewing a massive amount of literature, and traveling extensively to collect specimens and recipes.

The result of these efforts represents the culmination of the literary tradition of Chinese pharmacology. Li Shizhen’s work, entitled *Bencao gangmu* (The Pharmacopoeia Arranged into Headings and Sub-Headings), contains 1,892 entries, classified into 16 main sections (e.g., Minerals, Trees, Reptiles) and 62 categories. The entries describe 275 minerals, 1,094 plants, 444 animals, and 79 miscellaneous substances (those in the sections Water, Fuel, and Earth). Li Shizhen himself contributed no less than 374 new entries.

Li classified the *materia medica* according to an essentially binomial system, describing species as variants of a genus. His work deals with minerals first, followed by plants, invertebrates, vertebrates, mammals, and humans. A typical entry is divided into sections concerned with nomenclature, places of occurrence, varieties, problems of identification, medical properties, uses, and prescriptions. The *Bencao gangmu* contains more than 11,000 recipes, about 8,000 of which were collected or devised by the author, and more than 1,000 illustrations. The sources, numbering about 1,000, consist of medical and pharmacological works, along with historical, literary, philosophical, and other texts. While Li – like most traditional pharmacologists before him – accepted the authority of the early, pre-Tang pharmacopoeias, he did not refrain from criticizing and correcting the views of later authors.

The manuscript of the *Bencao gangmu*, completed in 1578, went through several revisions until 1590, when Li took it to a Nanjing publisher for publication. It is uncertain whether the author was able to see his work printed before he died in 1593: recent research has suggested that printing may have not been completed until 1596 rather than 1593 as often indicated. The *Bencao gangmu* was re-edited several times in China and Japan. References in early sinological works reached the attention of eighteenth- and nineteenth-century Western scientists, including Carl von Linnée (Linnaeus) and Charles Darwin, who refer to it in their own works. (Editor's note: More detailed material can be found in Métailié 2001.)

See also: ►Medicine in China, ►*Bencao gangmu*, ►Ethnobotany in China, ►Tang Shenwei

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Li Zhi (Li Ye)

Ho Peng Yoke

Considered by the historian of science George Sarton as essentially an algebraist, Li Zhi (1192–1279) was one of the greatest mathematicians of his time. He is known by some as Li Ye, a name that he was supposed to have taken at the later stage of his life to avoid the word *zhi* which was adopted by a member of the royalty. He used an algebraic process known as *tianyuanshu* (method of the celestial element) to set up equations of any degree. He was not the originator of this method, but it was through his writings that the *tianyuanshu* was handed down to later generations. It was introduced to Japan and had a profound influence on Japanese mathematics. Known as *tengenjitsu* to Japanese mathematicians, it enabled Seki Takakazu (also known as Seki Kowa, ca. 1642–1708) to develop a formula for infinite expansion, which is now arrived at using infinitesimal calculus. (See the article on Seki Kowa for a more complete description of the method.)

Li Zhi was born in Luancheng in modern Hebei province. He served the Jurchen government as a magistrate in Junzhou (in modern Henan province). In 1232 the Mongols captured Junzhou and Li Zhi made his escape taking refuge in various places and living as a recluse. He became a noted scholar in north China. Qubilai Qan intended to give him an official appointment, but he declined the offer. He read widely and was a voluminous writer. Unfortunately most of his books are lost. According to one source, before Li Zhi died he told his son Li Kexiu to burn all his writings except the *Ceyuan haijing* (Sea Mirror of Circular Measurements) which he wrote in 1248, saying that posterity might find it useful. Somehow, another mathematical text, the *Yigu yanduan* (New Steps in Calculation) which he wrote in 1259, also escaped the fire. It is only through these two works that we know about Li Zhi's contributions to mathematics.

Consisting of 170 problems, the *Ceyuan haijing* begins with a diagram of a circle inscribed in a right-angled triangle. Diameters of the circle parallel to the vertical and horizontal sides of the triangle, and tangents to the circle parallel to these two sides of the triangle produced 15 different right-angled triangles of different sizes. Li Zhi worked out the relations between the sides of these triangles, and between the diameter of the circle and the parallel sides of two of the trapezia formed in the diagram. His understanding of the properties of the circle and the right-angled triangles enabled him to work out many of his problems with great ease. The same problem that his contemporary Qin Jiushao (ca. 1202–ca. 1261) solved with a tenth degree equation was handled by Li Zhi simply using a quartic equation instead.

The *Yigu yanduan* contains 64 problems involving mainly a square and a circle, with a few cases on two different circles, two different squares, and a circle together with either a rectangle or a trapezium. Again equations of higher degrees are used. This text stabilized the terminology used in Chinese mathematics about equations of higher degrees.

See also: ►Mathematics in Japan, ►Seki Kowa

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Līlāvatī

Takao Hayashi

The *Līlāvatī* is a Sanskrit work on arithmetic and mensuration (computational geometry) composed in or a little before AD 1150 by Bhāskara II, one of the greatest Indian mathematician–astronomers. The *Līlāvatī* is sometimes regarded as the first part of the *Siddhāntaśiromaṇi*, a masterpiece on *gaṇita* (mathematics) in its broad sense (including mathematical astronomy), the other parts being *Bījagaṇita*, *Grahagaṇitādhyāya* (Chapter on planetary computation) and *Golādhyāya* (Chapter on spherical astronomy), but in manuscripts the four parts have been handed down to us independently.

In medieval India, mathematics proper comprised two major fields, *pāṭīgaṇita* (mathematics of algorithm) and *bījagaṇita* ("mathematics of seeds" or algebra). The *Līlāvatī* is the most typical and the most influential work of *pāṭīgaṇita*. More than 600 manuscripts of the work have been reported so far and more than 30 extant commentaries attest that it was the most popular mathematical textbook in India used by a number of people on the entire subcontinent. Moreover, the work was translated not only into Indian languages of the North and of the South but also into Persian several times in the sixteenth and the seventeenth centuries, into English in the nineteenth century, and into Japanese in the twentieth century (Pingree 1970–94: A4, 299–308, and A5, 254–257).

The great popularity is due not only to the promotion of his works through a school (*maṭha*) established by his grandson, Caṅgadeva (Pingree 1970–94: A4, 299), but also to the elegant but plain Sanskrit and to the well-organized contents of the work itself. The *Līlāvatī* consists of about 270 verses of various meters for rules and examples and of prose paragraphs mainly for solutions of the examples: a rule is prescribed for a type of problem and it is usually followed by one or two examples, which in turn are followed by solutions. The sectioning of the book is not always clear but it seems reasonable to divide it in 14 chapters. The contents of each chapter are as follows:

1. Terminology (*paribhāṣā*): gives conversion ratios between various units for currency, weight, length, area, and capacity.
2. Determination of the places for numbers (*saṃkhyāsthānanirṇaya*): enumerates the names of the first 18 decimal places from *eka* (1) to *parārdha* (10^{17}). This is the Hindu traditional list that had been fixed in the time of Śrīdhara (eighth century AD) (Hayashi 1995: 64–70).
3. Eight elementary operations (*parikarmāṣṭaka*): prescribes rules for the eight operations (addition, subtraction, multiplication, division, square, square-root, cube, and cube-root) in three sections, namely, those for integers, for fractions, and for zero. The rules for integers are based on the place-value notation. For multiplication several additional rules are also given. The first four rules for zero are as follows ($a > 0$): $a + 0 = 0 + a = a$; $a - 0 = a$; $a \times 0 = 0 \times a = 0$, but, when other operations follow, the product, being called *khaguṇa* (a quantity that has zero as a multiplier), retains a besides the zero, and the zero is canceled if the succeeding operations contain zero as a divisor; and $0 \div a = 0$ and $a \div 0 =$ *khahara* (a quantity that has zero as a divisor). The rule, $0 - a = -a$, is not given here because negative numbers are avoided in *pāṭīgaṇita*; it is given in the *Bījagaṇita* of the same author. In that work, the infinity of the *khahara* is compared to that of God.
4. Miscellaneous (*prakīrṇaka*) operations: includes the rule of inverse operations, the optional-number computation (the rule of false position), the inequality computation (algorithms for two sets of algebraic normal forms), the square computation (three algorithms for the simultaneous indeterminate equations, $x^2 + y^2 - 1 = u^2$, $x^2 - y^2 - 1 = v^2$), the multiplier computation, the rule of three (which is essential for *pāṭīgaṇita* according to Bhākara II), the inverse rule of three, and barter. The "multiplier computation" was an algorithm for the equation, $x - \sqrt[a]{x} = b$ (the "multiplier" signifies a), which had been treated as one of the "class" (*jāti*) problems by Śrīdhara, by Mahāvīra, and by Śrīpati. Bhāskara II reduced several other "class" problems of similar types, which had been given different algorithms by his predecessors, to this type, and treated other "class" problems involving simple linear equations under the "optional-number computation."
5. Procedure for mixture (*miśraka-vyavahāra*): includes interest, investment, and proportional distribution of gain, filling a pond with water through several

pipes, buying and selling, equation of properties after the exchange of jewels, purity of gold, and combination.

6. Procedure for series (*śreḍhī-vyavahāra*): treats the sums of a natural series, of the sums of natural series, of a square series, and of a cubic series; the sum, the first term, etc. of an arithmetic progression; and the sum of a geometric progression.
7. Procedure for fields (*kṣetra-vyavahāra*): consists of four sections, namely, trilaterals, quadrilaterals, needle figures, and circle and sphere. The first section deals with the Pythagorean theorem and its application, rational right triangles, and the area, the perpendicular, etc. of a triangle. In the second section, besides the areas of equilateral, rectangular, and equiperpendicular quadrilaterals, Bhāskara II discusses in detail how to calculate the diagonals of an inscribed quadrilateral and criticizes Brahmagupta's method for its "heaviness" (*gurutva*). The third section, based on the property of similar triangles, deals with the lengths of various segments of a "needle figure" (*sūcī-kṣetra*), which is a trilateral formed by the base of a quadrilateral and by its flank sides extended to meet each other. In the fourth section, Bhāskara II employs the two approximations, 22/7 and 3927/1250, for π, and gives the formulas, $A = cd/4$, $S = 4A$ and $V = Sd/6$, for the area of a circle and the surface and the volume of a sphere, respectively, where d is the diameter and c the circumference. In his *Golādhyāya*, he criticizes Lalla's formula, $S = cA$, and derives his own for S and V by decomposing a sphere into a number of annuli in one place and into segments like orange peels in another in the former case, and into a number of pyramids in the latter (Hayashi 1997: 214–217). The same section also contains applications of the relationship, $a^2 = 4h(d\text{-}h)$, where a is a chord and h the corresponding "arrow" or the height, a list of the sides of inscribed regular polygons (up to a nonagon), and Bhāskara I's approximation formula for a chord, $a = (4db(c-b))/(5c^2/4-b(c-b))$, where b is the corresponding arc.

The next four chapters repeat traditional rules for three-dimensional figures.

8. Procedure for excavations (*khāta-vyavahāra*): deals with the volumes of excavations shaped like a rectangular solid, a truncated pyramid, a pyramid, and a cone.
9. Procedure for brick-piling (*citi-vyavahāra*): deals with the relationships of the volume, the height, the sectional area, and the number of the layers, of a wall made of bricks, the volume and the height of a constituent brick, and the number of the bricks.
10. Procedure for sawing (*krākacika-vyavahāra*): deals with the total area of the sections of a lumber cut by a saw, in order to evaluate the work of sawing.
11. Procedure for heaped-up grain (*rāśi-vyavahāra*): deals with the volumes of grain heaped up on the ground in the shape of a cone, heaped up against a flat wall, and heaped up inside and outside of a corner. The height of the heap is taken to be one-ninth, one-tenth, or one-eleventh of the circumference of the base according to whether the grain is fine or coarse.
12. Procedure for shadows (*chāyā-vyavahāra*): based on the property of similar triangles and on the Pythagorean theorem, deals with the shadows made by a gnomon; does not contain the calculation of the time of a day from the shadow of a gnomon, a calculation which was included in this "procedure" by Bhāskara II's predecessors.
13. Pulverizer (*kuṭṭaka*): deals with linear indeterminate equations of the type, $y = (ax + c)/b$. It is Bhāskara II who for the first time included a whole theory of the pulverizer in a book of *pāṭī*, although Mahāvīra had already treated it to some extent in his *pāṭī* book. This is because it requires neither algebraic symbolism nor "intelligence" (*mati*), which are essential for *bījagaṇita* or algebra according to Bhāskara II. He repeats the same rules for *kuṭṭaka*, together with several additional ones for negative coefficients, in his *Bījagaṇita*.
14. Chain of digits (*aṅka-pāśa*): treats permutations of the nine digits (excluding zero). An example for the last rule, for example, reads as follows: "How many varieties of numbers are there with digits placed in five places when their sum is thirteen? It should be told, if you know." This was an entirely new topic introduced by Bhāskara II, although a rule for calculating ${}_nC_r$ had traditionally been included in the chapter on "mixture" by Śrīdhara, Mahāvīra, Āryabhaṭa II, and Bhāskara II himself.

The above description of the *Līlāvatī* is based mainly on the Ānandāśrama edition, which differs from the Hoshiarpur edition in many respects: for example, the last mentioned topic, ${}_nC_r$, is placed at the end of the chapter on series in the Hoshiarpur edition (Hayashi 2002). It has been conjectured that those two editions represent the Northern and Southern recensions, respectively, but the history of transmission (including recensions) of the *Līlāvatī* is yet to be investigated on the basis of all the existing manuscripts.

See also: ►Algebra in India, ►Arithmetic in India, ►Bhāskara II

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Liu Hong

Jiang Xinoyuan

Liu Hong was a Chinese astronomer (AD 129–210), descended from the imperial family of the Eastern Han Dynasty. Liu Hong was very interested in astronomy from his childhood. About AD 160, he was assigned to be an officer of the Imperial Observatory. In this position, he participated in determining a series of astronomical dates. In AD 174–175, he offered *Qi Yao Shu* (The Art of Seven Planets) and its reformulated edition *Ba Yuan Shu* (The Art of Eight Elements) to the imperial government. The two works have been lost, but there are indications that they related to Buddhist astrology in Middle Asia. In AD 187–188, he composed the *Qian Xiang Li* (Qian Xiang Calendar), a work of traditional Chinese mathematical astronomy. The method to describe lunar motion in this work was so advanced that the imperial government adopted it immediately. In AD 206, he examined and approved the formal edition of *Qian Xiang Li*. This is one of the best calendars in ancient China. It used new data for the tropical year ($365\frac{145}{589}$ days) and the synodic month ($29\frac{773}{1457}$ days), calculated the advance of the lunar perigee, established the concept of the moon's path, and calculated the regression of node, established the first table of the lunar apparent motion in ancient China, and also made progress in the calculation of eclipses and planetary motion.

See also: ►Calendars in East Asia

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Logic

C. K. Raju

It is believed in the West that logic began with Aristotle and that logic is universal. The core of Western thought – including present-day formal mathematics and the philosophy of science – is premised on the belief that logical truths are universal, that they are necessary truths, and that logical deduction is certain and infallible. These beliefs about logic, however, are untenable, both historically and philosophically, in a larger picture which takes the rest of the world into account.

Philosophically, present-day formal logic, like the twelfth century BCE text, *Organon*, attributed to-Aristotle, supposes that deduction relates to two-valued logic. In such a logic, an affirmation A conjoined with its negation ($\sim A$) makes a contradictory pair, from which any conclusion B whatsoever can be validly inferred by the rule of inference known as *reductio ad absurdum*: ($A \wedge \sim A \Rightarrow B$), to put it symbolically, with "$\sim$" denoting "not," "$\wedge$" denoting "and," and "$\Rightarrow$" denoting the usual (material) implication. For example, A could be the proposition, "This pot is red," so that its negation $\sim A$ would be the proposition, "This pot is not red." From the contradictory pair ($A \wedge \sim A$), one can validly infer something completely unrelated like B: "The age of the cosmos is 8,000 years." Such proofs by contradiction are common in present-day mathematics. However, such a deduction would be invalid with a variety of logics that one can conceive of. The alleged certainty of deduction, therefore, rests on the belief that two-valued logic is universal or at least special in some way.

However, the various logics used for inference in India, prior to even the historical Aristotle, were neither two-valued nor even truth-functional. The *Dīgha Nikāya* provides an example. As the Buddha explains in the *Brahmajāla Sutta*, there are four alternatives:

1. The world is finite; this is one case.
2. The world is not finite; this is another case.
3. The world is both finite and infinite; this is the third case.
4. The world is neither finite nor infinite; this is the fourth case.
5. There are no other cases.

The semantic interpretation of the third case is that the world may be finite in one direction, but infinite in another. This presents no inherent absurdity, and could conceivably be in the nature of things.

The meaning of the fourth case, not so well brought out in the English translations of the *Dīgha Nikāya*, may be better understood as follows. Consider a person who refuses to take a position, and denies that he affirms any of the first three cases above. His position can only be described by the fourth case.

The need for such a fourth case is apparent from the thinking then prevalent. Likewise, the absence of any further cases is a reference to further negations used by pre-Buddhist thinkers like Sañjaya the Sceptic, who tried to wriggle out of even this fourth position, and whose comprehensive refusal to take any position whatsoever was described by the Buddha as being like the "wriggling of the eel."

These four cases are systematically used by later-day Buddhist thinkers like Nāgārjuna and Dinnāga who taught at the University of Nalanda. The latter developed a theory of (logical) quantifiers, "for all," "for some," etc., based on this sort of logic. From the perspective of present-day formalist treatments of logic, it should be noted that Buddhist logic is not multi-valued but is rather a quasi truth-functional logic.

The Jains had a related but different logic called the logic of *syādavāda* ("perhaps-ism"), based on the idea of *anekāntavāda* (no-one-point-of-view-ism). Attributed to Bhadrabāhu, instead of four alternatives, this logic has a sevenfold judgment (*saptabhangīnaya*) based on seven possible combinations of three primary values: *asti* (is), *nāsti* (is not), *avaktavya* (inexpressible), taken one, two, and three at a time.

Syad asti. ("Perhaps it is.")
Syad nāsti. ("Perhaps it is not.")
Syad asti nāsti ca. ("Perhaps it both is and is not.")
Syad avaktavya. ("Perhaps it is inexpressible.")
Syad asti ca avaktavya ca. ("Perhaps it is and is inexpressible.")
Syad nāsti ca avaktavya ca. ("Perhaps it is not and is inexpressible.")
Syad asti nāsti ca avaktavya ca. ("Perhaps it is, is not, and is inexpressible.")

Haldane sought to interpret the Jaina logic of *syādavāda* by temporalizing the three primary values. Consider an experiment in which a person is asked to judge whether or not a sensory stimulus, at the threshold of perception, is present. If this experiment is repeated several times, a person might in one case judge the stimulus as present, in another as absent, and may remain undecided sometimes. Combining these possible experimental outcomes in all possible ways gives us the seven different judgments used by *syādavāda*. Thus, it is quite possible that a person may, at one time say that a stimulus is present, but may, on a later repetition of the same experiment, say, about the same stimulus that it is absent, and on a third occasion say that he is unable to decide.

Haldane's interpretation of *syādavāda*, making it intelligible in a mundane context, seems, however, not to be correct. It is one thing to say, "This cat is now alive, and will be dead some time later." This is true of most known cats, and presents no difficulty: A is true at one time, and $\sim A$ is true at another time. However, it is altogether another thing to say, "This cat is both alive and dead at this moment of time." That sort of thing happens only to Schrödinger's famous cat (or its kittens). It is the latter sort of statement that is meant in Buddhist and Jaina logic, as is clear from the meaning explained by the Buddha. In fact, on Buddhist thought, as further elaborated by Nāgārjuna, a thing – anything – does not persist for more than an instant of time. Therefore, a statement about a cat, for instance, must refer to that cat at a given instant of time, for an identical cat does not exist at two different instants of time.

In terms of the present-day formal semantics of logical worlds, one might put things as follows. The different possibilities visualized in Buddhist and Jaina logic refer not to multiple logical worlds assigned to different instants of time, but to multiple logical worlds assigned to a single instant of time. In other words, Buddhist and Jaina logics relate to a world view in which time is perceived to have a nontrivial structure, an (atomic) instant of time is perceived not as a featureless geometrical point but as a microcosm. Hence, members of a contradictory pair can well be simultaneously true.

This can be understood at the mundane level as follows. Consider the statement, "This pot is both red and black." We could rewrite this, less informatively, as, “This pot is both red and not red.” Since earthen pots made by hand are rarely of a single color, this is a statement about a naturally prevailing state of affairs that is commonly observed. The statement, as framed, seems like a contradiction. But, it could be argued that this is an imprecise natural-language statement which should actually be written more carefully as, “This part of the pot is red, and that part of the pot is not red.”

However, such a reinterpretation raises some issues. First, there is the issue of the whole not being the sum of its parts. It is being assumed that the pot can be subdivided into parts. If the pot is physically shattered to carry out this subdivision, one can continue to speak of parts of the pot, but one cannot continue to speak of the pot. Therefore, the reinterpretation does not capture the exact sense of the natural-language statement. Thus, the idea of a thing being both true and false is not such an odd idea, and no catastrophic consequences need follow from it.

Second, how can we be sure that the apparent contradiction can always be resolved by suitably shattering the identity of the pot? Thus, a certain part of the shattered pot may continue to be both red and black, so one may want to divide the pot in a particular way. Now it may happen that, in a certain part of the pot, red and black are so entangled that it may not be clear how to separate them. The remedy obviously seems to be to make a finer division of the pot, and a still finer division, and so on, until the pot is suitably atomized. However, there is an assumption here. The assumption is that the entanglement and the resulting contradiction will somehow eventually resolve themselves with this process of reduction and that the entanglement cannot persist at the atomic level, where a thing either is, or is not. Apart from the fact that atoms are neither red nor black, there are several problems with such an assumption. For example, this assumption is contrary to what our most sophisticated theories of physics tell us. The behavior of physical systems at the atomic level is described by quantum mechanics, which tells us that there may exist entangled states that cannot be disentangled without fundamentally altering the system. The existence of such entangled states, incidentally, provides the hope today for future technology based on quantum computing, and it has various physically measurable consequences.

On the structured-time interpretation of quantum mechanics, these entangled states are interpreted to arise because time really has a microphysical structure (in the sense explained above, in the context of Buddhist and Jain logic) so that the logic of the microphysical world is quasi truth-functional. (In the structured-time interpretation of quantum mechanics, such a quasi truth-functional logic is related to the postulates of formal quantum mechanics.) To summarize, the logic of the empirical world may well be quasi truth-functional: i.e., we might have a situation where a proposition is both true and false at a single instant of time. Hence, we cannot automatically assume that the “contradictory” properties of a pot can be made to disappear by atomizing the identity of the pot.

Theoretically, from the viewpoint of present-day formal logic, one can conceive of an infinity of different logics, such as 2, 3,..., *n*-valued logics, or non-truth-functional logics. Among the infinity of logics that are available how can we be sure that two-valued truth-functional logic is the correct and universal choice? Suppose the choice is made culturally. That is, suppose we say that two-valued logic is what has been conventionally used in the West, and this is the logic that should be chosen since the West is culturally dominant. (A similar argument was given against intuitionists; it was argued that they were not adequately socially dominant among mathematicians, hence they were incorrect!) However, if such a weak argument is the ultimate basis of deduction, then deduction can at best give us a local cultural truth. On the other hand, suppose the choice is made empirically, then, as we have already seen above, we might end up with the logic of quantum mechanics, which need not be two-valued. Therefore, it is not clear that there is anyway the existing choice of logic in the West can be justified.

The possibility or necessity of determining logic empirically strikes at the root of another fundamental difference between Western and non-Western perceptions of logic. In the West, logical truths are regarded as necessarily true, and are privileged over empirical facts, regarded as being only contingently true. Present-day mathematical proof is required not to involve the empirical, since that would diminish the sureness attached to a mathematical theorem. Hence, also, the present-day belief in the philosophy of science, that when the conclusions of a physical theory are refuted by experiment it is the hypotheses that stand refuted, and not the process of inference which led from hypothesis to conclusion. (Here it is necessary to distinguish between validity and correctness. The point is that it is believed that no empirical fact can invalidate a correct mathematical proof.)

Therefore, even if one were to go about trying to settle the nature of logic empirically, this would have consequences which would be startling from a Western perspective. Empirical observations are fallible, and subject to revision. So if the nature of logic is decided empirically, logical truth would have to be regarded as more fallible than empirical truth: deduction would have to be regarded as more fallible than induction, since the nature of the logic used for deduction could only be decided inductively. This would stand much of Western thought on its head.

This would, however, leave much of non-Western thought unaffected. The belief that metaphysical (e.g., mathematical) truths are privileged over empirical truths is not necessarily shared by the non-West. In traditional Indian thought, for example, logical truths are ranked below empirical truths. Thus, the empirically manifest (*pratyakṣa*) is regarded the first *pramāṇa* (proof), and this is a means of proof accepted by all traditional Indian schools of thought, without any known exception. Inference (*anumāna*) or deduction is regarded like estimation as an inferior means of proof by the Lokāyata school and rejected, just as analogy is regarded as an inferior means of proof by Buddhists, and rejected in comparison with the empirically manifest and inference.

Thus, there appears to be no serious way out of this dilemma about the nature of logic, and most of Western thought would hence need to be reworked in the future to avoid this incorrect assumption that two-valued logic is somehow universal.

From a historical perspective we can understand how this Western myth about the universality of logic developed. The word "logic" derives from "logos" meaning "word" or "reason" – a term imbued with deep religious significance by the (Neoplatonist) philosophers of Alexandria, like Proclus, who refer to it as "divine." The reason for this, as stated by Plato, was that geometrical truths based on reason were thought to be eternal – like the soul, and unlike empirical things (like the body) that are by nature perishable. Proclus explains that mathematics derives from the Greek word *mathesiz*, meaning learning, so that mathematics is the science of learning. According to Socratic belief, all learning is recollection of knowledge already in the soul; hence it was thought that mathematics, since it embodies eternal truths, and stirs the soul reminding it of its past lives, thus justifies its name as "the science of learning" or the "science of the soul." This belief in eternal truths was also understood quite literally as implying a world which existed eternally, a subject on which Proclus wrote a book.

After the Christian church revised its doctrines of creation and apocalypse in the fourth century BCE, it found this belief in eternal truths, past lives, and an eternal world, implicit in mathematics and logic, contrary to the revised doctrines. The church viciously persecuted the philosophers of Alexandria, burning their books, smashing their temples, lynching them, and eventually making a law declaring a death penalty on them. The philosophers found a more congenial base in Jundishapur in Iran.

This religious significance of logic or reason, however, remained part of early Islamic rational theology (*aql-i-kalām*), and it received a big boost when the philosophers moved from Jundhishapur to the Bayt al-Hikmā (House of Wisdom) in Baghdad, with the support of Caliph al-Māmun. The belief in reason then acquired such force in Islam that even key opponents of the philosophers, like al-Ghazālī, conceded that God was bound by logic and could not create an illogical world or a world in which something might have contradictory properties.

Though incidental to al-Ghazālī's primary objective, this concession about logic marked a fundamental shift which has gone unnoticed. Plato and Proclus had thought that logical and mathematical truths were necessary truths in the sense that they were eternally true or true for all time. In al-Ghazālī's vision, Allah continuously created the world afresh each instant; therefore nothing could last eternally. With al-Ghazālī's concession that Allah could not create an illogical world, the notion of necessary truth acquired a new meaning. That is, al-Ghazālī regarded logical (and mathematical) truths as necessary truths in the sense that they were true in all conceivable worlds (that Allah could create), and not in the sense that logical truths were eternally true.

Western thought developed in European universities from the twelfth century BCE onwards under the influence of hundreds of Arabic texts translated into Latin. Particularly important were the texts written by al-Ghazālī's Islamic opponent Ibn Rushd (Averroes). For Ibn Rushd, the term "Aristotle" was a generic term for "the Greek sage," linked to the book called the *Theology of Aristotle*, one of the translations of the Baghdad House of Wisdom. Thus, for Ibn Rushd reason and religion continued together.

This Arabic knowledge flowing into Europe alarmed a section of the church and was regarded as spreading heresy at the time of the Crusades and Inquisition. Aquinas and the schoolmen undertook to make this knowledge theologically correct.

The first step in this process of theological purification was to deny any Arabic–Islamic contribution whatsoever in these eleventh century BCE Arabic texts, and to attribute wholesale to Aristotle, or some other Greek, the authorship of any desirable part of these works. (Theologically unacceptable parts were attributed to various others, like Plotinus.) Since the church could hardly acknowledge publicly that all its knowledge came from Islamic sources, so it had to be pretended that the heathen were mere carriers of what formerly was Western knowledge. The evidence linking these late and obviously accretive texts to the historical Aristotle is expectedly slight, and requires a giant leap of faith, but religious history is no stranger to such leaps of faith. This concocted story based on flimsy evidence has been uncritically accepted and repeated for centuries, but hardly stands up to the slightest critical scrutiny. In the process of denying the Arabic–Islamic contribution, the Indian contribution from the Nyāya school, which used a similar system of syllogisms (with two-valued logic), and was probably translated in the Bayt al-Hikmā, may also have been denied. The point here is not the priority for the syllogism – priority does not have the same importance in the non-West as it has in the West – the point is to understand the historical process by which the syllogism developed. In India, given the wide-ranging nonviolent debates between clashing traditions, it was important to evolve a systematics of argumentation. It is easier to believe that the syllogism developed in response to some such social need than to believe the tale that a single individual called Aristotle apparently created a complex theory *ex nihilo*.

Could the similarity between the Indian and the "Aristotelian" syllogism be due to transmission? Certainly, there were regular contacts between India and Greece from before the time of Aristotle, as recounted by Herodotus or as evidenced by Alexander's attempt to find the sea route to India after his army mutinied at the frontiers of India. Second, as a key beneficiary of Alexander's loot of Egyptian, Persian, and Babylonian books, Aristotle also had the benefit of access to a wide variety of world literature. Third, we know from the rock edicts of Aśoka the Great that he sent an envoy to Ptolemy II to teach righteousness (*Dhamma*) to the Alexandrians and Macedonians. Fourth, India had a roaring trade with Alexandria at the time of the Roman empire, and Roman historians complained that this trade was draining a major part of the surplus of the empire. Fifth, Augustine taunted the Alexandrian philosophers for being interested in "the mores and disciplines of Inde." So, transmission of knowledge between India and Alexandria certainly could have taken place (in either direction) over a wide-ranging period.

Whether such transmission involved the syllogism is another matter. It seems not to have been much used in Hellenic tradition. Therefore, it lacks credibility to imagine the pre-Hellenic existence of a syllogistic logic, from eleventh century BCE Arabic or later Byzantine Greek texts. The known facts are that the use of the syllogism among Arabs does not begin before the ninth century BCE, and among Europeans not before the twelfth century BCE; everything else is conjecture.

Apart from denying the slightest credit to the non-West in all the accumulated knowledge in the eleventh century Arab texts, the second step in the Christianization process of these texts was to revise the significance of logic and reason. Reason was no longer the window to the soul but was promoted in Christendom as a means of argument used to persuade the infidel who would not listen to arguments from the scriptures, but would accept arguments based on reason. Hence, reason (and the logic used by Aristotle) was declared to be "universal." It is in this way that it historically came to be believed in the West that logic began with Aristotle and is universal, although both beliefs are incorrect when a larger picture is taken into account.

In India itself, the Nyāya tradition was attacked by the Advaita Vedantist S'rīharṣa, in the ninth century BCE using arguments similar to those of Nāgārjuna. The Navya–Nyāya (new Nyāya) logic emerged subsequently.

See also: ►Ibn Rushd, ►Nyāya

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For a different translation using Chinese texts, see

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Long Count

Vincent H. Malmström

One of the most original creations of pre-Columbian Mesoamerica was the so-called "Long Count," a system of recording events in time with unique precision. No parallel system existed in any other society until the Julian Day count was begun in Western Europe in 1582. Because it was most widely used by the Maya, its development was first credited to them, but subsequent research has shown that the earliest inscriptions which employed the Long Count not only lay well outside of the Maya core-area geographically, but also predated the rise of the Maya historically.

The Mesoamerican Long Count was a meshing of the two time-reckoning systems that had been already been in use in the region for about a millennium: a sacred almanac of 260 days and a secular calendar of 365 days. In both counts a vigesimal system was used to group the days into "bundles," for a total of 13 in the sacred almanac and a total of 18 in the secular calendar. The 5 remaining days in the latter count were considered "unlucky" or "worthless." The basic unit of the count was the day, or *kin*, in Maya. Twenty days constituted one *uinal*, and 18 uinals made up one *tun*, for a total of 360 days. (The *tun* was the only deviation the Maya allowed from a strictly vigesimal system, and was only employed in their count of days.) Twenty *tuns* comprised a *katun* (7,200 days) and 20 *katuns* constituted a *baktun* (144,000 days). The fundamental premise of the Long Count was that it recorded the number of days that had elapsed from a date in the distant past, which marked the beginning of the present cycle of the world. Because the Maya recorded their Long Count dates by enumerating, in order, the number of *baktuns*, *katuns*, *tuns*, *uinals*, and *kins* which had elapsed from that date, together with the number and name of the day in both the sacred almanac and secular calendar which it represented, any given day was identified by a minimum of nine elements. Thus, in the present convention for transcribing Long Count days, the first day of the Long Count was designated as 13.0.0.0.0. 4 Ahau 8 Cumku (Fig. 1).

Long Count. Fig. 1 One of the earliest Long Count inscriptions found to date is that recorded on Stela C, discovered by Mathew Stirling at Tres Zapotes in 1939. Although the top of the stela containing the *baktun* value was missing, it was located in 1969 and found to be a seven. In writing numerals, the Maya used a dot for values up to four and a bar to represent five; hence Stela C's *baktun* value was shown as two dots and one bar. In the photo above we see that the *katun* value has one dot and three bars equaling 16, the *tun* value has one dot and one bar totaling 6, the *uinal* value again has one dot and three bars representing 16, and the *kin* value near the bottom of the inscription contains three dots and three bars for a total of 18. Thus, the full numeric inscription was read as 7.16.6.16.18. and equates to 5 September 31(or 32 BCE). Stela C now reposes in the Museum of History and Archeology in Mexico City (photo by author).

Although many attempts were made to reconcile the Long Count with the Christian calendar, one of the first credible explanations was that offered by the American newspaper editor John Goodman in 1905. According to his calculations, the Maya had fixed the beginning of the present cycle of world as 11 August 3114 BCE – a date that accords with Julian Day number 584,283; hence, his correlation has been identified by that value. However, because Goodman was not an academic, little attention was paid to his findings until 1926 when a Mexican astronomer named Juan Martínez Hernández recalculated the beginning date of the Long Count as 12 August 3114 BCE, yielding an equivalent Julian Day number of 584,284. The following year, when the British archeologist J. Eric Sydney Thompson made his own attempt to reconcile the two calendars, he determined that the correct date should be 13 August 3114 BCE, for an equivalent Julian Day number of 584,285. Because all three of these correlations produced results within 2 days of each other and have subsequently been shown to accord most closely with known astronomical events, the so-called "Goodman–Martínez–Thompson" is now the accepted means of equating the Long Count with our own calendar. (It should be noted, however, that in 1935 Thompson revised his calculations and adopted Goodman's original formula of 584,283 instead; unfortunately, this "correction" served to confuse the correlation issue for an entire generation because it rendered all astronomical equivalencies impossible. Subsequently,

Long Count. Fig. 2 *Baktun* 7 inscriptions, which represent the earliest form of the Long Count, are all found in a restricted area stretching from the Pacific coast of Guatemala and Mexico across the Isthmus of Tehuantepec to the Gulf of Mexico. All of them are associated with early Olmec ceremonial centers (map by author).

Long Count. Fig. 3 Later examples of the Long Count, all dating to the so-called "Classic Period" (AD 250–900), occur only in areas occupied by the Maya. Apparently the Long Count neither reached other peoples in Mesoamerica nor, if it did, was adopted by them. Its presence among the Maya helps to explain their preeminence in pre-Columbian astronomic studies (map by author).

Malmström (1978, 1992), among others, has conclusively demonstrated that the 584,285 correlation is the only one which has astronomical validity.)

As early as 1930, the American mathematician John Teeple concluded that the Long Count had been devised on a date that the Maya recorded as 7.6.0.0.0. 11 Ahau 8 Cumku. Teeple had been struck by the fact that 73 cycles of the 260-day sacred almanac equated with 52 cycles of the 365-day secular calendar and that the day numbers and names of each count then came back into phase with each other. He believed that the Maya had also employed 73 cycles of larger intervals, such as *katuns*, in order to define longer spans of time, and that to fix the beginning of the present era of the world at an appropriately early date, they had projected their count backward for a total of 146 *katuns*, or 7 *baktuns* and 6 *katuns*. This meant that the Long Count had been originated on 18 September 236 BCE – a date that Thompson rejected as being too early because it assigned its creation to a people other than the Maya, who he championed.

In a paper published in 1978, Malmström, using a different premise – namely that the originator of the Long Count was bound by the recognition of the astronomical importance of 13th August as its initiating impulse – reached the same starting date for its origin as Teeple had done. Also in his paper he argued that, by using internal evidence contained in the Long Count, it is possible to establish both the beginning dates of the secular 365-day calendar and the sacred 260-day almanac as well. The former, he stated, was set in motion at the summer solstice around the year 1320 BCE, whereas the latter was initiated with the zenithal passage of the sun over Izapa in southernmost Mexico on 13 August about the year 1358 BCE. (Each of these dates may vary by as much as 4 years, due to the fact that the indigenous Mesoamerican calendars did not correct for leap years.) All of the earliest, or *baktun* 7, Long Count inscriptions have been discovered along an axis which extends from the Soconusco region of southern Mexico and adjacent Guatemala to central Chiapas into the Gulf coastal plain of Veracruz – an area which constituted the original homeland of the Zoque-speaking Olmec people (Figs. 2 and 3).

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Lunar Lodges in Chinese Astronomy

F. Richard Stephenson

Probably during the first millennium BCE, Chinese astronomers grouped the stars visible from their country into about 280 small constellations, each containing an average of about five stars. Among these star groups, twenty-eight asterisms encircling the sky in the general vicinity of the celestial equator were regarded as of special significance. Although their general appearance was much similar to that of the other constellations, these select star groups, known as *xiu* (lunar lodges) came to be of great importance in astrology and positional astronomy. The expression *xiu* is the derivative of a term *su*, meaning, "to stay the night". Although many of the lunar lodges were not near the ecliptic, they represented the nightly resting places of the Moon in its monthly circuit across the sky. During the first millennium AD, the Chinese system of mapping the stars, together with its associated lunar lodges, spread to other areas of East Asia, notably Korea and Japan.

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Just when the Chinese first divided the stars into groups is not known with any accuracy and this is also true of the *xiu*. A somewhat idealistic date for the origin of the lunar lodges can be deduced by considering precession of the equinoxes. Chinese astronomy is equatorial, rather than ecliptic, in character. Calculations reveal that in antiquity the mean great circle through the *xiu* was a significantly better approximation to the celestial equator than at present, with the best fit around 2500 BCE. Although attractive, such an artificial date has little to commend it. Several of the individual lunar lodges would still lie at a considerable distance from the mean circle, while there is no evidence of an advanced culture in China at such a remote period.

Direct historical evidence for the existence of the lunar lodges is lacking until about 3,000 years ago. The two earliest sources of information are quite diverse. Several of the ancient folk songs assembled in the *Shijing* (Book of Odes) – some probably dating from around 1000 BCE – allude to about ten star groups in total. Most of these constellations can be identified with lunar lodges as cited in later texts. Again, several bronze vessels which were cast at much the same period as the folk songs were composed are inscribed with the names of a few lunar lodges. It may thus be inferred that at least some of the *xiu* had acquired special significance

Lunar Lodges in Chinese Astronomy. Fig. 1 Laquer chest, with lid engraved with names of all 28 lunar lodges. The chest was discovered during excavations of a tomb dating from 433 BCE. (The chest is in Hubei Provincial Museum, Wuhan).

by early in the first millennium BCE. However, to encounter the earliest preserved list of all twenty-eight lunar lodges we have to move considerably forward in time.

A date of origin of the lunar lodges at least by the middle of the first millennium BCE was established as the result of a major archaeological discovery in 1978. In that year, a lacquer chest was unearthed from a tomb in Hubei province in Central China (see Fig. 1). This chest had been the property of a nobleman by the name of Yi who had died around 433 BCE, during the Warring States Period. On the lid of this chest are engraved the names of 28 constellations in a roughly circular pattern. In general, the various ideographs are identifiable with the names of the lunar lodges found in later lists, and are in the correct sequence. Of course, the existence of the 28 *xiu* as an entity could be much earlier, but at present we have no direct evidence to prove this.

Table 1 gives a standardized list (together with translations) of all 28 lunar lodges as found in texts of from the third century BCE onwards. In this table the *xiu* are numbered in their traditional order, commencing with *Xue* (located near the autumnal equinox in Virgo). In groups of seven, the lodges were traditionally associated with four mythical creatures: the first seven *xiu* with the Azure Dragon of the east, the next seven with the Dark Warrior of the north, the third seven with the White Tiger of the west and the last seven with the Red Bird of the south. Among the first seven lunar lodges, a few names relate to various features of the Dragon. However, the remaining *xiu* designations are little more than a random assemblage and in general they are much more mundane than the names of the Western zodiacal signs.

An early almanac known as the *Yueling* (monthly observances), probably dating from the Warring States Period (481–256 BCE), marks the passing months by the position of the Sun in various *xiu* as well as the culmination of certain lunar lodges at dawn and dusk. By at least the Former Han Dynasty (202 BCE–AD 9), a series of "determinative stars" (*chuxing*) – see Table 1 – were selected to specify right ascension. This coordinate was known as *ruxiudu* (degrees within a lodge). The meridian through each determinative star was adopted as the western boundary of a zone of right ascension bearing the same name as the lunar lodge itself. As a result, the term *xiu* came to mean both the asterism and the range of right ascension which it defined.

Commencing in the late second century BCE, several preserved lists give the equatorial extension of these zones in *du* ("degrees", of 365.25 to a circle.) Although the mean range in right ascension of each zone was 13°, the widths of individual *xiu* were far from regular. *Dongjing*, the widest lunar lodge, covered 33°, whereas *Zuixi* was only about 1° in extent. Table 1 gives the calculated widths during the Former Han Dynasty. As yet, the reason for this uneven spacing has not been fully explained. In some respects, the *xiu* resembled the Western zodiacal signs, which from ancient times were used to define celestial longitude. However, the signs of the zodiac were each 30° in extent and – unlike the lunar lodges – the effect of precession caused a gradual easterly displacement relative to the 12 constellations after which they were named.

For almost every solar eclipse occurring during the Former Han Dynasty, the official history of the period, the *Hanshu*, gives an estimate of the right ascension of the Sun to the nearest degree, followed by an astrological prognostication. Several later histories follow a similar practice. For instance, on a date equivalent to AD 120 January 18, the following entry is recorded in the *Houhanshu* ("History of the Later Han Dynasty"):

> The Sun was eclipsed. It was almost complete; on Earth it was like evening. (The Sun) was 11° in *Xunu* ("Maid"). The Female Ruler was upset by it; two years and three months later, Deng, the Empress Dowager, died.

At this date, the right ascension of ε Aqr, the determinative star of *Xunu* was 286° so that the estimated coordinate of the Sun would be 297°; this is in agreement with the computed right ascension of the Sun.

The lunar lodges were also used to specify the right ascensions of other star groups as well as the changing positions of the Moon and planets. The positions of temporary objects – meteors, comets, and novae or supernovae – were often described in this way. For

Lunar Lodges in Chinese Astronomy. Table 1 The Twenty-Eight Lunar Lodges

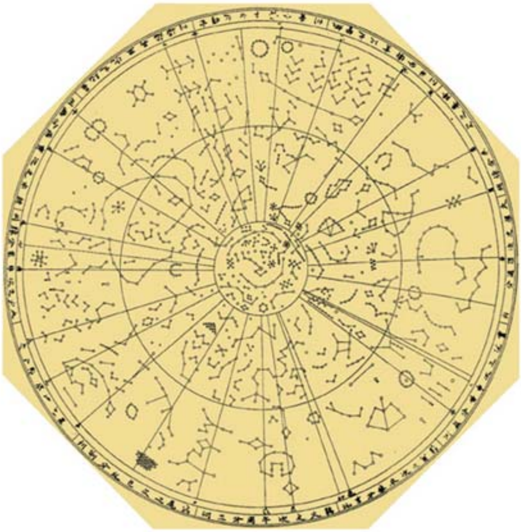
Number	Name	Translation	Determinative Star	Width (in°)
1	Jue	Horn	α Vir	12
2	Kang	Neck	κ Vir	9
3	Di	Base	α Lib	15
4	Fang	Chamber	π Sco	5
5	Xin	Heart	σ Sco	5
6	Wei	Tail	μ Sco	19
7	Ji	Basket	Γ Sgr	11
8	Nandou	S. Dipper	φ Sgr	27
9	Niu	Ox	β Cap	8
10	Xunu	Maid	Ε Aqr	12
11	Xu	Emptiness	β Aqr	10
12	Wei	Rooftop	α Aqr	17
13	Yingshi	Encampment	α Peg	9
14	Dongbi	E. Wall	Γ Peg	9
15	Kui	Stride	Ζ And	16
16	Lou	Harvester	β And	11
17	Wei	Stomach	35 Ari	15
18	Mao	Mane?	17 Tau	11
19	Bi	Net	Ε Tau	18
20	Zuixi	Turtle Beak	φ Ori	1
21	Shen	Triad	Δ Ori	8
22	Dongjing	E. Well	μ Gem	33
23	Yugui	Ghost Vehicle	θ Cnc	4
24	Liu	Willow	Δ Hya	15
25	Qixing	Seven Stars	α Hya	7
26	Zhang	Extended Net	Ν Hya	17
27	Yi	Wings	α Crt	18
28	Zhen	Axle Tree	Γ Crt	17

example, the passage of Halley's Comet in AD 66 through 8 lunar lodges between *Jianniu* and *Yi* is recorded in an early commentary on the *Houhanshu*.

Early measurements of the right ascension of Halley's Comet have proved of great importance in studying the orbit of the comet. For instance, at the very close approach of Halley's Comet to the Earth in AD 837, its position in the appropriate *xiu* was estimated to the nearest degree on several successive nights. At the time, the comet was moving rapidly across the sky at roughly 2°/h. The Chinese observations enable the date of perihelion to be estimated to the nearest 0.1 day. In AD 1006, the right ascension of a brilliant supernova was recorded as 3° in the lunar lodge *Di*. This and other contemporary observations have enabled the remnant to be convincingly identified.

The *Xingjing* (Star Manual), a star catalog which has been dated by astronomical computation to around 70 BCE, gives the earliest preserved measurements of north polar distance for the determinative stars of the *xiu*, as well as for many other stars. Individual results are typically quoted to the nearest 0.25° or 0.5°. Using these and similar measurements in later catalogs, together with several carefully executed star maps from around AD 1000 onwards, it is possible to identify the individual constituents of the *xiu* with stars listed in modern Western catalogs with considerable confidence. Certain lunar lodges, such as *Shen* (equivalent to the central portion of Orion), contain some very bright stars. Other *xiu*, such as *Yugui* (part of Cancer) consist of stars only barely visible to the unaided eye. Such marked differences are perhaps surprising, bearing in mind the importance of the lunar lodges. However, the brightness of a star was regarded as having little bearing on its astrological significance.

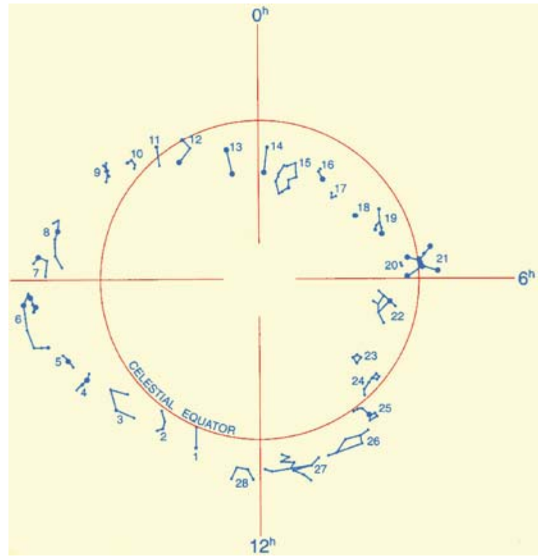
The earliest known chart of all 28 lunar lodge asterisms dates from around 25 BCE. This colorful representation is painted on the ceiling of a tomb which is located in the city of Xi'an and came to light in 1987. Many later star maps are extant – some displaying considerable detail and revealing much astronomical skill. These often depict the night sky on a circular plan (a polar projection) with the *xiu* boundaries shown as straight lines radiating from the north celestial pole at the center of the chart (see Fig. 2). Several illustrations of the lunar lodges have been found in tombs in recent decades. It is interesting to note that whereas Western representations of the zodiacal signs almost always use



Lunar Lodges in Chinese Astronomy. Fig. 2 Careful drawing of a Chinese star map dating from AD 1453. This was found in Longful Temple and is now in the Beijing Ancient Observatory. (Drawing: courtesy, Prof Pan Nai, Shanghai).

Lunar Lodges in Chinese Astronomy. Fig. 3 Chinese painting showing the 28 lunar lodges and 12 signs of the Western zodiac. This is painted on the ceiling of a tomb at Xuanhua, near Beijing, and dates from AD 1116. (Photo: Courtesy Prof Chen Meidong, Beijing).

the various symbols – e.g., a crab for Cancer, two fish for Pisces – Chinese illustrations of the *xiu* typically portray the outlines of the constellation patterns themselves (see Fig. 3). In artefacts of a nonastronomical nature, these illustrations are often quite stylised. For example, the blades of several well-preserved Korean swords are engraved with the configurations of all 28 *xiu*.



Lunar Lodges in Chinese Astronomy. Fig. 4 Celestial positions of the 28 lunar lodge asterisms. (This is my own illustration).

Individual determinative stars cover a wide range in declination: from around 0 up to some 30° (see Fig. 4). As a result, with the passage of time the differential effect of precession causes the widths of the *xiu* in right ascension to change somewhat. This effect has been most significant for *Zuixi*, historically the narrowest lunar lodge. In the Former Han Dynasty, it had a width of 1.2°. However, measurements made around AD 1280 by the great Yuan Dynasty astronomer Guo Shoujing reveal that by his time the width of *Zuixi* had decreased to almost zero. Over the next few centuries, *Zuixi* was tacitly assumed to be of zero width until the seventeenth century, by which time the calculated width was -0.4°! A well-preserved Japanese celestial globe of the time depicts only 27 lunar lodge boundaries.

Around AD 1650, the Jesuit Adam Schall von Bell, who was then Astronomer Royal of China, took the bold step of reversing the order of *Zuixi* and the adjacent lodge *Shen*, thus assigning a width of 11.4° to *Zuixi*. The revised width of *Shen* was now only 0.4°, but the effect of precession would gradually widen this lunar lodge with the passage of time. Jesuit missionaries, who made such a profound impression on Chinese astronomy in the seventeenth and eighteenth centuries, introduced improved techniques of measurement, as well as knowledge of the far southern stars which were invisible from China. However, they did not attempt to supplant the indigenous lunar lodge system (which was fundamentally equatorial) with the ecliptical scheme which was standard in the West.

Chinese astrography does not seem to have had any significant influence on cultures outside East Asia. In India, a parallel scheme to the *xiu* developed. Although there are similarities between the two systems, there are also marked differences. Vedic texts from at least as early as 1000 BCE list 27 or 28 *nakṣatra* (star groups in the path of the Moon). Like the Chinese lunar lodges, the *nakṣatra* had determinative stars (*yogatārā*). However, no measurements of the positions of the *yogatārā* can be traced until the fifth century AD. By this time, the *xiu* had already been established in China for many centuries. There is some evidence that a few of the *yogatārā* stars coincided with the Chinese *chuxing*. However, it has been shown that early Indian astronomers did not fully agree on which stars were regarded as *yogatārā*. In any event, most reference stars are quite distinct on the two schemes. The origin of the various similarities is presently unknown.

Today the lunar lodge system has been abandoned in East Asia – except at the popular level – in favor of Western techniques of specifying star positions.

See also: ►Stars in Chinese Astronomy

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Lunar Mansions in Indian Astronomy

K. V. Sarma

In Indian astronomy the 27 or 28 *nakṣatras* (constellations) with their *yogatārās* (junction stars), all situated in the zodiac, correspond to the lunar mansions called *xiu* in the East Asian and *manāzil* in the Islamic tradition. *Nakṣatra* (lit. *na-kṣatra*, non-moving, fixed; *nakta-tra*, 'guardian of the night'), meaning 'star', refers to the 27 asterisms or star groups that occur on or on the sides of the zodiac. It refers also to the 27 equal spaces into which the zodiac can be divided, each space being equal to: 360°/27 = 13°20′ or 800′, commencing from the First point of Meṣa, which is the starting point of the zodiac in Indian astronomy. Now, the zodiac is

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Lunar Mansions in Indian Astronomy. Table 1 Constellations of Hindu astronomy

No	Nakṣatra	Presiding deity	Gender	Plurality	Yogatārā
1	Kṛttikā	Agni	Feminine	Plural	η Tauri
2	Rohiṇī	Prajāpati	Feminine	Singular	α Tauri
3	Mṛgaśiras	Soma	Neuter	Singular	λ Orionis
4	Ārdrā	Rudra	Feminine	Singular	α Orionis
5	Punarvasu	Aditi	Masculine	Dual	β Geminorum
6	Puṣya	Bṛhaspati	Masculine	Singular	δ Caneri
7	Āśleṣā	Sarpa	Feminine	Plural	α Caneri
8	Maghā	Pitṛ	Feminine	Plural	α Leonis
9	Pūrvaphalgunī	Aryamā	Feminine	Dual	δ Leonis
10	Uttaraphalgunī	Bhaga	Feminine	Dual	β Leonis
11	Hasta	Savitā	Masculine	Singular	δ Corvi
12	Citrā	Indra	Feminine	Singular	α Virginis
13	Svātī	Vāyu	Feminine	Singular	α Bootis
14	Viśākhā	Indrāgnī	Feminine	Dual	α Librae
15	Anurādhā	Mitra	Feminine	Plural	δ Scorpii
16	Jyeṣṭhā	Indra	Feminine	Singular	α Scorpii
17	Mūlā	Nirṛti	Feminine	Singular	λ Scorpii
18	Pūrvāṣāḍhā	Āpaḥ	Feminine	Plural	δ Sagittarii
19	Uttarāṣāḍhā	Viṣvedevāḥ	Feminine	Plural	α Sagittarii
20	Śroṇā	Viṣṇu	Feminine	Singular	α Aquilae
21	Śraviṣṭhā	Vasu	Feminine	Plural	β Delphin
22	Śatabhiṣaj	Indra	Masculine	Singular	λ Aquarii
23	Pūrva/Proṣṭhapad	Ajekapād	Masculine	Plural	α Pegasi
24	Uttara/Proṣṭhapada	Ahirbudhnya	Masculine	Plural	γ Pegasi
25	Revatī	Pūṣī	Feminine	Singular	ζ Piscium
26	Aśvinī	Aśvin	Feminine	Dual	β Arietis
27	Bharaṇī	Yama	Feminine	Plural	41 Arietis

divided into 12 equal parts, each being 30°, called 'sign' or *rāśi*, to accommodate the 12 solar months. Hence, each *rāśi* holds, inside it, two and a quarter *nakṣatra*-spaces, each distinguished by a prominent star which is called *yoga-tārā*.

Since the performance of rituals and sacrifices at specified times, days, seasons, and years was obligatory for the Vedic Indians, they were interested in the preparation of a workable calendar to be able to ascertain the specified times. This required the study of the motions of the sun and the moon, which moved along or near the zodiac. The fixed stars and constellations provided the astronomers with a stellar frame of reference against which they could follow and measure the movements of the sun, the moon, and the planets. Hence Indian astronomy identified and concentrated on the study, from very early times, of these stars only, to the exclusion of the general array of stars that stud the heavens. Thus the *nakṣatra* system of the Hindus came into being.

The *nakṣatras* had been identified even during the time of the *Ṛgveda,* though only those which were relevant to specific Vedic prayers were mentioned therein. In the *Yajurveda* and the *Atharvaveda*, however, all the *nakṣatras* were mentioned in the order in which they appear on the zodiac, since in those texts contexts required their mention in a row. In the *Yajurveda* literature, the several *nakṣatras* were assigned presiding deities, pictured as male or female or neuter, and the plurality specified. Legends have also been narrated to explain some of the characteristics of the *nakṣatras,* besides specifying them as benefic or malefic, which aspect was elaborated in later astrological literature.

Yogatārā (Junction star) is the cardinal star in a *nakṣatra* which is made up of several stars. Normally, the *Yogatārā* would be the brightest star in the group, and the zodiacal signs would mostly be named after that star. The several constellations of Hindu astronomy, the details regarding them, and their *Yogatārās* are listed in Table 1.

It is interesting that besides the above details, the work *Nakṣatra-kalpa,* an ancillary text of the *Atharvaveda,* also provides, among other things, the number of stars making up each constellation.

See also: ►Astrology in India, ►Astronomy in India

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Lunar Mansions in Indian Astronomy. Table 1 Lunar mansions and their modern identification

1.	*al-sharaṭān* (also *al-naṭḥ*)	βγ or βα Arietis
2.	*al-buṭayn*	εδρ Arietis
3.	*al-thurayyā*	The Pleiades
4.	*al-dabarān*	α Tauri
5.	*al-haqʿa*	$\lambda\varphi^{1,2}$ Orionis
6.	*al-hanʿa*	γξ Geminorum; also *al-taḥāyī*, ημν Geminorum (to which also γξ Geminorum are sometimes added)
7.	*al-dhirāʿ*	αβ Geminorum
8.	*al-nathra*	ε Cancri or M 44
9.	*al-ṭarf*	κ Cancri + λ Leonis
10.	*al-jabha*	ζγηα Leonis
11.	*al-zubra* (also *al-kharātān*)	δθ Leonis
12.	*al-ṣarfa*	β Leonis
13.	*al-ʿawwāʾ*	βηγε Virginis (to which δ Virginis is sometimes added)
14.	*al-simāk*	α Virginis
15.	*al-ghafr*	ικλ Virginis
16.	*al-zubānā*	αβ Librae
17.	*al-iklīl*	βδπ Scorpii
18.	*al-qalb*	α Scorpii
19.	*al-shawla*	λυ Scorpii; sometimes instead, *al-ibra*, for the same stars or for M 7
20.	*al-naʿāʾim*	γδεησφτζ Sagittarii
21.	*al-balda*	A starless region between nos. 20 and 22
22.	*saʿd al-dhābiḥ*	ανβ Cparicorni
23.	*saʿd bulaʿ*	με Aquarii (sometimes Fl. 7 or ν Aquarii are also included)
24.	*saʿd al-suʿūd*	βξ Aquarii + c^1 Capricorni
25.	*saʿd al-akhbiya*	γπζη Aquarii
26.	*al-fargh al-muqaddam* (or *al-fargh al-awwal*)	αβ Pegasi
27.	*al-fargh al-muʾakhkhar* (or *al-fargh al-thānī*)	γ Pegasi + α Andromedae
28.	*baṭn al-ḥūt* (also *al-rishāʾ*)	β Andromedae

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Lunar Mansions in Islam

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The old Arabs, before their acquaintance with Greek-based astronomy, had their own folk astronomy. They knew the fixed stars and used a number of stars and asterisms, the so-called *anwāʾ*, for orientation in nightly desert travels and for fixing seasons and predicting weather, especially rain. At an unknown time, and through unknown channels, they received from India the system of the 28 lunar mansions (*manāzil al-qamar*), stars or asterisms or spots in the sky, roughly along the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), near which the moon was seen in the sky during its monthly revolution. Each mansion was identified with one of their *anwāʾ* stars or asterisms. The complete list is presented in Table 1.

Later, after the spread of Greek-based "scientific" astronomy in the Arabic–Islamic civilization, i.e., from the eighth century onward, astronomers knew about this system and gave exact identifications of the mansions' stars from among the 1,025 stars fixed up in the star catalogue in Ptolemy's *Almagest*. But the lunar mansions were not actually used by the Arabic–Islamic astronomers in their work. Their place was mostly in astrology. Here they were included in the numerous systems of divination, and in this context they were also borrowed into the Latin translations of Arabic astrological works, in Spain, in the late tenth century and, more often, in the twelfth and thirteenth centuries. Thus their corrupted, Latinized names are found throughout European astrological writings from that time on.

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Luoxia Hong

JIANG XIAOYUAN

Luoxia Hong was a Chinese astronomer active in the Western Han Dynasty about 100 BCE. He came from southwest China as a folk astronomer. When the Emperor Wu (140–87 BCE) decided to draw up a new calendar, Luoxia Hong and more than 20 other astronomers were called together in the capital Chang'an. These folk and imperial astronomers put forward their plans for a new calendar. After comparing 18 plans, the emperor believed that the best one was put forward by Luoxia Hong and another astronomer Deng Ping. The new calendar was applied to the whole country in 104 BCE and called *Tai Chu Li* (Tai Chu

L

Calendar). This calendar became the standard model for nearly 2,000 years. It was a lunisolar calendar with the 19-year and 7-leap cycle, and included the calculation for the motion of the sun, moon, planets, and for eclipses. In fact it was a mathematical astronomy system. The emperor intended to confer an official position on Luoxia Hong to cite his achievements, but Luoxia refused it and preferred to live in seclusion.

Luoxia Hong made an equatorial armillary sphere to measure the data of his new calendar. He is one of the candidates for the inventor of this instrument.

See also: ►Calendars in East Asia, ►Armillary Sphere

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Mādhava of Saṅgamagrāma

R. C. Gupta

During the Muslim rule in north India, there was a decline in Hindu culture. This adversely affected the creative spirit in indigenous art, literature, and science. Southern India was comparatively less affected, and traditional culture and the sciences flourished there. The followers of Āryabhaṭa I made enormous contributions to the development of mathematical sciences. It was a golden age of Indian mathematics.

Mādhava of Saṅgamagrāma, who flourished about AD 1400, was the first great astronomer and mathematician of the Late Āryabhaṭa school, which he in fact founded. Saṅgamagrāma has been identified as the modern Irinjalakkuda, a town near Cochin in Kerala State. Mādhava belonged to the Emprantiri subcaste group of Kerala Brahmins. We have no knowledge about his parents and teachers, or of the exact dates of his birth and death. Various dates ranging from AD 1336 to 1418 are used in his works. Hence the period of activity of his life has been roughly fixed from AD 1340 to 1425.

There is no doubt that Mādhava was an extraordinarily brilliant man. He used his talent and sharp intelligence to acquire knowledge by private study, and could thus overcome the difficulty of finding a good Guru because of his inferior status in the dominant Namputiri Brahminic community. He was a self-taught genius and not a gifted pupil. He was generally referred to as *Golavid* (Master of Spherics) by subsequent scholars and followers of his School, such as Nīlakaṅṭa Somayāji (AD 1444–1545) and Acyuta Piṣāraṭi (AD 1550–1621).

Mādhava wrote all his works in Sanskrit, the classical language of India. One of his earliest works is the *Candra-Vākyāni* (Moon Sentences). This was composed as a revision of Kerala's ancient traditional astronomical work attributed to Vararuci, who lived 1,000 years earlier. The *Candra-Vākyāni* gives 248 mnemonic phrases regarding the longitudinal position of the moon for each of the 248 days which comprise a period of nine anomalistic months.

The *Sphuṭacandrāpti* (Computation of True Moon) contains 51 verses and is a work of the *Karaṇa* category. A *Karaṇa* is a handbook on practical astronomy. In this one, he provides an ingenious method for finding the true position of the moon.

Mādhava's *Veṇvāaroha* (Bamboo Climbing) is an elaboration of his *Sphuṭacandrāpti* and consists of 74 verses. In this work the author created a facile procedure to find the true lunar positions at intervals of about half an hour. It is dated as AD 1403, and is the most popular astronomical work of Mādhava. Acyuta Piṣāraṭi wrote a Malayalam commentary on it.

A recently identified astronomical work of Mādhava is *Agaṇita-grahacāra.* It is an extensive work on planetary computations using somewhat novel methodologies. It is a treatise of the *Karaṇa* category and must have been composed just after AD 1418 which is the latest date mentioned.

Among other unpublished works of Mādhava there are two short astronomical tracts. One is the *Madhyamānayanaprakāra* (Method for Computing Mean Positions) which is extant in a unique manuscript at the India Office Library. The other is *Lagnaprakaraṇa,* of which at least three manuscripts exist in South India. This work deals with computations of ascendents.

It is possible that Mādhava composed a work on *Golavāda* (Spherics) which earned him the appellation *Golavid.* But the reported manuscript from a private collection has been eaten by white ants. Mādhava was also the author of a number of stray or free verses which have been cited by later authors and commentators.

Scientific Contributions

The traditional "moon sentences" of Vararuci (fourth century), used in Kerala, gave daily longitudes of the moon only up to minutes of the arc or angle. Mādhava computed more sophisticated moon sentences which expressed the longitudes correctly up to seconds. By making use of the popular system of alphabetic numerals, called the *Kaṭapayādi Nyāya,* these mnemonic phrases were made short and aphoristic. Mādhava also provided a value of π using a system of word numerals (*bhūta-saṁkhyās*).

The knowledge of an accurate value of π enabled Mādhava to obtain a better value of the traditional

Sinus Totus (Total Sine, or radius). Mādhava's sine table is quite precise and accurate. He may have used traditional methods for getting the table or the newly discovered power-series expanion of sine (see below). For computing sine for the argument intermediary between any two tabulated angles, he knew a formula which is equivalent to the modern Taylor series approximation up to the second order. Higher interpolation based on second order finite differences had been known in India since the time of Brahmagupta (seventh century AD).

For computing π to any desired degree of accuracy, Mādhava discovered a number of series including the one $/4 = 1 - 1/3 + 1/5 - 1/7...$, often called the Leibniz series after the German mathematician G.W. Leibniz.

Another formula perhaps known to Mādhava is now called the Gregory Series, after the Scottish mathematician James Gregory (1638–1675). The Indian proof is found in the *Yuktibhāṣā* (AD sixteenth century) and other works.

One of Mādhava's major achievements was the discovery of the power-series expansions of sine and cosine, and which are equivalent to

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + ...,$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + ...,$$

The two Sanskrit verses which embody the method of computing sine based on power-series up to x^{11} are quoted by Nīlakaṇṭha in his commentary on the *Āryabhaṭīya* (II, 17b).

In this connection it is relevant to discuss a small tract called *Mahājyānayana-prakāra* (Method for the Computation of the Great Sines). It gives the power-series methods for computing *Mahājyās* (Great Sines). Unfortunately there is no mention of an author's name in it, although Mādhava's rule for computing sines up to x^{11} is mentioned. Sarma attributed the tract to Mādhava, but Gold and Pingree consider it to be the work of his follower(s). Perhaps Mādhava explained his theory during lectures to his pupils, whose lecture notes may be the basis of the above tract.

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Magic and Science

KAREN LOUISE JOLLY

The concepts "magic" and "science" are products of Euro-American history; thus their use in other regions of the globe, from the colonial era to modern anthropological studies, is intertwined with Western intellectual history. Consequently, understanding the meaning of, and relationship between, magic and science in the context of western notions of rationality is essential when examining phenomena in non-Western societies placed in these categories. Magic and science are, in essence, labels used to exclude and include according to an intellectual value system rooted in European history. They are part of the cultural baggage taken abroad by Euro-American travelers, and used to identify "otherness" in foreign cultures. In non-Western cultures, similar practices of "magic" were not necessarily excluded or marginalized by the growth of science as they were in the West.

The European evolution of these two words from the classical (Greco-Roman) era to the twentieth century shows a growing gap between magic as occult or hidden knowledge on the one hand, and science and religion as public knowledge on the other. Increasingly in the European intellectual tradition, science was defined in narrower ways while pushing magic out of the realm of knowledge. This contributed to an evolutionary paradigm applied by Westerners to non-Western societies, of progress from magic to religion to science, a model now called into question by modern anthropologists. Because of this conceptual evolution in the intellectual history of Europe, "magic" and "science" can be used in a number of senses in modern

English usage (see the *Oxford English Dictionary*). The gradual transformation of the word science as a distinctive rationality valued above and against magic is part of a uniquely European duality not generally found in non-Western societies, where magic can exist side-by-side with science and religion.

History of the Terms in the Western Intellectual Tradition

European intellectual history is full of self-imposed oppositions: temporal–spiritual, natural–supernatural, pagan–Christian, devil–God, magic–religion, and magic–science. All of these are subject to a moral scale of Good versus Evil, a distinction in Western thought that has its roots in the Judeo–Christian monotheistic system positing a single, omnipotent, all-good Deity. This way of thinking is very different from, for example, the Chinese world view embodied in *Yin* and *Yang*, opposites that create balance (positive–negative, active–passive forces) without the identification of Evil versus Good. Thus, the Western dualities are not, as some westerners visiting other cultures have assumed, universals found in all cultures; rather, they are a particular product of the belief systems and intellectual history of Europe.

Nonetheless, despite these polar oppositions in European thought, changes in definitions over time caused overlaps and gray areas. Thus magic, as the opposite of religion or science, has a history that complicates the way the word is used at different times and places by different classes of people. The self-defined shape of European history is one of progress from magic to religion to science: from root definitions in classical culture (Greco-Roman), through the medieval magical and religious mentality, through major religious and intellectual changes (renaissances) in the medieval and early modern world, to the development of science as a separate discipline in the modern world. At the same time, this chronological picture is muddied by the slippery definition of magic as it changes in relation to the growth of religion and science. Throughout the development of these distinctions, from the fourteenth through the nineteenth and twentieth centuries, Europeans and Americans went abroad and applied these differing notions to the peoples they met.

The root meaning of magic contains a sense of exclusion found throughout the history of the term: in the Roman world, the Latin *magia,* derived from *magi* (Persian astrologers like the Magi of the Christmas story), implied a foreigner, even when the practitioner was a Roman. This was someone who possessed secret and powerful knowledge both feared and respected, displayed in the ability to manipulate unseen or spiritual agencies, in such arts as divination, astrology, curses, oracles, and amulets to ward off evil (Luck 1985). Thus the word magic has at its root a sense of marginality in its otherness and its paranormal, unknown, and supernatural associations, but also a strong sense of power held exclusively and secretly by the *magus.* The root word for science, on the other hand, is more normative: *scientia* includes knowledge, art, or skill. It derives from the Greek heritage a strong sense of human rationality, but comes to include divinely revealed knowledge as well in the Christian era (from ca. 200).

In the progress model, the magic of the European past is associated with the medieval period (ca. 500–1350), in contrast to the rationality of the Renaissance (fourteenth and fifteenth centuries) and Enlightenment (eighteenth century) intellectual revolutions. "Medieval" thinking has earned the label "magic" from later generations on several grounds. The medieval otherworldly emphasis and reliance on divine revelation led to a lack of distinction between natural and supernatural and contributed to an allegorical way of thinking about nature, so that objects such as a flower and events such as storms or illnesses were read as divine messages. Medieval thinking rested on a belief in a wonder-working, ever-present God and also a magic-working evil presence in the devil; sometimes the miracles of God's saints and the tricks of the devil appear similar in method in the eyes of later thinkers (Flint 1991; Thomas 1971). Specifically, the belief in supernatural powers in words is found in both Germanic animism (worship of nature spirits) and the Christian tradition: in Germanic animism charms (ritual words and actions) invoke the inherent virtues of a plant. In the Christian Eucharist, bread and wine are changed into flesh and blood through prayer. The two were joined in Christianized folk medicine in the production of charms using Christian prayers as the powerful words (Jolly in Neusner et al. 1989). To Protestants (after the sixteenth century) and anthropologists (late nineteenth century), these practices are all magical in their manipulation of nature through word-magic (as opposed to true religious prayer as supplicatory). Yet to the medieval mind, magic was defined by *who* – God or the Devil – not by *how* – supplication versus manipulation. Thus medieval thinking was rejected as backward by later rationalists and was used to describe cultures that had not advanced out of magical or superstitious thinking.

Religion, in the history of European "progress," moves away from magical thinking and opens the door for rationalism. The tradition of logic and deductive reasoning dates back to the Greeks and partially survived into the Middle Ages through Roman-Christian church leaders and thinkers; the recovery of Aristotle through Arab sources in the twelfth century helped spur a renaissance in learning among medieval scholars so that human reason was placed alongside divine revelation as a way of knowing truth. This interest in the potential of human reason to understand things in conjunction with divinely revealed knowledge cleared a space for reason to function independently over the succeeding centuries. The separation of natural from supernatural, and reason from revelation, allowed thinkers to focus on the human study of natural phenomena. Magic in this context became things not in the category of the divine (miracles) and not subject to human reason either: black magic associated with the devil and witches, such as curses and evil spells, or the low magic of ignorant persons based on false reasoning, such as herbal charms and love potions. High, white magic was associated with the intelligentsia of the high Middle Ages and Renaissance (twelfth through fifteenth centuries). These early scientists dabbled in the occult, a gray area in between divine knowledge and human reason: occult phenomena were insensible (not subject to human sense perception), such as magnetism, gravity, or the pull of the stars, but might be intelligible (something to be reasoned about); these occult phenomena, classified as "natural magic," became the sciences of astrology, astral medicine, and alchemy, for example.

In the Scientific Revolution, science became a separate, and increasingly higher, discipline from religion; it came to mean exclusively the human (versus divine) study of natural (versus supernatural) phenomena. This secularization of knowledge was the product of the Italian Renaissance of the fourteenth and fifteenth centuries and the Enlightenment of the seventeenth and eighteenth centuries. Simultaneously, Protestant ethical values contributed to this process a utilitarian view of the created order that effectively circumscribed religion into a rational system: God made the world to work by certain laws that humans could understand and systematize (Tambiah 1990). Human study could produce a true understanding of reality independent of divine insight. Magic was now clearly marked as something not rational: it could be proven to be a hoax (prestidigitation or sleight-of-hand), and was relegated to the entertainment industry where it could be enjoyed as an illusion, a deception that could be scientifically explained. As science became the religion of the modern west, magic was being exorcised from modern consciousness not as demonic but as irrational and backward.

This simple pattern of progress from magic to religion to science is misleading in two ways: it is anachronistic in applying later definitions of magic back on to earlier periods where the word had different meanings, and it does not take into account the overlaps and continuities whereby magic survives alongside religion and well into science. For example, the Scientific Revolution is compromised by intellectual dabbling in the occult: the great shift from a geocentric worldview (earth at the center) to heliocentric (sun at the center) was founded not just on forward-looking developments in mathematics and astronomy but was motivated by a backward-looking interest in a supposedly Egyptian magical tradition, Hermeticism (Tambiah 1990). Differences of class in relation to conceptions of magic further complicate this picture of Euro-American intellectual history: the older ways of folk belief, in medicine for example, as a viable, not magical, method of manipulating nature or spiritual agencies was retained among many classes long after the religious authorities or the intellectual elite had dispensed with it, and in some cases had begun investigating it as witchcraft (antireligion) or fraud (unscientific). All of these divergent attitudes toward magic were carried abroad by Europeans and Americans: magic as demonic, evil, and fearful; magic as medieval or backward; magic as unscientific, irrational, or uncivilized; but always as something "other."

Modern ethnography, the study of cultures, is a product of this western history and its intellectual legacy of magic versus religion or science. The earliest ethnographers were explorers and missionaries, some of whom made an effort to observe and document these "new" peoples. The paradigm of progress some missionaries used in meeting nonurban, preliterate peoples was to categorize them as children needing to be fostered into adulthood; other colonizers used a model to exploit the "Indians" as subhuman slaves. For the missionaries, conversion was one step in the maturing process necessary for the native peoples to reach the "level" of civilization mastered by the Europeans.

Modern anthropology attempted to break with the religiously biased view of these missionaries and take an objective observer stance which was, none the less, still colored by an evolutionary model of progress from magic to religion to science (Herbert 1991). This model is clearly evident in the works of early nineteenth-century founders Edward Tylor and Sir James Frazer and into the twentieth century in Jacob Bronowski and Bronislaw Malinowski (Tambiah 1990). The anthropological definition focused on magic as unscientific manipulations of nature or supernatural forces and classified it according to its false premises (imitative magic, contagious magic, sympathetic magic). These notions of magic were assumed as a universally valid construct applicable cross culturally. Consequently, observed peoples were placed into the spectrum of development from magic to science. This model is the subject of debate in late twentieth-century anthropological scholarship, by such authors as Francis Hsu and Stanley Tambiah, who question whether the European concept of magic can be used accurately to classify a set of phenomena in a non-European culture.

Indigenous Views in Non-Western Societies

In Western thought, then, magic has become something marginal, separate from or opposite to a mainstream tradition of religion or science. Non-Western practices of magic seen in their own cultural context are not the opposite of religion or science, but are complementary to their political, social, religious orders; magic is not the "other" in their worldview, but is part of the norm. Magical practices in non-Western societies can function as part of their cultural identity, alongside scientific development or as a subgroup of religion. In many parts of the world, syncretism is more prominent as a response to alternate worldviews, resulting in coexisting modes of rationality rather than competing ones.

The ancient civilizations of Asia offer examples of traditions developing their own modes of rationality with different dynamics than the European model, between the spheres of religion, science, and magic. In China, the traditions are as complex and overlapping as they are in Europe: ancestor-worship, Confucianism, Daoism, and Buddhism as belief-systems evolved and interacted amid the simultaneous development of science and technology. These belief-systems cannot be easily categorized as religion, philosophy, or magic along Western lines. The Buddhist emphasis on the world as illusory and the Daoist focus on metaphysics lent themselves more readily to practices resembling magic in a Western sense (appeals to supernatural aid, fortune-telling), as did ancestor worship. Confucianism, on the other hand, has both religious and philosophical elements; its concern with the social and political world resembles more the secular humanism of the western tradition. All of these coexist as alternate, and sometimes complementary, modes of rationality in China.

Similarly in the Chinese world, science and technology do not necessarily replace magico-religious belief: villagers' responses to crisis (for example, a plague) incorporate both medicinal remedies such as serums proven through experimentation in the Western scientific tradition, and rituals seeking to appease the gods. While Westerners would be under some pressure to justify such magical practices with some rational or pseudoscientific explanation, the Chinese do not feel compelled to argue about where or how the practice fits into some duality of true or false, natural or supernatural, orthodox or heretical, scientific or magical. Ancestor worship and recourse to geomancers (practitioners of *feng shui,* the art of finding spiritually correct locations for buildings) and fortune tellers (Daoist priests or other spiritualists) continue in twentieth-century China and in Chinese communities in the West without shame or apology (Hsu 1983).

Elsewhere in Asia, "magic" continues as part of mainstream culture because it is closely linked with cultural identity. In Korea, female shamans perform ritual cures and exorcisms (*kut*) as part of the uniquely Korean fabric of life, alongside imported traditions from China and the West; in this way shaman practice is part of a unique Korean identity (Kendall 1985). Shintoism in Japan, like ancestor-worship in China, is part of the Japanese cultural heritage embedded in everyday life, so much so that it easily accommodated an incoming religious system such as Buddhism or the development of science and technology, with which it has no reason to quarrel. Thus, syncretism, rather than opposing dualities, is a common pattern in the dynamics of magic, science, and religion in Asian cultures.

In many of the ancient near eastern and south Asian cultures, practices resembling magic (fortune-telling, amulets, and sorcery) form a subgroup of either religion or science/medicine. Magicians in India, for example, are closely linked with the religious traditions of Hinduism, Buddhism, and Islam. Indian thought emphasizes the illusory nature of the physical world; religious masters (gurus, yogi, and other mendicants) are able to manipulate the natural world precisely because they have reached a state of enlightenment where the world is truly an illusion to them. Likewise street magicians and stage entertainers practice "deceptions" (sawing people, producing trees from a basket, pulling an egg or a bird out of a bag, making ropes rise) that echo Hindu or Islamic stories and thus embody certain truths about the world as a wondrous, deceptive, and illusory place that one looks *through* to find meaning. Although such street magicians are a separate, low (Muslim) caste in India, they are a prominent part of India's cultural landscape, popular as reflections of Indian values (Seigel 1991).

The interconnection of belief, science, and magic is also seen in Islamic culture. Medieval Islam fostered scientific, technological, and medical research because of their belief in a monotheistic Deity who made all things rational for humans to study (a view that eventually sparked medieval European science). Yet Islam also has magical–mystical subgroups, some of whom were condemned by Islamic law: their explorations of astronomy have astrological connections, as in Europe; their mathematical concepts have occult meaning to some; Sufi mystics distanced themselves from the Islamic intellectual heritage and sought knowledge through other, spiritual or interior, means. While these branches of Hinduism, Buddhism, or Islam may be minority groups, they are not marginal to their own cultures. Rather, they form an important extension of mainstream ideas that influences the whole culture, although not without conflict.

Societies in Africa, the Pacific, and Southeast Asia that did not have the urban, literate characteristics of these older civilizations provide clear examples of how poorly the conceptual dichotomy of magic versus science works as a model for understanding cultures where so-called magical practices are part of the norm. In Mali (Africa), the *Sundiata,* a twentieth-century version of an oral tradition dating back to the thirteenth century, speaks of the war magic used by Malian sorcerers to make a tribe successful so that others feared them; their magic oracles dispensed wisdom for successful living, a combination of prophecy and character insight. Likewise, many Pacific island cultures practiced a kind of potent magic in love, war, and healing that relied on a sorcerer's ability to conjure nature and spirits.

These practices encompass both white and black magic in the European paradigm, to both heal and curse; such mastery is always dangerous to the practitioner because of the power of the sources he or she is using. In New Caledonia (Melanesia), sorcerers concoct love potions; in Samoa (Polynesia), chants ward off a headache caused by a god. In Pohnpei (Micronesia), tribal groups employ sorcery to win a war, calling on ghosts or natural forces such as tides; during the Spanish occupation, they used both the borrowed technology of guns and their own tradition of sorcery to hold off attacks (Hanlon 1992). Marquesans (in French Polynesia) also practiced a kind of war "magic" closely linked to their tribal identity: chants of power specific to their people and location used words ritually to invoke natural/supernatural forces to aid them in battle. The concept of *mana* in Polynesian cultures embodies this sense of powerful forces that can be channeled through words and actions, and is a more authentic construct for understanding their practices than is "magic."

Such beliefs and practices, prior to European contact, were part of political and social value systems; the practitioners were feared for their power, but were not marginal to an intellectual belief system, as they became in European culture. The retention of these beliefs in the power of the old ways after contact, sometimes in defiance of, and sometimes integrated with, Western beliefs, is a form of cultural resistance and identity.

Many non-Western cultures, confronted with the European intruder, perceived the actions of the newcomer in terms of their own construct of supernatural or occult power. For example, in the Americas, native American Indians identified literate Europeans (mostly missionaries) as shamans, and their books as tools for manipulating natural/supernatural forces. Literacy was a powerful form of knowledge to acquire, and therefore was classified with other powerful forms of knowledge in their culture held by their shamans (magic and magicians to the Europeans). Thus literacy, and the Christian religion wound around it, was incorporated into the native belief system (Axtell 1988). Indeed, in the same way that the taking of photographs was feared by some groups as a type of sorcery for capturing their souls, so too the writing down of history and ethnographic observations (by Westerners) is sometimes perceived as a kind of sorcery: the power of shaping and defining cultural identity past and present.

Just as the magic-religion divide is indistinct, so too the magic-science line is easily crossed. Westerners cast doubt on the ancient Polynesians' ability to navigate the Pacific to reach new islands such as the Hawaii chain without the technological tools used by Europeans to accomplish such tasks. New research and recreated voyages, however, confirm the knowledge of wind, sky, and water, and the skills of navigation contained in the remnants of Polynesian chants and other oral traditions, usually categorized as magico-religious rituals. This ambiguous line between magic and science is also visible in modern globalized medical practices that incorporate both Western medical techniques and traditional medicine from non-Western societies. The Chinese practice of acupuncture, once viewed in the United States as magic or pseudoscience, is now being mainstreamed into American medicine in lieu of drugs. In Java, a doctor claims the ability to produce heat and electricity from his own body for healing purposes and he documents this ability using the Western scientific mode of proof (experimentation, repeatability), performing spontaneous combustion on video (*Ring of Fire*). Such global syncretism is increasing rather than decreasing, blurring the distinctions between magic and science as defined in European intellectual history.

Traditionally, then, magic has been defined in opposition to science or religion in Western intellectual development. However, such practices in non-Western cultures that appear to resemble this category or are similar to practices Westerners label magic, may not in those cultures have been defined as a class in opposition to some concept of religion or science. The realization that "one man's religion (or science) is another man's magic" is leading to redefinitions of these terms and the development of meanings and categories unique to each cultural context.

See also: ►Navigation in Polynesia, ►Navigation in the Pacific

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Magic Squares in China

Ho Peng Yoke

By modern definition a magic square is an arrangement of numbers in a square whereby the sum of the numbers in every individual row, in every individual column and in each of the two diagonals of the square is identical. Figs. 1 and 2 are examples of magic squares. In Fig. 1 all rows, columns and diagonals add up to the sum 15 and in Fig. 2 they add up to 34.

4	9	2
3	5	7
8	1	6

Magic Squares in China. Fig. 1 Magic square of 15.

4	9	5	16
14	7	11	2
15	6	10	3
1	12	8	13

Magic Squares in China. Fig. 2 Magic square of 34.

Each number occupies a cell. There are 9 cells in Fig. 1 and 16 cells in Fig. 2. Figure 1 is known as a 3 × 3 magic square or a magic square of the order 3; similarly Fig. 2 is a 4 × 4 magic square or a magic square of the order 4. Methods for constructing these two magic squares as well as some magic squares of higher orders are given in the *Xugu zheqi suanfa* (Continuation of Ancient Mathematical Methods for Elucidating the Strange), composed in 1275 by Yang Hui. Numbers can also be arranged to form a circle or even a cube that shares some of the properties of the magic square. Nowadays all these come under the heading "number theory" or even "mathematical recreation" in libraries. However, the word "magic" in the magic square has lost some of its original meaning.

Chinese magic squares have attracted the attention of modern mathematicians and historians of science. Studies by modern scholars have brought forth many interesting results, but how and why certain Chinese magic squares were constructed cannot be fully understood if one approaches the subject entirely from the standpoint of modern mathematics. The modern Chinese equivalent of the term "mathematics" is *shuxue*, but prior to the middle of the nineteenth century the same term had a much wider meaning, embracing mathematics, philosophy, astrology, and divination. Studies from the angle of modern mathematics have recently been supplemented by investigations from a different perspective.

The first-century book *Da-Dai Liji* (Record of Rites by the Elder Dai), contains the following arrangement of numbers:

2,9,4 7,5,3 6,1,8.

This set of numbers also occurs in a probably earlier mathematical text, the *Shushu jiyi* (Memoir on Some Traditions of Mathematical Art), said to be written in the year 190 BCE by Xu Yue. This is the earliest magic square on record. It was used mainly in astrology and divination. Then during the twelfth century one of Zhu Xi's (1130–1220) disciples Cai Yuanding (1145–1198) identified the Bright Hall and the Nine-palace arrangement as the legendary Luoshu chart mentioned in ancient texts. Together with another legendary chart, the Hetu River Diagram, the riddles of the universe were supposed to be embodied therein. Hence the two charts were used to interpret not only natural phenomena, but also philosophy and human behavior. They even found their use in Daoist ceremony and magic. Numerology played a profound role in Chinese magic squares. The occurrence of certain numbers, e.g., 5, 9, 25, 49, 50, and 64 in Chinese magic squares is significant. All these were closely associated with the Hetu and Luoshu charts and with the *Yijing* (I Ching, The Book of Changes).

Yang Hui's *Xugu zheqi suanfa* is the earliest and best source for Chinese magic squares. The methods of construction of some of the larger magic squares remind us of the foot movements of the Daoists performing ceremonies and magic. About three decades later Ding Yidong wrote his *Dayan suoyin* which contains a number of magic squares and magic circles constructed on a similar basis. Then in about the year 1593 Chen Dawei collected a number of magic squares in his *Suanfa tongzong* (Systematic Treatise on Arithmetic) without involving himself with the theoretical aspect of the subject. In 1661 Fang Zhongtong (1633–1698) wrote the *Shuduyan,* which contains magic circles, cubes, and spheres, besides magic squares. Next comes Zhang Chao's (b. 1650) *Xinzhai zazu* (Miscellanea of Zhang Xinzhai), which includes a Supplement to the magic squares of Cheng Dawei's work. The last description of magic squares by a traditional Chinese scholar came in the latter part of the nineteenth century when Bao Qishou wrote his *Binaishanfang ji* (Collections of Writings in the Binai Mountain Studies).

The Luoshu chart magic square probably first went to India and then to the Arab countries, where other magic squares were later developed in their individual ways. From the Arab countries magic squares were said to be first brought to Europe by a Byzantine, Manuel Moschopoulos (fl. ca. 1295–1316). Transmission of knowledge between China and her western neighbors was seldom unidirectional. In 1956 a thirteenth-century 6 × 6 Muslim magic square was excavated near the city of Xi'an. Magic squares even had a role to play in trade between China and the Arab countries in the past. In 1906 when Queen Mary of the British Empire visited Hyderabad in India she was presented with a Chinese porcelain plate decorated with Arabic inscriptions and a magic square. This plate is now preserved at the Victoria and Albert Museum in South Kensington. It was manufactured in the eighteenth century at the world renowned Chinese kiln center, Jingdezhen. It was used originally by the Muslims as a medicine bowl, so that the inscriptions were taken from the *Qu'rān,* and the magic square was believed to possess powerful virtues for protecting life, healing the sick, and bringing about a comfortable delivery when a pregnant woman sat on it. Other specimens of Chinese porcelain plates bearing magic squares in a corrupted form are among the collections of museums and private collectors today.

See also: ►Yang Hui, ►Xu Yue, ►Astrology, ►Divination

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Magic Squares in Indian Mathematics

Takao Hayashi

The oldest datable magic square in India occurs in Varāhamihira's encyclopedic work on divination, *Bṛhatsaṃhitā* (ca. AD 550). He utilized a modified magic square of order four in order to prescribe combinations and quantities of ingredients of perfume. It consists of two sets of the natural numbers 1–8, and its constant sum (p) is 18. It is, so to speak, pan-diagonal, that is, not only the two main diagonals but also all "broken" diagonals have the same constant sum. Utpala, the commentator (AD 967), also points out many other quadruplets that have the same sum.

One of the four candidates for Varāhamihira's original square, with a rotation of 90°, coincides with the famous Islamic square, which al-Bīrūnī and al-Zinjānī frequently used as a basic pattern for talismans.

Varāhamihira called his square *kacchapuṭa* (the carapace of a turtle?), which reminds one of the title of a book on magic, *Kakṣapuṭa* (date unknown). The book contains a method for constructing a magic square of order four when a constant sum (p) is given. It also contains a square having the sum 100, which is attributed to Nāgārjuna.

In his medical work, *Siddhayoga* (ca. AD 900), Vṛnda prescribed a magic square of order three to be employed by a woman in labor in order to have an easy delivery. Its sum is 30. This is the first datable instance of a magic square of order three in India, although there is a legend that a Garga, who may or may not be the author of the *Gargasaṃhitā* (ca. first century BCE or AD), recommended magic squares of order three in order to pacify the *navagraha* (nine planets).

The famous Jaina magic square, which is incised on the entrance of a Jaina temple, Jinanātha, in Khajuraho, is assignable to the twelfth or the thirteenth century on a paleographical basis. It is pan-diagonal. Several Jaina hymns that teach how to make magic squares have been handed down, but their dates are uncertain.

As far as is known, Ṭhakkura Pherū, a Jaina scholar, is the first in India who treated magic squares in a mathematical work. His *Gaṇitasāra* (ca. AD 1315) contains a small section on magic squares that consists of nine verses. He gives a square of order four, and alludes to its rearrangement; classifies magic squares (*jaṃta* = Sanskrit *yantra*) into three (odd, even, and evenly odd) according to the order (n), i.e., the number of cells (*kuṭṭha* = Sanskrit *koṣṭha*) on a side of the square; gives a square of order six; and prescribes one method each for constructing even and odd squares.

The method for even squares divides the square into component squares of order four, and puts the numbers into cells according to the pattern of a standard square

2	3	5	8
5	8	2	3
4	1	7	6
7	6	4	1

Magic Squares in Indian Mathematics. Fig. 1 Varāhamihira's magic square (p = 18).

a

10	3	13	8
5	16	2	11
4	9	7	14
15	6	12	1

b

2	11	5	16
13	8	10	3
12	1	15	6
7	14	4	9

c

10	3	5	16
13	8	2	11
4	9	15	6
7	14	12	1

d

2	11	13	8
5	16	10	3
12	1	7	14
15	6	4	9

Magic Squares in Indian Mathematics. Fig. 2 Magic squares reconstructed from Varāhamihira's square (p = 34).

8	11	14	1
13	2	7	12
3	16	9	6
10	5	4	15

Magic Squares in Indian Mathematics. Fig. 3 The Islamic square of order four (p = 34).

30	16	18	36
10	44	22	24
32	14	20	34
28	26	40	6

Magic Squares in Indian Mathematics. Fig. 5 Nāgārjuna's magic square (p = 100).

16	6	8
2	10	18
12	14	4

Magic Squares in Indian Mathematics. Fig. 6 Vṛnda's magic square of order three (p = 30).

7	12	1	14
2	13	8	11
16	3	10	5
9	6	15	4

Magic Squares in Indian Mathematics. Fig. 7 Jaina magic square of Khajuraho (p = 34).

a

12	3	6	13
14	5	4	11
7	16	9	2
1	10	15	8

Original Square

b

1	7	12	14
10	16	3	5
8	2	13	11
15	9	6	4

Rearranged

Magic Squares in Indian Mathematics. Fig. 8 Pherū's square of four and its rearrangement (p = 34).

a

$a-3$	1	$a-6$	8
$a-7$	9	$a-4$	2
6	$a-8$	3	$a-1$
4	$a-2$	7	$a-9$

$a = \frac{p}{2}$ (p: even)

b

$b-3$	1	$a-6$	8
$a-7$	9	$b-4$	2
6	$a-8$	3	$b-1$
4	$b-2$	7	$a-9$

$a = \frac{p+1}{2}$, $b = \frac{p-1}{2}$ (p: odd)

Magic Squares in Indian Mathematics. Fig. 4 Patterns for magic squares of order four given in the *Kakṣapuṭa*.

M

of order four. That for odd squares first places in the central column the arithmetical progression whose first term and common difference are unity and (n + 1), respectively; and then, starting from the numbers in the central column and proceeding by knight move, successively increases the number by n. The square thus obtained is the same as the one obtained by the so-called diagonal method (cf. Fig. 21).

Nārāyaṇa wrote a comprehensive work on mathematics entitled *Gaṇitakaumudī* (AD 1356). Its last chapter, called *bhadra-gaṇita* (Mathematics of Magic Squares), comprises 55 verses for rules and 17 verses for examples, and is devoted exclusively to magic squares and derivative magic figures *(upabhadra)* of various shapes (cf. Figs. 22–23).

The topics treated are: definitions of technical terms; determination of the mathematical progressions

1	32	34	33	5	6
30	8	28	27	11	7
24	23	15	16	14	19
13	20	21	22	17	18
12	26	9	10	29	25
31	2	4	3	35	36

Magic Squares in Indian Mathematics. Fig. 9 Pherū's square of order six (p = 111).

a

	n^2	
	.	
	.	
	.	
	.	
	.	
	$2n+3$	
	$n+2$	
	1	

Central Column

b

37	48	59	70	81	2	13	24	35
36	38	49	60	71	73	3	14	25
26	28	39	50	61	72	74	4	15
16	27	29	40	51	62	64	75	5
6	17	19	30	41	52	63	65	76
77	7	18	20	31	42	53	55	66
67	78	8	10	21	32	43	54	56
57	68	79	9	11	22	33	44	46
47	58	69	80	1	12	23	34	45

Square of Order Nine Obtained (p = 369)

Magic Squares in Indian Mathematics. Fig. 11 Pherū's construction method for "odd"-order magic squares.

a

15	9	6	4
8	2	13	11
1	7	12	14
10	16	3	5

Standard Square

b

			4				8
	2				6		
1				5			
		3				7	
			12				16
	10				14		
9				13			
		11				15	

First Stage

c

63	33	30	4	59	37	26	8
32	2	61	35	28	6	57	39
1	31	36	62	5	27	40	58
34	64	3	29	38	60	7	25
55	41	22	12	51	45	18	16
24	10	53	43	20	14	49	47
9	23	44	54	13	19	48	50
42	56	11	21	46	52	15	17

Magic Square Obtained (p = 260)

Magic Squares in Indian Mathematics. Fig. 10 Pherū's construction method for "even"-order magic squares.

a

1	8	13	12
14	11	2	7
4	5	16	9
15	10	3	6

b

1	14	4	15
8	11	5	10
13	2	16	3
12	7	9	6

Magic Squares in Indian Mathematics. Fig. 12 Nārāyaṇa's squares of four made by "horse-move" ($p = 34$).

a

−5	9	19	17
21	15	−3	7
1	3	25	11
23	13	−1	5

$a = -5, d = 2$
$p = 40$

b

−14	14	34	30
38	26	−10	10
−2	2	46	18
42	22	−6	6

$a = -14, d = 4$
$p = 64$

Magic Squares in Indian Mathematics. Fig. 13 Nārāyaṇa's squares of four made by an arithmetical progression.

a

7	15	22	20
23	19	8	14
10	12	25	17
24	18	9	13

$p = 64$
Cf. Fig. 12a

b

16	14	7	30	23
24	17	10	8	31
32	25	18	11	4
5	28	26	19	12
13	6	29	22	20

$p = 90$
Cf. Fig. 21

Magic Squares in Indian Mathematics. Fig. 14 Nārāyaṇa's squares of four made by *n* sets of arithmetical progressions.

$\frac{35}{2}$	$\frac{49}{2}$	$\frac{59}{2}$	$\frac{57}{2}$
$\frac{61}{2}$	$\frac{55}{2}$	$\frac{37}{2}$	$\frac{47}{2}$
$\frac{41}{2}$	$\frac{43}{2}$	$\frac{65}{2}$	$\frac{51}{2}$
$\frac{63}{2}$	$\frac{53}{2}$	$\frac{39}{2}$	$\frac{45}{2}$

$t = \frac{33}{2}, p = 100$
Based on Fig. 12a

Magic Squares in Indian Mathematics. Fig. 15 Nārāyaṇa's squares of four made by addition of a number (t).

a

2	3	2	3
1	4	1	4
3	2	3	2
4	1	4	1

Prelim-A

b

5	0	10	15
10	15	5	0
5	0	10	15
10	15	5	0

Prelim-B

c

17	13	2	8
1	9	16	14
18	12	3	7
4	6	19	11

B over A
$p = 40$

d

8	2	13	17
14	16	9	1
7	3	12	18
11	19	6	4

A over B
$p = 40$

Magic Squares in Indian Mathematics. Fig. 16 Nārāyaṇa's method for "even-womb" squares (I): folding method.

a

1				2			
		8				7	
4				3			
		5				6	

First Stage

b

1	32	49	48	2	31	50	47
56	41	8	25	55	42	7	26
16	17	64	33	15	18	63	34
57	40	9	24	58	39	10	23
4	29	52	45	3	30	51	46
53	44	5	28	54	43	6	27
13	20	61	36	14	19	62	35
60	37	12	21	59	38	11	22

Magic Square Obtained ($p = 260$)

Magic Squares in Indian Mathematics. Fig. 17 Nārāyaṇa's method for "even-womb" squares (II): according to the pattern of the standard square (Fig. 12a).

M

1	195	194	193	5	6	190	7	9	10	186	185	184	14
169	27	171	25	173	23	175	22	20	178	18	180	16	182
168	167	166	32	33	34	162	35	37	38	39	157	156	155
141	142	143	53	52	51	147	50	48	47	46	152	153	154
140	139	138	60	61	62	134	63	65	66	67	129	128	127
113	114	115	81	80	79	119	78	76	75	74	124	125	126
112	111	92	88	89	90	98	110	93	94	95	101	100	106
85	86	105	109	108	107	99	87	104	103	102	96	97	91
84	83	82	116	117	118	77	120	121	122	123	73	72	71
57	58	59	137	136	135	64	133	132	131	130	68	69	70
56	55	54	144	145	146	49	148	149	150	151	45	44	43
29	30	31	165	164	163	36	161	160	159	158	40	41	42
28	170	26	172	24	174	21	176	177	19	179	17	181	15
196	2	3	4	192	191	8	189	188	187	11	12	13	183

$n = 14, p = 1379$

Magic Squares in Indian Mathematics. Fig. 18 Nārāyaṇa's method for "odd-womb" squares (I): zigzag method.

100	92	93	94	5	6	7	8	9	91
20	89	83	84	16	15	87	18	82	11
30	29	78	77	75	26	74	73	22	21
40	39	38	67	65	66	64	63	32	31
41	52	43	44	56	55	47	48	59	60
51	42	58	57	46	45	54	53	49	50
61	69	68	37	35	36	34	33	62	70
71	72	28	27	25	76	24	23	79	80
81	19	13	14	86	85	17	88	12	90
10	2	3	4	96	95	97	98	99	1

$n = 10, p = 505$

Magic Squares in Indian Mathematics. Fig. 19 Nārāyaṇa's method for "odd-womb" squares (II): transposing method (conjectural reconstruction).

to be used in magic squares by means of *kuṭṭaka*, i.e., indeterminate equations of the first degree; how to make a square of order four by *turagagati* (horse move); the number of pan-diagonal magic squares of order four, 384, including every variation made by rotation and inversion.

Then Nārāyaṇa gives three general methods for constructing a square having any optional order (n) and constant sum (p) when a standard square of the same order is known – (1) by means of an arithmetical progression having an appropriate first term (a) and common difference (d), (2) by means of n sets of arithmetical progressions whose common differences are all unity, and (3) by adding an appropriate number (t) to every term of the standard square.

Nārāyaṇa next explains two methods each for constructing *sama-garbha* (even-womb) or evenly even, *viṣama* (odd-womb) or evenly odd, and odd squares when the sum is given. The two methods for

a

4	5	1	2	3
5	1	2	3	4
1	2	3	4	5
2	3	4	5	1
3	4	5	1	2

Prelim-A

b

20	25	5	10	15
25	5	10	15	20
5	10	15	20	25
10	15	20	25	5
15	20	25	5	10

Prelim-B

c

19	15	6	27	23
25	16	12	8	29
26	22	18	14	10
7	28	24	20	11
13	9	30	21	17

B over A: $p = 90$

Magic Squares in Indian Mathematics. Fig. 20 Nārāyaṇa's method for odd squares (I): folding method.

22	21	13	5	46	38	30
31	23	15	14	6	47	39
40	32	24	16	8	7	48
49	41	33	25	17	9	1
2	43	42	34	26	18	10
11	3	44	36	35	27	19
20	12	4	45	37	29	28

$n = 7, p = 175$

Magic Squares in Indian Mathematics. Fig. 21 Nārāyaṇa's method for odd squares (II): diagonal method.

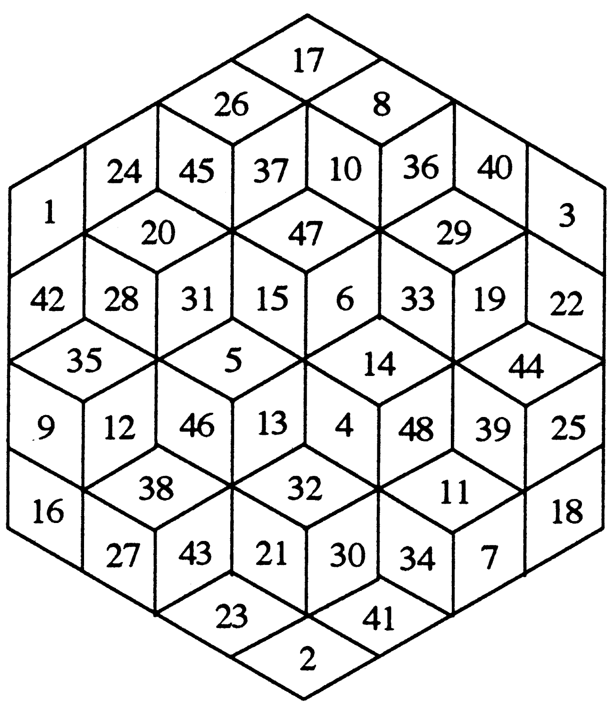
the first kind are (1) by folding two preliminary squares *karasaṃpuṭa-vat* (just like the folding of two hands), and (2) by arranging numbers in the component squares of order four according to the pattern of a standard square. For the second kind they are (1) by putting numbers zigzag in the square and (2) by transposing certain numbers in the natural square. These two methods are not completely mechanical, and require *mati* (intelligence). The methods for the third kind are (1) by folding two preliminary squares just as in the case of the first kind and (2) by starting from the central cell of any side of the square and proceeding diagonally.

In the last section Nārāyaṇa gives a number of examples for two kinds of derivative magic figures, *saṃkīrṇa* (miscellaneous) and maṇḍala (circular). Both

a

1	24	37	36	2	23	38	35	3	22	39	34
42	31	6	19	41	32	5	20	40	33	4	21
12	13	48	25	11	14	47	26	10	15	46	27
43	30	7	18	44	29	8	17	45	28	9	16

Preliminary Magic Oblong



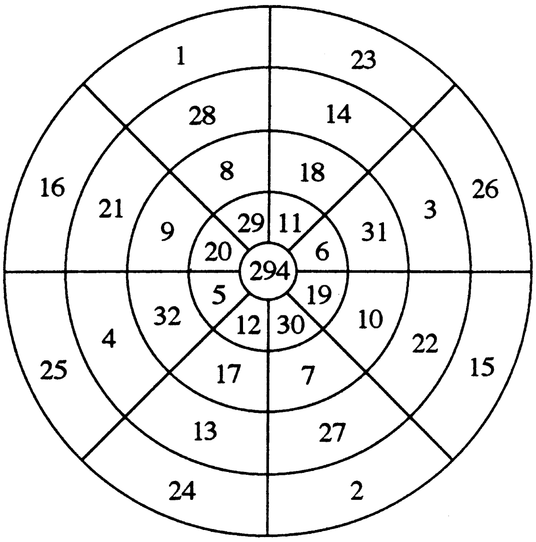
b

Magic Lotus: $p = 294$

Magic Squares in Indian Mathematics. Fig. 22 (a) Nārāyaṇa's magic lotus with six petals: preliminary magic oblong. (b) Nārāyaṇa's magic lotus with six petals ($p = 294$).

1	16	25	24	2	15	26	23
28	21	4	13	27	22	3	14
8	9	32	17	7	10	31	18
29	20	5	12	30	19	6	11

a Preliminary Magic Oblong



b Magic Circle: $p = 360$

Magic Squares in Indian Mathematics. Fig. 23
(a) Nārāyaṇa's magic circle: preliminary magic oblong.
(b) Nārāyaṇa's magic circle (p = 360).

1	8	$a-7$	$a-2$
$a-5$	$a-4$	3	6
7	2	$a-1$	$a-8$
$a-3$	$a-6$	5	4

$a = \frac{p}{2}$

Magic Squares in Indian Mathematics. Fig. 24 Pattern for magic square of four by Laghunandana.

kinds are made by rearranging ordinary magic squares. In his encyclopedic work on Hindu Law, *Smṛtitattva* (ca. AD 1500), Laghunandana gives a method for making squares of order four having any optional sum that is determined according to the purpose (see Table 1).

Significant scholarly work has been done on the importance of magic squares both mathematically and philosophically. Cammann and Roşu both discuss the significance of magic squares in Indian thought and compare Indian, Islamic, and Chinese magic squares.

Magic Squares in Indian Mathematics. Table 1 Purposes of magic squares of order four

Sum (p)	**Purpose**
20	To neutralize poison
28	To protect crops from insects
32	To accelerate delivery
34	To protect travelers
50	To exorcise evil spirits
64	To protect warriors
72	For women having no children
84	To soothe crying children

Hayashi discusses the magic squares of Varāhamihira, of Pherū, and of Nārāyana, providing the first modern translations of their works on magic squares. Datta and Singh's posthumous work, revised by K. S. Shukla, mainly treats Nārāyana's magic squares. Kusuba provides an English translation with mathematical commentary, as well as an edition of the Sanskrit text, of Nārāyaṇa's work on magic squares. Singh gives an English translation of the entire *Gaṇita-kaumudi* including the chapter on magic squares.

See also: ►Varāhamihira, ►Nārāyaṇa

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Magic Squares in Islamic Mathematics

JACQUES SESIANO

One of the most impressive achievements in Islamic mathematics is the development of general methods for constructing magic squares. A magic square of order n is a square divided into n^2 cells in which different natural numbers (mostly the n^2 first naturals) must be arranged in such a way that the same sum appears in each of the rows, columns, and two main diagonals. If, in addition to this basic property, the square remains magic when the borders are successively removed, we speak of a "bordered square." If the sum in any pair of complementary diagonals (i.e., pairs of parallel diagonals lying on each side of a main diagonal and having together n cells) shows the constant sum, the square is called "pandiagonal."

Squares are usually divided into three categories: odd-order squares ($n = 2k + 1$, k natural), evenly even squares ($n = 4k$), and evenly odd squares ($n = 4k + 2$). There are general methods for constructing squares of any order from one of these three categories. Except for the smallest possible order, $n = 3$, there are numerous possibilities of forming magic squares of any given order. There may be, however, some limitations concerning additional magical properties; for instance, there are no pandiagonal squares of evenly odd order.

Information about the beginning of Islamic research on magic squares is lacking. It may have been connected with the introduction of chess into Persia in early Islamic times. Initially, the problem was a purely mathematical one; thus, the Arabic ancient designation for magic squares is *wafq al-a'dād* (harmonious disposition of the numbers). We know that treatises were written in the ninth century, but the earliest extant ones date back to the tenth century. It appears that, by that time, the science of magic squares was already established. Not only was the construction of a magic square, simple or bordered, explained for various orders, but also several additional conditions or refinements were considered. For example, the construction of "composite squares" was well known: if $n = r \times s$, with $r, s \geq 3$, one may fill successively, according to a magical arrangement for the order r, r^2 subsquares of order s (Fig. 1). Another contemporary achievement was the construction of bordered squares in which the even numbers are separated from the odd ones (Fig. 2).

Treatises explaining general constructions were common in the eleventh and twelfth centuries. They also explain how to construct a magic square for a given sum, or for a word of n letters or n words to be put in the first row, since a number among the units, the tens, the hundreds, and one thousand is associated with

31	36	29	76	81	74	13	18	11
30	32	34	75	77	79	12	14	16
35	28	33	80	73	78	17	10	15
22	27	20	40	45	38	58	63	56
21	23	25	39	41	43	57	59	61
26	19	24	44	37	42	62	55	60
67	72	65	4	9	2	49	54	47
66	68	70	3	5	7	48	50	52
71	64	69	8	1	6	53	46	51

Magic Squares in Islamic Mathematics. Fig. 1 A composite square.

36	16	108	110	10	113	8	116	118	2	34
50	48	24	100	107	97	7	102	18	46	72
52	56	60	103	91	89	23	3	58	66	70
96	54	17	47	51	81	83	43	105	68	26
94	13	29	49	59	57	67	73	93	109	28
11	27	35	45	69	61	53	77	87	95	111
92	117	101	85	55	65	63	37	21	5	30
32	80	121	79	71	41	39	75	1	42	90
38	78	64	19	31	33	99	119	62	44	84
82	76	98	22	15	25	115	20	104	74	40
88	106	14	12	112	9	114	6	4	120	86

Magic Squares in Islamic Mathematics. Fig. 2 A bordered square separating the numbers according to parity.

81	7	116	66	80
79	78	68	64	61
63	56	70	84	77
67	76	72	62	73
60	133	24	74	59

Magic Squares in Islamic Mathematics. Fig. 3 Magic square from a given first row.

each of the 28 Arabic letters. The words occurring in the first row are either proper names or words of a religious nature (Fig. 3; the five words correspond to the numbers 81, 7, 116, 66, and 80). Pandiagonal squares are constructed in various ways for evenly even orders, but incompletely for odd orders (the method fails for certain orders).

From the thirteenth century on, magic squares become more and more associated with magic and divinatory purposes. Consequently, some texts merely picture squares and mention their attributes. Some others, though, keep the general theory alive, mostly to enable the reader to construct amulets by himself.

Interest in magic squares in Europe first arose toward the end of the Middle Ages, when two sets of squares associated with the seven planets were learned of through astrological and magic texts (whence the name), but without any information on their construction. Thus, the entire theory had to be built anew, and it is only in very recent times that the extent of Islamic research has come to light. It should also be remarked that the methods of construction spread eastward around the twelfth century toward India and China.

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Magic Squares in Japanese Mathematics

Yoshimasa Michiwaki

The study of Magic Squares in Japan began in the beginning of the Kan-ei period (1624–1643) with the import of *Suan fa tong zog* published in 1592 by Chen Dawei of China. Almost all the famous *wasan* (Japanese mathematics) experts, such as Takakazu Seki (or Seki Kowa, ca. 1642–1708) studied squares. On a smaller scale, the study has continued, and we have gained some new insights lately.

The study of squares concerns itself with some aspects of combinatorial mathematics, so some of its general methods are applied as well. For example, some parts of perfect 5 × 5 squares are made by the "Knight Jump Arrangement". The study of compositions, which was started by a Russian scholar, is limited to perfect 4 × 4 squares, but the method was also applied to 8 × 8 squares, as in the study by Motoaki Abe. Rakuho Abe obtained a fantastic result of irregular, perfect 7 × 7 squares. This is shown below:

16	24	20	17	37	14	47
23	28	48	1	38	6	31
39	7	45	9	42	18	15
40	4	29	25	21	46	10
35	32	8	41	5	43	11
19	44	12	49	2	22	27
3	36	13	33	30	26	34

An irregular, perfect 7 × 7 square.

In this the total of the diagonal or pandiagonal numbers is 175; the total of the four corner numbers (16 + 47 + 34 + 3) is 100; the total of the numbers around the centers (9 + 21 + 41 + 29) is 100; and the total of the middle numbers of the four sides (17 + 10 + 33 + 40) is also 100.

In the middle of the Heian period, i.e., in 970, Tamenori Minamoto edited *Kuchi-zusami* for the education of young nobility. In the 12th chapter we find this sentence: 4 and 2 make a shoulder, left 3 and right 7, legs are 6 and 8, head 9, body 5, tail is 1:

4	9	2
3	5	7
8	1	6

The legs, head, and tail seem to be those of some animal (a tortoise?), and maybe they suggest the arrangement of numerals. We are not sure how

Minamoto came by this knowledge of squares, but the 3 × 3 square in *Kuchi-zusami* is the oldest record as far as we know.

A book by Yūeki Andō (1624–1704), a clansman of Aizu, is the first in the world in which the author explains a general way to make squares by increasing from 3 × 3 to 30 × 30 squares (see Table 1).

Magic Squares in Japanese Mathematics. Table 1 A general way to make squares

A

7	4	1
8	5	2
9	6	3

B

2	9	6
3	5	7
4	1	8

C

4	9	2
3	5	7
8	1	6

D

12	19	8
9	13	17
18	7	14

For example, if we exchange positions in square A so that 1 ↔ 6, 3 ↔ 8, 9 ↔ 4, and 2 ↔ 7, we get square B. Then the four corners are all even numbers. If we then turn these four corner numbers 90° clockwise, we get square C.

21	16	11	6	1
22	17	12	7	2
23	18	13	8	3
24	19	14	9	4
25	20	15	10	5

5 × 5 square, with a 3 × 3 square inside.

In the 5 × 5 square like the figure shown above, the thick-lined square is a 3 × 3 square. Change it into D of Table 1. Next, work on the four corners of the outside square, and exchange positions in the following manner: 1 ↔ 15, 5 ↔ 23, 25 ↔ 11, and 21 ↔ 3. Do not turn the four corner numbers, because they are odd numbers. You will complete the work by putting D, the 3 × 3 square, inside it.

Takakazu Seki commented on the general way of making squares in the books, *Hōjin-no-hō* and *Ensan-no-hō*, written in the third year of the Tenwa period (1683). He divided them into odd-celled squares and two types of even-celled squares. Squares by Katahiro Takebe (1664–1739) are introduced in Volume 4 of the *Ichigen Kappō*, written by Shukei Irie.

In 3 × 3 squares, put the numerals in order, turn the center joined by both diagonals, lines, and rows 45° leftward. Then turn the center of the lines and rows 180°:

7	4	1
8	5	2
9	6	3

⟶

4	1	2
7	5	3
8	9	6

⟶

4	9	2
3	5	7
8	1	6

Yoshisuke Matsunaga (1692–1744), a pupil of Seki's pupil, wrote *Hōjin-Shin-jutsu*. There are also studies by Yoshihiro Kurushima (d. 1757), and by Naonobu Ajima (1732–1798). The question on step children is in *Jingōki* by Mitsuyoshi Yoshida. The question is close to that of Joseph's problem in the West.

Shūtarō Teramura (1902–1980) studied how many "parent–child" squares could be made in all, and in 1926 he made 605 squares. Following are some examples.

In the first, the parent square is a perfect 8 × 8 square. The child one (between thick lines) is a perfect 4 × 4 square (shown below):

2	29	51	48	1	30	52	47
56	43	5	26	55	44	6	25
15	20	62	33	16	19	61	34
57	38	12	23	58	37	11	24
4	31	49	46	3	32	50	45
54	41	7	28	53	42	8	27
13	18	64	35	14	17	63	36
59	40	10	21	60	39	9	22

A parent–child square, 8 × 8, with a 4 × 4 square inside.

In another example, the parent square is also a perfect 8 × 8 square, and the child one (upper-middle part) is a perfect 4 × 4 square, as shown below:

2	29	51	48	1	30	52	47
56	43	5	26	55	44	6	25
13	18	64	35	14	17	63	36
59	40	10	21	60	39	9	22
4	31	49	46	3	32	50	45
54	41	7	28	53	42	8	27
15	20	60	33	16	19	61	34
57	38	12	23	58	37	11	24

A parent–child square.

To make a perfect 4 × 4 square, choose optional numbers for x, y, z, u, and t. $X = x + y + z + u$. Make the square as follows:

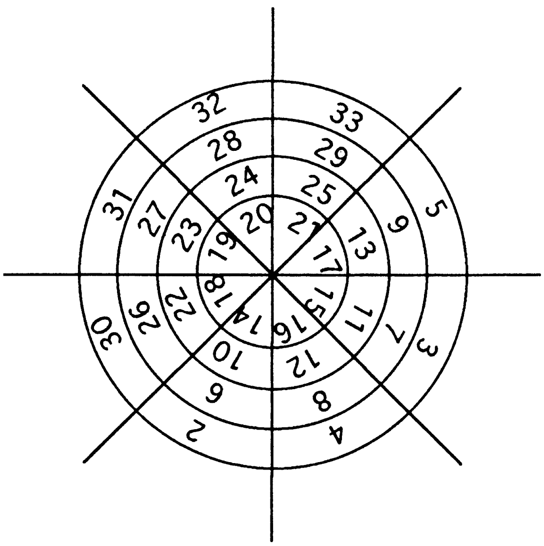
x	y	z	u
$z - t$	$u + t$	$x - t$	$y + t$
$1/2X - z$	$1/2X - u$	$1/2X - x$	$1/2X - y$
$1/2X - x + t$	$1/2X - y - t$	$1/2X - z + t$	$1/2X - u - t$

To make perfect 8 × 8 squares, choose optional numbers for a, b, and c, and construct the square as in Table 2.

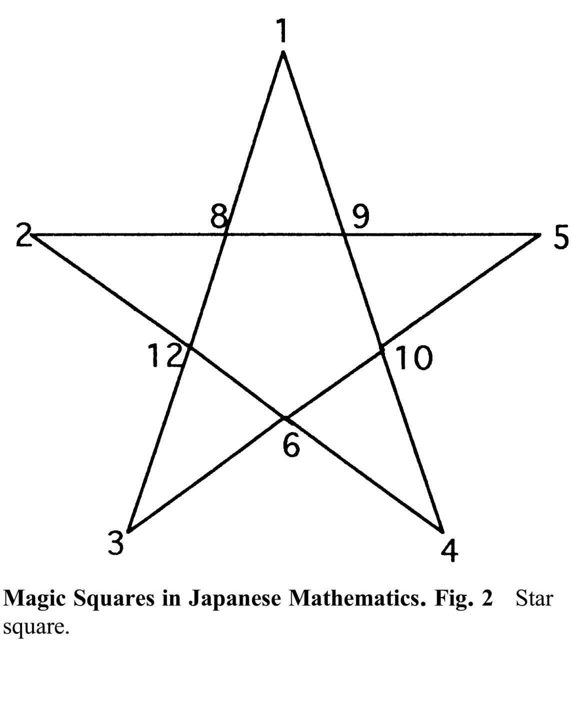
In an N square, in which a line has n divisions, and which consists of n^2 numerals, the total of the vertical and horizontal lines should be the same as that of both diagonals. This square is a Magic Square, and if each sum of the numbers of all the parallel lines is the same, the square is a Perfect Magic Square. The study of Michiwaki and Moriyama (1963) tells how to make it.

Magic Squares in Japanese Mathematics. Table 2 Making perfect 8 × 8 squares

a	b	c	d	e	f	g	h
$c+x$	$d-x$	$e+x$	$f-x$	$g+x$	$h-x$	$a+x$	$b-x$
$e+y$	$f-y$	$g+y$	$h-y$	$a+y$	$b-y$	$c+y$	$d-y$
$f-y$	$h+x$	$a-x$	$b+x$	$c-x$	$d+x$	$e-x$	$f+x$
$-e-y$	$-f+y$	$-g-y$	$-h-y$	$-a-y$	$-b+y$	$-c-y$	$-d-y$
$-g+z$	$-h-z$	$-a+z$	$-b-z$	$-c+z$	$-d-z$	$-e+z$	$-f-z$
$-a$	$-b$	$-c$	$-d$	$-e$	$-f$	$-g$	$-h$
$-c-z$	$-d+z$	$-e-z$	$-f+z$	$-g-z$	$-h+z$	$-a-z$	$-b+z$



Magic Squares in Japanese Mathematics. Fig. 1 Circular square.



Magic Squares in Japanese Mathematics. Fig. 2 Star square.

There are also many special squares. The best examples of circular squares are introduced in Takakazu Seki's *Hōjin-no-hō* and *Ensan-no-hō* (see Fig. 1).

Star squares were studied by Shigematsu Urata and Rakuhō Abe in 1955 (see Fig. 2).

The first cubic square in Japan was introduced as "cubic design" in *Rakusho-kikan* by Yoshizane Tanaka (1651–1719). In it, he piled up the following 4 × 4 squares in order:

(1)

14	54	43	19
59	3	30	38
22	46	51	11
35	27	6	62

(2)

20	44	53	13
37	29	4	60
12	52	45	21
61	5	28	36

(3)

33	25	8	64
24	48	49	9
57	1	32	40
16	56	41	17

(4)

63	7	26	34
10	50	47	23
39	31	2	58
18	42	55	15

Arata Sakai started the study of perfect 4 × 4 cubic squares in 1938, and Shigematsu Urata completed it in 1948. Motoaki Abe made a 5 × 5 cubic square in the latter part of the Taishō period. A 7 × 7 cubic square was made by Motoaki Abe and Shōji Shimada.

In 1948 Rakuhō Abe made a perfect 6 × 6 cubic square with a plane 6 × 6 square as its base, but the diagonal total was not regular. Michiwaki and Moriyama studied the way to make special perfect 9 × 9 cubic squares, and the way to count their numbers.

See also: ►Seki Kowa, ►Takebe Katahiro, ►Ajima Naonobu

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Magnetism in Chinese Culture

CHEN CHENG-YIH (JOSEPH)

In Chinese civilization, the *ci-shi* (lodestones) and their ability to attract iron are mentioned in a number of Zhou period Classics. It is stated in the *Shanhai Jing* (Classic of the Mountains and Rivers) that lodestones are found at *ao-ze.* A remark in the *Guan Zi* (Book of Master Guan) indicates that the finding of lodestones was once viewed by ancient prospectors as an indication for the possible presence of other mineral deposits. Both the *Gui Gu Zi* (Book of the Devil Valley Master) of the fourth century BCE and *Lushi Chun Qiu* (Master Lu's Spring–Autumn Annals) of 239 BCE mention that the lodestone attracts iron.

The attractive interaction between the lodestone and iron was interpreted as being caused by *xiang gan* (mutual influence), a sympathetic response between two interacting entities. Wang Chong, in the *Lun Heng* (Discourse Weighed in Balance) of AD 82 offers the interpretation that some items attract others, while some cannot, because their *qi* is different and consequently they cannot mutually influence one another. The character *qi* literally means vapor or breath. In the course of time, it took on a number of proto-scientific significances: the basic constituent entity of all things in nature and the media of the *yinyang* interactions. There are a number of scholars who translate *qi* as "energy," "field," or "matter-energy," but in ancient times, the concepts of energy and field were not yet explicitly developed. *Qi*, as it is given in the Chinese texts, is not identified by its intrinsic properties, but by its general relationship with others. Though the pattern relationship is identifiable with certain aspects of the modern concept of energy, field, or matter-energy, it is better to preserve the term *qi* and not to translate it.

A later account (AD 300) by Guo Pu also comments on the role of *qi* in such interactions.

The lodestone draws iron, and amber collects mustard-seeds. [Since] their *qi* are invisibly interconnected and their measures are silently met, the mutual influence between them consequently occurred.

Such a view of interaction at a distance involving *qi* is compatible with modern views.

The strength of such attractive interactions was later discussed in terms of the weight of iron pieces or the number of needles that the lodestone was capable of supporting.

Tao Hong Jing stated in the *Ming Yi Bie Lu* (Informal Records of Famous Physicians) that some "[lodestones] could suspend a chain of more than ten needles".

Based on such quantitative measures of the attractive power, lodestones were graded as follows:

> A piece of genuine lodestone is called the *yan nian sha* if it is capable of attracting, on its four sides, one catty of iron piece (the equal weight of the lodestone); called the *ji cai shi* if it is capable of attracting, on its four sides, eight ounces weight of iron piece; and called simply the *ci shi* if it is capable of attracting, on its four sides, four ounces of iron piece *(Lei Gong Pao Zhilun)*.

M

The directional property of lodestones was probably first used in the *sinan* ceremony, a practice evolved directly from the tradition of using a gnomon and the positions of the sun and stars to determine the time and directions. The term *sinan* means "south verification" or "south controller." The discovery of lodestone's south pointing property led naturally to its association with the term *sinan* and the *sinan* (south verification) devices. However, early mentions of the *sinan* devices provide little information on their construction. In the *Gui Gu Zi* there is mention of the fact that when the Zheng people engage in collecting jade, they always carry with them a *sinan* to avoid being lost.

The device described by Wang Chong has been widely considered to be the earliest form of the magnetic compass.

The Chinese literature of the period ranging from the Han to the Tang dynasties provides a number of hints that, by the first century AD, the fact that the directive property of the lodestone could be transferred to small pieces of iron was discovered, and by the seventh century AD, the magnetized needle began to appear in certain compasses, replacing lodestones for greater precision. But the records are not sufficiently specific to provide a definitive account of these developments. Explicit descriptions of magnetic properties and compass construction are found in the work of the Song dynasty.

Properties of magnetized needles are discussed in the work of Shen Gua (1029–1093). We have from his *Meng Xi Bi Tan* (Meng Xi Essays) of 1086, the following description of declination:

> *Fang Jia uses the lodestone to rub the point of a needle*;
> *The needle is then able to point to the south*.
> *It does not, however, point directly at the south*,
> *It always inclines slightly to the east*.

Following this description is the passage on the needle supporting methods:

> [The needle] can be supported by making it float on the surface of water, but it is rather unsteady. It may be balanced on the finger-nail, or on the rim of a cup, so that it can turn more easily, but such supports being hard and smooth [mean it] is liable to fall off. The best way of supporting the needle is by suspension. The method uses a single cocoon fiber of new silk to suspend the needle. By attaching silk to the center of needle with a piece of wax the size of a mustard-seed and hanging in a windless place, the needle will then always point to the south undisturbed.

He discusses three types of needle-supporting methods: floating, pivot, and suspension. For the study of magnetic properties, Shen Gua preferred the suspension method using a silk thread. The other two methods of supporting the needle, by floating it on the water surface and by pivoting it on a hard smooth surface, correspond to those used in the wet and dry compass, respectively.

Shen Gua's work also discusses magnetic polarity. He noticed that some needles pointed north and some south. He believed that different natures caused this, just as animals shed at different seasons.

An important discussion of the magnetic compass is found in the *Wujing Zongyao* (Collection of the Most Important Military Techniques) of AD 1044.

> When troops encountered gloomy weather or dark night, and could not distinguish the directions, they would let an old horse in the front lead them, or else they would make use of the south-pointing carriage, or the south-pointing fish to identify the directions. Now the carriage method has not been handed down. In the (south-pointing) fish method, a thin leaf of iron is cut into the shape of a fish two inches long and half an inch broad, having a pointed head and tail. It is then heated in a charcoal fire until it becomes thoroughly red-hot, taken out by the head with iron tongs, and placed so that its tail is in the *zi* direction (due north). In this position, it is quenched with water in a basin, so that its tail is submerged for several tenths of a inch. It is then kept in a *miqi* (tightly closed box). To use it, a small bowl filled with water is set up in a windless place, and the fish is laid as flat as possible upon the water surface so that it floats, whereupon its head will point in the *wu* direction (south).

The passage not only provides a clear discussion on the construction of a compass, but also reveals a different method for magnetizing iron pieces. Thus no later than the early Song dynasty (960–1279), two methods of magnetizing were known. Other than rubbing with the lodestone, an iron piece could also be magnetized by quenching it from red heat through the Curie point, held in a north–south direction (in the magnetic field) of the earth. The discovery of the thermoremanence phenomena was of great scientific significance. Since the earth's magnetic field is relatively weak and the soft iron does not retain its magnetism long, questions were raised as to whether such magnetized iron could function satisfactorily as a compass. Recent archaeological evidence revealed a long history of steel development in China, beginning from the later part of the spring-autumn period of the Zhou dynasty. By the second century BCE, two methods for steel production from pig iron were developed, one by the puddling of molten iron and the other by decarbonization of cast iron in the solid state without the formation of graphite. Thus, good steel and steel needles were certainly available in the early Song dynasty.

An important use of the compass is in navigation. Clear and accurately datable statements on such a use are found in the *Pingzhou KeTan* (Pingzhou Table Talk) of 1119, when the author says that ships' pilots look at a south-pointing needle or sample of the mud collected from the sea bottom to determine their whereabouts in dark weather. This is confirmed in other books of the period.

Based on these statements and other sources, Needham has concluded that "description of the use of the compass for navigation on Chinese ships antedates the first knowledge of this technique in Europe by just under a century, but there are indications that it was used for this purpose in China somewhat earlier."

Needham is also of the view that "Chinese sailors remained faithful to the floating-compass for many centuries. Although the dry pivoted compass had been described early in the twelfth century AD, it did not become common on Chinese vessels until it was reintroduced from the West in the sixteenth century by the Dutch and Portuguese by way of Japan. Associated then with it was the compass-card (the windrose attached to the magnet) which had probably been an Italian invention at the beginning of the fourteenth

Magnetism in Chinese Culture. Fig. 1 Clay figurine with a dry-pivoted compass in its arm unearthed in 1985 from the tomb of Zhu Jinan.

century." The European mariner's compass is characterized by sixteen compass points in contrast to the 24 of the Chinese compass. The discovery of the clay depiction of a dry-pivoted compass in the tomb of Zhu Jinan (1140–1197) in 1985 raised a number of pertinent questions. The compass depicted in the arm of the two clay figurines unearthed from the tomb has 16, not 24, compass-points. Since the tomb was sealed in 1198, the compass depicted here could not have been influenced by those reintroduced from the West.

Both the dry-pivoted and floating compass were used in Chinese ships. The choice was often based on accuracy. It should be noted that, though the gyroscope was invented in China around the first century BCE by Ding Huan, no known reference to its use in connection with the mariner's compass is available.

See also: ►Navigation, ►Metallurgy, ►Compass, ►Shen Gua

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Magnetism in Mesoamerica

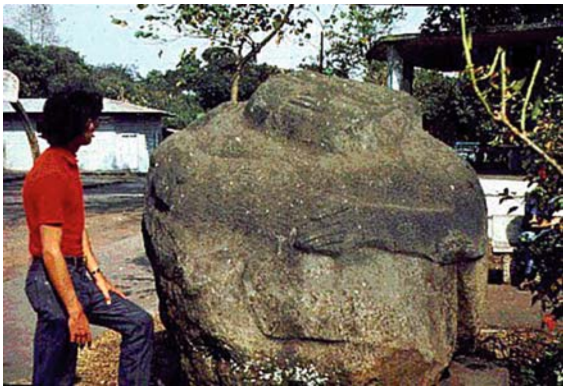
Vincent H. Malmström

That the pre-Columbian peoples of Mesoamerica were familiar with the property of magnetism has been suggested by several researchers, among them the geographer Robert Fuson and the anthropologist Michael Coe. Indeed, a flattened oblong piece of hematite discovered during Coe's excavation of the Olmec site of San Lorenzo in southern Veracruz state in 1966 has been thoroughly examined by John Carlson, who suggests that it probably was fashioned for use as a compass. (In tests, however, it never aligned more closely than about 35° with the Earth's magnetic field.) In 1975, a basaltic sculpture at the site of Izapa, on the Pacific coastal plain of Mexico near the Guatemalan border, was found to possess a strong magnetic field. Variously described as being the representation of either a frog (Norman 1976) or a turtle's head (Malmström 1976), it has a

Magnetism in Mesoamerica. Fig. 1 The black volcanic sands of the beaches near Izapa are the nesting place of a deep-carapaced black turtle that migrates between the Guatemalan coast and the Galápagos Islands. Perhaps local fishermen associated magnetism with the homing instinct of these creatures. Interestingly, the Chinese also associated turtles with magnetism, using the term "black turtle rock" for basalt and making their early compasses in the shape of turtles. (Photo by the author.)

north-seeking pole in its snout and a south-seeking pole at the back of its head. The discovery led the latter researcher to speculate that the stone's carver may have associated the property of magnetism with the homing instinct of the turtle. Because it was the only magnetic object found at the site, critics of the notion that it was a human artifact argued that it may have been struck by lightning and its magnetic field had been induced in that manner (Fig. 1).

However, in 1979, several additional magnetic sculptures were discovered in the Pacific coastal plain of Guatemala, including seven which now repose in the central plaza of the town of La Democracia, and two more which were identified at the nearby sugar plantation of El Baúl. Those at La Democracia are extremely crude depictions of human beings, and, because of their rotundity, have been termed the "Fat Boys" by archaeologists. When an entire body is depicted, the two magnetic poles are usually found on either side of the navel; when only a head is portrayed, the two magnetic poles are almost invariably centered on the right temple (Fig. 2).



Magnetism in Mesoamerica. Fig. 2 In the sculptures known as the "Fat Boys," magnetism appears to have been associated with certain qualities of the human being. We can only speculate that when the magnetic pole was located at the navel, it may have symbolized the life force, or the continuity of life, whereas when it was located in the right temple, it may have represented consciousness, memory, or intellect. (Photo by the author.)

The sculptures at El Baúl include a rampant jaguar, with magnetic poles in each upraised paw, and a tablet showing two men seated on a bench with their arms folded over their chests. This single block of stone has four magnetic poles, one north-seeking pole between each of the men's folded arms and one south-seeking pole below each man in the space beneath the bench. In 1983 a small humanoid sculpture in the plaza of Tuxtla Chica, Mexico, just back of Izapa, was found to be magnetic in the right side of its head. Clearly, the patterns of polarity discerned suggest a conscious intent on the part of the sculptors to fashion their carvings around a known center of magnetic attraction, for in none of the stones has any inset of foreign material been made. That such recurring patterns could have been the result of random lightning strikes must also be ruled out. Because the "Fat Boys" are considered to date from 1500 to 2000 BCE, it is possible that these sculptures represent the oldest known magnetic artifacts in the world. But to what use, other than art and magic, this knowledge was put, we have no answer as yet (Fig. 3).

Magnetism in Mesoamerica. Fig. 3 Because all evidence of magnetism in Mesoamerica is associated with basaltic sculptures whose size prohibited their movement on more than a local scale, the knowledge of this property apparently was limited to a small area of volcanism on the Pacific coastal plain of southernmost Mexico and adjacent Guatemala. (Map by the author.)

See also: ►Compass

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Mahādeva

K. V. Sarma

Mahādeva (ca. 1275–1350) composed the extensive set of planetary tables, *Mahādevī*, named after him and dated 28th March, 1316. He belonged to a family of astronomers and in his work *Grahasiddhi* describes himself as the son of the astrologer Paraśurāma, son of Padmanābha, son of Mādhava, son of Bhogadeva of the Gautamagotra, a follower of *Sāmaveda* and a performer of sacrifices. The planetary tables contained in the *Mahādevī*, prepared for facilitating the computation of the daily almanac, were extremely popular in the Gujarat and Rajasthan regions, and numerous manuscripts of the work have been located in these places. While the basic text was restricted to 43 verses, the author himself wrote a set of instructions for using the tables, called *Grahasiddhi*, which also were extensively used. The popularity of *Mahādevī* is also attested to by the several commentaries that were written on the work, including that of Nṛsiṃha (1528), Dhanarāja (1635) and Mādhava, and a host of anonymous commentators.

Mahādeva is a synonym of Śiva, one of the trinities of Hinduism, and so formed one of the words commonly used to name Hindus. There are several astronomers of medieval India who bore the name Mahādeva. Among these are: Mahādeva, younger brother of Viṭṭhala, from Gujarat, author of *Tithicakranirṇaya*, also called *Tithinirṇaya, Tithiratna,* and *Mahādevasiddhānta*; Mahādeva, author of *Jātakāpaddhati*, called also *Mahādevapaddhati* after his name; Mahādeva, son of Luṇiga and author of commentaries on the *Cintāmaṇisāraṇikā* of Daśabala and the *Jyotiṣaratnamālā* of Śrīpati; Mahādeva of the Kauṇḍinyagotra, son of Bopadeva, and author of *Kāmadhenu* called also *Tithikāmadhenu*; Mahādeva, son of Kahnaji Vaidya, author of *Muhūrta-dīpaka* in 57 verses, written in 1640, *Praśnapradīpa* called also *Praśnaratna* (1647), *Bhāveśaphalapradīpa* (1647), *Kālanirṇayasiddhānta* (1652), and a commentary on his own *Muhūrtadīpaka* (1661); Mahādeva Pāṭhaka (1842–1899), son of Revāśaṅkara, and author of *Varṣadīpaka*, called also *Varśadīpikā* (1861), *Jātakatattva*, written in 1872, *Pitṛ mārgapradīpa* in 57 verses (1874), *Varṣapaddhati*, a compilation (1874), and *Āśubodhajyotiṣa.*

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Mahāvīra

R. C. Gupta

The Rāṣtrakūṭa dynasty of the medieval period was founded in the Deccan, South India, by Dantidurga about the middle of the eighth century AD. A king of this dynasty named Amoghavarṣa ruled from AD 815 to 877. The long period of his rule is known for its material prosperity, political stability, and academic fertility. He was rich, powerful, and peace-loving, and he patronized art and learning.

In the later part of Amoghavarṣa's reign there lived a great mathematician named Mahāvīrācārya. Mahāvīra was a Digambara Jaina and wrote an extensive Sanskrit treatise called *Gaṇitasāra saṅgraha* (Compendium of the Essence of Mathematics) about AD 850. It is devoted to elementary topics in arithmetic, algebra, geometry, mensuration, etc. The work is important because it is a collection summarizing elementary mathematics of his time and providing a rich source of information on ancient Indian mathematics. It is written in the style of a textbook and was used as one for centuries in all of South India. Its importance is greater still because the *Pāṭīgaṇita* of Śrīdhara (ca. AD 750), written in the same style as the *Gaṇitasāra saṅgraha*, is not extant in full.

Mahāvīra shows sufficient originality not only in presenting older material lucidly, but also in introducing several new topics. A commentary called *Bālabodha* in Kannada was written by Daivajña Vallabha. A Sanskrit commentary was composed by Varadarāja. Dates for these two commentators are not known, nor are their works available in print. There were other translations in the eleventh century and in 1842.

The nine chapters of the *Gaṇitasāra saṅgraha* are as follows:

1. Terminology (70 verses)
2. Arithmetical operations (115 verses)
3. Operations involving fractions (140 verses)
4. Miscellaneous operations (72 verses)
5. Rule of three (43 verses)
6. Mixed operations (337 1/2 verses)
7. Geometry and mensuration (232 1/2 verses)
8. Excavations (68 1/2 verses)
9. Shadows (52 1/2 verses)

The total number of verses, 1,131, shows that the book is quite comprehensive. Another noteworthy feature is that the Jaina tradition of Indian mathematics is also preserved within the scope of the *Gaṇitasāra saṅgraha*.

The authorship of the astronomical work *Jyotiṣ-apaṭala* is also ascribed to Mahāvīra. Some manuscripts of this title are mentioned in the *Jina-ratna-kośa* and the *New Catalogus Catalogorum*, but no author is mentioned. Another work attributed to him is *Chattisu*, but this is also a sort of elaboration of part of the *Gaṇitasāra saṅgraha* made by Mādhavacandra Traividya (about AD 1000). Whatever the case, the reputation of Mahāvīra relies solely on his *magnum opus*.

During ancient times, unit fractions were considered quite important. There are some interesting results in the *Gaṇitasāra saṅgraha* on this topic. One rule gives a practical method for expressing any given fraction as a sum of unit fractions. Let p/q be the given fraction (p being less than q). We add a suitable integer x to q such that $(q + x)$ become exactly divisible by p, say, r times. Then Mahāvīra's rule is

$$\frac{p}{q} = \frac{1}{r} + \frac{x}{(r \times q)}.$$

Mahāvīra made a very significant remark in connection with the square-root of a negative number. He said "A negative number is non-square by its nature, whence there is no (real) square-root from it."

This remark is the first clear recognition of the imaginary quantities in mathematics which had to wait for several more centuries for their formal definition.

Mahāvīra was one of the earliest Indian mathematicians to deal with the lowest common multiple which he calls *niruddha*. It was evolved to simplify operations with fractions.

Arithmetical and geometrical progressions were already handled earlier. An extensive treatment is available in the *Gaṇitasāra saṅgraha*. In the absence of modern theories of logarithms and equations, problems were solved by methods of trial and repetition.

Mahāvīra seemed to be expert in handling all sorts of equations reducible to quadratic forms and gave a variety of examples of them.

In mensurational problems in geometry, Mahāvīra usually gave two rules: one for rough and the other for better or accurate results. He dealt with all the usual plane figures. For π, he conformed to the Jaina values 3 (rough), and $\sqrt{10}$ (better). He was the first Indian to deal with mensuration related to an ellipse which he calls *āyata-vṛtta* (elongated circle), but his rules are approximate.

For an ellipse of semimajor and semiminor axes his "accurate" results are:

$$\text{Area} = b\sqrt{(4a^2 + 6b^2)},$$

$$\text{Perimeter} = \sqrt{(16a^2 + 24b^2)}.$$

For the exact rectification of the ellipse, one had to wait for about 800 years to acquire the powerful tool of calculus. In this situation Mahāvīra's first attempt is to be appreciated.

Regarding the volume of a sphere of radius r, Mahāvīra gave the formula

$$v = \frac{9}{2}r^3,$$

which was the practical rule of Jaina tradition. He gave another rule for the purpose, but it gives a better result only with an emendment of the text. For the curved surface of a spherical segment, his rule has been newly interpreted to yield the formula

$$S = \pi r^2 \theta \sin\theta,$$

where θ is the semiangle subtended by a diameter of the base of the segment at the center of the sphere. This peculiar formula gives quite a good result in all practical cases (i.e., for θ up to 60°). The modern exact formula is $2\pi r^2(1 - \cos\theta)$. For the volume of frustum-like solids, Mahāvīra gave a generalization of Brahmagupta's rule based on the theory of averages.

In the end we mention Mahāvīra's extensive contribution to the formation of rational figures. He calls a triangle or quadrilateral *janya* (generated) when its sides, altitudes, and other important measures can be expressed in terms of rational numbers.

See also: ►Śrīdhara

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Mahendra Sūri

K. V. Sarma

Mahendra Sūri, Jain astronomer, and pupil of Madana Sūri, was a protégé of the progressive minded Sultan Fīrūz Shāh Tuglaq, who ruled in Delhi from AD 1351 to 1388. The Sultan was one of the pioneers of the cultural exchange between Hindus and Muslims and was much interested in astronomy. His most important contribution in this field was the introduction of the astrolabe into India from the Islamic world. He induced Mahendra Sūri to study the astrolabe and familiarize Indian astronomers with the instrument through the Sanskrit language. This persuasion resulted in Mahendra Sūri's writing the *Yantrarāja* (King of Instruments), in 1370, the first work written in Sanskrit on the astrolabe.

The *Yantrarāja* sets out in five chapters the theory of the astrolabe, the construction of the instrument with its several planes and designs, and lines, circles, and other markings to be made on the planes while making the instrument and graduating it for making observations and recordings. It is to be noted that Mahendra Sūri first describes the ordinary astrolabe, which he calls *saumya-yantra* (northern instrument), wherein the astrolabe is projected from the south pole, and then the *yāmya-yantra* (southern instrument), where the instrument is projected from the north pole. He then introduces a *miśra* (mixed) instrument, which he calls *phaoñīndra-yantra* (the serpentine instrument), wherein the two types are combined.

The commentary on the *Yantrarāja* by the author's pupil, Malayendu Sūri (fl. 1377) explains the practical application of the instrument for taking readings. He also provides tables of the latitudes of about 75 cities in and outside India, and also one for 32 fixed stars. In this connection the commentator says that the Muslims have recorded more than 1,022 stars, but that he has selected only 32, being those required for practical use in Indian astronomy and astrology. There is still another commentary on the work, which is more elaborate than that of Malayendu Sūri, written by Gopīrāja about AD 1540, which is still in manuscript form.

See also: ►Astronomy in India, ►Astronomical Instruments in India, ►Astrolabe

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Makaranda

K. V. Sarma

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Makaranda was a resident of Kāśī (or Benares, Varanasi). In AD 1478 he wrote an extensive astronomical manual with the title *Makaranda*. This was doubly significant, first because the title was reminiscent of his own name, and, second because it called the computed result obtained *makaranda* (honey), and gave the several astronomical terms names of parts of plants, such as *guccha* (flower cluster), *kanda* (bulb), *vallī* and *latā* (creeper), and the like. Makaranda based his work on the parameters of and practices prescribed by the modern *Sūryasiddhānta*, to which he added certain corrections to insure greater accuracy, and provided a number of astronomical tables for ease in computing the daily almanac.

Makaranda's tables, which are often long and extend to several centuries, involved much labor and ingenuity in their preparation. They cover such subjects as *tithi* (lunar day, five tables), *nakṣatras* (asterisms, four tables), *yogas* (complementary positions of the sun and the moon, three tables), *saṇkrāntis* (entry of the sun into the zodiacal signs, three tables), mean motion of planets and their anomalies (11 tables), length of daylight on different days (one table), weekdays (two tables), and eclipses and allied matter (ten tables).

In order to render the work of the user easier, Makaranda provides, in certain cases, two sets of tables, one for single years and the other for groups of years, all from the epoch date of the commencement of Śaka year 1400 (AD 1478). Thus, when calculations are made for a date which is several years after the epoch, multiples of the group-years can be skipped, just taking note of the readings for the number of group-years skipped and applying the same to the relevant year of the current group. In the case of *tithis* the group is taken as 16 years; for *nakṣatras* and *yogas*, it is nearly 600 years, from AD 1478 to 2054, in 24 year periods. For the precession of the equinoxes, it is nearly 100 years, from AD 1758 to 1838, in 20-year periods, and for *saṇkrāntis* for 400 years, from AD 1478 to 1877, in 57-year periods.

Makaranda's tables were widely used in the entire northern belt of India, comprised of Gujarat, Rajasthan, Uttar Pradesh, Bihar, and Bengal, as attested by the profusion of manuscripts of the work found in this region. The work has also been commented on by several authors, from Ḍhuṇḍirāja (fl. 1590), through Purusottama Bhatta (fl. 1610), Divākara (fl. 1606), and Kṛpakara Miśra (fl. 1815), to Nīlāmbara Jhā (b. 1823). The *Siddhāntasudhā* of Paramānanda Ṭhakkura is based on the work of Makaranda.

See also: ►*Sūryasiddhānta*, ►Lunar Mansions, ►Astronomy in India

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Maps and Mapmaking in Africa

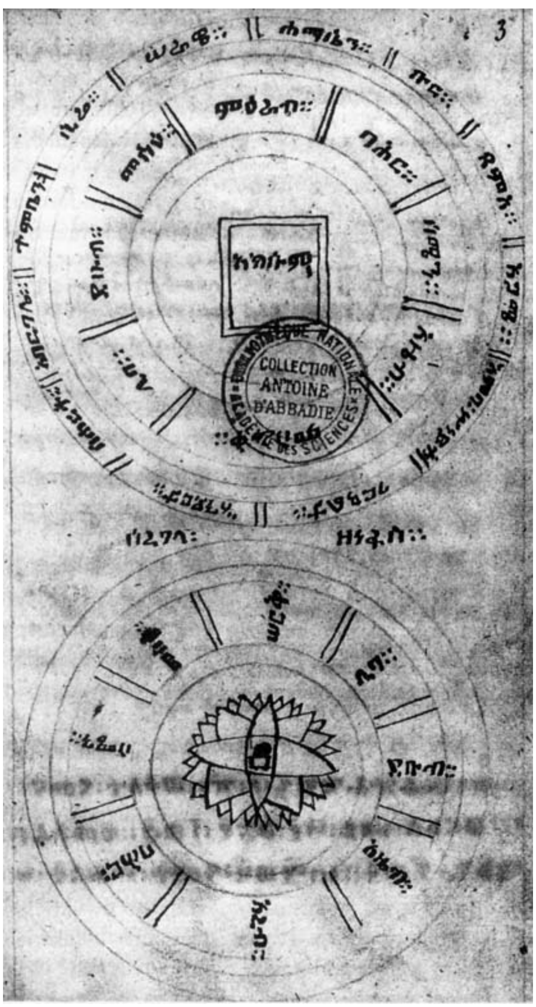
Thomas J. Bassett

With the exception of medieval Islamic mapmaking, the corpus of precolonial African maps is too small for us to generalize about distinctive cartographic traditions. B. F. Adler (1910) provides the only summary of sub-Saharan mapping, and most of his examples are maps solicited from Africans by European explorers. The paucity of extant maps may be explained by a number of factors. First, among literate cultures like the Muslim Hausa and Jula of West Africa, there existed effective substitutes such as travel guides written in Arabic script. These commonly took the form of itineraries that listed the names of towns between a starting point and destination (e.g., the road from Bornu to Mecca). In 1824 Joseph Dupuis provided examples of these "native charts" kept by merchants and pilgrims which he used to construct his own maps of West Africa. Second, the scarcity of maps in nonliterate societies may be explained by a common recourse to drawing maps on the ground. European explorers witnessed this indigenous form of mapmaking and were frequently impressed by its accuracy. However, the ephemeral nature of ground maps has left us with few traces of this apparently widespread practice (see below). Third, the demand for maps was probably very limited because of the hazards of traveling beyond one's territory. Even merchants risked being captured by neighboring groups if they did not travel in caravans, carry letters of introduction, or have contacts in distant communities. Under these circumstances, there was little demand for maps as conveyors of geographical knowledge to outsiders. Finally, in searching for African maps, we should be wary of looking for Western forms of mapping in societies whose spatial concepts and relationships to land are fundamentally different. Western maps are constructed upon culturally specific notions of property, territory, and political authority over bounded areas. One should not assume a priori that African peoples hold these concepts. Moreover, as Paul Bohannan shows in his discussion of the "genealogical map" of the Tiv of central Nigeria and the "rain shrine neighborhoods" of the Tonga of Zambia, there is tremendous variety within Africa itself in the conceptualization of space. Rarely does one find the expression of socio-spatial relationships in two-dimensional maps. Despite this restricted development of mapmaking in precolonial Africa, there are a number of interesting maps to consider.

One of the earliest examples of African mapmaking is an Egyptian map dating from about 1150 BCE. Fragments of the picture map depicting the Wadi Hammamat area between Thebes and the Red Sea port of Quseir are preserved on papyrus in the Muzeo Egizio at Turin. Other ancient Egyptian examples include plans of gardens and maps of the afterlife painted on stone during the second millennium BCE.

One of the foremost cartographers of the Middle Ages was al-Sharīf al-Idrīsī. He was born in Ceuta, Morocco, in 493 AH/AD 1100 and is believed to have died there in 560/1165. He was the court geographer of the Norman king of Sicily, Roger II, for whom he wrote his celebrated *Nuzhat al-mushtāq fī' khtirāq al-āfāq* (The Book of Pleasant Journeys into Faraway Lands, also known as the Book of Roger). This work contains a world map and 70 sectional maps that build upon both the Balkhī and Ptolemaic cartographic traditions. Although written in the twelfth century, al-Idrīsī's work was still influential five centuries later among North African chartmakers. The portolan charts of the al-Sharafī al-Ṣifāqsī family that thrived in the Tunisian town of Sfax for over eight generations are compilations based on al-Idrīsī and Catalan sea charts.

A distinctive form of schematic mapping dating from the eighteenth century is represented in Ethiopian manuscript maps of Tigre (Fig. 1). These maps consist of three concentric circles in which Aksum, the center of Ethiopian Christiandom, is situated in a box in the innermost circle, as in the figure here; the outer circles are divided into segments that contain the cardinal directions and the names of outlying districts. At least five versions of this map are known to exist, two of which are found in the manuscript titled *Kebrä Nägäst* (The Glory of Kings). Below the circle map is a "wheel of wind" or "wind rose" in which the cardinal directions are again shown with east at the top. More research is needed to examine the relationships between these circle maps and the texts in which they are found.



Maps and Mapmaking in Africa. Fig. 1 Ethiopian map of Tigre. From the Bibliothèque Nationale de France, Collection Antoine d' Abbadie 225 fol. 3-cliché A85/489.

Evidence of African maps and mapmaking in the nineteenth century is largely found in European accounts of exploration and travel. In many instances, African mapmaking was stimulated by European interest in the geography of unexplored areas. A well-known example is the map drawn by Sultan Bello for Hugh Clapperton during his visit to the Sokoto Caliphate in 1824. Clapperton was particularly interested in the course of the Niger River whose outlet was one of the great geographical mysteries of the day. Sultan Bello drew a map in the sand showing the Niger's course and later reproduced this map on paper which Clapperton published in the account of his journey. Although dismissed by some Europeans as a "rude representation," Bello's map and geographical writings were valued by later explorers like Heinrich Barth in 1859. His map is also of interest because it demonstrates the "rule of ethnocentricity" common to most mapmaking traditions, in which the territory of a cultural group – in this case the Sokoto Caliphate – is placed in the middle of the map.

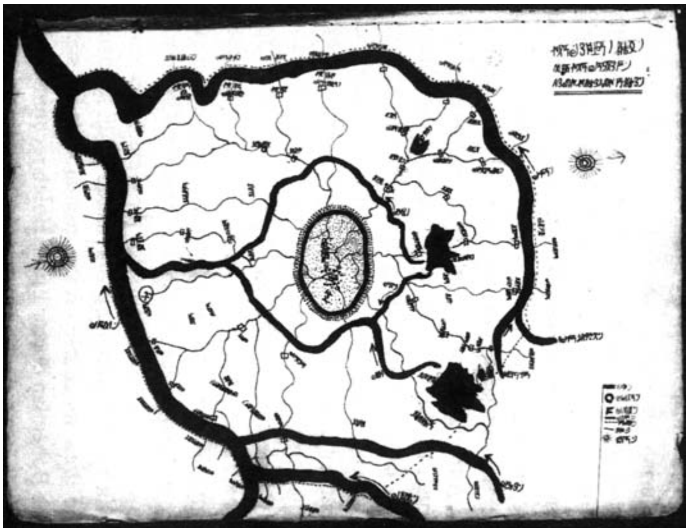
There are many other examples of Africans drawing maps on the ground in response to European questions on the geography of a particular region. The explorer Charles Beke was shown the incorrect course of the Gojab River south of Abyssinia by a Muslim merchant named Hádji Mohammed Núr who drew its course on the ground with his stick. In 1881, the Bohemian doctor Emile Holub recounts a similar experience when traveling in the mid-1870s in the Marutse Empire of the upper Zambezi River. Before leaving to explore the headwaters of the Zambezi, Holub asked the Maurtse chief, Sepopo, to suggest a good travel route. To Holub's great interest, Sepopo drew a map in the sand whose accuracy was confirmed by two other persons familiar with the area. While on a frontier reconnaissance mission in the dense tropical forests of southeastern Liberia in 1899, the French explorer Capt. Henri d'Ollone asked a person named Tooulou to draw on the ground with a piece of charcoal the distribution of the different ethnic groups in the region. After a moment's reflection and to d'Ollone's great surprise, Toolou drew a detailed ground map showing the location of villages, rivers, and mountains, as well as ethnic groups. The information gained from solicited maps was occasionally incorporated into European maps. For example, sections of the map of the Sahara produced by the French geographer Henri Duveyrier in 1864 were based on maps drawn in the sand by "Cheikh-'Othmàn." The German geographer Karl Weule preserved the maps he solicited by requesting that they be drawn on paper that he provided. Three of these solicited maps are found in Adler's 1910 book.

Among the Luba of central Africa, ephemeral maps were a common feature of initiation ceremonies. During one stage, the initiate is taken into a meetinghouse where elders have chalked maps on the wall showing major lakes and rivers, the location of various chiefdoms, and the dwelling places of spirits. While facing the map, initiates are quizzed about the residence of certain chiefs and spirits within the Luba kingdom. In the final stage of initiation, elders teach initiates about the origins of Luba kingship and customary taboos. In recounting the origin myths, elders use memory boards (*lukasa*) as mnemonic devices to aid their storytelling. These small rectangular boards are covered with beads and shells that map the migration history of the founding royal family. Rivers and villages are represented by the patterning of beads and shells into configurations that are recognizable to initiates.

An example of cosmographical mapping is found among the Bakongo of Zaïre in their initiation and funerary art. The Kongo cosmos is pictured ideographically as the sun moving through four phases: dawn, noon, sunset, and midnight. The cosmogram is composed of a cross representing the cardinal directions with a small circle at each end point. The horizontal line (*kalunga*) divides the realms of the living and the dead through which all persons travel. Only the most courageous and generous in life return as immortal spirits in natural forms and forces in the landscape.

A more secular and ambitious mapmaking took place in the Kingdom of Bamum in contemporary western Cameroun under the leadership of King Njoya. Njoya stands out as a highly creative and politically astute individual who collaborated with a succession of German, British, and French authorities to consolidate his rule. He was responsible for developing an alphabet which enabled him to write the history of his kingdom in his own language. He also appears to have been a self-taught mapmaker whose earliest preserved work (1906) is composed of a plan of his farm and a route map between Fumban, the capital of Bamum, and his fields. Njoya further honed his mapmaking skills when the German cartographer Moisel visited Bamum in 1908. One of Njoya's most impressive mapping projects was a topographic survey of his kingdom that employed up to 60 individuals. When the British took control of western Cameroun from the Germans in 1916, Njoya displayed his political skills by presenting a map of his kingdom to the British political officer stationed in Foumban. This map with its southerly orientation shows a well-defined territory in which all roads lead to the royal capital and historic center of political authority (Fig. 2). In his letter to the King of England that accompanies the map, Njoya seeks British protection against the Germans. In this context, Njoya's map becomes an instrument of power that legitimates his (contested) claim to be the ruler of Bamum and symbolizes his willingness to collaborate with colonial authorities.

In conclusion, the dearth of African maps seems to imply that mapmaking was not a common means of expressing spatial information. One could even argue that the maps solicited by explorers reflected European mapping traditions rather than African custom. However, the ability of individuals from across the continent to produce consistently accurate ground maps suggests that this was an indigenous practice. Ironically, these ephemeral maps led to the drawing of new and improved maps of Africa by Europeans who ultimately employed them in their partition of the continent into colonies.



Maps and Mapmaking in Africa. Fig. 2 King Njoya's map. From the Public Record Office, Kew, CO 649/7 (Crown copyright reserved).

See also: ►al-Idrīsī, ►Balkhī School

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Maps and Mapmaking in Ancient Egypt

Hans Barnard

Maps, plans and models present a reduced version of the real world, either existing or anticipated, by incorporating selected properties of reality, while intentionally disregarding others. The selection process is governed by the purpose of the final result. Maps and plans are two-dimensional representations of a three-dimensional reality, usually drawn at a smaller scale. This scale need not be uniform for a map to be useful, as clearly shown by the map of the London Underground, and can in special cases be 1 : 1 or even larger than reality. Selected details are replaced by symbols (such as the circles representing cities on a modern map of the world) or ignored (like individual buildings on the same map of the world). Other features are given a distinctive appearance (such as the color of the highways on a modern roadmap) or size (like the exaggerated width of the roads on the same roadmap). Many maps, plans and models are not in fact based on the real world, but rather predate reality which is then changed to fit such designs, blueprints, mock-ups or prototypes. These must have been as perplexing to members of an ancient culture as the Ancient Egyptian maps of the Netherworld, depicting the geography encountered in the afterlife, are to us. Maps and plans from different periods or cultures may not only have an unexpected subject matter, but the scale, symbols and orientation are often very different from what we are used to. Likewise, our convention of having North at the top of a map would not have been understood in Ancient Egypt as this would have the water of the Nile flowing up.

Maps were most likely used in Ancient Egypt since the beginning of the Old Kingdom (2575–2150 BCE according to the chronology of Baines and Malek 2000: 36–37). There are no unambiguous examples of maps from this early period, but there is ample evidence that at least certain members of Ancient Egyptian society were able to create and understand reduced representations of reality (Harrell 2001; Shore 1987). On the well-known Predynastic Narmer palette (dated about 3000 BCE, found in Hierakonpolis, now in the Egyptian Museum in Cairo) one of the images seems to represent a walled city in bird's eye view (Fig. 1). This is obviously not a map in the modern sense, nor is it meant to be, but nevertheless a representation of a geographical reality (a walled city) in a way in which it would not have presented itself to the artist (but rather in bird's eye view). Other early examples of maps include the "topographic design" on a Predynastic ceramic vessel (3700–3100 BCE, provenance unknown, now in the Petrie Museum in London), clearly showing rivers and mountains, and the very schematic "Map of the Netherworld" in the wooden coffin of General Sepi of the 12th Dynasty (1938–1755 BCE, found in al-Bersha, now in the Egyptian Museum in Cairo), showing the landscape awaiting the deceased according to the "Book of the Two Ways." (Fig. 2). Such "mythological" maps do not seem to have a complement in reality, but they must be placed in Ancient Egyptian perspective in which the Netherworld must have been deemed a physical reality and objects could magically obtain a measure of reality just by having been drawn.

A remarkable find from the third Dynasty (2650–2757 BCE) is a sketch of a vaulted roof (on a piece of pottery found in Sakkara, now in the Egyptian Museum in Cairo) on which the lengths of the (temporary) supports or (permanent) beams necessary

Maps and Mapmaking in Ancient Egypt. Fig. 1 Bird's eye representation of a walled city on the reverse of the Predynastic Narmer Palette (about 3000 BCE), found in Hierakonpolis, now in the Egyptian Museum (image courtesy of Eternal Egypt ►http://www.eternalegypt.org/ created and maintained by the Egyptian Center for Documentation of Cultural and Natural Heritage and IBM).

Maps and Mapmaking in Ancient Egypt. Fig. 2 Map of the Netherworld, illustrating the Book of Two Ways, in the coffin of General Sepi (12th Dynasty, 1938–1755 BCE), found in al-Bersha, now in the Egyptian Museum (image courtesy of Eternal Egypt ►http://www.eternalegypt.org/ created and maintained by the Egyptian Center for Documentation of Cultural and Natural Heritage and IBM).

to build such a vault are clearly indicated in numbers (Arnold 1991; Edwards 1993). Several more elaborate plans of buildings survive from the Middle Kingdom (1975–1640 BCE). Some were apparently meant as architectural plan, such as the drawing of a garden or a temple on a paving slab from the temple of Pharaoh Mentuhotep of the 11th Dynasty (1975–1940 BCE, found in Luxor, now in the Metropolitan Museum of Art in New York), others seem to depict an existing structure, such as the drawing of his granaries inside the coffin of General Sepi (Arnold 1991; Peck 1978). Many models, mostly of workshops and boats, are known from the Middle Kingdom, for example the exquisite series of models from the tomb of chancellor and chief steward Meketre of the 11th Dynasty (1960–1948 BCE, found in Luxor, now partly in the Metropolitan Museum of Art in New York and partly in the Egyptian Museum in Cairo). Plans and models may not only have been used during the building of a structure, but alternatively to demonstrate its appearance to the client or as a votive item to offer to the gods (Arnold 1991).

As with many other aspects of Ancient Egyptian society, most of our information on ancient maps and plans dates to the New Kingdom (1539–1075 BCE). Examples of mythological maps from this period include those of the Netherworld, for instance in the tomb of Sennedjem in Deir al-Medina dating to the 19th Dynasty (1292–1190 BCE) and as an illustration with Spell 110 of the Papyrus of Any (19th Dynasty, found in Luxor, now in the British Museum in London). These maps are based on texts from the "Book of the Dead" (or the "Book of Going Forth Day by Day"). Astronomical (or astrological?) maps can be found painted on the ceiling of the tombs of the royal architect Senmut in Deir al-Bahri (near Luxor), dated around 1450 BCE, and of Pharaoh Seti I of the 19th Dynasty (1290–1279 BCE) in the Valley of the Kings. These display individual stars and the signs that were associated with them, which are markedly different from the Mesopotamian signs that are used today (Wells 1999). A cosmographical map was carved in the lid of the stone sarcophagus of Uresh-nefer of the 30th Dynasty (380–343 BCE, found in Sakkara, now in the Metropolitan Museum of Art in New York). This complicated image shows the goddess Nut, representing the sky, bending herself over an image of the world, depicted as two concentric disks. The god Shu, representing light and air, is also shown, directing the sun in its course (Hernandez Marin 1992–1994).

There are several plans of buildings and gardens preserved from this period. Some seem likely to depict actual structures, such as the plan of a house in the tomb of Djehuty-nefer and the plan of a garden in the tomb of Sennefer (both in Luxor and dating to the 18th Dynasty, 1539–1992 BCE), others appear to have served as architectural plans. Examples of the latter include part of a plan of a tomb, possibly that of Ramesses IV, on a length of papyrus (1156–1150 BCE, found in Luxor, now in the Museo Egizio in Turin) and another plan of a tomb, possibly that of Ramesses IX, on a flake of limestone (1126–1108 BCE, found in Luxor, now in the Egyptian Museum in Cairo). These plans are not drawn to scale, but have the measurements that were evidently deemed important, written out. Another remarkable feature is that the elevations, rather than ground plans, are shown of the passages between the rooms. The fact that such features occur on both plans indicate that these were most likely drawn to certain rules, much like modern architectural plans, but with different conventions.

The first unequivocal maps also date back to the New Kingdom. One depicts the events during the battle between the most famous Pharaoh of the 19th Dynasty Ramesses II (1279–1213 BCE) and the Hittite king Muwatallis at Qadesh (near modern Homs in Syria) in May 1274 BCE (Baines and Malek 2000: 202–203). Examples of this map can be found, among other places, on the first pylon of Luxor Temple and on the northern wall of the great pillared hall of the Great Temple in Abu Simbel. Shown are the Orontes, the city of Qadesh and the placement of the troops.

A second map from this period, drawn on a length of papyrus found in Deir al-Medina (near Luxor), is most reminiscent of a modern map (Harrell 2001; Shore 1987). It shows the gold mines, stone quarries and settlements in the Wadi Hammamat area, about halfway between Luxor and Quseir (on the Red Sea coast), and can be considered the oldest known geological map (Harrell and Brown 1992). The map, now kept by the Museo Egizio in Turin, was probably prepared by Amennakhte, son of Ipuy, for Pharaoh Ramesses IV (1156–1150 BCE) of the 20th Dynasty (Fig. 3).

Another ancient map with a modern appearance is from the Zenon Archive, dating to the Greco-Roman period (332 BCE–395 CE). This map was found on a length of papyrus recovered from the cartonnage of a mummy unearthed at the necropolis of Ghoran and is now kept in the Institut de Papyrologie de la Sorbonne in Paris (Harrell 2001; Shore 1987). It shows a schematic plan of the dikes and canals on a plot of land in the Fayum, an oasis southwest of Cairo, belonging to Apollonius, head of civil administration under Ptolemy II Philadelphus (285–246 BCE). Astronomical ceilings from this period have been preserved in, for instance, the temples of Edfu and Esna as well as in the Hathor Temple in Denderah (now in the Musée du Louvre in Paris). These show both Egyptian stars, similar to those in the tombs of Semnut and Seti I, and the Hellenistic version of the Mesopotamian zodiac, a fusion that had started during the 27th Dynasty (525–404 BCE), the "Persian Period." The belief that the position of the stars can influence human destiny was probably introduced at a later date.

Alexandria was the capital of Egypt during the Greco-Roman period and by far the most powerful and influential city in the region. Thanks to the patronage of the Ptolemaic rulers and the renowned library of Alexandria (with about 500,000 "books") scholarly and scientific knowledge advanced greatly. This was partly fueled by a renewed onomastic tradition, compiling existing knowledge in long lists. One of the librarians of Alexandria was Eratosthenes, born in Cyrene (Libya) and brought to Egypt by Ptolemy III Euergetes

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Maps and Mapmaking in Ancient Egypt. Fig. 3 The Eastern part of a topographical and geological map of Wadi Hammamat, in the desert between the Nile and the Red Sea, drawn on papyrus around 1150 BCE (kept in the Museo Egizio in Turin, photograph used with the kind permission of J. A. Harrell).

(246–221 BCE) as a tutor for his son. He is said to have collected a comprehensive geography of the then known world, which is lost but was cited extensively by the Greek geographer Strabo (63 BCE–24 CE). Eratosthenes was also the first to attempt to calculate the circumference of the earth, by comparing the difference in the height of the sun in Alexandria and in Aswan, and came surprisingly close to the actual figure (Berthon and Robinson 1991). A compilation of geographical and astronomical knowledge that did survive is that of Claudius Ptolemy, an Egyptian who lived and worked in Alexandria around 150–200 CE (Dilke 1987: 177–200). His works form the basis of many early Arabic and European maps, especially after some of his works were rediscovered at the end of the thirteenth century CE in Istanbul (Constantinople) by the monk Maximus Planudes (Berthon and Robinson 1991).

The first maps of Egypt by outsiders were drawn in the early Christian period and have been preserved in, for instance, the fifth century CE "Nile mosaic," in Zippori (Sepphoris) in Israel, and the "Mosaic Map" in Madaba (Jordan). The early Christian view of the world that was developed by Cosmas Indicopleustes ("India traveler") also has its roots in Egypt. Born in Alexandria in the sixth century CE, Cosmas was a merchant who, according to his moniker, traveled extensively. Later in life he converted to Christianity and settled in Saint Catherine's Monastery in the Sinai. There he wrote *Christian Topography*, in which he describes the world as a chest, owned by God, of which the lid is the sky and the bottom holds the lands and the seas. The sun orbits a large mountain rising from the bottom of the chest and casting a shadow that is responsible for the night (Dilke 1987: 261–263; Berthon and Robinson 1991). This seems a rather unsatisfactory conclusion of a development that started over 3,000 years earlier and had already resulted in the brilliant works of Amennakhte and Eratosthenes.

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Maps and Mapmaking of the Australian Aboriginal People

David Turnbull

One of the most common forms of representation in Australian Aboriginal culture is the map. Bark paintings are often maps, as are sand sculptures, body painting, and rock art. Spear throwers and log coffins may be decorated with maps. Message sticks and Toas (waymarkers) may incorporate geographical information. In 1957 the anthropologist Donald Thomson visited the central Australian desert country belonging to the Pintupi people and described his experience:

> I was able to…live and hunt with a group of desert-dwelling aborigines who still followed the life of their ancestors… On the eve of our going (return) Tjappanongo produced spear throwers, on the backs of which were designs deeply incised, more or less geometric in form. Sometimes with a stick or with his finger, he would point to each well or rock hole in turn and recite its name, waiting for me to repeat it after him… I realized that here was the most important discovery of the expedition that what Tjappanongo and the old men had shown me was really a map, highly conventionalized, like the marks on a "message" or "letter" stick of the aborigines, of the waters of the vast terrain over which the Bindubu hunted.

Tjappanongo was clearly endeavouring to convey topographic information and hence was non-problematically drawing a map. Peter Sutton argues such maps should be distinguished from iconic representations which, while spatial, are largely symbolic and performative (Sutton 1998a: 362). However, it seems plausible to accept an inclusive definition of a map as a device for organizing knowledge spatially, Courts of law are now accepting paintings of the Dreaming tracks of the ancestral beings as evidence of ownership and hence the distinction between maps and icons is becoming blurred (Turnbull 1998). Why then are maps so ubiquitous in a culture that has no written language and, purportedly, has little of the social complexity held to characterize contemporary Western culture? The answer is that Aboriginal culture is far from simple, having as it does one of the richest religious systems in the world, and that its central values are embodied as knowledge; knowledge that is spatially organized because the land and relationships to it underpin everything. Aboriginal culture is spatialized linguistically, socially, religiously, artistically, and epistemologically. Aboriginal ontology is one of spatialized activities, of events and processes, people, and places. To talk of things is to speak of the relationships of processes at named sites, it is to consider the connections between actions of the ancestral beings and humans. Every moment of daily life is replete with spatial references; asking someone to move over may be phrased as "move northwards please". Dreams and narratives are cast in a framework of spatial coordinates. Visiting groups at ceremonial gatherings distribute themselves in a spatial replication of the location of their homelands. Ceremonial and initiation grounds are spatially constructed and oriented either to other sacred sites or to the sun. The pervasiveness of spatiality in Aboriginal daily life jointly derives from the semantic structure of the language in which the subjects of sentences are not things but relations and from the centrality of the land in Aboriginal cosmology. It is the land that is the source of value and meaning, of rights and obligations. Everywhere is sacred since all the land was created in the Dreaming by the activities of ancestral beings as they moved across the landscape. These journeys left Dreaming tracks, knowledge of which is recreated in song, story, and ceremony. Everyone has a spiritual linkage to the land by virtue of birth such that they are the land. Knowledge of the Dreaming tracks, of the activities that created the land of one's birth, is therefore evidence of possession of the land and by the land. Continued prosperity of the land depends on the fulfilment of the ceremonials and rituals which are in effect both a celebration of ownership and a continuation of the act of creation. The landscape is the source of meaning and value and the repository of history and events and can be read as a map of itself and its own creation (Watson, Helen and the Yolngu community at Yirrkala 1993: 36).

However, it is knowledge that is the primary marker of status and the primary item of exchange (Palmer 1991). Surface knowledge is the outside knowledge that anyone can speak of; inside knowledge is that which only the initiated can speak of and which is gradually revealed through life as maturity is attained. The way the Yolgnu of Eastern Arnhemland structure their system is typical of the ways in which it is possible for Aboriginal groups to have a detailed understanding of their environment. Their knowledge system is dependent on the joint articulation of two modes of patterning. One is genealogical – *gurrutu* the kinship system; the other is spatial – *djalkiri* the footsteps of the ancestors or the Dreaming tracks (Watson, Helen, the Yolngu community at Yirrkala, and David Wade Chambers 1989: 37). The kinship system provides an unlimited process of recursion that enables all things to be named and related and thus imposes an order on the social and natural world that gives it coherence and value. It provides the framework within which social obligations with regard to life, death, marriage, and land can be negotiated. The other mode of patterning is provided by the stories, myths, or Dreamings that relate the travels and activities of the ancestors in creating the landscape in the form of tracks or songlines that traverse the whole country. The kinship system and the songlines together form a knowledge network that allows for everything to be connected. The concept of connectedness is an extremely powerful one in Aboriginal culture and is exemplified by the Yolgnu term *likan*, which in the mundane sphere means elbow – the connection of the upper and lower arm – and in the spiritual sphere connotes the connections among ancestors, persons, places, and ceremonies. A wide variety of Australian Aboriginal paintings have been interpreted as being simultaneously geographic and social; they represent both the tracks of the ancestors and detailed maps of places. Hence bark paintings are encoded knowledge of connections.

The Kunwinjku people of Western Arnhemland paint both bark and bodies at the Mardayin ceremony in the "X-ray" style that shows internal body parts. In the Mardayin ceremony the bodies of the initiates are painted so that in effect their own body parts are mapped with a design that represents the body parts of the ancestral beings and features of the landscape. These paintings can be read on one level as maps of the way Kunwinjku "conceive of the spatial organization of sites in their land in terms of an abstract model of the divided yet organically related body parts of the ancestral beings that created those lands. Such sites are described as transformations of the actual body parts of the ancestral being, and all the sites thus created are considered to be intrinsically connected" (Taylor 1989).

The connective function of bark paintings like this helps children to learn the shape of the *wanga* (territory, land, country) and to have respect for it and the animals in it by integrating the activities of the ancestors,

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people, and places. Ownership of the land thus means having the right speak of the land, the right to have the knowledge of it, and also to have responsibility for both the land, and the knowledge and for its sustenance and transmission.

While the land may have boundaries that can be known with precision, it is not good custom to display them, because they are permeable rather than fixed entities with rites of access being required and most frequently granted. "Boundaries are to cross" (Williams 1983), and "the content of ownership is the right to be asked" (Myers 1986: 99). Areas can be owned by more than one group, and routes can be common property. Boundaries are more properly the subject of negotiation and exchange in ceremony, ritual, and protocol. Protocols are exemplified in the formal role of the go-between, the diplomat or *djarrma* the messenger. Moreover Yolgnu conceptions of place do not correspond to Western legal notions of enclosure but are more typically open and extendable "strings" of connectedness (Keen 1995). Consequently, while Australian Aboriginal groups constantly map their land, this is a very different process from that of the dominant white society. Being mapped in the white manner may have advantages, for example, in making native title claims. In fact it has become standard procedure for anthropologists to record Dreaming tracks on Western topographical maps as evidence that this knowledge is the property of the claimants. Aboriginal relationships with country do not equate with the notions of boundary precision, exclusion, and individual property rights and the linkages to the state implicit in Western maps. Aboriginal maps keep those relationships alive by celebrating and performing connections between people and land in stories, ceremony, and painting.

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Maps and Mapmaking: Celestial East Asian Maps

F. Richard Stephenson

For the purpose of this article, East Asia will be understood to comprise the three countries of China, Korea and Japan. In common with many other aspects of culture, mapping of the night sky in both Korea and Japan began much later than in China and closely followed the Chinese tradition.

The origins of celestial mapping in East Asia are lost in the mists of time. Very ancient rock carvings clearly depicting the Big Dipper have been found in North Korea, and these are considered to be date from several thousand years BCE. Occasional stellar names – such as *Dou* (the Ladle: presumably the Big Dipper) and *Huo* (the Fire Star: probably identified with the bright red star Antares) – are recorded on Chinese bone inscriptions from the Shang Dynasty (ca. 1500–1050 BCE). Several of the folk songs in the *Shijing* (Book of Odes) – some of which may date from around 1000 BCE – mention star groups. One of these odes cites the names of four asterisms: the Celestial Han River (i.e. the Milky Way), the Draught Ox, the

Winnowing Basket and the Ladle. The description of the Ladle is fairly specific: “In the north there is the Ladle; it raises its western handle”. The apparent motion of the Big Dipper around the north celestial pole has provided a convenient seasonal and hourly marker to a variety of civilisations since remote antiquity.

The first known systematic list of constellation names from East Asia dates from around 433 BCE. This was uncovered in 1978 from a tomb in Hubei province and lists the names of all 28 *xiu* (lunar lodges): asterisms which were of key importance in astrology and positional astronomy. There is a persistent tradition that detailed mapping of the stars began in China during the fourth century BCE with the work of astronomers such as Shi Shen and Gan De. However, the evidence to support this notion is relatively late: no earlier than the seventh century AD. Modern investigations of the measurements in a portion of a star catalogue supposedly compiled by Shi Shen and preserved in the eighth century *Kaiyuan Zhanjing* (Kaiyuan Treatise on Astrology) have indicated a date around 70 BCE.

The earliest catalogue of constellations covering the whole of the sky visible from China is preserved in the *Shiji* (Records of the Historian). This was compiled by Sima Qian around the middle of the Former Han Dynasty (202 BCE to AD 9) and gives brief qualitative descriptions of about 100 star groups. Later catalogues list as many as 280 separate asterisms.

The oldest surviving astral map from China dates from the first century BCE, towards the end of the Former Han Dynasty. Beginning with this dynasty, the development of celestial mapping in China can be traced with increasing confidence, although it is known that many important star charts and celestial globes have failed to survive. Since the stars appear to us as scattered points of light, any attempts to divide them into groups must necessarily be artificial. This is illustrated by the great diversity between the constellation patterns as depicted on Eastern and Western charts of the night sky. Chinese and other East Asian stellar maps further differ from their Western counterparts in the following ways:

- There is virtually no symbolic representation of the constellations by human or animal figures, etc;
- Star groups tend to be much smaller, typically containing only about five stars;
- Individual stars are represented by circles or dots of almost equal size – regardless of brightness; and
- An equatorial (rather than ecliptic) co-ordinate system is standard, with division of the sky into 28 unequal zones of RA, the *xiu*.

Chinese celestial mapping reveals negligible traces of Western influence (whether of European, Arab or Indian origin) until as late as the seventeenth century when the Jesuits introduced improved knowledge and techniques.

Whereas many Western constellation names are derived from Babylonian and Greek mythology, Chinese names tend to be much more mundane. From an early period, the celestial vault came to be regarded as a direct counterpart of the Chinese empire. Star groups, together with certain individual stars, were regarded as representing members of the imperial family, courtiers and other officials – as well as domestic animals, crops and important buildings (from palaces to prisons). Any event occurring in a particular constellation – such as the appearance of a planet or comet, or “new star” – was regarded as an omen of change affecting the terrestrial equivalent.

Until about 30 years ago, very few Chinese celestial maps were known to be extant from before AD 1000. In his *Shiji*, Sima Qian asserted that an “astronomical chart” was depicted on the ceiling of the tomb of Qin Shihuang, the first Emperor of China, who died in 213 BCE. This has yet to be excavated. However, recent excavations at a variety of sites have brought to light a number of important star charts, mostly decorating the ceilings of tombs. The earliest surviving such artefact depicts only 28 star groups – the lunar lodges. This rather crude but colourful painting adorns the ceiling of the tomb of an official of the Former Han Dynasty. It was discovered accidentally in 1987 during building work in Xi’an, near the site of the Former Han capital. Coins found on the floor of the tomb date from around 25 BCE. Individual constellations are depicted in a ring of approximate diameter 2.5 m; stars – represented by small circles – are joined into groups by straight lines, as in most later astral maps.

No further chart of the night sky is preserved until the sixth century AD, but there is documentary evidence that a number of accurate stellar charts and celestial globes were produced by leading astronomers in the intervening time. Around AD 250, Chen Zuo is said to have produced a map of the stars based on the schools of the ancient astronomers. This was said to represent 1,464 stars in 283 groups – numbers which were to become almost canonical. The purpose of such artefacts was to predict the risings and settings of the constellations as well as to follow the movements of wandering celestial bodies such as planets and comets. Unfortunately, none of these works survived for more than a century or two.

A star map dating from AD 526 was discovered during excavations at Luoyang – another ancient capital of China – in 1973. This chart is painted on a tomb ceiling of the late Wei Dynasty (AD 386–557), and is some 3 m in diameter. The Milky Way features very prominently, but the constellations are very sketchily depicted. Clearly, there is no particular reason why stellar maps painted on tomb ceilings should compare in quality with those produced by contemporary astronomers.

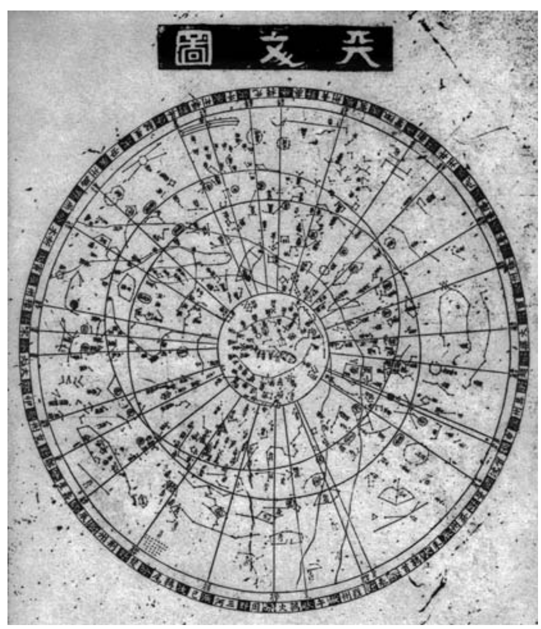
After AD 526 until well into the tenth century AD, only a single important celestial map survives. This paper chart, measuring approximately 110 × 25 cm, was amongst the vast number of manuscripts uncovered by Sir Aurel Stein in a Buddhist grotto at Dunhuang (Xinjiang province) in 1907. The crude but attractive chart, which is now in the British Library, portrays – in 13 sections – the whole of the night sky visible from China. Stars are depicted in three colours (red, black and yellow), possibly reflecting a tradition which had its roots in the Warring States Period. A suggested date for this interesting artefact is around AD 700.

A few decades ago, two huge star maps, dating from AD 941 and 952, were uncovered from the tombs of Prince Qian Yuanguan and his wife Wu Hanyue. Qian Yuanguan was ruler of the small state of Wuyue in eastern China, the capital of which was close to present-day Hangzhou. The two star charts, each some 2 m in diameter, were engraved on thick stone slabs which formed the ceilings of the tombs. Regrettably, the map from the tomb of Wu Hanyue was destroyed during the cultural revolution, although an accurate scale drawing is preserved. Fortunately, the chart from the tomb of Qian Yuanguan still survives, although it is badly damaged. This latter chart depicts with fair accuracy the 28 lunar lodge constellations, together with a few polar star groups. The celestial equator and north circumpolar circle (circle of constant visibility) are also carefully positioned.

Many astral maps and celestial globes are known to have been produced during the highly advanced Song Dynasty (AD 960 – 1279) in China, but most have long since disappeared. Only one of the *original* artefacts of any consequence, dating from AD 1247, is known to exist today. This remarkable chart was produced by a scholar and was intended for the instruction of a future emperor. It is exhibited at the Suzhou (=Soochow) Museum in Jiangsu province. The circular chart, 1.05 m in diameter, is engraved on a stele measuring 2.2 × 1.1 m. The surface is still in very good condition and rubbings are occasionally taken. Entitled *Tianwen-tu* (Astronomical Chart), the map portrays the whole of the sky visible from central China on a polar projection. A recent count asserts that it depicts 1,436 stars in 277 constellations. Celestial equator, ecliptic and polar circles are shown, together with radial lines representing the boundaries of the lunar lodges; the Milky Way is also clearly depicted. Modern measurements demonstrate that most star positions are accurate to within about 2°, which represents tolerably good precision (Figs. 1 and 2).

The great Song Dynasty astronomer Su Song is known to have produced a celestial globe 1.7 m in

Maps and Mapmaking: Celestial East Asian Maps. Fig. 1 "Star observing tower" at Kyongju, Korea, dating from AD 647 (photograph courtesy of Prof Nha Il-Seong, Seoul).



Maps and Mapmaking: Celestial East Asian Maps. Fig. 2 Computerised reversal (i.e. black on white) from rubbing of the Suzhou star chart (the star chart is in the Suzhou Museum, Jiangsu Province, China).

diameter in AD 1092. This was said to represent 1,464 stars in 283 constellations – standardised figures since ancient times. Although the globe was destroyed a few decades afterwards, star charts in extant copies of Su Song's *Xinyi xiang fayao* (New Design for an Armillary and Globe) are believed to reproduce closely the star patterns on the celestial globe. Copies of an these charts, which were first printed in AD 1094, are still available, although the earliest extant version dates from AD 1781; this is now in the National Library at Beijing. The entire night sky as seen from Central China is portrayed in five sections. One of these sections, depicting the southern hemisphere, has a central void; this corresponds to the region of the sky near the south pole which was permanently below the horizon at the Chinese capital (Kaifeng) of the time. Apart from isolated constellations such as *Denglonggu* (Frame of the Lantern, identical with the Southern Cross), no far southern stars appear to have been mapped in any detail until the Jesuit era. Careful modern measurements show that typical positional errors on the Su Song maps – or at least the extant copies – are fairly large, some as much as 4°.

In recent decades, several well-preserved celestial charts have been uncovered during excavations of Buddhist mausoleums of the Liao Dynasty (which flourished in Northern China between AD 916 and 1125). Two of these colorful artefacts, painted on the ceilings of tombs, are particularly interesting. As well as depicting stylised versions of the 28 lunar lodge patterns, they also show symbols – rather sinified – representing the 12 signs of the Western zodiac. A large bell, cast in AD 1174, is also adorned with the zodiacal signs. The signs of the zodiac were first introduced into China around AD 600, with the translations of Buddhist *sūtras*. Not long afterwards, during the Tang Dynasty (AD 618–907), horoscope astrology – based on Western methods – became popular in China. However, this had negligible effect on official practice – e.g. at Court. No significant pictorial relics survive until long after the end of the Tang.

A number of substantial star maps are preserved from the Ming Dynasty (AD 1368–1644), but apart from those revealing Jesuit influence (after about AD 1630), none is of the caliber of the Suzhou chart of AD 1247. Commencing in the late Ming, members of the Society of Jesus made important contributions to astronomy in China, and for nearly two centuries (from AD 1644 to 1826) Western missionaries held the position of Astronomer Royal in China. Today, many fine Jesuit celestial globes and maps produced in China still survive. These include works by Adam Schall von Bell (AD 1634), Ferdinand Verbiest (1673) and August von Hallerstein (1757). The Jesuit astronomers did not try to supplant the Chinese constellations with those of Western origin. However, they measured stellar positions in existing asterisms with hitherto unrivalled precision and in some cases added further stars to individual groups – as well as bringing knowledge of the far southern stars which are invisible from China. All significant representations of the night sky throughout the Qing Dynasty (AD 1644–1911) either directly or indirectly reveal Western influence in these ways and are thus outside the scope of this article.

Korea

The earliest surviving astral map produced in Korea dates from AD 1395. Entitled *Ch'onsang yolch'a punyajido* (chart of the regular division of the celestial bodies), this left a lasting impression on celestial mapping in Korea. Indeed, until the end of the last dynasty (the Yi) in AD 1910, virtually all surviving star charts produced in Korea which do not show Western influence appear to be based on it. History records that the original celestial map, which is 90 cm in diameter and engraved on a marble slab measuring 2.1 × 1.2 m, is an accurate reproduction of a much older map which had been presented to Koguryo, one of the three early kingdoms of Korea, by a Chinese emperor. Although this stele was abandoned in a river during a battle in the Korean peninsula in AD 670, a rubbing still survived in 1395, and this was used to make a new engraving. On the reverse of the stele is a virtually identical copy which may possibly date from AD 1425. Both the AD 1395 chart and a careful stone replica produced in 1687 are still preserved in Seoul museums. They are in good condition, although the earlier artefact has suffered damage down the centuries – notably during a Japanese invasion in AD 1592 (Fig. 3).

Each of the stone engravings depicts the usual circles and lunar lodge boundaries, as well as the Milky Way. However, several constellation patterns differ considerably from medieval Chinese representations, while modern measurements of the star positions suggest an early date – possibly around 30 BCE. Hence the two steles may well preserve traditions of celestial mapping which are far older than the detailed Chinese charts which are still accessible today.

Japan

In 1973, a crude chart showing the 28 lunar lodges in a square measuring 80 × 80 cm was discovered on the ceiling of a Japanese tomb dating from around AD 700. This work, the earliest Japanese celestial chart so far discovered, clearly shows Chinese influence. Detailed maps and globes of the night sky based on Chinese originals are known to have been produced at various stages in later Japanese history. However, none has survived before the sixteenth century. A chart compiled by Ase Yasuyo around AD 1315 was the oldest extant

Maps and Mapmaking: Celestial Islamic Maps. Fig. 3 Computer scan of Korean star chart engraved in AD 1687. This chart, engraved on stone, is an accurate copy of a damaged stone chart dating from AD 1395 (illustration courtesy of Prof Nha Il-Seong, Seoul).

Japanese celestial map until it was destroyed near the end of the Second World War. Fortunately, some replicas still exist. The chart – in two sections – showed the Chinese constellations, ecliptic, celestial equator, Milky Way and the lunar lodge boundaries. It was designed to assist the observation of lunar conjunctions with stars.

The two oldest extant star maps of Japanese origin both date from around AD 1540. Each is circular, extending from the north celestial pole to the region of perpetual invisibility (the area of sky always below the observer's horizon), and shows the traditional Chinese constellations and co-ordinates. Both the Suzhou celestial map of AD 1247 and the Korean chart of AD 1395 have had an important effect on Japanese celestial cartography and many copies of each from the seventeenth century onwards can be found in Japan.

In recent decades, the study of East Asian celestial cartography has been enhanced by the growing worldwide interest in records of comets and supernovae recorded in China, Korea and Japan. The positions of these celestial bodies were often carefully described in relation to specific star groups. In order to trace the movements of comets (notably Halley's Comet) or deduce the locations of past supernovae, it is necessary to make a detailed investigation of the individual constituents of asterisms with reference to modern star catalogues. This work continues.

See also: ►Lunar Lodges, ►Kitora

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Maps and Mapmaking: Celestial Islamic Maps

Emilie Savage-Smith

The earliest evidence of Islamic interest in celestial mapping is a vaulted ceiling in a small eighth-century provincial palace, known as Quṣayr ʿAmrah, in the desert of present day Jordan. One of the bathrooms in this palace has a domed ceiling painted to resemble the vault of the heavens. It is the oldest astronomical dome of heaven preserved today. Though the ceiling has badly deteriorated, enough remains to ascertain that the artist was influenced by late Antique and Byzantine two-dimensional flat maps of the skies. The iconography of the constellation figures, the lack of stars, and the method of projection are in keeping with classical and early Western medieval maps of the heavens. The sequence of the constellations on the domed ceiling, however, is not as one would see it when looking up into the sky, but rather as it would appear when looking down onto a celestial globe (see Savage-Smith, Celestial mapping).

The celestial globe is the oldest form of celestial mapping, for its origins can be traced to Greece in the sixth century BCE, though the earliest preserved example is an eleventh-century Islamic globe made in Valencia. This three-dimensional model of the skies presented the stars as seen by an observer *outside* the sphere of stars, so that the relative positions of the stars are the reverse, east to west (or right to left) of their appearance when viewed from the surface of the earth. Islamic celestial globes were made from the ninth through the nineteenth centuries, steadfastly maintaining the basic classical design and encouraging the concept of a spherical universe rotating around the earth.

No flat two-dimensional star maps on paper or parchment from Islamic lands have survived, if indeed any were made, although planispheric maps of the skies drawn on parchment exist today from the Roman and Byzantine worlds. Displaying the entire surface of a sphere on a flat surface – such as parchment or paper or a metal plate – requires a system of mathematical projection. In addition to the method called stereographic projection known in late antiquity, other methods for flat mapping were described in the early eleventh century by the versatile scholar Abū al-Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī (b. 973) working in Iran. Three of his proposed methods correspond in modern terms to orthographic projection, azimuthal equidistant polar projection, and globular projection. His ideas, however, appear to have had no direct effect upon subsequent celestial mapmaking in the Islamic world, and no maps employing these novel methods are known today (see Savage-Smith, 'Celestial mapping').

The evidence for Islamic interest in flat mapping of the entire sky is found only in instrument design and production. The flat, planispheric astrolabe was, in fact, the most commonly used form of celestial map in the Islamic world, for it consisted of a pierced star map placed over a projection of the celestial coordinate system as it related to the observer's position on earth. The resulting representation of the positions of the stars with respect to the local horizon forms a two-dimensional model of the heavens. The method of stereographic projection required for the astrolabe's construction was certainly described by the Greek astronomer Ptolemy in the first century AD, though not the instrument itself. It was also Ptolemy who compiled a star catalog giving coordinates for 1,022 stars, with descriptions of 48 constellation outlines based mostly on Greek mythological characters which served as mnemonic devices for mapping the skies. This star catalog was the basis for all the medieval Islamic star catalogs as well as instruments employing stars (See Kunitzsch and Knappert). It seems certain that the astrolabe was a Greek invention, but its design and production were perfected in the Islamic world, where it was manufactured in many variations from Spain to India from the early ninth through the nineteenth century.

The influence of early modern European celestial mapping is evident in an astrolabe plate engraved in Iran in 1654–1655 by the instrument maker Muḥammad Mahdī of Yazd. His metal plate reproduces the northern and southern hemispheric maps from a planispheric celestial map printed about 1650 by the Parisian engraver Melchior Tavernier, whose brother Jean-Baptist Tavernier had made six trips to the Near East before his death in 1689 and probably served as the conduít by which the map reached Iran. Tavernier's star map included the new chartings of the southern skies at the end of the sixteenth century, and these were carefully rendered by Muhammad Mahdī, who changed the labels of the Ptolemaic constellations into Arabic, but did not attempt to give Arabic names to the newer non-Ptolemaic constellations. Muḥammad Mahdī made at least two additional copies of these plates, but they appear to have had no subsequent influence on Islamic celestial cartography (See Savage-Smith, Celestial mapping; and also Savage-Smith Wake field).

Celestial space was also often represented by schematic diagrams that did not involve the mathematical determination of coordínates (necessary for globes) or methods of projection (required for planispheric maps or astrolabes). In such diagrams, concentric circles were often used to indicate in general terms the orbits of the planets and the sphere of the stars about the earth, which was viewed as being at the center of the universe. More complex and abstract diagrams illustrating the orbit of an individual planet employed concentric and eccentric circles to explain the peculiarities of the planet's path (see Van Brummelen).

Mapping the entire sky or heavens was not the only form of celestial mapping to occupy Islamic thinkers. Maps of individual constellations rather than the entire sky had the advantage of not employing a coordinate system or requiring knowledge of projection methods. The most important guide to constellation diagrams in the Islamic world was undoubtedly an Arabic treatise written in the tenth century by ʿAbd al-Raḥmān ibn ʿUmar al-Ṣūfī, a court astronomer in Isfahan. He provided two drawings of each of the 48 classical constellations, one as it would be seen in the sky by an observer on earth and one as it appears on a celestial globe (see Wellesz). According to one account, al-Ṣūfī obtained his images by laying very thin paper over a celestial globe and tracing the constellation outlines and individual stars. While taking pains to make clear to the reader the mirror–image relationship between constellations as imagined in the sky and those on a celestial globe, by treating each one individually al-Ṣūfī ignored the spatial interrelationships of the constellations to each other. Al-Ṣūfī also preceded the discussion of each constellation with a survey of traditional Bedouin constellations visualized in the same area of the sky, such as the constellation of a lion much larger than Leo with gazelles running before the large lion.

Numerous copies of this popular treatise exist today, with dress and general presentation of the figures changed to reflect local artistic fashions and conventions, and many later writers incorporated the constellation images into their treatises. Sometimes in later works the constellations were illustrated without stars, with only the animal or human mythological form that gave rise to the constellation outline, and occasionally even the understanding of the mythological figure was lost or confused. The diagrams of individual constellations of stars yielded an easily understood nonmathematical guide to portions of the skies, while giving wide scope to the artist in interpreting the animal and human outlines.

Another form of Islamic celestial mapping was the emblematic or symbolic representation of celestial bodies (planets as well as constellations of stars) and their spatial relationships. The 12 zodiacal signs were often represented as emblematic motifs rather than as constellation diagrams. No attempt was made to represent the stars forming the asterism or even the basic outline of the constellation. Rather, each constellation was represented by a commonly accepted convention, such as a two-headed man sitting cross-legged for Gemini, or for Libra a squatting man with scales over his shoulders or held overhead. The seven classical planets (Moon, Mercury, Venus, Sun, Mars, Jupiter, and Saturn) were designated by human personifications. Venus, for example, was portrayed as a woman playing a lute-like instrument or Jupiter as a man reading a book. In astrological writings, zodiacal signs were related to the planets by a series of “domiciles.” Thus the moon was most frequently associated with, or domiciled in, Cancer, and the sun in Leo. The remaining five planets were each assigned two zodiacal signs as their domiciles; Venus, for example, was assigned to both Libra and Taurus. Artisans working in metal or with manuscript painting would represent these spatial relationships by depicting Taurus as a bull ridden by a lute player (Venus), or Cancer with a lunar disk, or Leo as a lion surmounted by the radiant disk of the sun. In a second system, the zodiacal signs were combined with the “exaltation” or “dejection” of a planet, which could also be represented symbolically. The lunar nodes (the northern and southern intersections of the moon’s orbit with the ecliptic) were referred to as the head and tail of a dragon, which came to be regarded as a pseudo-planet associated with Sagittarius and Gemini and often represented graphically. Such symbolic representations of celestial bodies and their spatial relations formed an important part of medieval Islamic understanding and graphic interpretation of the heavens. They did not require the difficult technical knowledge necessary for geometrically projected mappings and they were an attractive subject matter for artists to interpret flexibly (see Savage-Smith, ‘The Islamic Tradition’).

Each type of Islamic celestial mapping was directed at a different audience. The fairly educated audience who could interpret the symbolic and allegorical representations of celestial bodies was probably more select than those who could appreciate a constellation diagram. Different still would be those who could appreciate as a scientific instrument the celestial globe with its stars positioned by coordinates or the astrolabe with the stellar coordinates projected geometrically onto a flat plate. The Islamic world’s apparent lack of flat stellar maps of the entire visible sky drawn on paper or parchment has yet to be fully explained (see Sabra).

See also: ►Globes, ►al-Bīrūnī, ►Astrolabe, ►Stars in Islamic Astronomy, ►al-Ṣūfī

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Maps and Mapmaking in China

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The Chinese have one of the world’s longest histories of mapmaking – more than 2,000 years. An adequate account of this history, however, has yet to be written. For some time spans, the first to the tenth centuries, for example, losses from warfare and neglect have probably been great. Almost no examples of maps remain, so that one must make inferences on the basis of textual sources and other evidence. For other periods, especially from about the seventeenth century on, so many maps, as well as supplementary textual sources, survive that no one has adequately surveyed them.

Despite these difficulties, it is still possible to make some broad generalizations. Before the twentieth century, mapmaking in China was an activity of the educated elite, those who formed the pool from which posts in the government bureaucracy were filled. In the course of their duties, these scholar-officials developed mathematical techniques and instruments needed to produce measured maps of high accuracy. Such maps have features familiar to users of modern maps – scalar indications, directional markers, conventional signs to represent topographic features, and a lack of perspective. Their look is planimetric, all features being represented as if lying on the same plane and as if viewed from above. Maps like these form only a portion of the body of surviving works, and partly for this reason it would be misleading to characterize Chinese mapmaking before the twentieth century as what we in the West now call science. As will be discussed later, it was a broader activity than the word "science" usually connotes, one that often involved measurement.

The foundations for quantitative mapping were established early in China's cartographic history. The magnetic properties of lodestones, or south-pointers, were known from about the third century BCE. There is textual evidence that during the second century BCE the idea of map scale was understood. Around this time Chinese surveyors and mapmakers already had considerable technical resources available to them for producing maps drawn to scale: graduated rods, carpenter's squares, plumb lines, and compasses for drawing circles, and even sighting tubes that could be used for measuring inclination. In addition, a reference frame suggestive of a coordinate system for identifying locations had been hinted at by astronomers who divided the heavens into sectors, or lunar lodges (*xiu*).

A few hundred years after these beginnings, Pei Xiu (223–271), a mapmaker known for large-area maps drawn to scale, formulated a set of principles necessary to produce accurate maps. These principles stressed the importance of consistent scale, directional measurements, and adjustments in land measurements to correct for irregularities in the terrain being mapped. The principles had some influence on later mapmakers. Jia Dan (730–805) drew a large-area scale map following Pei Xiu's principles, as did Shen Kuo (or Gua, 1031–1095). But none of the works by these mapmakers survives, so that it is impossible to judge how well they followed Pei's principles. Moreover, none of Pei's own work survives, so it is not known how well Pei followed his own ideas.

Some researchers have claimed that maps dating from the fourth to the second century BCE are evidence that mensurational techniques were being applied to mapmaking (Cao, Vol. 1, plates 1–2). One of these, discovered in Hebei Province, is a bronze architectural plan of a mausoleum. Perhaps better-known examples are two silk maps discovered at Mawangdui, near Changsha, Hunan (Cao, Vol. 1, plates 20–21, 25–26). Other early maps are a set of maps drawn on wood discovered at Fangmatan in Gansu (Cao, Vol. 1, plates 4–17). There is some disagreement over what areas the maps found at Mawangdui and Fangmatan represent and how they should be reconstructed. Such questions need to be resolved before it can be determined whether the maps were drawn to scale. Pei Xiu, in articulating his principles of mapmaking, had complained about the lack of accuracy in maps before his time. It is not yet clear whether his assessment of his predecessors was justified.

In any case, a map produced within a half century of Shen Kuo's death suggests that mapmakers were capable of following Pei's principles quite rigorously: this is the much celebrated *Yu ji tu* (Map of the Tracks of Yu [the Great, legendary emperor]) (Cao, Vol. 1, plates 57–59; ►http://www.henry-davis.com/MAPS/EMwebpages/218.1.html). It was carved in stone in 1136 and measures 80 × 79 cm. It represents all of China, and is impressive for the accuracy of its depiction of China's coastline and the courses of the Yellow and Yangtze Rivers. The map is also notable for the square grid imposed on its surface. According to a note on the map, each grid increment represents 100 Chinese miles. The grid is thus a scaling device, not a coordinate system like latitude and longitude. After the *Yu ji tu* the best known examples of grid maps are printed in the *Guang yutu* (Enlarged Terrestrial Atlas, ca. 1555) by Luo Hongxian (1504–1564) (Cao, Vol. 2, plates 147–156). This atlas is a revision of a map no longer extant, the *Yutu* (Terrestrial map, 1320) by Zhu Siben (1273–1337). It contains a general map of China and individual maps of provinces, all with grids. According to Luo, the grid, in addition to serving as a scaling device, served as an aid in aligning sections of maps drawn or printed on different sheets.

The origins of the Chinese cartographic grid are unknown. Its use is certainly consistent with Pei Xiu's call for scale and attention to directions, and it has some similarities with the lunar lodges long used in Chinese astronomy. The polymath Zhang Heng (78–139), credited with an armillary sphere, a seismograph, and a topographic map, has been suspected of using a grid. But there is no direct evidence that any mapmaker before the *Yu ji tu* employed the device.

On other Chinese maps made at roughly the same time as the *Yu ji tu*, the grid is conspicuous by its absence, perhaps an indication that their makers were not particularly concerned with measurement and scale. A number of these maps are, like the *Yu ji tu*, engraved in stone, but are not considered as accurate as the *Yu ji tu*: for example, the *Hua yi tu* (Map of Chinese and

Foreign Lands, 1136) (Cao, Vol. 1, plates 60–62; ►http://www.henry-davis.com/MAPS/EMwebpages/218.html), engraved on the other side of the stone on which the *Yu ji tu* appears, and the *Jiu yu shouling tu* (Map of the Prefectures and Counties of the Nine Districts [the empire], 1121) (Cao, Vol. 1, plates 63–65). As their titles suggest, these maps, like the *Yu ji tu*, represent all of China. An example of a stone map depicting a smaller area is the *Pingjiang tu* (Map of Pingjiang Prefecture, 1229) (Cao, Vol. 1, plates 79–81). It, too, lacks a grid, and its scale has been found to vary from about 1:1,300 to 1:2,800 in the central portion and from about 1:10,000 to 1:77,000 at the periphery.

The evidence thus suggests that by the twelfth century Chinese mapmakers had the resources to produce measured maps of high quality, but in many cases did not make full use of those resources. This is not necessarily a defect. In general Chinese mapmakers seem to have regarded their task as encompassing more than representation according to a consistent scale. The Chinese word *tu*, commonly translated as map, also means picture, diagram, or chart. As the range of meaning suggests, the forms of Chinese mapmaking extend beyond what are easily recognizable as forerunners of modern measured maps.

Maps served a variety of functions for which uniform scale might be necessary or desirable: navigation, water conservancy, public works, defense and military planning, government administration, and record keeping for land tax accounting. But they also served purposes for which attention to scale might not be so important: they might be used to symbolize political power, to represent unseen other worlds, or to illustrate configurations of energy (or *qi*), knowledge of which was useful in "siting" (*dili* = land patterns or geonomy, or more popularly, *fengshui* = wind and water or geomancy) (Fig. 1).

Maps and Mapmaking in China. Fig. 1 Pictorial map of Hainan island dating from the nineteenth century. Notes on the map describe marriage and other ceremonies of the Li people. The mapmaker has distorted the shape of the island so that it resembles a rectangle, an auspicious form. North is at the bottom. Ink and color manuscript, 184 × 93 cm. Courtesy of the Library of Congress (G7822.H3E62 18–.H3 Vault).

The media used for mapmaking also show considerable diversity. Already mentioned have been flat maps engraved on bronze and stone, drawn on silk, wood, and paper, and printed with woodblocks on paper. Maps were also painted on walls of caves and tombs. Three-dimensional relief models were also made. One of the largest of these, described in the *Shi ji* (Records of the Grand Historian, ca. 91 BCE, by Sima Qian), is contained in the tomb of Qin Shihuang (d. 210 BCE), founding emperor of the Qin Dynasty (221–207 BCE). It supposedly consists of representations of the heavens above and the empire below, with mercury-filled streams representing rivers and the sea.

Mapmaking in pre-twentieth-century China did not develop into a distinct specialty of learning as it did in Europe. As the variety of map functions suggests, mapmaking was located at the intersection of a number of activities and traditions of learning. This is consistent with the educational background of the intellectual elite who made maps. Their educations generally emphasized broad learning, frequently encompassed humanistic and scientific disciplines, and often centered around texts. Not surprisingly the activity of mapmaking often involved textual study. This was the case with Pei Xiu, Jia Dan, Shen Kuo, and Luo Hongxian, those who are credited with advancing quantitative mapmaking techniques.

Among the major sources of geographic information a mapmaker might consult were the dynastic histories, which conventionally included geographic records, and local gazetteers, compendia of historical and geographical information focusing on China or one of its various subdivisions. Gazetteers often included maps, usually at the head of the geographic section. These maps often lack scalar indications and are frequently pictorial. In such instances, they do not seem to have been intended to be used or studied in isolation, but were meant to be complemented by the accompanying text. The maps give an idea of the spatial relationships between geographic features, while the texts provide detailed information on distances and directions. This relationship between image and text does not seem to have been restricted to maps in gazetteers. Jia Dan and Shen Kuo, for example, say that their maps were accompanied by extensive notes, and Luo Hongxian's *Guangyu tu* consists mostly of text.

The relationship between map and text seems to reflect the close ties among painting, calligraphy, and poetry. From about the tenth century on, many Chinese artists, themselves often members of the bureaucratic elite, conceived the highest work of visual art as a combination of all three arts, each contributing in different ways to the aesthetic effect of the entire artifact. *Tu* (maps or pictures) of geographic subjects often had poems inscribed on them, suggesting that maps were valued like other forms of visual art for their emotional and expressive effects (Figs. 2 and 3). In addition to employing quantitative techniques and devising means to present the information gleaned from those techniques, Chinese mapmakers drew upon the resources of the visual arts to express their responses to the land. The "language" of Chinese maps thus seems to have been more than one of denotation, of correspondence to material realities. This seems to be true even with maps of utilitarian function. Scholars have long noted, for example, that some of the representations on the nautical chart in the *Wubei zhi* (Treatise on Military Preparations, ca. 1621, comp. Mao Yuanyi) resemble elements often seen in Chinese landscape paintings (Cao, Vol. 2, plates 168–171).

Maps and Mapmaking in China. Fig. 2 Poetry on scroll bearing map, stamped in red ink (at *lower left*). The couplet, by the poet Du Fu (712–770), reads: "Most certainly this is Jiangnan's lovely landscape;/In the season when the leaves fall I meet with you again." The couplet was stamped in response to a long map, a detail of which appears in Fig. 3. (*Minsheng yanchang quantu* (Complete Map of the Salt Fields in Fujian, 1746). Courtesy of the Library of Congress (G7823.F8H5 1746.M4 Vault Shelf).

One result of the interactions between mapmaking and other areas of learning seems to be that grid maps in particular and measured maps in general constitute a small proportion of the surviving corpus of Chinese maps made before the twentieth century. The disparity in the numbers of measured maps and more pictorial maps seems especially pronounced during the seventeenth through the nineteenth centuries, long after the development of woodblock printing, which made possible the relatively quick production of multiple copies of maps (see Fig. 3). This disparity has fostered the conclusion that after the sixteenth century Chinese mapmaking declined, as mapmakers seemed to pay less attention to quantitative techniques and accuracy.

It is just as reasonable to view Chinese cartographic history after the *Yu ji tu* not simply as a decline in mapmaking, but as an implicit, if not conscious, rejection of the measured map as the representing mapmaking at its best. A mathematical map is reductive in at least two ways: a quantitative approach regularizes the earth's surface, and is less challenging and demanding than a qualitative approach. A mathematical map can be drawn by almost anyone; pictorial maps with their greater detail require more advanced drawing skills. The compilation of a map like the *Yu ji tu* is an impressive achievement. But once it is drawn, it is simple to draw it again. Pictorial maps are visually more complicated.

Chinese mapmakers seem to have noticed the same difference and preferred maps that allowed them to demonstrate artistic skill. An index of this preference is the large number of manuscript maps intended as final products, even after the development of printing. In Western Europe manuscript maps intended as final products are rare after the advent of printing. Mathematical techniques and printing technology made possible the production of large numbers of exact copies of originals. Yet in China, scholar-officials often copied maps by hand, introducing variations, or drew their own maps. The production of manuscript maps was an opportunity to display skill with the brush both in painting and in the art of writing – possibly one reason for the close ties between mapmaking and landscape painting.

Thus it is no surprise that in China there was little innovation in measured mapping, little interest in developing quantitative technique further, after the twelfth century. Improvements in the mariner's compass

Maps and Mapmaking in China. Fig. 3 Mingsheng yanchang quantu (Complete Map of the Salt Fields in Fujian, 1746; detail). The look of this map belies its use in law enforcement – as an aid to prevent salt smuggling. Ink and color in silk, 33 × 571 cm. Courtesy of the Library of Congress (G7823.F8H5 1746.M4 Vault Shelf).

and measurements of celestial latitude, for example, do not seem to have influenced Chinese mapmakers, as such developments affected European mapmaking. In addition, Chinese mapmakers did not develop projection techniques for transferring points from a spherical to a plane surface. Mapmakers seem to have believed the earth's surface was generally flat, so that, in their minds, drawing maps on plane surfaces would not result in appreciable distortion.

In 1267 a Persian astronomer presented the Chinese imperial court with a "geographic record" that represented the earth as round, but the representation seems to have had no effect on Chinese mapmaking. The Chinese did not begin to adopt techniques of spherical projection until the late sixteenth century when Jesuit missionaries, notably Matteo Ricci (1552–1610), introduced Ptolemaic cartography with its coordinate system into China. Some Chinese copied Ricci's maps, and in the eighteenth century, Jesuits were commissioned by Chinese emperors to survey and map the entire empire. In carrying out this work, the Jesuits employed Chinese assistants. But even so, Chinese adoption of European techniques was slow, since the Jesuits were limited in their access to China, and many Chinese intellectuals resisted a view of the earth as round. The bulk of maps made in China continued to be made in the traditional manner up to the late nineteenth century. There was little uniformity in mapmaking, even within the government. Maps might be planimetric; they might be pictorial; they might be drawn to scale; they might not be; they might have grids (Fig. 4); they might lack them; even if they had grids, they might not be drawn to scale (Fig. 5); and late in the nineteenth century they might have square grids as well as lines of latitude and longitude. They also varied in physical format and could be made on sheets, scrolls, fan-folded strips, and bound volumes (see Extra).

Circumstances in the nineteenth century, however, fostered change in this situation. As China weakened as a result of domestic problems and encroachments by European powers, many Chinese intellectuals began to believe that China needed reform. Some pointed out that European maps were superior to those of the Chinese. In response, the government tried to standardize mapmaking practices, stipulating that standard projections and scales be used. Progress in instituting these changes was difficult since there was a shortage of personnel capable of employing the necessary techniques. Not until after the collapse of the empire in the twentieth century did the European conception of cartography as primarily quantitative fully supplant the traditional Chinese idea of a map as an intersection of various lines of learning including the literary and visual arts.

In the first half of the twentieth century the quality of measured maps improved as more Chinese were trained in the earth sciences. During the Second World War, however, accurate measured maps were still not in good supply – a situation that hampered the Chinese military. To remedy that situation, the Chinese government took steps to promote cartography. In 1956 it established a State Bureau of Surveying and Mapping which undertook to produce a series of topographic maps for the whole country. Since then more institutions have

Maps and Mapmaking in China. Fig. 4 *Huangchao zhi sheng fu ting zhou xian quantu* (Complete Map of Provinces, Prefectures, Subprefectures, Departments, and Counties under the Qing, 1864). This map has a grid in which each grid increment equals 200 Chinese miles. A legend explaining the various signs on the map appears on the right. Woodblock print, hand-colored to show provincial boundaries, 57 × 58 cm. Courtesy of the Library of Congress (G7820 1864.H8 Vault).

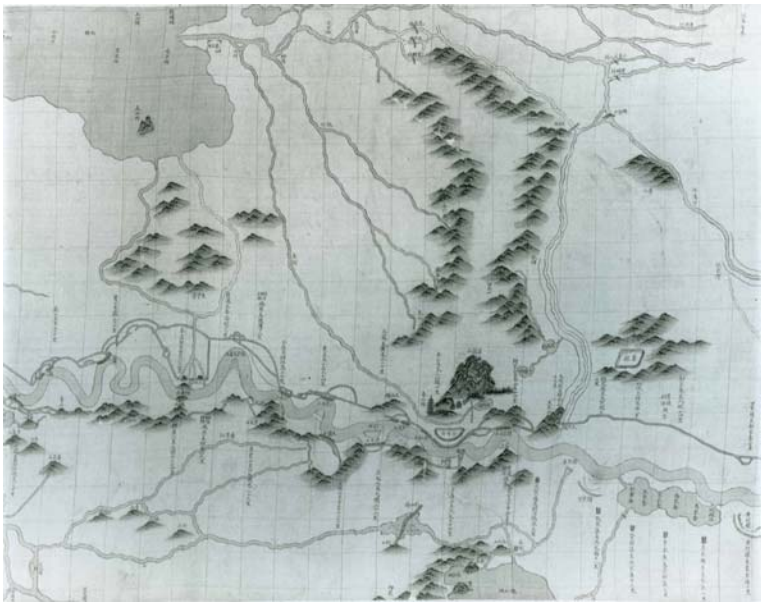
been established to make maps, and others, such as the Wuhan Technical University of Surveying and Mapping, have been set up to teach cartography. As part of China's effort to modernize, Chinese cartography has employed the latest technological advances: remote sensing, satellite photography, and geographic information systems.

Extra: Maps and Mapmaking in China: A Controversy

Some scholars would question whether the Jesuit surveys deserve the brief account they are given here. The surveys have been taken as evidence that China entered the early modern world as early as the eighteenth century (see, for example, Needham and Hostetler).

I have no objection to describing the Jesuit surveys as early modern. Describing the Jesuit atlas as early modern emphasizes its departure from traditional Chinese practices. Most maps made under the Qing were not early modern. Maps drawn to scale were part of the Chinese mapmaking tradition, but according to the available evidence, pictorial maps were made in far greater numbers. Traditional Chinese mathematical cartography was not the same as modern mathematical cartography in that it did not employ spherical coordinates or map transformations. Thus the Jesuit surveys were not representative of what Chinese mapmakers were doing or were even capable of carrying out; the influence of the Jesuit surveys was limited primarily to the central government.

The claim that the use of early modern maps justifies calling Qing-dynasty China an early modern map culture comparable to early modern European map cultures rests on a superficial resemblance. An equation of Qing China and early modern Europe is possible only if the use of mathematical maps for the exercise of political control is the sole criterion of early modernity. But to use this single criterion is to overlook the many ways in which Qing-dynasty China differed from early modern Europe intellectually, socially, and economically. The predominance of the mathematical map in Europe did not come about simply because of its usefulness for political control and inventory. Modern cartography is not simply a matter of mapmaking technique and map use. There is a philosophy of nature associated with it. That philosophy implies that certain methods, based on mathematical reasoning, should be used to understand nature. That philosophy of nature and the emphasis on mathematical reasoning were largely absent from the Qing scholarly world until late in the



Maps and Mapmaking in China. Fig. 5 *Huanghe tu* (Map of the Yellow River, nineteenth century, before 1854; detail). This map is oriented with south at the top and shows flood-control works along the lower course of the Yellow River before 1854. Distances between places are given in notes on the map, and from these it does not seem that the mapmaker attempted to maintain a consistent scale. The grid appears to have been drawn after the image was completed, perhaps as an aid to copying. A manuscript map could not be reproduced by woodblock printing without destroying it, so hand copying skills were important for mapmakers. Ink and color on silk, 38 × 183 cm. Courtesy of the Library of Congress (G7822.Y4A5 18 – H9 Vault Shelf).

nineteenth century. Chinese evidentiary scholarship, for example, does not yield anything resembling Newtonian mechanics. The inadequacy of the mathematical map as a measure of the modern becomes clear when one recalls that mathematical maps of the entire empire were available in China as early as the twelfth century. On that basis one could locate, as some have on other grounds, early modern China in the Song dynasty. The problem is that after the twelfth century Chinese mapmakers generally turned away from the mathematical.

Furthermore, a number of political, social, and intellectual developments occurring in early modern Western Europe did not occur in Qing-dynasty China – for example, those fostering the formation of modern democratic institutions. One could argue that those conditions still have not fully arisen in China. A case in point is the dissemination of information. Modern mathematical maps were widely circulated among the middle class in Europe; it was simply not the case that modern maps were understood and used only by a few in early modern Europe. Such widespread familiarity with modern mathematical maps was slow to come in Qing-dynasty China, if it ever did come. It does not seem likely that left to themselves, Chinese mapmakers would have developed the map transformations of modern cartography. In fact they tended to resist them and what they implied about the world's size and shape. Map transformations are predicated on an understanding that the earth is spherical; Chinese mapmakers before the late nineteenth century generally dealt with the earth's surface as if it were flat. Modern cartographic techniques may be available to anyone in principle, but historically they have not been acceptable to everyone. There was something that stopped Chinese mapmakers from adopting the map transformations brought by the Jesuits. Qing rulers used early modern cartography, but Chinese mapmakers did not produce early modern maps until late in the nineteenth century. If one wants to understand what Chinese mapmakers were doing under the Qing, one does not study the maps produced as a result of the Jesuit surveys. They had little effect on Chinese mapmakers. They did not participate in the modern cartographic revolution until well after the Jesuit surveys. This statement may perpetuate an image of a China resistant to change, but in making their own maps, they were. The image in some cases is justified.

In addition, to describe the Jesuit atlases as Chinese is to portray the Jesuits simply as Qing operatives – a disingenuous characterization at best. The Jesuits had their own purposes for carrying out the surveys. Their information was not intended solely for the Qing court. It was sent back to Europe where it had more influence on mapmakers than in China. There it changed the cartographic image of China, made it more accurate, and the importance of that geographic information for economic expansion is well known.

What is being said here is not to deny that European maps and Chinese maps have some similarities. Otherwise it would not make sense to speak of European and Chinese "maps." In both traditions pictorial and mathematical mapmaking were practiced. But the two traditions differed in the valuation placed on the two modes of mapmaking. In China pictorial mapmaking became dominant; in Europe mathematical mapmaking became dominant. In one history, text was more important than image as a bearer of information; in the other text was less important and was moved to the margins and eventually off the map. Among Chinese mapmakers there was little movement toward marginalizing text. Indeed, practices of evidentiary scholarship made the study of texts central.

As far as mapmaking is concerned, the evidence so far does not allow one to identify a specific dynastic period as equivalent to early modern Europe. The attempt to do so seems to privilege what happened in Western Europe as a norm when it is by no means clear that all societies have to go the way of Europe. It still makes sense to distinguish Western European culture from Chinese culture, as recent political events make abundantly clear.

See also: ►Zhang Heng, ►Armillary Spheres, ►Geomancy in China, ►Maps and Mapmaking: Chinese Geomantic Maps, ►Shen Gua (or Kuo)

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Maps and Mapmaking: Chinese Geomantic Maps

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The Chinese geomantic map is a type of cartographic expression of a landform that portrays a place as geomantically auspicious or inauspicious. In search of an auspicious site for a grave, settlement, temple, or house, geomancers often make extensive field surveys using compasses. Determining an auspicious site, which is often found on a foothill, is a complex business achieved by considering landforms, watercourses, and the direction that the locality faces. The results of important surveys are often recorded in maps. Although the geomantic sketch map is a large-scale map, the scale is not accurate beyond the immediate area of the auspicious site, because the map is normally based on eye measurements and impressionistic descriptions of a locality.

Chinese geomantic maps have basically the same surveying and cartographic methods and identical or similar map symbols. A geomantic map may represent an auspicious site (the geomancy cave: normally designated as a grave or a house site) by the symbol of a small single circle or an even smaller circle inside a small circle. A geomantic map is a topographic map featuring mountain ranges most prominently, because the auspicious vital energy is said to flow through these ranges before accumulating in a geomancy cave. Mountain ranges are expressed in stylized but realistic shapes, using different symbols for different parts of a mountain: a single black line marks the end of foothills and the beginning of flat land; a serrated demarcation line shows slopes along the edge of mountain ridges; the mountain ridges and peaks are colored black. Broken lines symbolize a smaller watercourse. A broken line with a solid line on one side may represent a bigger river. A large lake, river or sea may adopt the symbol of scales, which are also used in other types of maps in East Asia.

The first main characteristic of a geomantic map is that it is a center-oriented map. The focus of the map is on the auspicious site of a given landscape which normally occupies the central position of the map. In the depiction of the topographic formations, only the mountains facing the auspicious site are presented in the map.

The second interesting point concerns the perspectives on the map. The point of perspective on the modern topographic map of contour lines is in the sky directly above the concerned landform. However, that for the relief formations of the mountain slopes on the geomantic map is on the ground at the auspicious site,

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while that for watercourses on the map is in the sky directly above the waters concerned.

The third point is that there is a lack of map symbols indicating cardinal direction. Unlike modern maps, the top of the geomantic map is assumed to be southward, because an auspicious site is normally facing a southern direction. Although geomancy maps did not adopt a symbol of direction, the exact direction that an auspicious site faces is often noted with Chinese characters which enable a map reader to tell directions.

The fourth point is that the geomantic maps are generally large scale maps focusing on a small catchment area or a small basin. Other non-geomantic traditional Chinese maps are normally small-scale maps.

The fifth point concerns the emphasis on mountain ranges in the map. Especially emphasized are the relationships between the key mountain ranges encircling an auspicious site because mountain ranges are believed to be the route of the flow of *qi* (vital energy) which influences people auspiciously.

The origin of cartographic skills used in the geomantic map is not clearly understood yet by modern scholars. Fully developed geomantic maps had already appeared in a Ming Dynasty (1368–1644) geomantic manual, *Renze Shuji*. The technique of presenting relief formations in Chinese geomantic maps is perhaps more sophisticated than that on any other type of map in traditional China. However, their cartographic contribution is yet to be evaluated.

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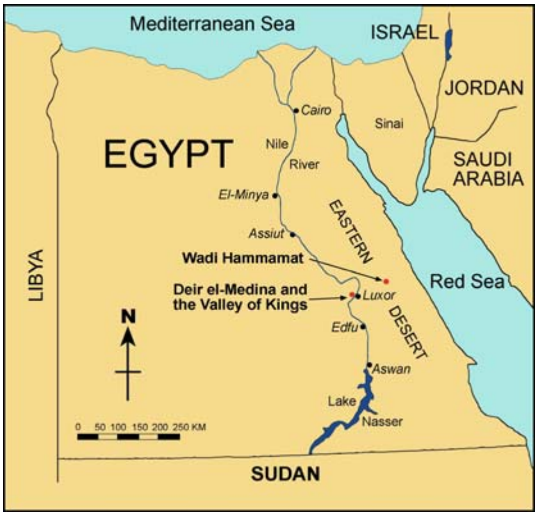
Maps and Mapmaking in Egypt: Turin Papyrus Map

James A. Harrell

Discovery and Reconstruction of the Map

An ancient Egyptian map drawn on a scroll of papyrus paper was discovered between 1814 and 1821 by agents of Bernardino Drovetti, the French Consul General in Egypt. The map came from a private tomb in the ancient village of Deir el-Medina, near the modern-day city of Luxor (ancient Thebes) in Egypt (Fig. 1). This village housed the workers responsible for excavating and decorating the royal tombs of the Egyptian New Kingdom (1539–1075 BCE) in the nearby Valley of Kings and Valley of Queens (Černy 1973; Bierbrier 1982; Romer 1984). Soon after it was found, the map was sold to King Charles Felix, ruler of the northern Italian Kingdom of Sardenia and Piedmont. In 1824, this king established the Egyptian Museum in Turin, the kingdom's capital, and here the map has resided ever since. The many map fragments were originally considered parts of three separate papyri that were designated as "Papyrus or P. Turin" 1869, 1879, and 1899. Most of these fragments were eventually recombined to form a single map about 280 cm long by 41 cm wide (Fig. 2). This papyrus has long been recognized as one of the oldest geographical maps to survive from antiquity and much has been written about it (e.g., Gardiner 1914; Goyon 1949; Shore 1987; Harrell and Brown 1992).

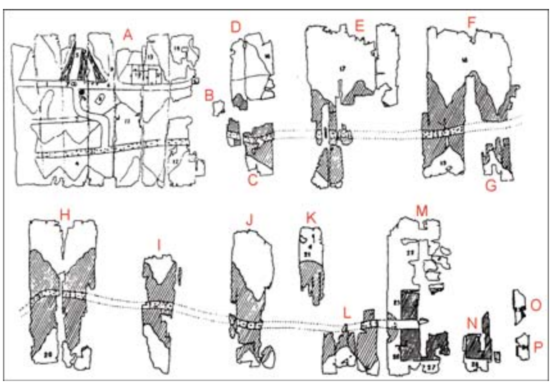
The current reconstruction of the map in the Egyptian Museum, which dates to the early 1900s, is incorrect in several of its details. A new arrangement of the map fragments has been proposed and this is shown in Figs. 3–6. The principal changes are the transposition of map fragments H-J and E, the placement of L at the bottom of E, and the narrowing of gaps between many of the fragments (which shortens the map to about 210 cm). This new reconstruction is consistent with the requirements that:



Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 1 Map of Egypt showing the locations of Deir el-Medina, the Valley of Kings, and Wadi Hammamat.

1. the adjoining fragments should correlate closely in terms of the features drawn on the map side, the texts and drawings on the map's backside (Figs. 7–8), and the fiber patterns in the papyrus paper;
2. the width of the fragments and the spacing between the breaks within them should match for those fragments that are vertically juxtaposed; and
3. the topography and geology of the area shown on the map should be taken into account. Figs. 3 and 5–8 are computer-generated photo-mosaics derived from digital scans of photographs taken of the papyrus.

The map was rolled up when discovered and subsequently handled, and this explains the especially poor preservation of the rightmost portion in Fig. 3, which formed the outer abraded surface of the scroll. An unknown amount of the papyrus has been lost at its right edge and so fragments K and N-P cannot be correctly placed. The map is not truncated here, but drawings of an unknown number of stone blocks and the accompanying texts are missing. The Egyptian Museum has many small map fragments that it left out of its reconstruction (and are also missing from Figs. 3–8) and eventually these pieces of the puzzle will be added to create a more complete map.

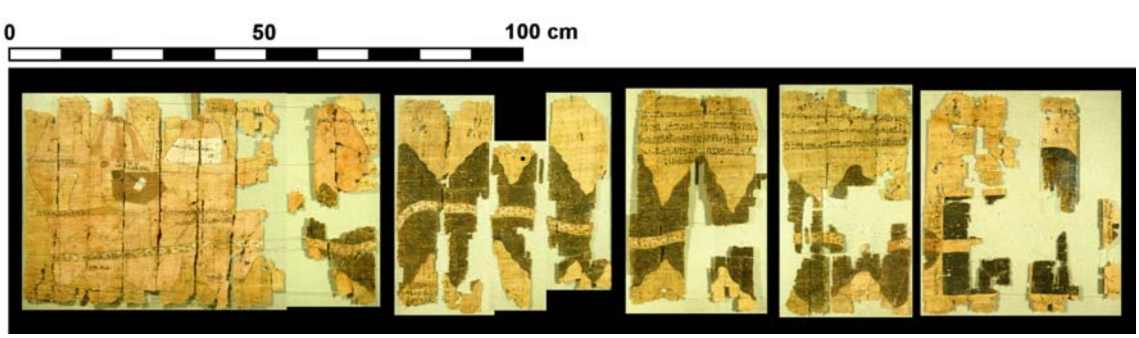


Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 2 The arrangement of the papyrus map fragments as currently displayed in the Egyptian Museum in Turin, Italy (adapted from Goyon 1949: Pl. 1 and 2; and reproduced in Harrell and Brown 1992: Fig. 2). The texts are identified by numbers (as in Fig. 4 and Table 1), and the fragments are identified by letters (as in Figs. 4–8 and Table 3).

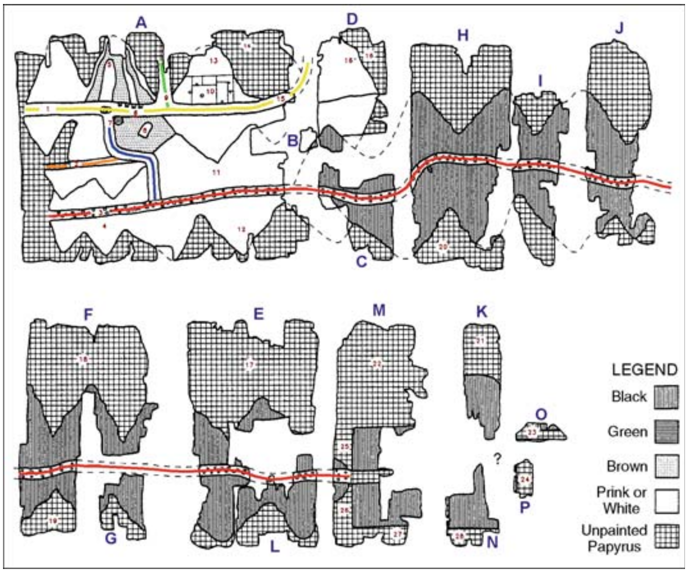
Topographic and Geologic Content of the Map

The Turin papyrus map is notable for being the only topographic map to survive from ancient Egypt and also for being one of the earliest maps in the world with real geographic content. Although there are a few older topographic maps from outside Egypt, they are all quite crude and rather abstract in comparison to the relatively modern-looking map drawn on the Turin papyrus. This map shows a 15 km stretch of Wadi Hammamat (Valley of Many Baths) in the central part of Egypt's Eastern Desert (Fig. 1). The top is oriented toward the south and the source of the Nile River with west on the right side and east to the left. There is no constant scale used on the map, but by comparison with the actual distances in Wadi Hamamat it is evident that the scale varies between 50 and 100 m for each 1 cm on the map.

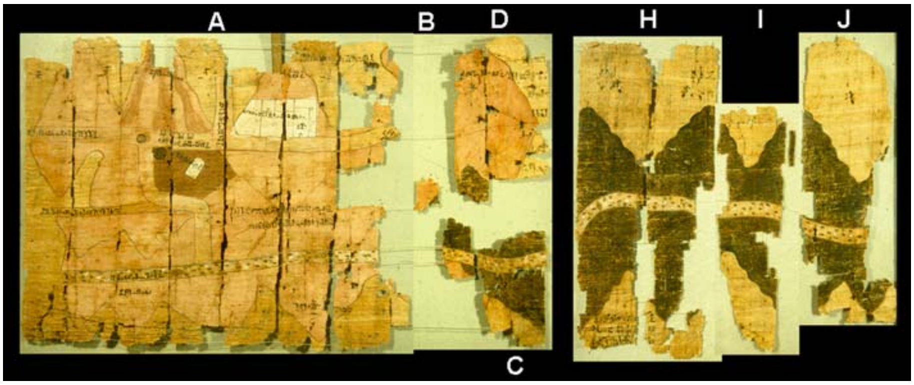
The topography and geology of the Wadi Hammamat area are shown in Fig. 9. The corresponding features on the ancient and modern maps are indicated by the colored lines in Figs. 4 and 9. From the good agreement between these maps, it can be seen that the papyrus clearly depicts Wadi Hammamat's long course and eventual confluence with wadis Atalla and el-Sid, the surrounding hills (shown as stylized conical forms with wavy flanks that are laid out flat on both sides of the valleys), the quarry for *bekhen*-stone, and the gold mine and settlement at Bir Umm Fawakhir (Well of the Mother of Pottery). *Bekhen*-stone (geologically, metagraywacke sandstone and siltstone) is a beautiful grayish–green ornamental stone that was highly prized by the ancient Egyptians. The only quarry was in Wadi Hammamat, and this was worked sporadically from the Early Dynastic period through Roman times (about



Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 3 Papyrus map as reconstructed by Harrell and Brown (1992).



Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 4 Schematic of the papyrus map showing the reconstruction by Harrell and Brown (1992: Fig. 3). The numbers refer to texts and the letters to map fragments as in Fig. 2. Corresponding features on this map and the modern one in Fig. 9 are indicated by the colored lines.

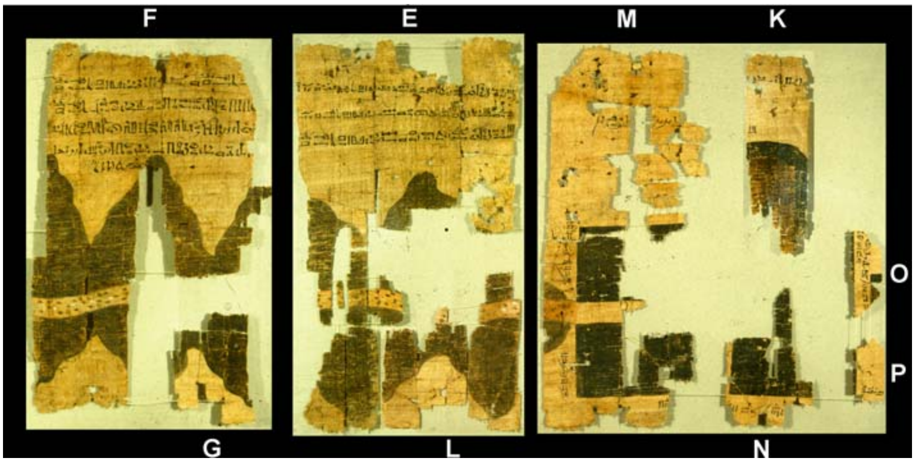


Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 5 The left (eastern) half of the papyrus map. See Table 1 for translations of the texts (as numbered in Figs. 2 and 4).

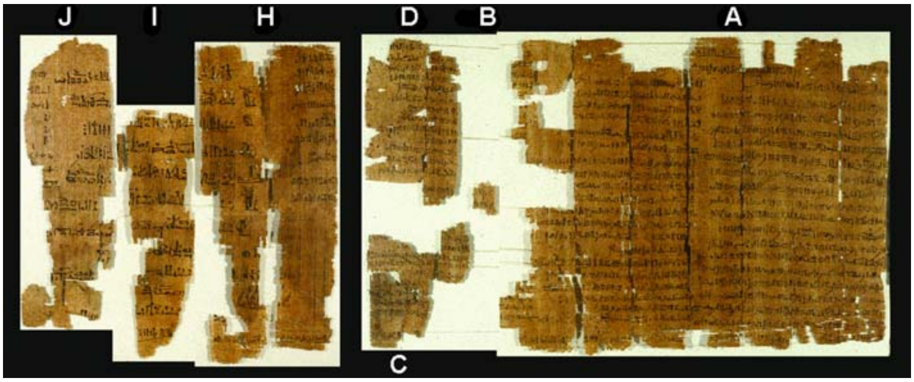
3000 BCE to 400 AD). The gold mine at Bir Umm Fawakhir was active during the New Kingdom and again in the Ptolemaic through Early Byzantine periods (about 1500 BCE to 600 AD).

Fragment A shows five cultural features associated with the gold-mining settlement, including: four houses, a temple dedicated to the God Amun (the large white area subdivided by walls), a monument stone honoring King Sety I (1290–1279 BCE of the New Kingdom's 19th Dynasty), a water reservoir, and, at the confluence of wadis Hammamat and el-Sid, a water well with an encircling wall that casts a shadow on its right side. The brown patch of ground opposite the settlement may represent an area where either mine tailings were dumped or farming was practiced.

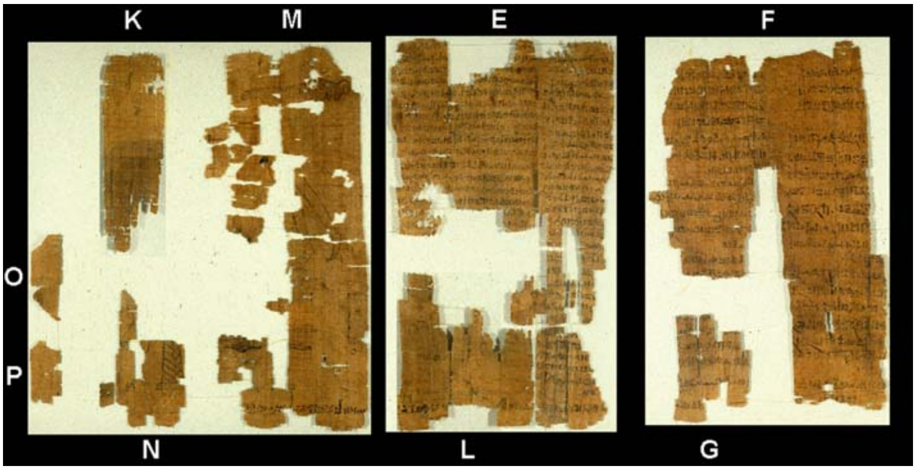
On map fragments A and H, within the main valley represented by multicolored dots, there are three small drawings of trees, which from their form can be identified as Tamarisks. The tree on fragment H (Fig. 10), which is drawn upside-down, is just opposite the *bekhen*-stone quarry (the green oval at the base of the brownish black hill) and at the center of the sharp bend in the valley. On the ancient map, this is the only major bend in Wadi Hammamat prior to its confluence with Wadi Atalla. As seen in Fig. 9, however, Wadi Hammamat actually has many sharp bends as well as wide meanderings. Because the ancient map was drawn on a papyrus scroll, which would have resembled a modern roll of paper towels, the author did not have the freedom to show the



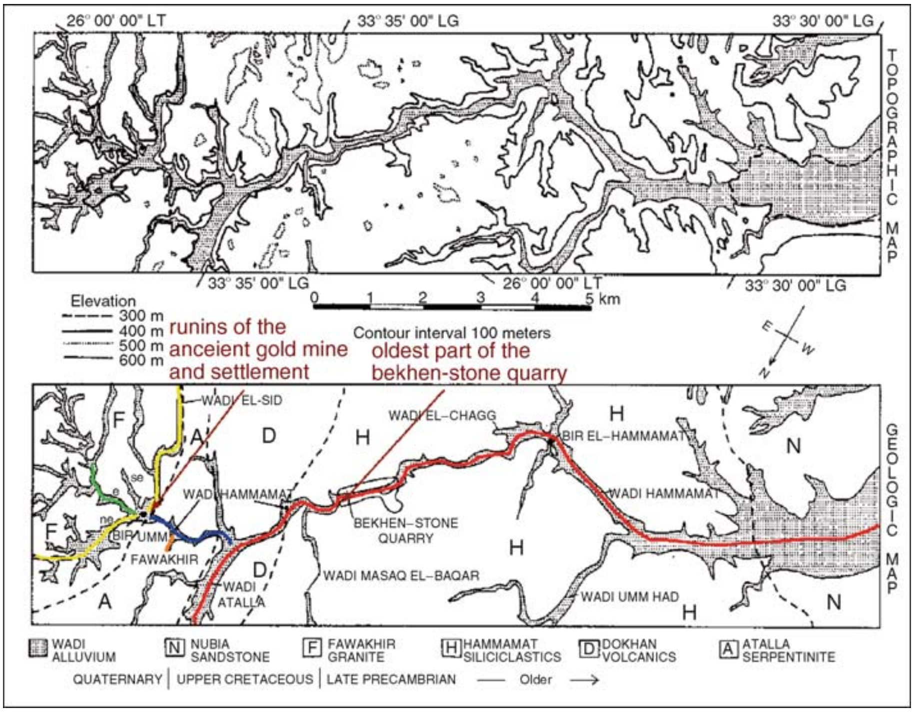
Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 6 The right (western) half of the papyrus map. See Table 1 for translations of the texts (as numbered in Figs. 2 and 4).



Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 7 The backside of the left (eastern) half of the papyrus map. See Table 3 for comments on the texts.



Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 8 The backside of the right (western) half of the papyrus map. See Table 3 for comments on the texts and drawings.



Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 9 Topographic (above) and geologic (below) maps of Wadi Hammamat (adapted from Harrell and Brown 1992: Fig. 4). Corresponding features on this map and the ancient one in Fig. 4 are indicated by the colored lines.

Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 10 Detail of the papyrus map (fragment H) showing an upside down tree in the wadi directly opposite from the *bekhen*-stone quarry, which is shown as a greenish oval embedded within the brownish black hillside.

true wandering course of Wadi Hammamat and so included only the most important bend, the one near the *bekhen*-stone quarry.

The papyrus map also has numerous annotations written in hieratic script (the cursive form of hieroglyphic writing) that identify the features shown on the map (see Table 1 for translations), including: the destinations of the valley routes (texts 1–3, 9, and 16 on fragment A), the distance between the *bekhen*-stone quarry and gold mine (text 17 on fragment E), the location of gold deposits in the hills (texts 4–5, 11–12, and 16′ on fragments A and D), the gold-mining settlement (texts 6–8 and 10 on fragment A), the *bekhen*-stone quarry (text 20 on fragment H), and the sizes of the quarried *bekhen*-stone blocks (texts 23 and 25–28 on fragments M-P). Text 18 on fragment F is especially important for understanding the purpose of the map because it refers to a *bekhen*-stone quarrying expedition and the destination of the quarried blocks.

Besides being a topographic map of surprisingly modern aspect, the Turin papyrus is also a geologic map because it accurately shows the geographic distribution of different rock types (the black hills with Hammamat siliciclastics, and the pink hills with Dokhan volcanics, Atalla serpentinite and Fawakhir granite) and the lithologically diverse wadi gravel (the brown, green, and white dots within the main valley that represent different kinds of rocks), and it also contains information on quarrying and mining (see Table 2 for a description of the geologic units). Additionally notable are the representation of iron-stained, gold-bearing quartz veins with three radiating bands on the pink hill above the gold-mining settlement on fragment A (beneath text 5), and text 11 on fragment A, which reads very much like a legend on modern

Maps and Mapmaking in Egypt: Turin Papyrus Map. Table 1 Translations of the Hieratic Texts on the Map Side of the Turin Papyrus (Adapted from Harrell and Brown 1992: Table 1)

Text number[1]	Translation
1	the road that leads to the sea
2	another road that leads to the sea
3	the road of *Tent-p-mer* [the translation of the last word is uncertain – it may be the name of an unknown locality or it may mean "treasurer" or "harbor"]
4	mountains of gold
5	mountains of gold
6	the houses of the gold-working settlement
7	cistern [or "water reservoir"; the text is written on top of the water sign]
8	stela of *Menma'atre*, life, health, and prosperity! [King Sety I, 1290–1279 BCE, of the New Kingdom's 19th Dynasty][2]
9	the road of *Ta-menti* [the last word is apparently the name of an unknown locality]
10	the shrine of *Amun* of the pure mountain
11	the mountains in which gold is worked, they are colored pink
12	mountains of gold and silver [or perhaps "mountains of electrum", where electrum is a natural mixture of gold and silver]
13	…the hill of *Amun*
14	the hill where *Amun* rests
15	[not translatable; appears to be part of a name for some locality]
16	[too fragmentary to translate, but it appears to be comments on travel from one unnamed locality to another; a travel time of "one day" and "gold" are mentioned]
16′	mountains of gold [appears to be a continuation of 16 but is a separate text]
17	distance from the gold-working settlement to the mountain of *bekheny*,…*khet* [this text is repeated three times, apparently for emphasis; the distance in units of *khet* is missing][3,4]
18	…the *bekheny*-stone that is found in the mountain of *bekheny*, the King…[name lost] life, health, prosperity, having sent the great magistrates to bring the portrait statue of *bekheny*-stone…to Egypt. They deposited it in the Place of Truth beside the Temple of *Userma'atre setepenre*, the great God [i.e., near the Valley of Kings at the mortuary temple of Ramesses II, 1279–1213 BCE, of the New Kingdom's 19th Dynasty; also known as the Ramesseum]…left it at the enclosure of the Tomb and there it lay being half worked in year 6[3]
19	[not translatable]
20	the place in which they work in the great business of *bekhen*-stone which was established as a quarry
21	the measurement of this…
22	[not translatable]
23	…of stone that is pulled by men from the east…3 cubits wide [about 1.6 m][4]
24	…*bekheny*…
25	breadth of 2 cubits, 2 palms [about 1.2 m]; thickness of 2 cubits, 3 palms…fingers [about 1.3 m]
26	breadth of 2 cubits [about 1.0 m]; thickness of 2 cubits
27	…palms…fingers
28	…palms; thickness of 2 cubits…palms

[1] See Figs. 2 or 4 for locations of texts. Note that "…" indicates missing text, untranslated ancient Egyptian words are italicized, and comments are given within brackets.
[2] All dates in this article are taken from p. 36–37 of Baines and Malek (2000).
[3] Texts 17 and 18 are written in a script that is bold, calligraphic and near-hieroglyphic in style. All other texts are written in a less elaborate hieratic script.
[4] The ancient Egyptian units of measure are as follows: 1 *khet* = 100 cubits; 1 cubit (the standardized distance from the elbow to the tip of the longest finger) = 7 palms (palm widths) = 28 fingers (finger widths); 1 cubit = 52.31 cm, 1 palm = 7.47 cm, 1 finger = 1.87 cm.

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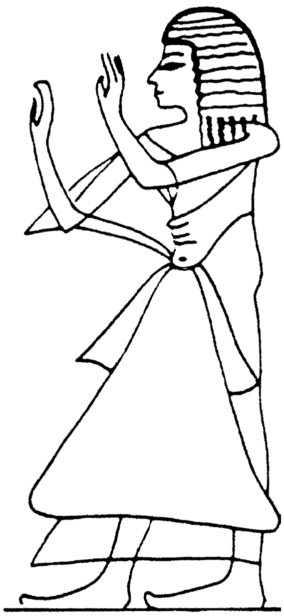
geologic maps by explaining what the pink coloring represents. The Turin papyrus is the oldest known geologic map in the world and it is all the more remarkable considering that it would be another 2900 years before the next geologic map was made and this was in France during the mid-1700s. There is no reason to think, however, that the ancient author intentionally set out to make a geologic map. From the colors used for the hills and wadi gravel, it is evident that he merely drew what he literally saw in the desert – the real hills and surface gravels have the same general colors as those on the map (Table 2).

Maps and Mapmaking in Egypt: Turin Papyrus Map. Table 2 Geologic Units in the Wadi Hammamat Area as Shown on the Map in Fig. 9 (Adapted from Harrell and Brown 1992: Table 4)

Geologic age	Name	Description
Quaternary	Wadi Alluvium	Sand with lithologically diverse pebbles and cobbles of many colors but especially white, pink, brown, dark gray, and green.
Upper Cretaceous	Nubia Sandstone	Sandstone. From a distance appears purplish-black due to a coating of "desert varnish".
Late Precambrian	Fawakhir Granite	Granite and granodiorite with abundant iron-stained, gold-bearing, hydrothermal quartz veins. From a distance appears pink to pale red due to natural coloring.
	Hammamat Siliciclastics	A variety of slightly metamorphosed sedimentary rocks, including (meta) greywacke sandstone to siltstone (the ancient Egyptian *bekhen*-stone), conglomerate and shale. From a distance appears dark brownish-gray due to a coating of "desert varnish".
	Dokhen Volcanics	A variety of slightly metamorphosed volcanic rocks, including (meta) rhyolite, andesite, and basalt. From a distance appears pinkish-brown due to weathering.
	Atalla Serpentinite	Serpentinite. From a distance appears pinkish-brown due to weathering.



Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 11 Amennakhte, son of Ipuy (modified from Romer 1984: p. 115). Redrawn from a relief carving on a stela erected in Thebes by his family after his death (now in the New York Metropolitan Museum of Art).

Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 12 Ramesses IV's year-three stela (CM 12) in Wadi Hammamat's *bekhen*-stone quarry.

The Map's Author and Purpose

The map was made about 1150 BCE by the well-known "Scribe of the Tomb" Amennakhte, son of Ipuy (Romer 1984: 106–115) (Fig. 11). It was prepared for one of the quarrying expeditions sent to Wadi Hammamat by King Ramesses IV (1156–1150 BCE) of the New Kingdom's 20th Dynasty (Peden 1994). The purpose of these expeditions was to obtain blocks of *bekhen*-stone that would be carved into statues of the gods, king and other notables. A now famous rock-cut inscription or stela (officially designated CM 12) was left on the quarry wall by this king to commemorate his final and largest expedition during the third year of his six-year reign (Christophe 1948) (Fig. 12). According to the

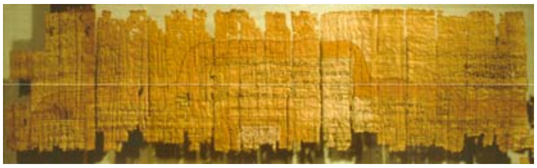
Maps and Mapmaking in Egypt: Turin Papyrus Map. Table 3 Comments on the Hieratic Texts and Drawings on the Backside of the Turin Papyrus Map (Adapted from Harrell and Brown 1992: Table 3)

Map fragment[1]	Comments
A (across top)	Synopsis: Amennakhte, in his house one morning, bears witness to a sworn oath and statement (not recorded in the text) by a "citizen" (name lost). Signed by Scribe of the Tomb Amennakhte (date lost). [this is almost certainly the earliest text written on the backside because Egyptian scribes filled in scrolls from top to bottom and right to left]
A (left half & top of right half)	Synopsis: A wooden statue of Ramesses VI is to be carved, and ornamented with a kilt of gold, and a crown of lapis lazuli (and another mineral?). It is to be placed in the mortuary temple of Ramesses II (the Ramesseum) in the Chapel of Hathor for the purpose of establishing a cult for the worship of Ramesses VI. The required offerings on festival days and the duties of the temple personnel attached to this cult are also described. [unsigned and undated, but Amennakhte's handwriting]
A (the rest of the right half)[2]	Synopsis, Part 1: Hori went to Karnak Temple in Thebes at the summons of Ramessenakhte, the High Priest of Amun. There he was told to gather a large quantity of copper [which would have been used for the tools wielded by the workers excavating the royal and private tombs] and bring them to the Temple. Hori returned to the necropolis in the company of two Guards of the Treasury, Paynodjom and Amenmose son of Tjewenany, and the servant Pnekhemope. Dated year 6, 3rd month of Akhet, day 20. Synopsis, Part 2: Hori returned to Karnak Temple in the company of Paynodjom and Amenmose plus the two Foremen of the Tomb, Nekhemmut (Hori's brother) and Anherkhe. They met with Ramessenkhte and turned over the requested copper to the Scribe Khonsmose, who received it for the Treasury of Amun. Dated year 6, 4th month of Akhet, day 7. Signed by Scribe of the Tomb Hori, son of Khons.
A (upper right edge), B & D	[untranslated, but possibly Hori's handwriting]
A (lower right corner) & C	[untranslated, but the handwriting is that of either Amennakhte or another, unknown scribe]
D (right edge & upper part of left edge)	[untranslated, but the handwriting is that of either Hori or another, unknown scribe]
H (right half), I & J	[untranslated, but appears to be a list, possibly of statues and their associated festival days; the large, bold, calligraphic and near-hieroglyphic script in this text is like that in texts 17 and 18 on the map side, and probably is Amennakhte's handwriting in his more formal script]
J (upper right edge), F (upper two-thirds of left half)	[untranslated, but appears to be a memorandum plus a hymn, possibly to Horus, that is in Amennakhte's handwriting]
F (lower one-third of left half)	[untranslated, but the handwriting may be that of Amennakhte or another, unknown scribe]
F (right half)	[untranslated, but Amennakhte's handwriting]
G	[untranslated, but Amennakhte's handwriting]
E	[untranslated, but possibly Hori's handwriting]
extending across the bottom edge of A, C, H, I, J, F, G, E, L & M	[untranslated, but one long line of text in possibly Hori's handwriting]
L & M (lower right edge)	drawing showing a scattering of squarish pebbles (?) plus two curved parallel lines, the latter similar to those used to indicate wadis on the map side
M	a grid-square in red ink with fragmentary drawings of the sky goddess Nut, and below, the god of air and light, Shu, or perhaps the god of Earth, Geb; a tiny stick-man is standing on Nut's back
M (top)	drawing of a crocodile
N	fragmentary drawings of a tree trunk (palm?) and a wing (either the vulture Goddess Nekbet or the falcon god Horus)

[1] See Figs 7 and 8 for locations of map fragments. Fragments K, O, and P have no texts or drawings.
[2] The gist of these two texts has been revised from Harrell and Brown (1992: Table 3) based on a new translation by Janssen (1994).

inscription, this included 8,362 men, which makes it the largest recorded quarrying expedition to Wadi Hammamat after one about 800 years earlier during the Middle Kingdom's 12th Dynasty. It is almost certainly for Ramesses IV's big expedition that the map was made, but what purpose it served is unclear. It could not have been a road map showing the way to the quarry because it only covers a small area with the 75 km between Wadi Hammamat and the Nile Valley excluded. Most likely, it was drawn as a visual record of the expedition to be viewed by either Ramesses IV or Ramessenakhte, the High Priest of Amun in Thebes, who organized the expedition for the king.

Although Amennakhte did not sign his name to the map, it is clear that he is its author. There are two pieces of evidence that support this identification. First, the text on the map side is in Amennakhte's distinctive handwriting, which is well known to Egyptologists who have studied his many other writings. And second, the first and earliest text on the backside of the papyrus (the first one listed in Table 3) was written and signed by Amennakhte. It is not at all surprising that Amennakhte would have made the map. As one of the two "Scribes of the Tomb" during Ramesses IV's reign (along with Hori, son of Khons, who also wrote some of the later texts on the back), Amennakhte was an important administrative official in the Theban region and this is where the map (text 18) says the blocks of *bekhen*-stone were taken. He is well known from his many other surviving works to be an individual with an unusual combination of scribal, cartographic and artistic skills as well as a "sense of geology". These attributes are especially well displayed on another of his papyri in Turin's Egyptian Museum. This is an architectural plan of Ramesses IV's tomb in the Valley of Kings (Carter and Gardiner 1917) (Fig. 13). It is by far the most elaborate and sophisticated tomb plan to survive from ancient Egypt. It has Amennakhte's distinctive handwriting labeling the parts of the tomb and giving their dimensions, and on the back is his last will and testament. The plan also includes elements of geology, such as a drawing of the king's sarcophagus in the central burial chamber painted to resemble the pink granite of Aswan from which it was carved, and the location of the tomb under a mountain of well-layered, inclined strata, which is an accurate depiction of the situation in the Valley of Kings.



Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 13 Ramesses IV's tomb plan drawn by Amennakhte, son of Ipuy (now in Turin's Egyptian Museum).

It is now known that Drovetti obtained both the quarry map and tomb plan, along with many other papyri, from Amennakhte's family tomb at Deir el-Medina. If the map was made for Ramesses IV's big quarrying expedition then why did Amennakhte keep it, and why did he and others reuse its backside for documents and drawings unrelated to the map? The answer to the first question is unknown, but that to the second is clear. Because papyrus paper was an expensive commodity in ancient Egypt, it was common practice among scribes to use the originally blank backsides once whatever was written or drawn on the front side was no longer needed. In other words, the papyrus map became scrap paper after the quarrying expedition it recorded lost its importance, perhaps following Ramesses IV's death a few years after the map was made.

Amennakhte's family tomb still exists as does, remarkably, his house in Deir el-Medina (Figs. 14 and 15). That it is his house is known from an inscribed door jamb, now removed for safe keeping that graced its entrance. It is interesting to contemplate that it may be in this very place where one of the world's oldest and most important maps was made over 3100 years ago.

Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 14 Ruins of the ancient village of Deir el-Medina, Egypt. Amennakhte's family tomb (no. 1338) is excavated into the hillside on the right, and his house (highlighted in red) is inside the rectangular, walled precinct at center.

Maps and Mapmaking in Egypt: Turin Papyrus Map. Fig. 15 House of Amennakhte, son of Ipuy in the ancient village of Deir El-Medina, Egypt. Only the ground floor (with four rooms) survives, but the remains of stairs (not visible) indicate that there was a roof terrace where people could work or sleep.

See also: ►Mining in Egypt

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Maps and Mapmaking in India

Joseph E. Schwartzberg

In comparison to Europe, the Islamic world, and East Asia, the cartographic achievements of South Asia appear modest and until the 1980s were scarcely recognized by historians of science. In recent years, new archaeological evidence, surviving sacred and secular texts, and other evidence have led to a change in scholarly opinion. We now believe that some form of mapping was practiced in what is now India as early as the Mesolithic period, that surveying dates as far back as the Indus Civilization (ca. 2500–1900 BCE), and that the construction of large-scale plans, cosmographic maps, and other cartographic works has occurred continuously at least since the late Vedic age (first millennium BCE). Because of the ravages of climate and vermin, surviving maps from prior to the eighteenth century are rare and are largely in stone, metal, or ceramic. However, cosmographies painted on cloth date back at least to the fifteenth century, while palm leaf architectural plans from seventeenth-century Orissa are believed to be copies of manuscripts originally prepared as early as the twelfth century. Few surviving maps on paper predate the eighteenth century.

Though not numerous, a number of map-like graffiti appear among the thousands of Stone Age Indian cave paintings; and at least one complex Mesolithic diagram is believed to be a representation of the cosmos. Other map-like grafitti continued to be produced by tribal Indians over most of the historic period. The principal reason for supposing that surveying was a feature of the Indus civilization is that the regularity of its planned

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grid-pattern urban settlements could not easily be achieved without it. Moreover, excavations have uncovered several objects that appear to have been simple surveying instruments and measuring rods. The uniformity and modular dimensions of the bricks for so much of the architecture over the vast extent of the Indus civilization are also noteworthy. During the ensuing period of the Vedic Aryans, the building of enormous sacrificial altars was an important religious activity. Texts known as *Śulbasūtras* set forth in great detail how these altars were to be constructed and called for drawing on the ground a plan prefiguring each altar. Again, a system of modular measures was employed. The ancient practice of building gigantic altars, once widespread, has died out over most of India, but survived into the latter half of the twentieth century in the Indian state of Kerala. Hindu temples were also built according to ancient detailed textual prescriptions, known as *Śilpaśāstras*, which also specified drawing on the ground, at full scale, the outline of the structure to be. That practice is still followed. Comparable, though simpler, rules applied, at least in theory, to the building of houses. The *Śilpaśāstras* also contained a variety of models for laying out towns and cities; however, the layout of present-day Indian settlements suggests that such models were seldom closely followed.

For the historic period, one of the earliest surviving artifacts that clearly embodies recognizable map symbolizations is an allegorical wall sculpture from Udayagiri in Madhya Pradesh, ca. AD 400, which shows the confluence of the Ganges and Yamuna Rivers in Madhyadesa (the sacred Central Region of India) over which the then Gupta Empire held sway. Other early datable works are sculpted bas relief cosmographies, some of which were quite elaborate. The earliest of these, depicting *Nandīśvaradvīpa*, the eighth continent of the Jain cosmos, was carved in Śaka 1256 (AD 1199–1200). It may safely be assumed that cosmographic paintings adorned the walls and portals of many ancient temples and monasteries of India's main religious groups – Hindus, Jains, and Buddhists – just as they still do in Jain religious edifices and in Buddhist establishments in other parts of the world. However, largely because of the ravages of time and partially because of the iconoclasm of Muslim invaders, virtually none of these survive from prior to the twelfth century, apart from fragmentary remains in the Buddhist caves at Ajanta.

Astronomy and its handmaiden astrology were well developed sciences in ancient India. The major texts provided detailed observations that enabled latter-day scholars to prepare elaborate celestial diagrams. Despite these, there is no unequivocal evidence that astronomical charts accompanied those early works or were otherwise drawn. Horoscopes were prepared to show the positions of major heavenly bodies at particular times (especially at times of birth), and iconic representations of those bodies as deities often appeared in sculpture and paintings, as did the signs of the zodiac. But none of these were formed into assemblages that one would readily designate as maps. During the Mughal period (1526–1857), however, planar astrolabes and celestial globes were manufactured in northwestern India. One Muslim family practiced the trade in Lahore over a period of several generations. Though some of these works used Sanskrit, rather than Persian, as was the norm, in naming various heavenly bodies, the tradition in which all were made has been dubbed "Islamicate." A variety of related objects in the form of giant masonry instruments appeared in the astronomical observatories constructed during the period ca. 1722–1739 by the Rajput king, Sawai Jai Singh, in his capital at Jaipur and in Delhi, Varanasi, Ujjain, and Mathura. Many of these are still usable.

At least five Hindu cosmographic globes are known, all based largely on *Purāṇic* texts from the mid-first millennium BCE to the mid-first millennium AD. The oldest of these is a brass globe, probably from Gujarat, dated Śaka 1493 (AD 1571). The largest (diameter ca. 45 cm) and most elaborate, and the only one to contain a substantial component of geographic information along with its mainly mythic elements, is a papier-maché globe, probably from eastern India, that appears to date from the mid-eighteenth century. One of the other globes is a painted wooden production, also thought to be from eastern India, probably from the mid-nineteenth century. Two are late nineteenth century bronze creations of unknown provenance. Unlike most Western globes, none of these was constructed with the use of gores, the triangular or moon-shaped pieces that form the surface of modern globes.

A number of planispheric world maps also survive. All but one of these, a crude Marathi map on paper, probably from the mid-eighteenth century, are essentially Islamicate productions, in which mythic elements (e.g., the Land of Gog and Magog) coexist with known geographic places. The largest and most ornate of the world maps is a richly illuminated eclectic painting on cloth, with text in Arabic, Hindustani, and Persian; it probably dates from the eighteenth century and may be of either Rajasthani or Deccani provenance. Additionally, a 32-sheet atlas of the "Inhabited Quarter" (i.e., the part of the world suitable for human life), forms part of a 1647 encyclopedic work by Sadiq Isfahani of Jaunpur in what is now Uttar Pradesh. The orientation on maps made by Muslims is typically toward the south.

Indigenous regional maps, mostly from the eighteenth and early nineteenth centuries, derive mainly form Rajasthan, Kashmir, Maharashtra, and Gujarat, probably in that order of frequency. These range in size from very large (several meters on a side) to page-size productions, the larger works being almost always painted on cloth. No clear schools of cartography emerge, though one can usually distinguish among regions of origin. Map symbols and orientation vary markedly, though some regional tendencies may be noted. No map has a consistent scale, though some contain textual notes on distances between places.

Route maps most commonly appear in strip form, occasionally as lengthy scrolls, and typically show the places and physical and man-made features encountered between two given points. Some route maps, largely relating to pilgrimages, which frequently take the form of circuits, are likely to be more complex. Surviving navigational charts are few in number, entirely from Gujarat, and in a tradition presumably derived from the Middle East. The oldest such known work is dated AD 1710.

The most common genre of maps are those that relate to relatively small localities, especially individual towns, as well as plans of specific forts, palaces, temples, gardens, and tombs. Such maps served many purposes: guides to pilgrims, aids for engineering projects, plans, or documents for military activities, commemorations of historical events, text illustrations, interior adornments, and so forth. Locality maps typically combine a largely pictorial rendition of specific structures, drawn in either an oblique perspective or in frontal elevation, with an essentially planimetric rendition of the encompassing space. Hill features on such maps (as well as on regional maps) are characteristically shown in frontal perspective. Colors for rendering hills, water features, and vegetation are naturalistic and not very different from what one would encounter on Western maps. The largest known Indian map, depicting the former Rajput capital at Amber in remarkable house-by-house detail, measures 661 × 645 cm. (260 × 254 in., or approximately 22 × 21 ft).

Although hundreds of Indian maps have now been studied and described, hundreds of additional recently discovered works await analysis; and it may be safely predicted in light of the interest aroused by recent research that many more maps will soon come to light.

See also: ►Astrology in India, ►Astronomy in India, ►Observatories in India, ►Jai Singh

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Maps and Mapmaking: Islamic Terrestrial Maps

Ahmet T. Karamustafa

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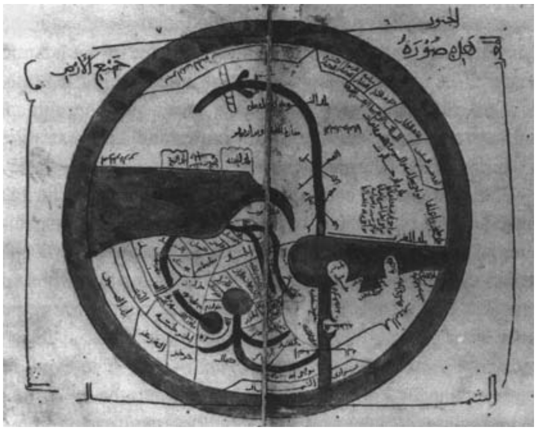
The cultural boundaries of premodern Islamic civilization (ca. 700–1850) extended from the Atlantic shores of Africa to the Pacific Ocean and from the steppes of Siberia to the islands of South Asia. Widely different traditions of empirical and theoretical cartography developed and coexisted within this cultural sphere. The academic study of these traditions is at its preliminary stages, and it is likely that further research will unveil hitherto unknown aspects of the cultural history of maps in the Islamic world (Figs. 1 and 2).

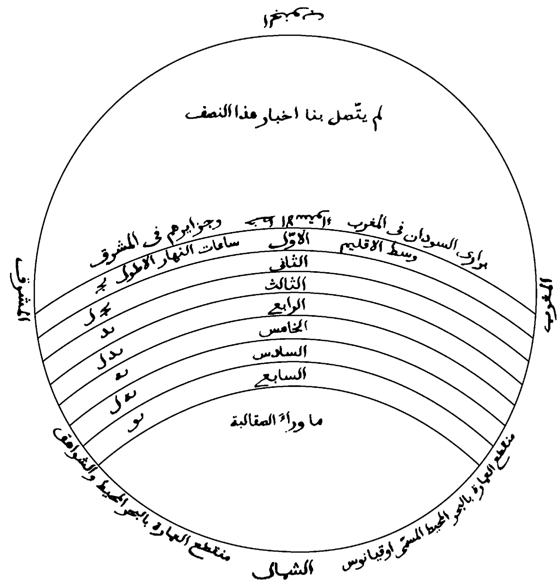
Practice

If one leaves aside purely literary references to maps and map use in historical sources for the first three centuries of Islamic history, the first significant corpus of Islamic terrestrial maps that survive are those that accompany texts written by the Balkhī school of geographers (al-Balkhī, al-Iṣṭakhrī, Ibn Ḥawqal, and al-Muqaddasī) during the tenth century. This set of maps normally comprised a world map, maps of the three seas (the Mediterranean, the Indian Ocean, and the Caspian Sea), and maps of seventeen regions of the Islamic world. Not based on any projection and lacking a scale, it is possible that these maps were based on geographical writings that described the postal routes and administrative divisions of the Islamic states.

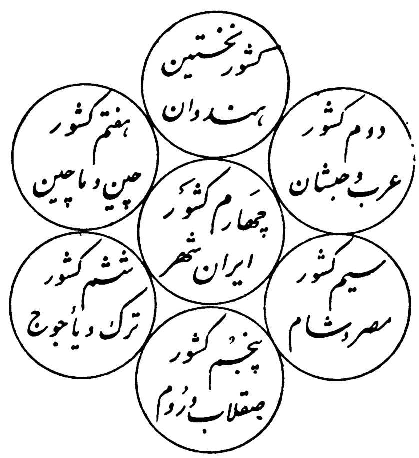


Maps and Mapmaking: Islamic Terrestrial Maps.
Fig. 1 Ibn Hawqal's map of the world. By permission of the Topkapi Sarayi Müzesi Kütüphanesi, Istanbul (A. 3346).

Maps and Mapmaking: Islamic Terrestrial Maps.
Fig. 2 al-Idrīsī's world map from the Sofia manuscript. By permission of the Cyril and Methodius National Library, Sofia (Or. 3198, fols. 4v-5r).



Maps and Mapmaking: Islamic Terrestrial Maps.
Fig. 3 Yāqūt's climate map. From *Jacut's geographisches Wörterbuch*, 6 vols, ed. Ferdinand Wüstenfeld (Leipzig: F.A. Brockhaus, 1866–73), vol. 1, between pp. 28 and 29 (fig. 4).



Maps and Mapmaking: Islamic Terrestrial Maps.
Fig. 4 al- Bīrūnī's seven *kishvars*. From al- Bīrūnī, *Kitāb al-tafhīm li-avāʾil ṣināʿat al-tanjīm*, ed. Jalāl al-Din Humāʾī (Tehran, 1974), 196.

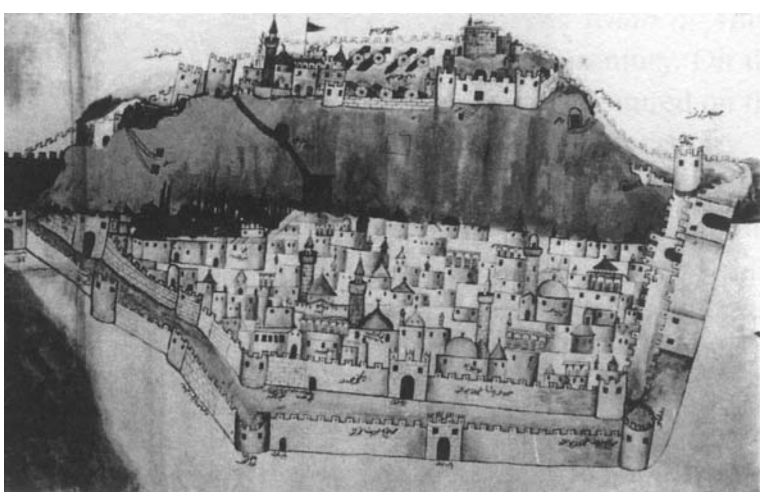
The other major cartographic school to develop in this period of Islamic history was the Ptolemaic. No early specimen of this school survived – the most spectacular of these seems to have been a world map produced for the ʿAbbāsid caliph al-Maʾmūn (r. 813–33) – and one has to turn to the celebrated geographical compendium of al-Sharīf al-Idrīsī, entitled *Nuzhat al-mushtāq fīʾkhtirāq al-āfāq* (The Book of Amusement for Those Yearning to Penetrate the Horizons) to appreciate fully the strength of the Ptolemaic cartographic tradition. Al-Idrīsī's work, completed in 1154 and accompanied by a large world map engraved on silver (no longer extant), contained a small world map and 70 sectional maps that collectively represented the whole of the known world. Latitudes and longitudes, not shown on the maps, were given in the text (Figs. 3–8).

Cartographic representation of the globe during the High Caliphal and Early Middle Periods (ca. 700–1250) was not confined to geographical mapping of the Balkhī and Ptolemaic schools. In their attempts to depict the world Muslims also resorted to geographical diagrams. At least three different traditions of

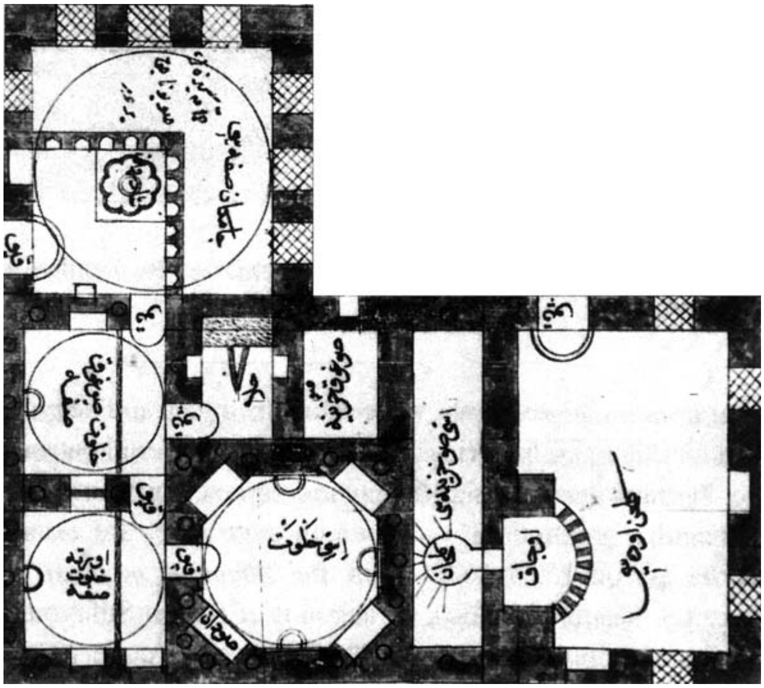
Maps and Mapmaking: Islamic Terrestrial Maps. Fig. 5 Seventy-two section scheme of sacred geography. By permission of the Topkapi Sarayi Müzesi Kütüphanesi, Istanbul (B. 179, fol. 52r).

diagrammatization were used: the seven-*climata* scheme, the seven-*kishvar* system, and the *qibla* charts. The seven-*climata* scheme, Ptolemaic in origin, divided the inhabited portion of the earth into seven zones (Arabic *iqlīm*) based on latitude calculations. In the seven-*kishvar* system, of Persian origin, the inhabited portion was represented in seven circular regions (Persian *kishvar*), arranged so that six of the regions totally engulfed the seventh central one. The *qibla* charts, occasioned by the religious prescription to perform various ritual acts in the direction of the Kaʿba in Mecca, divided the world into four, eight, 11, 12, or more sectors around the Kaʿba.

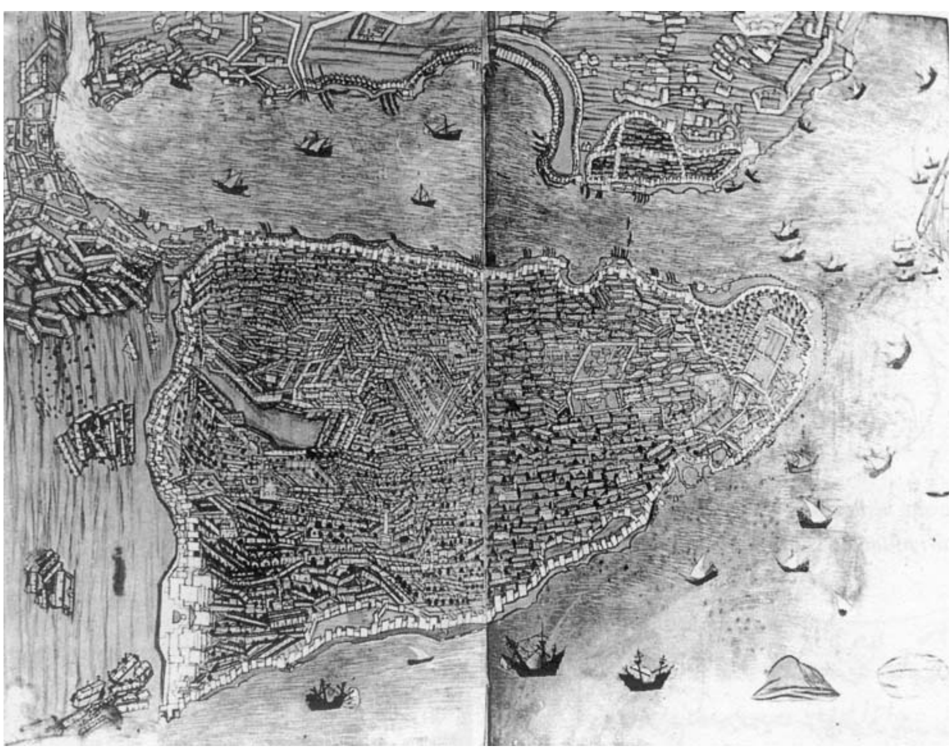
These cartographic traditions, originally developed during the tenth and eleventh centuries, formed the basis of further cartographic activity during the Later Middle Period and the Period of the Great Regional Empires (ca. 1250–1850). There took place a certain degree of interaction between the Balkhī and Ptolemaic schools, the most notable outcome of which was the attempt to place a graticule on the circular world map by Ḥamd Allāh Mustawfī (d. 1339) and Ḥāfiẓ-i Abrū (d. 1430). The formation of the Gunpowder Empires during the sixteenth century opened up new directions in Islamic mapmaking. We are particularly well informed about Ottoman maps and mapmaking. Graphic representation of space was used systematically for administrative purposes in the spheres of military operation and state-sponsored architectural construction. At least two new genres, visual itineraries and town views, were also introduced and heavily used in illustrated histories produced under imperial patronage. Perhaps the most significant and representative of such spectacular productions – of which over 30 are extant for the period 1537–1630 – is the *Mecmūʿ-i menāzil* of Maṭrakçı Naṣūḥ (d. 1564), an account of



Maps and Mapmaking: Islamic Terrestrial Maps. Fig. 6 Plan of the fortress of Van. By permission of the Topkapı Sarayi Müzesi Arşivi, Istanbul (E. 9487).



Maps and Mapmaking: Islamic Terrestrial Maps. Fig. 7 Plan of a Turkish bath. By permission of the Bild-Archivder Österreichischen Nationalbibliothek, Vienna (Cod. 8615, fol. 151a).



Maps and Mapmaking: Islamic Terrestrial Maps. Fig. 8 Plan of Istanbul from the Hünernāme. By permission of the Topkapı Sarayı Müzesi Kütüphanesi, Istanbul (H. 1523, fols. 158b–159a.).

Sultan Süleymān I's campaign into eastern Anatolia, Persia, and Iraq in 1533–1535. Not much is known on cartographic production in the Safavid and Mughal Empires.

Theory

Quite apart from cartographic practice and only tenuously related to it, a strong tradition of rigorous investigation of the earth was maintained in Islamic civilization from at least the ninth century onward. In addition to purely narrative geographical accounts, serious attention was paid to geodesy – the measurement of distances, or the determination of exact points, on the curved surface of the earth. As a result, a considerable number of geographical tables exist in Arabic and Persian, normally included in astronomical works. These either list places under climates, with no longitudes given and only the latitude of the climates specified, or assign longitude and latitude values for each place individually. The question of projection was also addressed in some detail. These theoretical aspects of Islamic cartography are perhaps best exemplified in the works of the scholar al-Bīrūnī (d. after 1050), whose output constitutes the culmination point of Islamic geodesy.

Map Use

The extant corpus of Islamic maps, when coupled with purely literary references to cartographic practice, suggest that the mapping instinct in Islamic civilization was by and large harnessed to the cause of scholarship and imperial artistic production. The majority of Islamic map artifacts were produced by the elite for the elite for the purposes of edification, illustration, and propagation of imperial glory. Practical application was the exception rather than the rule and remained confined to military maps and architectural drawings, which developed into distinct traditions only in the Ottoman Empire. The products of elite high culture, however, were infinitely more likely to be preserved, if only in literary form, than their popular or folk counterparts, so that the surviving cartographic record of premodern Islamic societies is only partially reflective of everyday mapping practices.

See also: ►Balkhī, ►al-Muqqadasī, ►al-Idrīsī, ►*Qibla*, ►Ottoman Science, ►Geodesy, ►al-Bīrūnī

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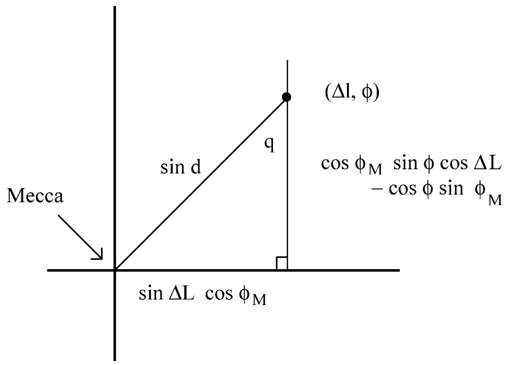
Maps and Mapmaking: Islamic World Maps Centered on Mecca

David A. King

Three remarkable world maps have come to light since 1989. The maps have Mecca at the center and are so devised that the direction of Mecca (*qibla*) and distance to Mecca can be read directly for any locality in the Islamic world between Andalusia and China (see the frontispiece for an illustration of the first world map). The maps are engraved on circular brass plates of diameter 22.5 cm and clearly hail from the same workshop. From considerations of the calligraphy and decoration they can be associated with Isfahan and dated ca. 1675. But they are all clearly copied from different originals, and so they are from a series of such world maps about which until recently we knew nothing.

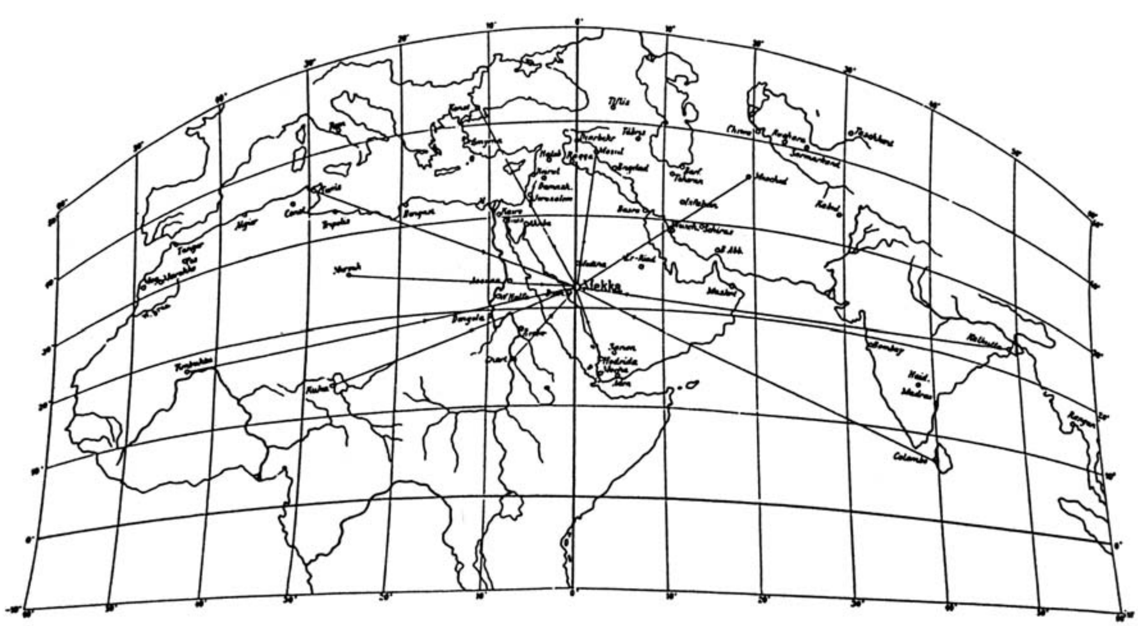
The highly sophisticated cartographical grid (see Fig. 1) is to be used in conjunction with the scale around the circumference, on which the *qibla* can be read, and with the nonuniform scale on the diametral rule, on which the distance to Mecca in *farsakhs* can be read. (A *farsakh* is equivalent to 3 mile.) There are some 150 localities marked on each of the maps, but the selection is not identical: their coordinates are at first sight based on those in the *Sulṭānī Zīj* of Ulugh Beg (Samarqand, ca. 1430), based in turn on those in the *Īlkhānī Zīj* of Naṣīr al-Dīn al-Ṭūsī (Maragha, ca. 1250), but there are several localities whose coordinates testify to the fact that they were taken from the common source of both the *Sulṭānī* and *Īlkhānī Zīj*es, namely, the mysterious anonymous *Kitāb al-Aṭwāl wa-l-ʿurūḍ li-l-Furs*, a source known to us only from citations by the astronomerprince Abu'l-Fidāʾ (Hama, ca. 1325). The *Kitāb al-Aṭwāl wa-l-ʿurūḍ* may be as early as the twelfth century. On the other hand several of the localities in India featured on the maps were not founded until the early fifteenth century. In fact, the earliest known geographical table featuring all of the localities on the two maps is found in a treatise on the astrolabe compiled in Najaf in 1702/03 by one



Maps and Mapmaking: Islamic World Maps Centered on Mecca. Fig. 1 The mathematics underlying the theory of the grid on the Isfahan world maps, enabling the user to read the *qibla* on the circumferential scale and the distance on the diametral scale. An approximation has been used on the world map so that the latitude curves are arcs of circles; this produces slight inaccuracies noticeable only on the edges of the map (that is, in Andalusia and China). Drawn by the author.

ʿAbd al-Raḥīm ibn Muḥammad, who wrote that he compiled his table from al-Ṭūsī, Ulugh Beg, "and others." But he also presented the *qiblas* and distances to Mecca for the 274 localities in his list, and at least some of these feature on various Persian astrolabes from the mid-seventeenth century, that is, some 50 year before he compiled his treatise. In fact ʿAbd al Raḥīm simply copied a table compiled in Kish near Samarqand in the first half of the fifteenth century. This was, in fact, the actual source of the geographical data on the three world maps. Since 1999, when the first two maps were published, Jan Hogendijk has found two sources, one from tenth-century Baghdad and the other from eleventh-century Isfahan, in which a solution to the qibla problem using conic sections is discussed. On the maps the circular arcs for the latitudes are excellent approximations to segments of ellipses. Now that we know what to look for, it is not too much to hope that a reference to a map grid based on this solution to the qibla problem might be found in some other early source.

Although the origin and development of these Mecca-centered world maps is still obscure, it is clear that they are entirely Islamic in their conception. Indeed they represent the culmination of Islamic mathematical cartography, and have no parallel in sophistication between Antiquity (the world map of Ptolemy, ca. 125) and European cartography of the seventeenth century. Prior to their rediscovery it was thought that the first



Maps and Mapmaking: Islamic World Maps Centered on Mecca. Fig. 2 The world map proposed by Carl Schoy ca. 1920 for preserving direction and distance to Mecca. There are major cartographic distortions for regions on the other side of the world. On the Isfahan world map, even though it was made ca. 1700, we are dealing essentially with the world as known to Ptolemy. (From Carl Schoy, *Gnomonik der Araber*. Berlin and Leipzig: Walter de Gruyter, 1923, between pp. 44 and 45.)

person to construct a world map centered on Mecca from which one could read off the *qibla* and distance to Mecca was the German historian of Islamic science Carl Schoy, who published such a map ca. 1920.

See also: ►*Qibla*, ►Ulugh Beg, ►*Zīj*, ►Astrolabe, ►Naṣīr al-Dīn al-Ṭusī, ►Astronomy in the Islamic World, ►Religion and Science in Islam I

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Maps and Mapmaking in Japan

Kazutaka Unno

The first record of Japanese mapmaking is an Imperial edict in AD 646 included in the *Nihon Shoki* (Chronicles of Japan), 720, ordering that each province reports its territorial range to the central government by means of a map. However, no fragment of such a map is extant now. The earliest extant maps relate to land ownership and date from the eighth century. These maps are almost all preserved in the Shōsōin, Nara, and consist of a map of Tōdai-ji temple precincts, 756, and over 20 maps of paddy fields. On these maps we can observe the traditional Chinese grid system. The majority of them are drawn on hemp.

The extant early general maps of Japan include: one dated the 12th month, the third year of the Imperial era known as Kagen (1305/06), now owned by the Ninna-ji temple, Kyoto; *Dai-Nihonkoku Zu* (Map of Great Japan) in the 1548 codex of an encyclopedia, *Shūgaishō* (Collection of Oddments); and *Nansembushū Dai-Nihonkoku Shōtō Zu* (Orthodox Map of Great Japan in Jambudvīpa) drawn in the mid-sixteenth century (Tōshōdai-ji temple, Nara). These maps show the coastline and the boundary lines between provinces by means of smooth curves, and have the common characteristic of showing the main routes from the province of Yamashiro, where the capital Kyoto had been located since 794, through almost all the provinces. Maps with such characteristics are called “Gyōki-type” maps, because they have an inscription indicating that the author was Gyōki (668–749), a revered Buddhist priest. But no one believes today that they were actually the work of Gyōki, for the capital in his time was not Kyoto but Nara, Yamato Province. Later, in the ritual of *Tsuina* (which had been instituted on Gyōki’s advice in 706 in order to offer prayers for national peace and the health of the people), a map of Japan came to be used to provide a concrete image of the country. It may be imagined that by association maps so used came to be called by his name.

The earliest extant map of the world is the *Go-Tenjiku Zu* (Map of the Five Indies), drawn by Jūkai, a Buddhist priest, in 1364, and now owned by the Hōryū-ji temple in Nara. The actually existing Buddhist continent called Jambudvīpa is drawn; India occupies a great part of the continent, and China, Persia, Japan, and many countries of Central Asia are shown. There are ten other extant maps which are copies made in later periods, and which belong to the same group. Incidentally, the above-mentioned *Shūgaishō* also contains a rough map of Jambudvīpa entitled *Tenjiku Zu* (Map of India).

European cartographical works were introduced to Japan in the late sixteenth century, and the coastlines of the Gyōki-type maps came to be drawn in detail, especially in the area of Kyūshū. This revision seems to have been done by the European pilots and by the Portuguese Ignacio Moreira, who resided in Japan between 1590 and 1592.

Exact maps of provinces were needed for state administration. But there are no known records about the compilation of national maps after the year 646 mentioned above (except for government orders of 738 and 796) until 1591, when the Toyotomi government embarked on such a project. The extant maps of two counties in Echigo Province are rare examples of the results of this project. The Tokugawa Shogunate, which succeeded the Toyotomi government and held its hegemony for two and a half centuries until 1867, gave orders for cartographical records of all provinces on five occasions during its reign.

These orders were issued in the tenth year of the Imperial era of Keichō (1605); about the tenth year of Kan’ei (ca. 1633); the 12th month of the first year of Shōhō (1645); the tenth year of Genroku (1697); and the sixth year of Tempō (1835). No detailed records remain as regards the first and second projects. After the third project, prescriptions aiming at some regularization of form were issued, for example, the scale was fixed at six *sun* to one *ri* (1:21,600). For the third project, the Shogunate also required the province to submit the plans of cities where the clan offices were located. These maps and plans are huge

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and beautifully colored. All of the maps of the fifth project, and some earlier ones, are still extant in the National Archives in Tokyo.

General maps of Japan based on the provincial maps were compiled on each occasion except the fifth project. The earliest extant official map of Japan is the so-called Keichō map of Japan, compiled in the mid-seventeenth century and now in the National Diet Library, Tokyo. On this map the eastern half of Honshū is completely curved to the north, and depicted as smaller than it actually is. The island of Shikoku, which actually has projections in all four directions of the compass, is drawn in a rectangular form.

The best of the official maps of Japan compiled during the Edo era is the so-called Shōhō map of Japan, based on the results of the third cartographical project, and completed around 1670. Compiled by the famous surveyor Hōjō Ujinaga, this map shows the shape of the Japanese archipelago which is very close to actuality.

These maps strongly influenced private works of cartography. *Nihon Bunkei Zu* (Map of Japan Divided into Parts), published in 1666, and the series of works by the painter Ishikawa Ryūsen beginning in 1687, were based on the Keichō map of Japan; the former was the first printed atlas of Japan. Seki Sokō's *Nihon Bun'iki Shishō Zu* (Easily Understandable Atlas of the Regions of Japan), 1698, and Nagakubo Sekisui's works (first edition, 1779) were also based on this "Shōhō map of Japan".

In traditional cartography, little attention was paid to the existence of spherical coordinates, but latitudes are shown in the portolan charts of Japan (ca. 1670, Mitsui Bunko Library, Tokyo; National Museum, Tokyo). The first map of Japan made under the influence of these charts and having a network of parallels and meridians was Mori Kōan's *Nihon Bun'ya Zu* (Astronomical Map of Japan), 1754. In this map, however, parallels and meridians were simply added to the already existing official map. We also find such a network on Nagakubo's maps of Japan, but with only the degrees of latitude. It is evident that they imitated Mori's idea, and moreover had a greater social influence, because these latter maps were often printed, while Mori's remained only a manuscript.

The first map of Japan that was based on actual observation of degrees of longitude and latitude was completed by officials of the Shogunate astronomical observatory in 1821. The surveying began in 1800 and mainly concentrated on the coastlines, as the title *Dai-Nihon Enkai Yochi Zenzu* (Maps of the Coastlines of Great Japan) shows. The supervisor of the surveying throughout was the astronomer Inō Tadataka, and all the maps thus made in this project are called "Inō's maps". The 1821 maps consisted of 214 sheets on a scale of 1:36,000, eight sheets of 1:216,000, and three sheets of 1:432,000.

The making of topographical maps by triangulation began in 1781, and in 1944 the entire country was depicted on maps with a scale of 1:50,000. Western style charts began to be systematically executed by the navy in 1871.

See also: ►Ino Tadataka

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Maps and Mapmaking in Korea

Gari Ledyard

Korea has a long history, but evidence of mapmaking comes only from about the fifth century AD, when a nobleman's survivors painted a map of Liaodong city (now in Liaoning Province, China, but then within the borders of the Korean Koguryŏ kingdom (37 BCE–668)) on a wall of his tomb. Since the tomb is in northern Korea, the map probably was meant to comfort him with an image of his far-off hometown. Koguryŏ's southern neighbors, the kingdoms of Paekche (18 BCE–663) and Silla (57 BCE–935) are known through written historical sources to have used maps in local administration, but no examples have survived. The same is true for the long Koryŏ dynasty (918–1392). The people of Koryŏ times had a sure sense of the peninsular outline of their country and are said to have commemorated it in the shape of the kingdom's standard silver bullion unit. Outlines of Korea also appear on a few Chinese maps of the twelfth century. Toward the end of the dynasty an enterprising scholar composed an elaborate map of the world – probably just the China–Korea region – and this work was probably connected in spirit to the *Kangnido* of 1402, which, in a copy of about 1470, is the oldest Korean-made map to survive.

The Artifactual Record

The succeeding Chosŏn dynasty built a much stronger and more durable state than had previously been known in the Korean peninsula. A vast amount of mapping was carried out in the fifteenth century, but aside from some prominent exceptions there is little remaining trace of this early production. Most surviving Korean maps are of the seventeenth century or later, and are most commonly found in albums, often hand-drawn but occasionally including wood-block prints. Larger maps are usually found preserved in silk or paper scrolls or on screens. A large sample of this material is now available in published color illustrations.

From the seventh century on, Korean kings presided over a strongly centralized, bureaucratic state. Provincial governors and district magistrates were responsible for producing maps of their areas in response to requests from central authorities for geographical, demographic, and fiscal information. Thus the central government maintained and frequently updated a broad range of data from which provincial and national maps could be compiled. The most complete such compilation to survive in its entirety is the *Sinjŭng Tongguk yŏji sŭngnam* (Complete Conspectus of Korean Territory, newly expanded; called the *Sŭngnam* for short) of 1531, descended from earlier editions going back to 1481.

Beginning in the late fifteenth century, the government generally limited publication and dissemination of maps for national security reasons, and the maps that were available, such as those in the *Sŭngnam*, were rather spare in detail. But security concerns also spawned the defense map (*kwanbangdo*) genre, which was rich in information relating to logistics and communciation.

Geomancy

In the late ninth century, Koreans began to articulate a national geomantic structure for their country. In its elementary form, geomancy (*p'ungsu*, Chinese *fengshui*) is an originally Chinese science employed in siting graves, human habitations, temples and shrines, and towns and cities. The landscape is the locus of forces which deliver energy and power through networks of montane "arteries" (*maek*) or riparian "veins" (*p'a*), which will be determined to be either favorable or unfavorable for the use envisaged for a particular site. Even today, specialists in this kind of knowledge can be found in most Korean communities, and indeed all over East Asia. But Korea is unique in developing this science into a nationwide framework for understanding and defining the physical aspects of the nation itself. From an early date the source of Korea's geomantic forces was seen to be located in Mount Paektu (2,744 m), which through Korea's mountain ranges and water sheds distributed vital forces to the entire country. It was thus of crucial importance to determine and map the mountain ranges of the land, so that the relationship of any particular spot to the overall network of "shapes and forces" (*hyŏngse*) could be clearly understood. Whether on the national or local level, a shapes-and-forces map (*hyŏngsedo*) would clearly configure the mountain ranges and water sheds, so that the physical lay of the land was easily perceived.

In the seventeenth century, following the Japanese (1592–1598) and Manchu invasions (1627, 1637), Korea went through a series of reforms which resulted in enhanced revenues and a more developed military. This was accompanied by economic growth and increased trade with China and Japan. In society at large these changes produced greater occupational diversity, a certain degree of social mobility, and a broader access to education. An intellectual movement in pursuit of "practical studies" (*sirhak*) extended scholarship into new areas of science and statecraft research. Thus it is not surprising that we see a development which might be called the privatization of cartography, leading to works by individual mapmakers that steadily grew in quality and diversity. Maps were no longer restricted to government offices but were much more broadly distributed throughout society. This resulted in a higher rate of preservation of maps into modern times.

In tracking this greater patronage we can notice two different kinds of map collections: administrative, and popular atlases. The administrative atlas typically would consist of a set of maps of Korea's eight provinces. Each provincial map would show the districts of the province, often with a shapes-and-forces accent that clarified the geographical character of the area. It would indicate principal roads and bridges, post stations and military bases, temples and schools, and other sites of official or civic importance. Distances between towns would be indicated either by notations on the map or in a table in the atlas. Accompanying essays would give a general historical and administrative overview of the province, and lists would be provided showing the rank of each magistracy, with statistics on its tax revenues, military reserves, and various other categories.

The popular atlas often had a similar organization, but it was distinguished by the addition of a general map of the world, or *ch'ŏnhado* (map of "all-under-heaven"), a general map of China, sketchier maps of Japan and the Ryukyu kingdom, and a map of Korea as a whole.

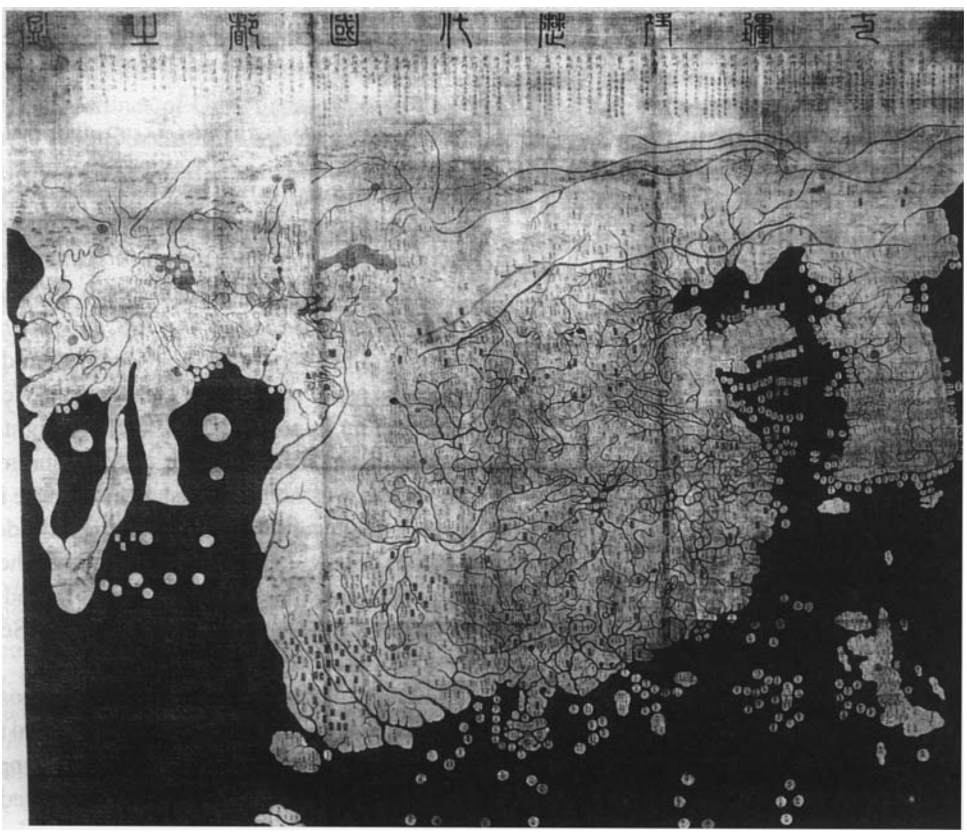
Korean Knowledge of Western Cartography

Jesuit missionaries, led by Matteo Ricci, began to introduce western maps of the world to China in the last years of the sixteenth century, and copies of printed editions of Ricci's world maps of 1602 and 1603 each reached Korea within a year of their publication. In 1708, a royal order was given to copy a variant version of the Ricci map, and this occasioned a Korean essay on Western cartography. Western maps continued to be imported throughout the eighteenth and early nineteenth centuries. A Jesuit-directed summation of mathematics and astronomy published in Chinese in 1723 updated Korean understanding of geographic latitude and explained methods of calculating longitude through the observation of eclipses, and Jesuit determinations of latitude and longitude for major Chinese centers and even for Seoul itself were found in the same source.

In spite of this more than passing exposure to western maps and mapmaking, one can find no visual trace of western influence on Korean maps themselves. An apparently Anglo-Chinese map from the 1790s was even printed by woodblock in Korea, in 1834, by the greatest Korean cartographer of all, Kim Chŏngho, yet Kim's own maps stay completely within the Korean tradition. On the other hand, there is abundant evidence that by the eighteenth century, Koreans were systematically compiling latitude and longitude data for their country, and although no indication of it is found on any Korean map of Korea, a kind of geodetic measurement did play a role in the accuracy of the data used to make the maps.

The Kangnido

The first rulers of the Chosŏn dynasty sponsored a number of projects designed to strengthen their legitimacy. Among these were a recarving on stone of a seventh century Korean star map and a terrestial map of the world. The star map reflected a very ancient Chinese astrographical tradition long superseded in both China and Korea, but the terrestial map, the *Honil kangni yŏktae kukto chi to* (Map of Integrated Lands and Regions and Historical Countries and Capitals) was based on two fourteenth-century Chinese maps. In 1402, Kwŏn Kŭn (1352–1409), a Confucian scholar and royal advisor, was ordered to supervise the compilation of a world map based on these two sources. The actual drawing was the work of Yi Hoe. To his images of China and the greater world, Kwŏn and Yi added Yi's own map of Korea and a recently imported image of Japan, thus, in their understanding, bringing the map to completion (Fig. 1).



Maps and Mapmaking in Korea. Fig. 1 *Honil kangni yŏktae kukto chi to* (Map of Integrated Lands and Regions and Historical Countries and Capitals). By permission of the Ryukoku University Library, Kyoto, Japan.

While this original *Kangnido* was lost long ago, a Korean copy made around 1470 and seized by Japanese invaders in the 1590s has survived in Japan. This copy contains Kwŏn Kŭn's original preface, which details the source materials.

At first glance, the *Kangnido* seems a collection of distortions. China and India make up a dominating, undivided mass in the center, while Europe and Africa hang from the western side and Korea hangs from the eastern as if these two masses were geographically equal. An upended Japan floats uncertainly in the East China Sea. The *Kangnido* was a conflation of other maps, with considerable relative distortion of the land masses, rather than cartography in the strict sense. As the first East Asian map to include Europe and Africa, and such features as the Mediterranean and Black Seas, the Arabian peninsula and the Persian Gulf, the Nile and the Red Sea, as well as to add Korea and Japan on the east, the *Kangnido* is an epochal achievement in Korean as well as world mapmaking.

Popular Cosmography: The Ch'ŏnhado

The *Kangnido* was in Korea too exotic to pass unrevised into the mainstream of Korean mapmaking. The unpronounceable names, in many cases Arabic originals filtered through Chinese transcriptions; the unimaginable distances; strange countries of which in many cases nothing was known – very little of this related to the concept of the world known in Korea. This world was essentially of Chinese definition. It was the *tianxia* (*ch'ŏnha* in Korean pronunciation) or "all under Heaven" that was at peace during the reigns of sage emperors, or that fell into disorder during the rule of bad ones. The geography of this world could be known through the Chinese classics and through the geographical sections and accounts of foreign countries in the long chain of Chinese dynastic histories that began to be compiled in the first century BCE. In addition there was the more fantastic and whimsical geography recorded in the *Shanhai jing* (Classic of Mountains and Seas), the older parts of which date from around the second century BCE but which evoke even more ancient myths and traditions. This source added to the classical geography such imagined places as the "Land of the One-armed," the "Country of Women," "Mount Incomplete," and many more. This mix of ancient historical places and imagined fantastic ones constituted the world that was mapped in the *ch'ŏnhado* (world maps) (Fig. 2).

Although based almost completely on Chinese source material, the numerous examples of *ch'ŏnhado* constitute a completely Korean genre of map. An inner continent dominated by China, with the Korean peninsula always clearly depending from the eastern side, is surrounded by a sea full of kingdoms, which itself is surrounded by a circular land strip with even more amazing places. The eastern and western sides of this ring feature trees near which the sun rises and sets.

The origins of the *ch'ŏnhado* genre are unclear. A number of scholars have believed that these maps were Buddhist in origin, and some have thought that the basic shape of the map could have been derived from geographic theories popularized by the Chinese naturalist philosopher Zou Yan (fl. third century BCE). While morphologically plausible, it is impossible to find any cartographic link over the nearly two millennia that separate Zou Yan from the emergence of the *ch'ŏnhado* in the sixteenth century.

I believe that the core of the *ch'ŏnhado* – its inner continent – evolved from the *Kangnido*. In addition to many geographical and morphological considerations, the Tenri *Kangnido* is also chronologically congenial to this theory, since it contains place names that fix its copying no earlier than 1568, making a plausible bridge to the sixteenth century *ch'ŏnhado*.

Korean National Maps

Under King Sejong (r. 1418–1450), the Korean court pursued a wide range of technical and scientific projects in astronomy, calendrical science, horology, musicology, pharmacology, agronomy, and geography and cartography. Distances between Seoul and the seat of each district, and between the districts themselves, were carefully measured and recorded. Polar altitude observations determined the latitude of the capital and of the extreme northern and southern frontiers, permitting an accurate estimate of the length of the country. Sejong also gave serious attention to the montane structure of the nation, collecting and studying data on the nation's mountain "arteries" and river "veins." King Sejo (r. 1455–1468), Sejong's son and follower, ordered the complete mapping of the country, including not only a national map but maps of each of Korea's eight provinces and approximately 330 counties.

The national map that resulted from this preparation was the *Tongguk chido* (Map of the Eastern Country), which was presented to King Sejo in 1463 by his two chief cartographers, Chŏng Ch'ŏk (1390–1475) and Yang Sŏngji (1415–1482), but is thought to be principally the work of the former. The general outlines of the peninsula's coastline are astonishingly suggestive of those on modern maps, while the shapes-and-forces treatment detailing the nation's mountain network and watersheds provides a rich appreciation of its physical geography. Every district of the kingdom is indicated, along with its distance from Seoul and its provincial affiliation. Equally distinctive is the map's chief flaw, an unduly flattened northern frontier. Early Korean mapmakers appear to have had considerable

Maps and Mapmaking in Korea. Fig. 2 *Ch'ŏnhado* (Map of the World). By permission of the National Central Library, Seoul.

difficulty in grasping the outline of the northern frontier, which was defined by the Amnok and Tuman (internationally, Yalu and Tumen) rivers that respectively flowed off the western and eastern slopes of Mount Paektu. It was not until the eighteenth century that this problem was essentially solved. So for about three centuries the conventional shape of the country was associated with Chŏng Ch'ŏk's outline, and cartographers now refer to such maps as in the Chŏng Ch'ŏk style.

The great summation of the administrative geography promoted by the fifteenth century Korean courts was the *Sinjŭng Tongguk yŏji Sŭngnam* (Complete Conspectus of Korean Territory, newly expanded), which was first drafted in 1481, and went through several revisions before the final one of 1531. Called the *Sŭngnam* for short, this work detailed the administrative history of Korea's provinces and districts. It connected each district to its earliest known organization in earlier dynasties; clarified its rank and position in the administrative and military chains of regional governance; listed its schools, monasteries, Confucian shrines, post stations, signal-fire stations, natural and economic resources, famous native sons and virtuous women; and concluded with a sampling of literature associated with its history and public and private institutions. The final edition of the *Sŭngnam* was so thorough and so well done that it was never supplemented or re-edited.

We know that the cartographer Yang Sŏngji, whose work over the years for Kings Sejo and Sŏngjong (1469–1494) had laid the foundation for the *Sŭngnam*, was well known for his strict views on defense and national security. He argued that maps should not circulate outside of a few designated government offices. These views may have been a factor in the spareness of detail on the *Sŭngnam* maps that appeared later in Sŏngjong's reign. Another important change on the *Sŭngnam* maps concerned the shapes-and-forces treatment. Even the *Kangnido*'s representation of Korea had displayed the principal mountain ranges of the kingdom. But on the *Sŭngnam* maps, shapes-and-forces indications completely disappeared. The reasons for this change are not clear.

During the first half of the eighteenth century there were new developments in the mathematical and observational sciences which had a strong impact on the maps of the later Chosŏn period. Much of this was connected with western knowledge, which had begun to flow steadily into Korea from Jesuit sources in China. Jesuit participation in the national mapping project of the Kangxi Emperor (1661–1722), which took place from 1709 to 1716, brought Jesuit cartographers who were mapping Manchuria to Korea's borders, and in 1713, Jesuit-trained Manchu and Chinese specialists made surveys and observations within Korea itself. The concepts of latitude and longitude, and related observational and mensurational techniques, were clearly described in Sino-Jesuit manuals which were introduced into Korea at least by 1715. A dramatic improvement in spatial representation is found on Korean maps that were developed during the following 30 or 40 years.

The man responsible for this cartographic revolution was Chŏng Sanggi (1678–1752), a brilliant scholar who labored for decades in the privacy of his home. He developed what he called the "hundred-*li* foot" (*paengni ch' ŏk*), a 100-*li* visual scale bar (metaphorically a "foot," I will call his unit a "scale-foot") calibrated in 10-*li* (4.3 km) intervals, which he inserted just after his introduction to his maps. Chinese books of that period specified a ratio of 200 *li* to one terrestial degree of latitude or longitude. This ratio was cited and used by late-eighteenth century Korean mapmakers (although the Korean *li* was considerably shorter than the Chinese), and calculations based on their maps show that they probably followed such a formula to determine geodetic distance. Perhaps Ch'ong Sanggi had used the same procedure.

Shapes-and-forces cartography made a strong return on Chŏng Sanggi's maps, and the vernacular painting style of the day depicted the mountain ranges in an attractive manner that created both cartographic clarity and an aesthetic dimension. A variety of symbols marked military bases, post stations, and other facilities Some copies of Chŏng's map's are works of art as well as cartographic masterpieces. His sons and grandsons continued to be active in cartography throughout the eighteenth century.

The Maps and Writings of Kim Chŏngho

In 1791, the Korean government sponsored the creation of a national grid for the purpose of complete cartographic standardization. While details of this project are uncertain, several albums of local maps copied on standardized *sŏnp'yo* (line guides) survive. Evidently the grid coordinates of each district seat were determined with reference to copies of Chŏng Sanggi maps owned by the government, and then marked on uniform line guides which were sent to district magistrates for development into standard district maps. The detail of these is astonishing. Every river and stream, every principal road and bridge, every public facility and many private ones such as schools, monasteries, and shrines, are indicated.

In 1834, an obscure cartographic genius named Kim Chŏngho (fl. 1834–1864) developed one of these national collections of district maps into a uniform national album, in which he re-edited hundreds of local maps into standard rectangular sheets. This national grid map was called the *Ch'ŏnggudo*, or Map of the Blue Hills, after an ancient poetic sobriquet for Korea.

Kim Chŏngho was himself a professional woodblock carver. It is not known whether he became one in order to market his maps, or began as a blockcarver and branched out into mapmaking. But it is as a blockcarver that he first comes to notice, in 1834, preparing for a famous scholar, Ch'oe Han'gi (1803–1875), a woodblock of a Chinese copy of an English hemispheric map of the world. Ch'oe obligingly returned the favor, writing an enthusiastic preface for the *Ch'ŏnggudo*. But this contact represents the only instance when the Korean world is known to have given any documentary notice to Kim's activities. This is in spite of the fact that in 1861, Kim would produce an even more remarkable national grid map that would bring him enduring fame. He must have been of very humble social status. We have no indication of his ancestry or native place. Traditions speak of endless trips throughout the country to check details and redo existing maps, and of a faithful daughter who took care of him and helped with the blockcarving. The traditional story holds that he was arrested in 1864, supposedly for endangering national security by revealing the nation's geography to potential enemies. But scholars doubt this, reasoning that such a grave incident would surely be reflected in official records, and noting that too many copies of the 1861 map (and of an 1864 recut edition) survive to permit belief that such a thing could have occurred. The 1860s were a time of great tension, with foreign incursions and a large-scale persecution of the country's Catholic community, which had been growing since 1784 in spite of many purges and constant suppression. Could Kim's printing of a foreign map of the world in 1834 have been taken against him? Ch'oe Han'gi, the actual patron of that project, had no problem with this, but then he was an upper-class scholar of influence and repute. Kim had no such insulation, and could have been the victim of petty policemen far down in the official structure. Whatever the reason, he disappeared in 1864 without a trace.

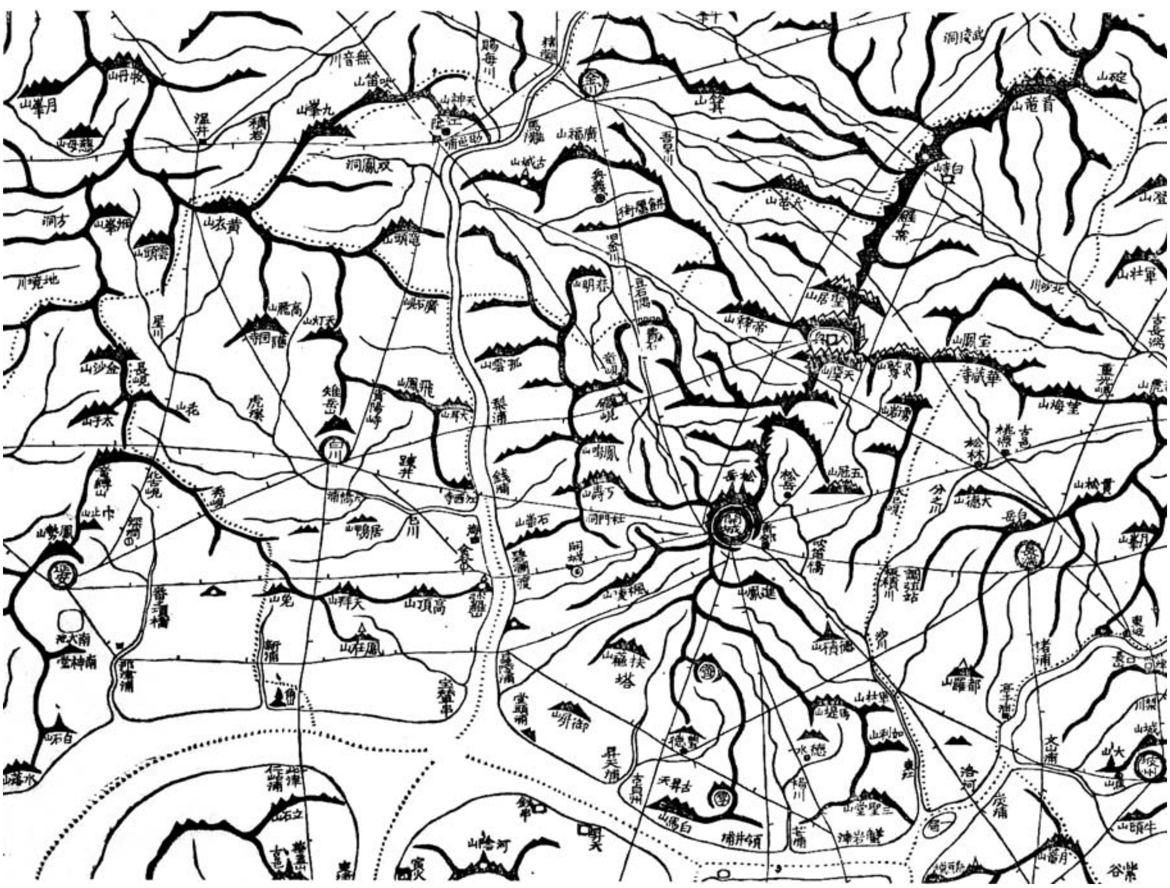
However humble Kim's status may have been, his writing shows that he was an accomplished scholar and a respectable writer of classical Chinese. From 1834 to 1861 his doings and whereabouts are completely unknown. In 1861, under the pseudonym Kosanja (The Master of Old Mountains), a second grid map appeared entitled *Taedong yŏjido* (Terrestial Map of the Great East (Korea)) Fig. 3. Kim's short preface deals mainly with the importance of maps for military affairs.

The *Taedong yŏjido* was a completely reconsidered cartographic image of the country. The shapes-and-forces treatment received here its greatest representation. Mountain ranges were now represented by a solid black line, thinner for lower ranges, thicker for higher ones, with special jagged teeth on the line to represent particularly rugged stretches, or white peaks to indicate snowy heights. The clarity of the overall effect is impressive. With the *Taedong yŏjido*, a complete union of cartographic display and woodblock publishing technique was achieved. Kim seems to have wished to present simply the earth and its natural and human features, with the cartographic structure left, so to speak, underground.

The complete printed *Taedong yŏjido* is likely to have been very expensive. To make his vision of Korea more cheaply available, Kim produced a single sheet version which put the whole nation on a rectangle of about 115 × 76 cm, giving it the title of *Taedong yŏji chŏndo* (Complete Terrestial Map of the Great East (Korea)). The short text that filled the Bay of Wonsan gave the map something of the quality of a patriotic morale poster. After introducing Mount Paektu as "the grandfather of Korea's mountain arteries," giving the dimensions of the seacoasts and northern rivers, and proclaiming the greatness of the nation's legendary founders Tan'gun and Kija, he concluded with his ringing climax: "'Tis a storehouse of Heaven, a golden city! Truly, may it enjoy endless bliss for a hundred million myriad generations! Oh, how great it is!"

The District Map

We have seen that in the late eighteenth century, the Korean government had taken special measures to see that all the districts of the country were uniformly mapped. Although the purpose of this program was to create a national standard, in fact local maps reflected the distinctive features of the district. These highly



Maps and Mapmaking in Korea. Fig. 3 *Taedong yŏjido* (Terrestial Map of the Great East (Korea)). Courtesy of the East Asian Library, University of California at Berkeley.

skilled, uniform maps of districts could not displace the traditional local maps in popularity.

The traditional local map must properly be called a map-painting. It was composed and executed by a practiced painter rather than by a mapmaker, and it set the community into the surrounding landscape in the manner of a landscape painting. The village was seen from a fixed orientation, most commonly with north at the top, and usually in bird's-eye view; roads, rivers, and walls divided up the space in realistic proportions. Distances were indicated by short notes inserted at a focal point in the road. Houses were nestled together in homey elevation, smoke rising from the chimney, a chicken pecking at the ground by the wall. The village well was in its proper place, but visited by ladies and water-boys. The school house with its surrounding pines was a miniature all by itself. In the distance, tucked into the hills, were the familiar shrines and monasteries. In Korean, as in the other East Asian languages, the word for "picture" and "map" was the same, and traditional Korean map-paintings exactly reflected that ambivalence.

City Maps

Seoul was the nation's first city, and was the home of virtually all of the nation's prominent people. Those who lived there seem to have been very fond of maps of the city mounted on folding screens in one of the principal rooms of the house. Although these maps often showed the close urban detail of streets and buildings, one does not get the feeling that those who bought them did so in order to find their way around. The city was large enough so that a bird's-eye view would be unable to reveal the order and scale of its streets and alleys. Thus most maps of Seoul are executed in aerial plan, although the surrounding mountains were characteristically drawn in pictorial elevation.

P'yŏngyang is Korea's oldest city. Once a capital of the ancient kingdom of Koguryŏ, it was always an important regional center in later dynastic days. As the capital of P'yŏng'an Province on Korea's northwestern border facing China, it had great strategic and commercial significance. Maps of the city are commonly encountered and must have always been a popular souvenir. Although maps in aerial plan are known, the favored orientation for its mappers was a bird's-eye view looking toward the city over the Taedong River from the east. More than maps of Seoul, those of P'yŏngyang took on many of the qualities of the map-paintings of smaller towns.

Defense Maps

After the invasions of Korea by the Japanese in 1592–1598 and the Manchus in 1627 and 1637, Korean statesmen adopted policies that put a high emphasis on defense and military preparedness. Thus for the years of the seventeenth through the nineteenth centuries, a great variety of defense maps (*kwanbangdo*) were produced. Most of them are unique and few were ever copied, accounting for the fact that most of those surviving today are original works. Some, such as the *Yogye kwanbang chido* (Map of the Defenses of the Liaoji Area) are vast panoramas that stretch from the northeastern coast of Korea northward toward the Amur River and westward to Beijing itself. Others show particular sections of the northern frontier. There are many having the character of charts that map Korea's coastal areas. There are detailed paintings of mountain fortresses. One sees in these works a great variety of styles, media, and painting skills. These maps, which in their day were in the category of classified information, are now prized for their unique approach to national and international cartography, and in many instances also for their highly stylized and artistic manner of execution.

Though one of East Asia's smaller countries, and always the object of Chinese cultural influences, Korea has had a proud and distinguished tradition of mapmaking all its own, and not a small number of unique cartographic achievements. The *Kangnido* is East Asia's oldest surviving world map, and by world standards at the time of its composition in 1402, one of the best realizations of world geography known from that time. The *Ch'ŏnhado*, though it reflects only Chinese geographic views and source material, is a map that China itself never produced. Chŏng Sanggi's maps of Korean provinces achieved a high standard of cartographic excellence and artistic distinction. Kim Chŏngho produced two great grid maps of Korea, and achieved a standard of cartographic imagination and excellence. Korea's great corpus of maps, now in Yi Ch'an's magnificent album, are deserving of serious attention and the further research efforts of the world's cartographic historians.

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Maps and Mapmaking: Marshall Island Stick Charts

William H. Davenport

The so-called stick charts of the Marshall Islands in the Pacific Ocean are a rare instance in which a kind of cartography was developed in a nonliterate culture. Their designation comes from the fact that they are constructed of slender sticks and twigs, and sticks lashed together into complex patterns. These patterns represent what occurs when mature ocean swells sweep past one or more of the coral atolls that make up the Marshall Island chain. The charts are not carried to sea, but are used as illustrative devices to train young men in the skills of piloting canoes through the archipelago, out of site of land, by noting various swell phenomena.

The basic concepts that are illustrated on the charts are refraction and reflection of ocean swells. When well-defined swells approach a shore they are bent according to the angle the swell line encounters when it reaches shallow water and the shore. This occurs because the portion of a swell slows down as it encounters shallow water, while the offshore, deep water part continues unaffected. This is wave refraction (Fig. 2).

Refraction occurs as long as a swell is in contact with shallow water and with a small roughly circular atoll this may be entirely around it. As a result, the surface waters off the protected side of the island will be confused by the intersections of opposed arms of the refracted swells. Further off the protected shore the swells reform as they continue on their course.

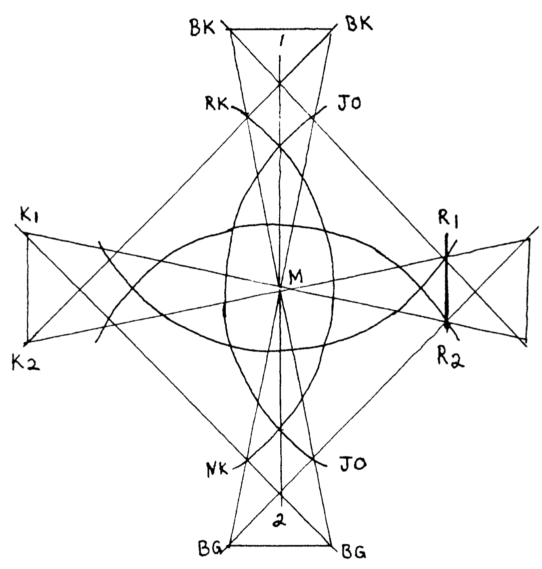
Wave energy is also reflected from a shore line which sends a smaller reflected wave back at a complementary angle, just as light striking a reflective surface or a ball striking a hard surface bounce back.

The Marshallese stick charts represent these phenomena: one or several lines of ocean swells approaching an island, their refracted and reflected swells, and the interactions of these with each other. The stick patterns on a chart can be quite intricate when more than one island and more than one swell system is depicted. In such cases a cardinal direction (rear) is indicated, which is the one generated by the north Pacific tradewind system, *rilib* (backbone), that strikes the Marshall Islands from a northeasterly or easterly direction.

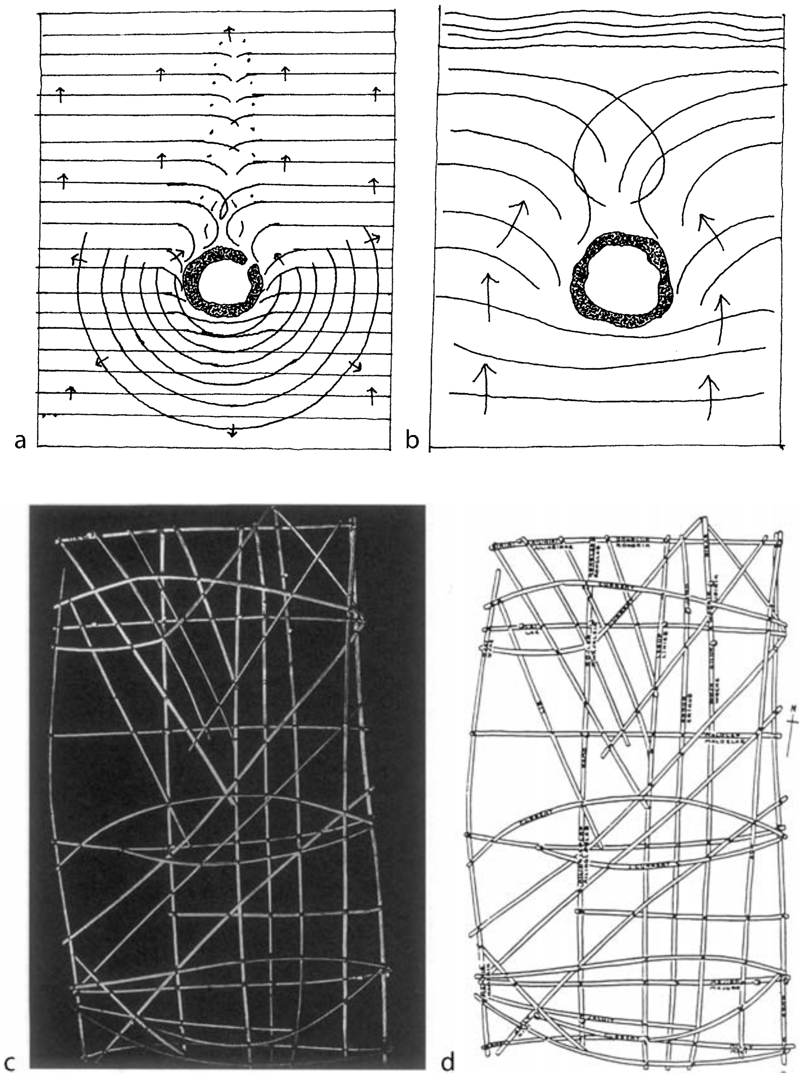
There are three kinds of charts: the *mattang* which illustrates the general principles of swell refraction and the intersection of swell lines; the *meddo* (sea) which depicts the relative positions of more than one island, wave data, and sometimes other pertinent hydrographic information; and the *rebbelith* which is like the *meddo* but includes many islands or most of the group, and has less detailed swell information. Sometimes shells are used to designate islands. There are some indications that the *rebbelith* type may have developed after Marshallese sailors learned about European nautical charts (Fig. 3).

A partial interpretation of the schematic diagram shown here (Fig. 1), taken from an actual *mattang*, will illustrate most of the wave phenomena used by Marshallese navigators. The center intersection of the chart (M) represents any island; at the right the vertical line R/1–R/2 represents the cardinal direction (rear) and dominant east-to-west swell (*rilib*). As *rilib* encounters island M it is refracted, the upper (northern) refracted arm (RK) is called *rolok*, the lower (southern) refracted arm (NK) is termed *nit in kot*. Opposing *rilib* is a weaker west-to-east swell called *kaelib*, both refracted arms of which are termed *jur in okme* (JO). Two other, usually weak, swell systems, one from the north called *bundokerik* (BK), and its opposed system, called *bundokeing* (BG) are also indicated as they are refracted by island M.

At sea where the *rolok* (RK) or *nit in kot* (NK) arms intersect at a certain angle with *jur in okme* (JO) as well as at other similar intersections of reflected and refracted swells their combined energies cause the water surface to peak up in a characteristic way and briefly break, producing a distinctive kind of white cap. This visible sign is called a *bot* (node). The narrow sector of sea in which *bot* are visible is termed the *okar* (root), because it leads to a tree, i.e., to land where trees grow. In the diagram, the line 1–M–2 represents the



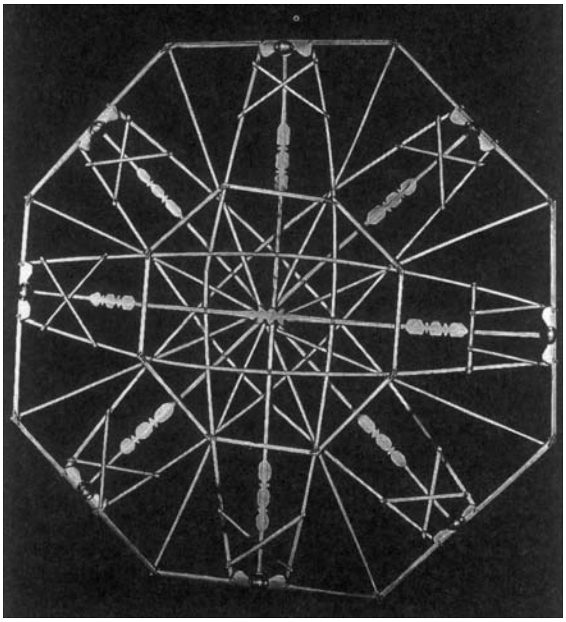
Maps and Mapmaking: Marshall Island Stick Charts. Fig. 1 Schematic diagram of a *mattang* chart.



Maps and Mapmaking: Marshall Island Stick Charts. Fig. 2 a, Wave reflection and refraction around an atoll. b, Wave refraction around an atoll. c, Meddo chart, collected by Robert Louis Stevenson. From the University of Pennsylvania Museum of Archaeology and Anthropology (negative number S8-140153). Used with their permission. d, Key to the Robert Louis Stevenson chart.

northern and southern *okar* of the *rilib* and *kaelib* swell systems. In following the *okar*, the navigator notes the change in angle of the intersecting swells, if the angle increases (because the refraction is greater) he is getting closer to land, and the converse. Usually, however, dead reckoning has been good enough for the navigator to know which side of an island he is on.

It is well to keep in mind that a coral atoll is a very low-lying island, and from a distance the trees growing on it are its most conspicuous feature. Even so, from a canoe, atolls are not visible for more than a few miles away. Actually, there are other useful signs that indicate an atoll over the horizon. Among them are flight directions and patterns of certain birds, high accumulations of overhanging clouds, colored reflections from lagoons on the undersides of cumulus clouds, and floating vegetation, and navigator's rely heavily upon them. However, at night and in situations of poor visibility the information derived from swells can be critical. The Marshallese navigator does not use the information from swells only for making direct landfalls. Rather, on a voyage which passes in the vicinities of intervening islands he can mark his progress toward his destination by noting the reflected and refracted wave signatures of unseen islands as he passes by them.



Maps and Mapmaking: Marshall Island Stick Charts. Fig. 3 Stick chart from a Marshall Islands *mattang* chart. From the University of Pennsylvania Museum of Archaeology and Anthropology (negative number S8-79948). Used with their permission.

See also: ►Navigation in the Pacific, ►Navigation in Polynesia

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Maps and Mapmaking in Mesoamerica

Barbara E. Mundy

When Spanish conquistadores first set foot in Mexico in the early sixteenth century, they found that many of the indigenous peoples they encountered made maps – graphic records of space. Since Mesoamericans had no previous contact with civilizations outside the New World, their mapping traditions developed independently and thus were distinct from those of Europe and Asia. Maps from central Mexico depended upon pictographic writing to convey place names and geographic information, and they were often drawn on native paper or cloth. Frequently, territorial maps would include historical narratives, also written with pictographic symbols. With the Spanish Conquest, the isolation of Mesoamerican mapping came to an end as it came under the sway of European forms and style. However, native peoples have continued using and making maps that are indebted to the native tradition.

Because preconquest Mesoamerican maps were frequently perishable, few such territorial maps survive today. Scholars therefore depend upon eyewitness Spanish accounts of native mapping in the decades after the Conquest as well as "pre-Hispanic-style" maps – those made in the decades after the Spanish Conquest that show little European influence – to reconstruct Mesoamerican mapping in the century or so before the Conquest. Unfortunately, the maps and mapping of earlier Mesoamerican civilizations – the Olmec, the Classic Zapotec, and the Classic Maya – are lost to time.

Nahua, or Aztec, maps are best known because Nahuatl speakers dominated central Mexico at the time of the Conquest. Nahuas also had the greatest degree of interaction with colonizing Spaniards. Many pre-Hispanic-style maps from the Nahua heartland in the Valley of Mexico (the site of the present-day Mexico City) survive. These maps had practical uses within Nahua society. For individuals, Nahua mapmakers carefully measured house lots, orchards, and gardens to make large-scale maps that documented their property. For neighborhoods, they drew up maps so that ward leaders could apportion lands and collect tribute. For towns, they created cadastral records that included individual maps of each family's plot. Not all Nahua maps showed such familiar territory: Nahua military spies mapped the layouts of foreign cities to help army commanders in planning their battles of conquest.

In the densely settled Valley of Mexico, scale-model maps were of some importance. Here, precise ways of measuring plots of land using ropes and measuring sticks were in evidence in the years after the Conquest. Two basic units of measurement coexisted in the Valley: the *quahuitl*, measuring about 2.5 m, and the *cemmatl* (which ranged from 2.5 to 1.77 m). Lines, representing one linear unit, and dots, representing 20, were used as counters. Fractions of the basic units could be shown with glyphs representing arrows (*cemmitl*), hearts (*cenyollotli*), bones (*omitl*), or hands (*cemmatl*). In some maps, area is also calculated and recorded in square *quahuitl*. Such measured precision in maps and specialization among maps may have been unique to the urbanized and hierarchical Nahua.

The Nahua were, however, very much like other Mesoamericans in making community maps, which were perhaps the most ubiquitous maps in the pre-Hispanic world. They are sometimes called *lienzos*, after the Spanish word for "linen," since many are painted upon cloth. These maps often showed the boundaries or extent of territory of a native city–state that the Nahua called an *altepetl*. To make community maps, mapmakers used pictographs arranged on a paper or cloth sheet to mimic the distribution of places and geographic features in space. Mapmakers did not carry out specific measurements of the contours of the landscape, but rather used symbols standing for the names of both places and physical landmarks, placing them relative to each other on the sheet. Thus community maps depended upon a mapmaker's knowledge of names – rather than absolute geography – to define the landscape. These community maps aimed not only to map territory, but also to record history. Given the primacy of the oral tradition in Mesoamerica, the maps may have functioned as mnemonic devices, designed to accompany the historian's account. The map's historical narrative, written in pictures and in pictographs upon the surface of the map, would often tell of a community's travels to reach its present territory. It might also show the battles a community fought and alliances it struck in order to cement its rights to lands. The Codex Xolotl of ca. AD 1540 is perhaps the earliest of such map histories known from the Valley of Mexico; the Mapas de Cuauhtinchan nos. 1–4 are notable map histories made outside of the Valley near the important pre-Hispanic center of Cholula.

The mapping by the Mixtec, who live in the modern state of Oaxaca, centered on community maps similar to those made by the Nahua, their northern neighbors. Since Mixtec communities tended to be small and independent, never coalescing into the complex hierarchical states of the Nahuas in the Valley, they had little need for the same kind of property, ward, and war maps. The community maps they made in abundance brought together spatial records with historical narratives, again recorded with pictures and pictographs. While Nahua community maps focused on peregrination and conquest, Mixtec ones emphasized genealogy – specifically the genealogy of each community's ruling family. In a characteristic community map, the Lienzo of Zacatepec of ca. AD 1540–1560, the boundary markers of Zacatepec's lands are written down with pictographic place names to create an inner frame within a rectangular sheet of cloth. Within this boundary map, the important ancestors of Zacatepec's rulers are shown with figures and named with pictographs.

While the Spanish Conquest inexorably changed Mesoamerican culture, native communities continued to make traditional maps to document their boundaries vis-à-vis those of adjacent communities and to keep records of community history. While these maps are best known from Nahuatl- and Mixtec-speaking communities, other ethnic groups in Mexico had their versions of community maps. Among them were the Otomí, Zapotec, Totonac, Huastec, Chinantec, Cuicatec, and Mazatec. Today, many towns and villages in Mexico still hold community maps. While these maps may have been redrawn and reinterpreted in the past five centuries, their roots remain in the native traditions of the preconquest period.

Less is known about the history of Maya mapping, even though the Classic Maya of AD 300–900 left us a rich record, written in a partly phonetic script, of their dynastic histories. Existing Maya maps from the postconquest period show the heavy influence of European forms and convention. These Maya maps use the European, not the Maya, alphabet to write place names. And other Maya records of territory take the form of written records rather than maps. Such quick conversion of Maya maps to European forms is perfectly understandable: having a writing system of their own, the Maya could easily adapt a foreign one to create territorial records that took a written, rather than a map form. In addition, the few Maya maps that we know of were probably not created to be used among the Maya, but to be presented to Spaniards in courts. Thus the effectiveness of these maps in proving territorial claims was only increased by shedding native conventions and adopting European ones.

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Maps and Mapmaking of the Native North Americans

G. Malcolm Lewis

When considering the topics of maps and mapmaking in native North America, Europeans and nonnative North Americans have until recently tended to treat them as either novel and exceptional or inferior equivalents of their own cartographies. This is particularly so in writings before the last quarter of the twentieth century. Unconsciously but repeatedly, they imposed their post-Renaissance categories in trying to understand facets of cultures epistemologically different from their own. There is no direct evidence that before the encounter and associated acculturation, any of the native North American languages and dialects had lexical equivalents of "map" and the probability of there having been any seems decreasingly likely.

During the last quarter of the twentieth century increasingly rigorous research focused on the artefactual maps past and present, with an inevitable emphasis on those made in the encounter context. For the most part, native North Americans were either unable or unwilling to participate in this research. From their perspective they could claim to have been uninvited and unaware of it. Most of the research was by historians of cartography, untrained in and largely unaware of cultural and social anthropology, ethnohistory, native North American studies, etc. For the most part they saw themselves as contributing primarily to the understanding of a supposedly universal cartography. The materials they studied were surviving native artefacts or, more usually but less satisfactorily, transcripts and accounts made by earlier generations of Europeans and nonnative North Americans. Almost inevitably, there was a tendency to compare and contrast with what they assumed to be the norms established by post-Renaissance cartography. The following text first summarizes their achievements before attempting to detect early twenty-first-century trends and anticipate future developments.

At or soon after their first encounters, Europeans reported that native North Americans made maps. Most of the early reports were of maps made for Europeans to communicate geographical information, as for example a map of the lower Colorado River made by a Halchidhoma Indian in 1540. Ever since, Europeans and nonnative North Americans have continued to solicit and receive geographical intelligence in this way, whether they were explorers, traders, soldiers, settlers, missionaries, government agents, field scientists, or cultural anthropologists. It was, and until very recently remained, an important aspect of frontier information exchange. Natives communicating in this way included men of every social status, less frequently women, and occasionally even children. It occurred in every culture area and in most, if not all, tribes. Because of the publicity given to nineteenth-century Arctic exploration, it has sometimes been assumed that the Inuit were particularly skilled mapmakers. There is, however, no evidence that the maps they made for Europeans were either better or significantly different from those made by Indians.

In the encounter process, most maps were made with pencil on paper. Occasionally, however, more traditional materials were used, e.g., bark, textile, skin, hard animal tissue, three-dimensional models, and even rock. The distinctive characteristics of these encounter maps were, however, neither the media nor the mapmaking processes. Although Europeans were slow to recognize it, the natives' maps differed fundamentally from their own in three important ways. The geometry was topological, a product of cultural tradition, individual experience, the shape and size of the medium, and the purpose for which the map was made. Unlike European maps, it was not a consequence of plotting locations on a graticule selected to conserve particular properties at the expense of others. They conserved neither scale, direction, nor shape, except for very small areas.

The second important difference was in the categorization and magnitudinal ordering of the phenomena represented. Whereas most European maps were general, serving a range of functions and a diversity of users, each native map was made for a specific purpose and audience. These determined content and emphasis and only the essentials were represented. Hence, large physical features occurring within the area mapped were frequently either omitted, diminutive, or highly generalized, whereas small but contextually significant features were included and perhaps exaggerated. Thus, a large, complexly shaped lake might be represented by a simple circle, ornamented perhaps by a detailed representation of one culturally or contextually significant peninsula. Similarly, an essentially straight line might represent a long, complex, maritime coastline.

The third important difference was in the natives' use of pictographs as the approximate equivalent of the Europeans' combination of words, toponyms, and conventional map symbols. Pictographs were constructed according to culturally established principles to communicate complex mixes of information about size, importance, number, relationships, time, distance, direction, and events, as well as material and organic phenomena. Richer and far more flexible than the symbols on European maps, their information content was rarely intelligible to the aliens. Indeed, when, as they so frequently did, European's copied natives' maps, they often omitted or generalized the pictographic content. Regrettably, most extant examples of encounter maps are contemporary transcripts or, worse still, printed engravings: a small, debased sample of the many that were made, now scattered in archives, museums, libraries, government departments, and private collections in Europe as well as North America. Nevertheless, in their time, this type of native map served the aliens well; they helped them to open up their *terrae incognitae*, locate resources, plan military campaigns, etc. Though usually unacknowledged, they were frequently incorporated into the first generation of maps made by the aliens. Sometimes, misinterpretation and insensitive incorporation resulted in gross errors on maps made by Europeans, as with the Great River of the West, the Long River, and the gross westerly displacement of the mouth of the Mississippi River on printed eighteenth-century maps.

For some parts of the non-Eurasian world there is uncertainty as to whether precontact natives did or did not make maps. Each culture had a strong oral tradition, an important part of which was concerned with landscape, place, and spatial relations. Place – and feature – names were the "survey pegs" of spatial memory. This was almost certainly so among pre-Columbian North Americans, but there is considerable direct and indirect evidence that they also expressed their oral maps cartographically. For example, in 1540, Francisco Vásquez de Coronado discovered a painted skin in an abandoned Zuni pueblo. The pueblo was the first of the Seven Cities of Cibola ever to be seen by Europeans, and the painting represented their relative sizes and a route, probably the one linking them. Although difficult to date, much, if not most, North American rock art predates contact with Europeans. A very small proportion of these works have map-like appearances, at least when viewed from the European cultural perspective. Lacking texts, however, and in the light of the characteristics of native maps as now known, proof is difficult. Establishing similitude between a topological representation and its referent is much more difficult than for a projectively constructed map. Some celestial paintings on the roofs of rock overhangs in the Southwest undoubtedly represent exceptional astronomical juxtapositions known to have occurred at precisely established dates in pre-Columbian times. Others, like Map Rock, Idaho (a name given by the earliest white settlers in the lower Snake valley, because the engraving on it looked to them like a map), do appear to represent topologically and pictographically the pattern of geographical features in the regions in which they are sited. These, however, are exceptional cases and irrefutable evidence for terrestrial maps in precontact rock art has still to be established, though the case for plans of small areas and features is much stronger.

Ironically, the strongest evidence for mapmaking in precontact times is afforded by very early postcontact accounts by Europeans of the indigenous use of maps, usage of a kind that could not have been derived from European practices. It is debatable whether at the time of first contact any of the native languages contained nouns equivalent to map, though at later stages many of them certainly did. Nevertheless, some Indians certainly possessed an ability to read network patterns as maps. Montagnais and Naskapi divination by scapulimancy involved inducing random patterns of cracks by heat or percussion on mammalian bones, and these were sometimes interpreted to be maps of actual river systems. Likewise, the women of these tribes sometimes read as trail networks patterns made by biting folded pieces of birchbark, especially when the patterns had emerged in mistake for something else intended. Maps inscribed or painted on the inner surface of birchbark (or on growing trees from which the bark had been conspicuously stripped) were frequently positioned at conspicuous or strategic sites in the Northeastern forests to convey to friends – and sometimes enemies – spatially organized information about recent events or planned activities. There are accounts of maps being made by older men to instruct young braves about to undertake long journeys for the first time. Map modeling with whatever materials were at hand was sometimes a cooperative activity, at its best leading to a geographical consensus prior to military plannings and strategic briefings. Cosmological maps were common and usually combined geographical with mythical elements, the former most frequently near the center. Where geographical features were endowed with religious meaning, they might be topologically displaced. For example, on Lakota maps of the Black Hills, the Devil's Tower, located 60 mile to the northwest, was placed within the so-called Race Track that circumscribed them. Southern Ojibway birchbark midé-migration scrolls preserve the tradition as to how the tribe received its religion: from the east via a great waterway. At the left end of some of the scrolls, the waterways of part of Minnesota are readily interpretable. A little to the right, Lake Superior is highly stylized, but further to the right (east) it becomes increasingly difficult to relate the linework to the Great Lakes–St Lawrence River waterway.

By the beginning of the twenty-first century understanding of the nature and roles of native North Americans maps was diversifying. There were at least three reasons. First, and most importantly, the ferment of ideas generated by Columbus' quincentenary scholarship had begun to influence the field. Secondly, scholars outside the field were focusing attention on often long-known but superficially less map-like evidence, especially behavioral, including ceremonial. Thirdly, least obviously, but hopefully in the longer term most importantly, a younger generation of researchers was beginning to emerge, of which some were native North Americans. It is still too soon to predict all the consequences of these factors but overt recognition of the following would seem to be very likely:

1. Native North Americans often expressed spatial arrangements other than graphically on flat surfaces.
2. Even when expressions of spatial arrangements were graphical, their geometry was not even approximately Euclidean.
3. Spatial arrangements were often expressed in nonmaterial modes, e.g., speech, gesture, and ceremony. Others in material modes were hitherto unrecognized except by a few specialists, e.g., landscape design and architectural space.
4. A given spatial expression was not necessarily restricted to one discrete world of European epistemology – geographical, celestial, or cosmographical, as reconstructed or remembered from the past, perceived in the present, or envisaged in the future. It could include elements of two or more of these.
5. The determinants of silences in a spatial expression were neither of scale nor metrical magnitude but unimportance in the context of the specific purpose for which it was made.
6. Like all their spatial expressions, geographical maps made for Europeans and Euro-Americans were always made for a specific purpose but they were the graphical components only of a much richer multimode repertoire. Behavioral modes, if any, used in conjunction with them were either misunderstood by or unintelligible to the aliens and were either unreported or misreported.
7. Woodward and Lewis (1998) have provided a platform on which to base comparative studies of native North Americans' maps with those of traditional peoples elsewhere.
8. Geographical Information Systems (GIS) technology will become a powerful tool in studying the geometrical structure of native North Americans' graphical maps.

Most native maps represented relatively small areas and/or were linear, but a few embraced areas as large as one-third of a million square miles. The information upon which a map of a very large area was based could not have been derived from the direct experiences of an individual or even the cumulative experience of one group. Most of the content must have been based on information received by gesture and speech, perhaps over several generations.

Potentially, at least, maps made by native North Americans are significant in four broad contexts: legal, historical, anthropological, and scientific. Though lawyers have been slow to recognize it, an understanding of the fundamental differences between native and Euro-American maps helps, in some cases, to explain disputes between the two cultures concerning treaty and land sale agreements. Likewise, but with a few notable exceptions, archeologists and historians have been slow to recognize the significance of maps made by natives in such contexts as exploration, mapping, locating resources, place – and feature – naming, etc. Similarly, cultural anthropologists have been slow to explore the relations between maps and other graphical forms or to use them as evidence in establishing worldviews, reconstructing lifestyles, etc. Scientists, including linguists, have not even begun to recognize their potential significance in such contexts as human cognition, genetic epistemology, information exchange, language, categorization of phenomena, etc. These failures stem, in part, from the absence of a cartobibliography to the primary materials. Furthermore, scientists remain unaware of the now considerable body of secondary publications that, for the most part, is confined to the literature of the humanities.

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Maps and Mapmaking in Asia (Prehistoric)

CATHERINE DELANO SMITH

There is plenty in Asian prehistoric art to interest the historian of cartography. It is sometimes difficult to draw a line between a picture of a place and a map of a place and it is, of course, impossible to know the original meaning of any graphic representation made in the period before writing. Nevertheless, there is a great deal of evidence that prehistoric people had both the mental capacity and the communicative and graphic skills to make maps. Such depictions were made on a variety of surfaces and in various ways but most commonly as paintings or engravings (petroglyphs) on boulders, rocks, cave walls, and cliff faces as well as on artifacts (bone, pottery, bronzes, etc.).

The earliest recognizable representation of spatial relationships involves: in Asia as in Europe, a continuous line – representing a boundary or enclosure – within which an event (animal trapping or herding, people standing or dancing) is taking place. For example, a painting on the wall of a Mesolithic rock shelter in Bhimbetka (Madhya Pradesh, India) shows, in profile, a family group mourning a dead child. The scene is placed in a hut, or some special place, which is represented by the encircling line. Similarly, a rock-carved enclosure from Mongolia (Bayan Khongor Province) provides a close parallel with enclosures in the Paleolithic art of the Franco-Cantabrian region of western Europe that have been identified as "hut or game enclosures." Yet another Asian parallel comes from Armenia. In this case, the enclosure depicted, possibly as early as the third millennium BCE, bears a marked resemblance to an early historic petroglyph from Jordan carved into a large stone with a text on another side referring to the enclosure as an animal pen.

Picture Maps

In all these examples, only one element of the composition, the enclosure, is rendered in plan (i.e., viewed from above); all other figures – persons, huts, and animals – are shown in profile (i.e., as seen from ground level). It is the defined space of the enclosure, however, that provides the cartographic key, the intended spatial relationships of the figures. These spatial representations are very simple as graphic compositions. Nevertheless, they contain the essence of a map and can be thought of as simple picture maps. In contrast, one of the most detailed prehistoric depictions of a village fails to meet the criteria for even a picture map, for there is nothing in it to suggest the critical *spatial* element. The petroglyphs in question, the Boyar *pisanitsas*, are found high on a cliff near Minusinsk, overlooking the Yenesei River in Siberia. They are thought to date from the last millennium BCE. The main assemblage is nearly 10 m long but nowhere in it is any feature or figure shown in plan. Nor is it easy to be certain, especially in the absence of an enclosure or frame, that the array of huts and scatter of human figures were created as an assemblage and are not merely a palimpsest of engravings made on quite different occasions, perhaps separated by long intervals of time.

However, another highly detailed rock painting, one of many on the cliffs at Cangyuan (Yunnan Province,

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China) dating from the last millennium BCE, can be thought of as a picture map. Not only are the huts neatly and obviously deliberately positioned along the perimeter of a circular enclosure, but also their arrangement is topologically consistent: the huts on the far side of the enclosure from the viewer have been drawn upside down in order to maintain the relationship between the piles supporting each hut and the line that represents the village boundary or fence. Other lines project from the central enclosure like paths and indeed there are figures, human and animal, shown in profile, walking along them.

Plan Maps

The identification of objects and landscape portrayed from above is always difficult and the more so in rock art where all external evidence is lacking and diagnosis has to rest on intrinsic visual characteristics. However, the visual similarity between certain landscape features, when viewed from high above (i.e., in plan) and some of the rock art found in Asia, suggests that such examples were intended to be mimetic. Thus, included in the assorted petroglyphs of Mugur Surgol (upper Yenesei) are representations of the local herders' huts (yurts) and their surrounding stockyards. Four different sets of rock markings – "map signs" – are involved: solid outlines (squares or rectangles), rectangular outlines with internal subdivisions or compartments, rectangular outlines filled with stippling, and empty outlines, also rectangular or subrectangular. Each of the petroglyphs in question usually comprises one solid or compartmentalized shape and one or more stippled, or empty, rectangular or subrectangular shapes. These assemblages have been interpreted by archaeologists as plans of the Mongolian-type yurts found among the local Tuva, together with the yards and enclosures around them. Similar "hut and yard" markings are found in the Altai Mountains. All these are strikingly like those dating from the end of the Neolithic and, especially, the middle Bronze Age (third and second millennia BCE) found in the western Alps, as for example in Mont Bégo, France. Another category of plan map is more typical of Mongolian rock paintings. In these, assemblages comprising relatively large rectangles, usually stippled within, associated with human or human-like figures and the outline of a bird (eagle) with wings outstretched, have been interpreted as representations, rich in religious symbolism, of local graves, again as seen from above. This style of burial is known to be ancient and both graves and grave plans may date from the late Bronze Age.

Celestial Maps

Given the long history of astronomy in many parts of Asia, prehistoric representations of at least the major constellations might be expected. Certainly by the end of the last millennium BCE, the period of the Han Dynasty in China, the use of "ball and chain" patterns to represent groups of stars was evidently an already established tradition. Fully fledged prehistorical celestial maps, however, have yet to be discovered, in the literature or in the field. There are indications of what is to come. In 1990, the discovery of a very early historical map painted on the vault of a tomb was reported (*The Times*, 1 February 1990). It shows the heavens divided into 28 lunar mansions, seven for each of the cardinal points, which are personified as a Daoist deity. The map, executed in pastel polychrome, matches the description given by the Han historian Sima Qian (ca. 145–87 BCE). Elsewhere in Asia, representations of constellations, as well as "ingenious calendars" and the solar and lunar motifs associated with cosmologial myths, are said to be common in the rock art of Armenia. This rock art dates largely from the third millennium BCE, the date also of an astronomical observatory that was excavated at Metsamor (Armenia). Similar motifs may also be found in the pottery decoration of the period.

Cosmological Maps

It would be surprising if cosmological maps were not proven to be by far the most important category of Asian mapping in prehistoric times, just as they have been throughout the historic period (prior to European involvement). A preoccupation with the origin and structure of the universe, and above all with the afterlife and its location, is a fundamental attribute of human life – a manifestation of humanity's "cosmic anguish." Most, if not all, prehistoric rock art would have been associated with religion, and much of it must have reflected various aspects of local belief. Those responsible for the paintings and peckings, often made in virtually inaccessible places, would have been shamans or members of a priestly élite. One notable characteristic of prehistoric rock art, in Asia as in Europe, is its concentration into what are best seen as former ritualistic or holy places, on or at the base of a particular mountain peak, in or within a close radius of a high mountain pass, for instance, or associated with burial places. Thus the "hut and yard" maps should be seen as a record of a fossilized prayer, perhaps for the safety or prosperity of the homestead and its inhabitants, and represented as an icon rather than as an exact configuration of a nearby homestead, yet to be uncovered by archaeologists. As the Chinese tomb painting already described demonstrates, celestial cartography and cosmological cartography often overlap in their religious significance. Individual cosmological motifs are widespread in Asian rock art, such as those relating to the structure of the cosmos (the Tree of Life or *axis mundi*) or to access to the next world (boats, ladders).

They are also found in certain types of decoration, such as the bronze drums from Borneo and other parts of Indonesia. However, examples of cosmological maps from the prehistoric period, as opposed to these individual motifs, are few. One Mesolithic rock painting from Madhya Pradesh, India, is thought to represent, with its three bands, the three parts of the cosmos (water, air, and earth).

At present, information about rock art in general in Asia is both chronologically and geographically patchy. Some localities – for example in central and southern India, the peripheral provinces of China and Mongolia, the upper reaches of the great rivers of Siberia (Ob, Yenesei, Lena, Amur), around the high passes of the Pamirs, and the mountains of Armenia in the vicinity of Uchtasar – are comparatively well known, but such regions are separated by vast areas of ignorance, either through lack of exploration or through lack of reporting, especially in literature accessible to western scholars. Undoubtedly, though, future research and the wider reporting of new discoveries will yield a wealth of prehistoric maps and map-like representations throughout most of Asia, characterized by strong regional traditions, most of which will have a close counterpart elsewhere in the world.

See also: ►Maps and Mapmaking: Celestial East Asian Maps, ►Lunar Mansions in East Asian Astronomy

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Maps and Mapmaking in Southeast Asia

Joseph E. Schwartzberg

Indigenous maps from Southeast Asia were drawn for a multitude of secular and religious purposes and exhibit remarkable diversity in respect to medium, style, and content. Even within individual countries and cultures the surviving cartographic corpus is likely to be quite varied, though Burma and Vietnam were moving toward a national style in recent centuries. Broadly speaking, maps fall within four main traditions:

1. Tribal, for groups that never came under the cultural dominance of the great traditions of Hinduism, Buddhism, or Islam
2. Hindu–Buddhist, for cultures primarily shaped by influences emanating from India
3. Sinic, for the Vietnamese
4. Malay, for Islamicized peoples in what are now Indonesia and Malaysia

The number of surviving maps is great for Burma and Vietnam, and relatively few for Thailand (largely because of the Siamese tradition of purging documents that were no longer of current utility), Cambodia, Indonesia, and Malaysia. For Laos and the Philippines, indigenous maps are not known to exist. The corpus of known indigenous maps, however, is not a reliable guide to past cartographic output, since the accidents of preservation and documentation depend in large measure on the attitudes of colonial powers and individual scholars with respect to indigenous culture. It is likely that many maps still await discovery, especially in Buddhist temples and monasteries on the Southeast Asian mainland.

Tribal maps are documented mainly for the Sakai, an isolated Negrito people of West Malaysia, the Bataks of Sumatra, and various Bornean groups collectively known as *Dayaks*. For all of these the traditional medium was bamboo, into which designs were etched to create the map image. For the Sakai the mapped images served as magical charms to help insure success in hunting, fishing, and other activities in the places depicted or to ward off diseases and natural hazards associated with those places. Batak maps were mainly cosmographic or divinatory. Dayak maps, the most recent of which are exceedingly vivid designs on paper (supplied and preserved by missionaries), relate mainly to mortuary cults and relate to routes taken by the dead to reach the netherworld or the upper world and to the activities that take place therein. Dayaks also had a system of reading pigs' livers as if they were maps to discern auguries of good or bad outcomes for contemplated actions in particular places. There are no reliable guides to when mapping commenced among Southeast Asian tribal groups.

Hindu–Buddhist maps were drawn on palm leaf, indigenous bark paper (often assembled accordian-style in long folding manuscripts), cloth, and other media. In dealing with maps in this tradition it is necessary to distinguish between essentially religious and secular productions. The former are largely cosmographic, most depicting all or part of the Buddhist cosmos. Maps of the terrestrial plane, centered on Mount Meru, the *axis mundi*, generally utilized a planimetric perspective. Those that also showed the manifold heavens

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and hells normally depicted the universe as if seen mainly in frontal elevation, but sometimes rotated the horizontal terrestrial plane 90° so as to maintain the traditional planimetric view for that region. Other Meru-centered maps show the mountain and its seven rings of surrounding mountains in vertical profile. One such depiction, more than 10 m in height, is carved into a cliff in Central Myanmar (Burma). A sumptuously illuminated cosmographic narrative, quite popular in Thailand, is the *Trai Phum* (Story of Three Worlds, *Traībhūmikathā* in Sanskrit). This work, compiled in ca. 1345, is a variant on the Jataka tales, relating to the past lives and wanderings of the Buddha. It has gone through a number of recensions and exists also in modified form in Myanmar and Cambodia. The longest manuscript, dating from BE 2319 (AD 1776), provides a continuous picture on 272 folding panels with an overall length of 32 m. Six of these panels depict Asia from the Arabian Sea coast to Korea. No surviving manuscript predates the sixteenth century. Hindu cosmographies were probably also painted in Southeast Asia, but apart from one attributed to Cambodia, none is known to survive on the mainland. Complex cosmographic works, however, continue to be made in various media in Bali.

The oldest known geographic map in the Hindu–Buddhist tradition, dating from the late seventeenth or early eighteenth century, is a long folded-panel work showing ecclesiastical and other property holdings in what is now southern Thailand. Thereafter, there is a long hiatus in Siamese secular cartography, but the period of the Chabri Dynasty, 1782–1851, saw a following of mapmaking under royal patronage. Maps then produced were mainly topographic and covered much of Southeast Asia. Some related also to maritime commerce, one extending as far as Japan, while others were strictly military. The maps were painted both, incorporated many standardized conventions, and were often quite large, the largest measuring S17 by 416 cm. (roughly 16 × 14 ft). Known Burmese secular maps do not predate the latter half of the eighteenth century. But one may safely assume that the mapmaking was by then a well-established art. Numerous maps, many covering rather large areas, were drawn for Francis Hamilton during his sojourn in Burma in 1795 and attest to the geographic sophistication of educated Burmese at that time. During the nineteenth century, if not earlier, the Burmese state engaged official surveyors and cartographers. Maps on European paper and cloth became increasingly common with the passage of time. Burmese maps were drawn largely for military and political intelligence purposes, sometimes to plan or to document specific campaigns. Others, showing property holdings and types of land use, were used for purposes of taxation. Many were used as aids for laying out new cities, monastic complexes, irrigation systems, and other public works. A common feature of Burmese maps was the use of a regularly ruled grid, very likely to transfer a sketch from one scale to another, though maps were never drawn to a uniform scale. Many of the maps from what is now Myanmar were actually drawn by ethnic Shans (a Thai people) and other ethnic groups within the Burmese political orbit. From insular Southeast Asia, only one presumably geographic map in an essentially Hindu tradition is known. Drawn on a batik shawl, this ornate and enigmatically patterned work probably dates from the early nineteenth century. It has no text, but is believed to relate to the former princely states of Surakarta and Yogyakarta, which, though ruled by Muslim sultans, maintained a largely Hindu court style.

Vietnamese cartography was mainly secular and, as in Burma, drawn for the military, administrative, and other political needs of the government. (Cosmographic maps did exist, but these were mainly in the Hindu–Buddhist tradition previously described.) The oldest textual references indicate that secular maps existed as early as the late eleventh century, though mapping appears not to have become a serious concern until the government was reorganized along Sinic bureaucratic lines some four centuries later. Thereafter, the map style was a regional variant of a general Sinic tradition, though changes were evident from one period to another. Many of the maps were bound, after the Chinese fashion, into atlases, which, with their abundant text, served also as gazetteers. The oldest atlas, made in the 1270s, related to a royal inspection tour of the then relatively circumscribed Vietnamese state, but it does not survive and its form is not known. In addition to atlases and regional maps, the Vietnamese drew route maps, maps of river systems and coastal maps to facilitate navigation; city plans, some of which were remarkably detailed; maps of individual forts and other edifices; and maps documenting tribute missions to the Chinese court in Beijing.

Surviving maps from the Malay cultural realm, though few in number, are quite diverse. The oldest, dating from the late sixteenth century, is a large cloth map covering the western third of Java. Most of the map space is given over to the depiction of the small chiefdom of Timbanganten, whose prince commissioned the work. The symbolization on this map is particularly distinctive and has no close analog in any other known work. All the remaining maps show varying degrees of European influence. A map of the Bornean Sultanate of Pontianak and another of part of East Central Java apparently related to administration and/or taxation. Others related to navigation and trade. One shows ports and commercial products of the Malay Peninsula. The others, covering most of Southeast Asia, are detailed hydrographic charts, copied onto cowhide, from an early nineteenth-century Dutch original, but with adaptations indicating independent depth soundings and new coastal observations.

These maps were drawn and used by wide-ranging Bugi pirates and contain abundant text written in the Bugi script, though Roman numerals were used to indicate ocean depths. Apart from the surviving nautical maps, there are textual and other grounds for supposing that Indonesians made use of maps in long distance navigation prior to the advent of Europeans in the region.

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Maps and Mapmaking in Tibet

JOSEPH E. SCHWARTZBERG

For purposes of this article Greater Tibet includes not only the present Autonomous Region of Tibet, within China, but also the Chinese provinces of Qinghai and Sikang, the Indian regions of Ladakh and Sikkim, much of Nepal, and Bhutan, which have all been, greatly influenced by Tibetan Buddhism and other aspects of Tibetan culture. Despite its small population, this region has given rise to a remarkably rich and varied cartographic tradition. Moreover, that anciently rooted tradition still survives, despite attempts by the West, China, and India to impose political and cultural hegemony over the lands of its development.

Given the pervasive role of religion in Tibetan culture, it is hardly surprising that maps serving a variety of religious functions form the greater part of the region's cartographic corpus. These are commonly painted on cloth *thaṇkas*, which frequently occupy a focal position in family and monastic altars. The most abstract of Tibetan religious maps are *maṇḍalas*, which are regarded as representations of the cosmos and serve as objects of meditation for clergy and laity alike. These assume many forms, in both two and three dimensions, and utilize a wide range of media. Elaborate *maṇḍalas* fashioned from colored sand or carved in yak butter may be created over a period of weeks, but are kept for even less time than it took to construct them, thereby demonstrating the transience of all earthly existence. Many cosmographic maps were divinatory. Others were didactic, for example, paintings of the *bhāvacakra* (wheel of life) depicting the various realms of existence through which souls may transmigate on the path to *nirvāna* (the ultimate aim of existence in which the soul is liberated from the painful round of rebirth). Other forms of didactic painting are essentially hagiographic, showing various incarnations of the Buddha, *bodhisattvas*, or revered lamas surrounded by collages of sacred landscapes depicting particular places associated with their existence, both on earth and in nonterrestrial portions of the Buddhist cosmos. Though largely mythic, such places are often shown with a considerable sense of verisimilitude. Maps showing the cosmos as a whole or major portions of it are numerous. Some of these are large mural paintings. A particularly vivid set of fresco murals in Bhutan shows the evolution of the cosmos as a succession of disaggregations of terrestrial and extraterrestrial elements in space–time as described in various Indian and Tibetan Buddhist texts dating back to the fifth century. In these and many other cosmographic maps Mount Meru, the *axis mundi*, and four principal surrounding continents in the terrestrial plane figure prominently. Maps of other continents are also painted, two of particular note being Sukhāvatī (the Western Paradise) and the mountain-girt utopian realm of Śambhala (whence James Hilton's "Shangri-la"). Bards used to wander about Tibet illustrating stories of the way to Śambhala with map scrolls on which routes began in recognizable places, but led ultimately to mythic space. To devout Tibetans, however, the distinction between the real and the mythic would seem a false dichotomy.

Geographically identifiable locales do figure prominently in Tibetan religious maps. Many show individual religious edifices and centers such as the Potala and Tashilunpo, the residences of the Dalai and Panchen

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Lamas, respectively; Lhasa and Shigatse, in which those two residences are, respectively, located; or Samye, Tibet's oldest monastic complex. Others show sacred landscapes in which groups of such centers, especially those proximate to Lhasa, are clustered. Some maps focused on Mount Kailas, in western Tibet, viewed as the earthly manifestation of Mount Meru, around which a complex of sacred pilgrimage places developed. Large sacred maps were displayed along the walls of the monasteries where they were held during certain holidays, when pilgrims would flock to major religious centers. One such painting, displayed annually in the Nepali town of Patan, has a length of more than 25 m and provides a rich panoramic view of the Vale of Kathmandu. Maps were made not only to serve the needs of pilgrims, but were also commissioned to commemorate pilgrimages completed. A particularly beautiful example, dedicated in AD 1802, depicts the patron and his entourage at many of the major pilgrimage places in central Nepal.

When Tibetans began to make maps is not known, but the roots of Tibetan cartography run deep. One of the most remarkable maps, depicting the anciently known world, appears in a modern recension of a dictionary of the Zang Zung language (probably Indo-European), formerly spoken in western Tibet. Though the places shown, reaching as far west as Egypt and Greece, were compressed into the form of a rectangular *maṇḍala*, thereby losing much of their geographic logic, most could be related to the period of Alexander the Great (late fourth century BCE). The map itself focuses on Parsogard, the Achaemenid capital from 550 to 522 BCE. There are grounds to believe that some version of this map was transmitted from antiquity to the present, despite the fact that no premodern version is known to survive. Another simpler, but equally cryptic, surviving world map was brought to Japan in AD 891.

Apart from the two world maps just noted, one map of Nepali provenance (but stylistically akin to Tibetan maps) covers a very large region of Central and Southwest Asia, with western limits at Baghdad and the Russian city of Saratov, on the Volga River. It has been argued that this map was commissioned ca. 1860 in relation to a contemplated, but never consummated, grand alliance to drive the British from Asia. This richly detailed map, despite its late date, includes numerous features that are essentially mythic.

A remarkable series of maps is that of the so-called Wise Collection in London's India Office Library. Wise's identity has not been established; but there are grounds to believe that the maps were prepared by Buddhist recruits (later dubbed *pundits*) from India's Himalayan territories who traveled over much of Tibet in disguise to gather intelligence. British training notwithstanding, the style of these maps is distinctly Tibetan.

With the aforementioned exceptions, regional maps from Tibet seldom cover more than a few thousand square kilometers. None is known to predate the late eighteenth century. As a group, the maps in question are remarkably detailed and utilize a well-developed set of symbolic and color conventions. They typically combine diverse perspectives: planimetric, high oblique, and frontal, depending on the features shown. Important buildings are sometimes shown as if seen from several sides simultaneously. There is no consistent orientation. Regrettably, only a few Tibetan maps have yet been studied as such by scholars with the needed cultural sensitivity and linguistic skills.

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Maps and Mapmaking in Vietnam

John K. Whitmore

The tradition of mapping began in Vietnam just over half a millennium ago. As the state of Dai Viet, led by the young king Le Thanh-tong (1460–1497), adopted the administrative model of the Ming dynasty in China and became more centralized, mapping served as one of the procedures to that end. The new bureaucratic structure placed officials in the provinces and districts and ordered that these officials gather and relay information to the capital of Thang-long (now Hanoi) on the land and people within their jurisdictions. Maps were part of the required information, and they led eventually to an atlas covering the entire country. This atlas and its maps in the Chinese mode set the pattern of administrative cartography well into the nineteenth century.

The same reign also saw the extension of Vietnamese territory to the south as Thanh-tong crushed the forces of Champa in 1471. A map showing the stages of the expedition became the model for military and commercial cartography in the following three centuries. As these centuries were a time of military and commercial expansion, particularly of the *Nam Thien* (Southern Push) further down the east coast of mainland Southeast Asia through Champa and into Cambodia, this style of map came to reflect the dynamics of the Vietnamese population.

International contacts in the late eighteenth and early nineteenth centuries led to a new style of administrative mapping which combined a more realistic Western (particularly French) style with stronger Chinese elements. Yet, by the end of the nineteenth century, as French colonialism controlled the Vietnamese state, there appeared a shift toward a more complete Sinic [Chinese] mode of illustrating maps.

No technical study of Vietnamese maps based on the original documents exists. Looking at reproductions, mainly in black and white, yields the following observations. The maps available to us are almost entirely hand drawn in black ink, some with added color to emphasize their features. Only in the mid-nineteenth century did printing begin to play a major role in cartography here.

The earliest extant map, most likely from the sixteenth century, is quite simple in form and style. Lines were drawn to show the rivers and the land separating them. Nothing indicates water in the streams, and the standard Chinese three-ridge pattern for mountains served to suggest the highland regions above the plains. Names (in Chinese characters) marked location with no other symbol employed.

This changed in the seventeenth century as the earliest existing major corpus of indigenous maps appeared. They had become more artistic. Water was drawn in the streams and off the coast (river currents and roiling sea waves). Mountains retained the same style, but more accurately designated Vietnam's uplands. In addition, palaces, temples, and walls appeared (in frontal elevation), while jurisdictional locations were marked by written characters in rectangular boxes with little sense of hierarchy among them. Other characters showed the locations of natural features and additional human constructions.

In the eighteenth century, Vietnamese cartography took on in places a more artistic and Sinic mode. This change appeared particularly in the style of portraying the mountains. In place of the simpler three-ridge style, there came to be a more naturalistic landscape mode which well fit the vertical karst topography of northern Vietnam (and southern China). In addition, waves lapped on the shore, and temples and walls received a more Sinic treatment. The maps were drawn in black ink with colors (red, gray, and blue, for example) used to highlight roads, buildings, and mountains.

The nineteenth century saw more sophisticated international influences appear in Vietnamese mapping. Southern political forces had contact with French military figures and adopted the Vauban style of fortification. Simultaneously, the new Nguyen dynasty chose to hew more closely to the contemporary Qing dynasty of China. Though elements of the old Le style would continue, more realistic elements appeared on Vietnamese maps within the context of Chinese forms. A regional division of the country led the north to maintain the old style as French forms appeared in the south. The central region around the capital of Hue gradually forged a national style which, by 1840, showed the country of Dai Nam and its hydrographic complexities in a European perspective.

While becoming more realistic in outline, the artistic style shifted from the earlier sketchiness to a more specifically Chinese mode. This change appeared particularly in the mountains with their vertical and naturalistic mode, continuing to match the karst topography of the north. The new international style developed through the nineteenth century until the French conquest in the 1880s. Thereafter, in the early years of the twentieth century, the reaction against French rule among Vietnamese literati led to the greater emphasis on the Chinese style over the realistic mode.

The first centuries of Vietnamese mapping (fifteenth to eighteenth) produced two different genres: one administrative, the other military/commercial. The first, the atlas, originated in Le Thanh-tong's governmental transformation of the 1460s. In it, each of the thirteen provinces had a map showing the location of its prefectures and districts and a list of the types and numbers of villages contained therein. In addition, the atlas included a map of the country, noting the location of each province, and a map of the capital Thang-long. Despite originating in the fifteenth century, the earliest extant atlas, the *Hong Duc Ban Do* (Maps of the Hongduc Era), comes from the mid-late seventeenth century. As noted above, a single map of the country, showing its administrative units, does seem to be from the sixteenth century. In the atlases, natural features, particularly rivers, and some human construction like city walls and temples were also noted. The maps generally are seen from the sea (the east) and hence have a Western orientation. Since the Le dynasty (1428–1787) rose from the then southern provinces of Thanh-hoa and Nghe-an, these two maps came first after those of the country and the capital.

The other genre involved itineraries of different kinds, each a series of maps showing the way (usually from the capital region around present-day Hanoi) out to a distant location. The genre seems to have originated in Le Thanhtong's major campaign south against Champa in 1470–1471. Again, the earliest extant example comes from the seventeenth century, the *Thien Nam Tu Chi Lo Do Thu* (Book of the Major Routes of Thien Nam). At that time, the southern route was joined to three shorter routes to China: northeast, northwest, and north (the standard route to Beijing). These maps, and particularly those of the southern route, provide much more detail of daily life than does the atlas. They illustrated features of the land, the rivers, and the sea as well as elements of Vietnamese common and commercial life (markets, inns, temples, military installations, etc.). Another seventeenth-century itinerary, the *Binh Nam Do* (Map of the Conquest of the South), comes from the southern regime of the Nguyen and takes us through their territory of central and southern Vietnam to Cambodia. It shows the path of the Southern Expansion (*Nam Thien*) of the Vietnamese people then taking place.

The eighteenth century produced new, more artistic versions of the seventeenth-century atlas and itineraries. In addition, a new itinerary appeared in various forms – that of the Vietnamese embassy north to the Qing capital of Beijing in northern China. Once across the Chinese border, the delegation traveled mainly by river and canal, and these sets of maps were drawn from that perspective, showing the mountains and villages stretching away from both sides of the route. Finally, at the end of the century, there appeared the only known map of the brief Tay-son dynasty (1788–1802), a single page showing Siam (Thailand) and the routes through it from north to south. This map, like all other pre-1800 ones, had very little sense of the river systems to the south, particularly the Mekong Delta and the Great Lake of Cambodia.

Three major developments led to cartographic change in the nineteenth century: the international context, the initial regional control of the country (north, center, and south), and the borrowing of the Chinese geography form. The combination of these three brought the gradual emergence of a new form of mapping. This single form, the geography with maps accompanying the text, replaced the Le atlas as an administrative tool. Curiously, the genre of the itinerary disappeared, continuing only in the reproduction of earlier texts.

Just as the northern and southern regional autonomy was finally integrated into the central government during the 1830s, so their styles merged with that of the center and its usage of European and Chinese elements, as seen in the *Dai Nam Toan Do* (Complete Map of Dai Nam). The map of the entire country, now stretching from China to Cambodia, in particular took on a more Western form. The coast and the southern rivers, even the Great Lake of Cambodia, appear much more familiar, and the provincial maps are more realistic in our eyes, showing rivers in a dendritic manner for example [having a branched form].

Blending the new maps with the geography form of the Chinese *yi-tong-zhi* (Vietnamese *nhat-thong-chi*), Nguyen cartography reached its peak first in the *Dai Nam Nhat Thong Du Do* (Maps of the Unity of Dai Nam) of 1861 and finally in the imperial geography, the *Dai Nam Nhat Thong Chi* (Record of the Unity of Dai Nam). The latter, compiled and printed between 1865 and 1882, is a text describing the country of Dai Nam, its capital of Hue, and the 29 provinces and presenting maps of each of them. Even though the French had already seized the six provinces of the south, the Tu-duc Emperor kept this section in the geography together with those of the center and north as a symbolic representation of the whole.

Mapping of the nineteenth century was thus almost entirely involved with administrative matters, like the old Le atlas. The only itineraries were copies of the seventeenth- and eighteenth-century maps. The country map in the administrative collections did, however, provide a broader international setting than had occurred under the Le. This was done in a form similar to the European mapping of the time.

The major new form of map in the nineteenth century was part of the *dia-bo*, the land registers. Recording the land plots of each village, these documents show them in outline and provide their dimensions and type. The government produced these maps in a number of survey (and resurvey) campaigns through the first half of the century. Another new form of map was the symbolic diagram of the imperial tombs. The resulting drawings emphasized the symbolic relationships of mountains and water, and show the strongly Chinese style adopted by the Nguyen dynasty.

Vietnamese mapping was mainly the result of 400 years of administrative effort. Beginning with Le Thanh-tong's reforms in the 1460s, the need to know the bureaucratic jurisdictions and their villages led to the Le atlases and the Nguyen geographies. The fifteenth-century military campaign began the Vietnamese itinerary which to all appearances became commercial. The Vietnamese cartographic tradition was almost entirely internal, not external. Until the 1830s maps rarely showed much beyond their borders, the major exception being the eighteenth-century embassies to China. In addition, all the routes illustrated were by land, not by sea.

See also: ►Geography in China

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Marāgha

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The observatory, located just outside Marāgha, the capital of the Ilkhānid kingdom, represents one of the most comprehensive examples of an astronomical research institution within the context of Islamic civilization. It is reported, on the authority of Naṣīr al-Dīn al-Ṭūsī, its first director, that construction of the observatory began under the patronage of Hūlāgū, Mongol conqueror of the region, in 657 AH/AD 1259. The remains of the observatory buildings still occupy a hilltop position near the city in Azerbayjan.

Construction at the site was overseen by Mu'ayyad al-Dīn al-'Urḍī, who wrote a treatise describing his efforts. In addition to the main observatory building, the site included a mosque and a residence for Hūlāgū, who took an active part in the work of the astronomers. The main building was described by contemporary witnesses as "huge" and there are reports that its library exceeded 400,000 treatises. There is also a report of a "high tower," as well as a domed structure which may have been the central building of the observatory. The dome was pierced, allowing sunlight to enter for the determination of equinoxes, as well as for measuring solar mean motions and elevations. There are still traces of a massive masonry-mounted mural quadrant, probably having a radius of more than 4 m, outside one of the observatory buildings.

Al-'Urḍī also had charge of constructing the observational instruments for the observatory, although it is doubtful that he would have constructed them all personally. He reports completion of their construction during 660 AH/AD 1261–1262. In addition to the mural quadrant, which was used to determine the latitude of the observatory as well as the obliquity of the ecliptic, the observatory included other large instruments: (1) an armillary sphere, consisting of five rings and an alidade (or sighting devise), and having a maximum radius of about 1.6 m, (2) a solstitial armilla, a bronze circle with diameter of about 1.25 m equipped with an alidade, which was placed in the plane of the ecliptic for determining solstice points, (3) an equinoctial armilla, similar to the solstitial armilla but with a second ring that could be aligned with the plane of the equator in order to determine equinoxes accurately, (4) an instrument with two holes on a sighting rod used to determine the apparent diameters of the sun and moon, as well as for observing eclipses, (5) an azimuth ring equipped with two quadrants and two alidades to measure angles of elevation, (6) a parallactic ruler which could make measurements equivalent to those made on a circle with a radius of 2.5 m, (7) an instrument for measuring azimuthal altitude and the sine of the complement of that angle of elevation, (8) a similar instrument to measure the azimuthal altitude and the sine of the angle of elevation, and (9) an instrument similar to a parallactic ruler, but not fixed in the meridian plane. In addition to these large instruments, there were many smaller ones, including planispheric astrolabes and quadrants, terrestrial and celestial globes, timekeeping devices, star charts, maps, and representations of the heavenly spheres.

Not only the observatory was the best equipped of the medieval period, but also it was the best staffed. In addition to Naṣīr al-Dīn al-Ṭūsī and Muʾayyad al-Dīn al-'Urḍī, such luminaries as 'Alī ibn 'Umar al-Qazwīnī, Fakhr al-Dīn al-Akhlātī, Fakhr al-Dīn al-Marāghī, Muḥyi al-Dīn al-Maghribī, Quṭb al-Dīn al-Shīrāzī, Shams al-Dīn al-Shirwānī, Najm al-Dīn al-Qazwīnī, 'Abd al-Razāk ibn al-Fuwwatī (the librarian), Kamāl al-Dīn al-Ayta, Athīr al-Dīn al-Abharī, al-Ṭūsī's two sons – Aṣīl al-Dīn and Ṣadr al-Dīn – and even a Chinese astronomer, Fao Mun Ji. (The presence of the latter indicates a growing interaction between the Islamic and Chinese astronomical traditions made possible and encouraged during the period of Mongol domination.) The activities of the scholars were supported by a full complement of technicians, instrument makers, and administrators.

The major result of the activities of the observatory was the production of a new set of astronomical tables, the *Zīj-i Ilkhānī*, completed in 671 AH/AD 1272, nearly 12 years after the observatory opened. Although the treatise contains many new observations, it did not incorporate any of the sophisticated critiques of the Ptolemaic cosmology being developed at that time in the observatory. The tables were widely used and frequently cited. The organization of the treatise (chronology, movements of stars in longitude and latitude, determination of times of ascendants, and astrological predictions) often served as a model for later zīj literature.

It was generally argued by astronomers that, in order to produce a full set of astronomical tables, observations should be made over a 30-year period (the time for Saturn to complete one revolution around the sky).

Most observatories prior to Marāgha had been forced to adopt less ambitious research programs, for they did not long survive the death of their founding patron. The Marāgha observatory is a notable exception. Hūlāgū, its royal patron, died in 663 AH/AD 1265 and al-Ṭūsī, the founder, died in 672 AH/AD 1274. After al-Ṭūsī's death, the observational activities continued at a somewhat slower pace under the leadership of Ṣadr al-Dīn al-Ṭūsī. Thirty years later, al-Ṭūsī's younger son, Aṣīl al-Dīn, was named head of the institution. This marks the last recorded activity on the site. Thus, this observatory continued to function for nearly five decades before being abandoned and falling into ruins.

One possible reason for the extraordinary longevity of this institution is the use of *waqf* funds to support the operation of the observatory. (A waqf is a grant of property in perpetuity for the support of religious or charitable institutions. Thus, not only many mosques are supported by income derived from waqf properties, but also orphanages, soup kitchens, hospices, schools, libraries, hospitals, and other public service institutions. The Marāgha observatory seems to be the only example in which an observatory receiving waqf support.) Several sources indicate that al-Ṭūsī, in addition to directing the observatory, was also charged with administering waqf funds throughout the state. Some sources indicate that about a tenth of all waqf revenues was earmarked for expenses of the observatory. It is not clear whether this unusual use of waqf funds generated any sort of public outcry. If nothing else, it seems to indicate that the work of the observatory was intended to be ongoing, not merely an intense short-term effort.

Perhaps the use of waqf funds to support the observatory was easier to justify in light of the extensive instructional activity carried on within its precincts. It was not uncommon to endow a *madrasa* (an institution of learning, usually focused on religious and legal sciences) with waqf funds. Our sources tell us that the observatory was a center of teaching in mathematical, astronomical, and related sciences. The educational program was apparently organized analogously to that of a madrasa, although the accounts in our sources are too vague to be certain.

In addition to teaching the classics of the ancient mathematical and mathematical astronomy traditions, the Marāgha observatory was also a focus for an important movement to criticize and reform Ptolemaic (Greek) astronomical theories. Ptolemy was perceived to have disregarded the essential sphericity and uniformity of the celestial motions postulated by Plato and other earlier thinkers. Ptolemaic theory described each planet as carried daily from east to west across the vault of the sky by the motion of the sphere of fixed stars. This diurnal motion is complicated by the observation that each planet sets a bit late in relation to the fixed stars and the planet moves across the heavens in a path not parallel to the fixed stars. Moreover, most of the naked-eye planets seem, from time to time, to slow to a stop and temporarily reverse their direction of motion (retrograde motion). To account for these observations, the Greeks had assumed that each planet must be fixed to a small sphere (epicycle) whose center is carried around by a larger sphere (the deferent), whose axis does not coincide with that of the fixed stars, and whose proper motion of rotation (zodiacal motion) is contrary to the east to west direction of the fixed stars and their diurnal motion. The motion of the epicycle center as seen from earth was not fully uniform, however, implying that the earth must not be at the geometric center of the motions on the deferent. The distance of the earth from the center of the deferent sphere (the eccentricity) was established by observational considerations. When this distance is determined, however, the observed angular velocities are only about half what is predicted. To remedy this problem, Claudius Ptolemy had postulated that uniform angular motion took place about a point (equant) located twice the value of the eccentricity from the earth along the line from the earth through the center of the deferent sphere. This postulate allows uniform motion in the sense of sweeping out equal angles in equal time increments when observed from the equant, but uniform motions in the sense of equal arcs traversed in equal increments of time does not occur. Herein lies the central problem that the Marāgha school of cosmography tried to resolve: how to construct a physical model of the spherical universe that fits the assumptions of uniform circular motion in both senses of that term and that gives predictions with the same level of accuracy as did Ptolemy's equant model.

Al-Ṭūsī, assuming that Ptolemy's circular motions were intended to be performed by true physical spheres and not just mathematical spheres, developed a system of spheres rolling inside one another to account for the observed zodiacal motions of the planets. The result of these motions, each truly uniform and circular in the Platonic sense, is that the planet follows the spherical path required by Greek cosmography while displaying the observed variations in velocity, thus overcoming the fundamental conceptual disjunction that Ptolemy had introduced by separating the circularity from the uniformity in the motions.

Al-Ṭūsī is best known among historians of science for his modification of a theorem of Proclus which demonstrates that when a circle, whose diameter is equal to the radius of a larger circle, rolls inside the circumference of the larger while rotating on its axis in the opposite direction with the same velocity, a point on the circumference of the smaller circle will execute a simple harmonic oscillation along a diameter of the larger circle. Al-Ṭūsī used his device, now known as a "Ṭūsī Couple," to describe the anomalous motion of the equant in Ptolemy's description of Mercury's motions.

It was further exploited by al-Ṭūsī's pupil, Ibn al-Shāṭir, and others at the Marāgha observatory.

Copernicus employed an essentially similar geometric device more than two centuries later in constructing his lunar model. This striking similarity of technique has led to questions concerning the originality of Copernicus. Arabic manuscripts describing al-Ṭūsī's model are known to have been in the Vatican Library by the time Copernicus journeyed to Rome, and some bear Latin annotations. Moreover, a late Byzantine Greek manuscript with a detailed exposition of al-Ṭūsī's scheme was also present in Italian libraries while Copernicus studied there. Tantalizing as such evidence may be, it is still not possible to determine with certainty whether the intellectual antecedents of the Copernican geocentric hypothesis may lie in Marāgha.

See also: ►Naṣīr al-Dīn al-Ṭūsī, ►al-ʻUrdī, ►al-Shīrāzī, ►Armillary sphere, ►Quadrant, ►Maps, Celestial, ►Astrolabe, ►Clocks and Watches, ►Astronomy in China, ►Astronomy in Islam, ►Astronomical Instruments in Islam, ►Observatories in Islamic World

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Māshāʾallāh

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Māshāʾallāh ibn Atharī was a Jewish astrologer who was born in the southern city of Basra ca. 730 in the later Umayyad caliphate and survived till ca. 815. If he was ever converted to Islam, as his name Māʾshāʾallāh seems to imply, it is not made clear in any of the original sources such as the *Fihrist*. His respectful tone toward the Caliphs in his *Fī qiyām al-Khulafāʾ* would certainly befit a Muslim more than a Jew. At any rate he wrote extensively in Arabic, and he was called upon by the second Abbasid Caliph al-Manṣūr (754–775) to assist in the laying of the foundations of Baghdad in 762. Hence by that time he was surely a well known astrologer active in the Babylonian region, representative perhaps of the Jewish culture long settled in the area.

A celebrated astrologer in his time, Māshāʾallāh was either the founder or a leader of a school of Jewish astrologers in Mesopotamia. Apart from his participation in the laying of the foundations of Baghdad, we know rather little of the circumstances of his life. Though sparse on biographical details, the principal Arab bibliographers al-Nadīm (*Fihrist*, AD 987) and Ibn al-Qifṭi (*Tāʾrīkhal-ḥukamāʾ*, ca. AD 1248) credit Māʾshāʾallāh with a sizeable number of works. On the other hand, the *Jewish Encyclopedia* confuses him in part with Maslama al-Majrīṭī, probably because of the similarity of names. Paul Kunitzsch has recently established that the Latin treatise on the astrolabe long ascribed to Māʾshāʾallāh and translated by John of Seville is in fact by Ibn al-Ṣaffār, a disciple of Maslama al-Majrīṭī.

In his astrological doctrine Māʾshāʾallāh seems to have depended principally on the Persian tradition, though a late Byzantine translation of one of his works shows that he could also quote from Greek authors such as Plato, Aristotle, and Hermes. Māʾshāʾallāh's works have not survived extensively in Arabic and it is thanks to the Latin translations, mostly by John of Seville in twelfth century Spain, that we have access to a large number of those ascribed to him.

Māʾshāʾallāh's contribution in Arabic astrology must be linked with the widespread use of astrological prognostication in the Mesopotamian area since very ancient times. The thirteenth century bibliographer Ibn Khallikān recalls the extensive use of this "projective tool" in the politics and social life of the early Arab empire. What has survived of Māʾshāʾallāh's works shows that the substance of his astrological knowledge owes but little to Greek philosophy proper. Assuredly, there flourished in Sassanian times a trend to borrow from Greek (Alexandrian) astrology, apparently only to consolidate a native tradition of learning. And it is this Sassanian lore above all that nourishes Māʾshāʾallāh's production. On the other hand, it is historically confirmed that the passion for Greek learning among the Arabs was engendered by the caliph al-Maʾmūn's (813–833) enthusiasm for the philosophy of Aristotle, too late for Māʾshāʾallāh to share significantly in this outburst. The fresh start taken by "scientific" astrology under al-Maʾmūn's prodding is noticeable in the works of al-Kindī, of Abū Maʾshar, and the members of the *Bayt al-Ḥikma* (House of Wisdom) founded by al-Maʾmūn. Compared with their works, those of Māʾshāʾallāh and of his generation show no clear and systematic use of the axioms of peripatetic philosophy to buttress the principles of astrological science as was done so decidedly a generation later.

Māʾshāʾallāh's reputation remained high in the following generation as witnessed by Abū Maʾshar's praise of him, according to the *Mudhākarāt* (Memorabilia) of Ṣaʾid ibn Shaḍān. Yet, it is mostly for one single astrological topic, the "projection of rays" (*matraḥ al-shuʿāʿāt*), that Abū Maʾshar lavishes praise on Māʾshāʾallāh.

An important historical factor affecting the preservation of Māʾshāʾallāh's works, and consequently of his reputation as a leader in Arab astrology, must be stressed at this point. As stated above, his works were virtually superseded in Arabic astrology by the works of the generation which followed his death. Why then do we possess so many of his manuscripts in Latin translation? This seems to have resulted from the special interest manifested in Māʾshāʾallāh's works by John of Seville (Johannes Avendauth, or Ibn Dawūd). Having set about to translate for the benefit of Latin scholars the works of the "prince" of Arab astrologers Abū Maʾshar (no Arab himself but Persian/Afghan since he came from the "Bactrian" city of Balkh), John enlarged his program of translation to include the corpus of Jewish astrologers of the early Abbasid era.

Within the scope of Arab astrological doctrines there developed a side which stemmed from the application of the scheme of planetary conjunctions in relation to the zodiacal signs and various triplicities in which they might occur. But it was Jupiter's special prerogative to foster religious life. The conjunction theory animating astrological history turned principally around the conjunctions of Saturn and Jupiter to signal the emergence, duration, and waning of sects (Arabic *milal*) when referred to religions, or of dynasties and empires (*duwal*) when applied to military domination. A basic element of the scheme was the association of each planet with what was classified as "great civilizations", mostly religions with cultures that set religion as their guiding light. Saturn as the most distant planet was appropriated to the Judaic faith, the Sun to the Roman Empire, and Venus to Islam. This was in a nutshell the astrological exercise of the "horoscope of religions" as it came to be known in the Latin West.

The most famous of such interpretations was embodied in Abū Maʿshar's *Great Conjunctions*. Associating the spread of the Judaic religion with the rule of the planet Saturn, the sway of the Roman Empire with that of the Sun, and of the Arab Empire with that of Venus, etc., the scheme thereby stressed the primeval character of the Jewish faith in accordance with the status of Saturn, the highest and most distant planet. The vicissitudes of planetary conjunctions thereafter unfolding along the variety of signs in which they occurred successively, rendered Judaic monotheism anachronistic. It was replaced in time by the Roman Empire, which in turn was displaced by "manicheism" when the prophet Mani appeared, until the rise of Islam.

In ninth-century Baghdad there was great concern among the Abbasid rulers and the Arab elites who were confronted with widespread social unrest among non-Arab subjects. One wave of unrest was further encouraged in *shuʿūbīya* (ethnic) groups by astrological predictions hinting at the impending end of Arab domination foreboded by planetary conjunctions. This was the occasion for the consolatory *Risāla fī mulk al-ʿarab wa-kammiyatihi* (On the Dominion of the Arabs and its Extent) which al-Kindī wrote for the Caliph, a consolatory Epistle in which he calculated that the conjunctions of Saturn with Jupiter held forth a total duration of 693 years for the Muslim Empire, which meant at that time four more centuries of Arab rule, whereas Abū Maʿshar's similar calculations in his *Great Conjunctions* foresaw only 310 years or so for it.

The association of Judaism with Saturn is not present in Māshāʾallāh's scheme of astrological history, although his interpretation of planetary conjunctions was extended to Islam and in particular to the rule of the Caliphs. Yet the status assigned to Judaic culture in the scheme of planetary conjunctions of Arab astrology stirred echoes in Jewish communities in Spain, inspiring their leaders in astrological science to use the scheme of conjunctions to confirm the unique "vocation" of Israel. This endeavor is at the core of the *Megillat ha-Megalle* by Abraham bar Ḥiyya of Barcelona. This book purports to illustrate the fate of Israel in the cosmic framework of universal history by referring to Holy Scriptures, Rabbinic literature, and philosophy. Yet the entire last chapter is devoted to the scheme of planetary conjunctions and its significance for the fate of Israel, confirming by "science" the data of sacred literature. The enterprise ostensibly aimed to counteract the "scientific" demoting of Judaic civilization to a lower historical role by Arab astrological writers. Another Jewish astronomer astrologer in Spain, Abraham ibn Ezra, also critiqued the theory of planetary conjunctions.

The medieval Anglo-Irish scientific literature used to include two versions of some work by Māshāʾallāh' in the form of Chaucer's *Treatise on the Astrolabe,* and an Irish tract following closely the text published by J. Heller in Nurnberg in 1549 under the title *De elementis et orbibus coelestibus*. Since the publication of Paul Kunitzsch's thesis, however, which shifts the authorship of the Latin source used by Chaucer from Māshāʾallāh the Jewish astrologer from Iraq, to Maslama, the eleventh century Arab astronomer from Spain, it would appear that this part of Māshāʾallāh's claimed influence upon Western literary tradition must be abandoned.

A compilation of Arab "authorities" in astrology called *Liber Novem Iudicum* (Book of the Nine Judges) included Māshāʾallāh as one of its principal authorities. The compilation of the Nine Judges did much to carry Māshāʾallāh's astrological rules and reputation to the four corners of medieval Europe.

See also: ►al-Maʾmūn, ►al-Kindī, ►Abū Maʿshar, ►Abraham bar Ḥiyya

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Mathematical Texts in Egypt

Annette Imhausen

While there is only indirect evidence for mathematical techniques in the Old Kingdom (2686–2160 BCE) and the New Kingdom (1550–1069 BCE), we do have texts detailing specific mathematical procedures from the Middle Kingdom (2055–1650 BCE) and the Graeco Roman Period (332 BCE – 395 CE).

Hieratic Mathematical Texts

The sources of the Middle Kingdom (the Rhind mathematical papyrus was written in the 2nd Intermediate Period, but states to be a copy of a Middle Kindgom original) are (in order of their publication; for respective editions see Collier and Quirke 2004 and 2006, Glanville 1927, Peet 1923a and 1923b, Schack-Schackenburg 1900 and 1902 and Struve 1930; a source book uniting photocopies and translations of most sources is Clagett 1999, for colour photographs of pRhind see Robins and Shute 1987):

– the Rhind mathematical papyrus (BM EA10057/58)
– the Lahun mathematical fragments (UC 32107A, 32114, 32118, 32134, 32159, 32162)
– the Berlin mathematical fragment 6619
– the Cairo Wooden Boards (CG 25368/8)
– the mathematical Leather Roll (BM EA10250)
– the Moscow mathematical papyrus (E4676)

They are all written in Hieratic (►http://www.digitalegypt.ucl.ac.uk/writing/hieratic.html), a cursive form of hieroglyphs. Most of the above listed sources were bought on the antiquities market, so that their exact provenance cannot be ascertained without doubt. Exceptional in this respect are the Lahun mathematical fragments, which were found between 1889 and 1899 by W.M.F Petrie during the excavation of Lahun, the pyramid town of Senusret II (1877–1870) (►http://www.digitalegypt.ucl.ac.uk/lahun/index.html). Nevertheless the form and content of Egyptian mathematical texts often allows us to determine their original context with some certainty.

We can distinguish two types of mathematical texts (and the individual sources listed above are compilations of one or both types): problem (or procedure) texts and table texts. Egyptian mathematical problem texts begin by stating a mathematical problem and then providing step-by-step instructions for its solution. We can differentiate several sections of a mathematical problem text.

1. Title, often in the form '*tp n ir.t* ...' 'method of calculating...' and highlighted by the use of red ink.
2. Announcement of the given data of the problem often followed by an explicit question of asking what shall be determined. The data are concrete values.
3. Procedure to solve the problem. This is spelled out via step-by-step instructions using the concrete data. Each instruction usually comprises one arithmetic operation (addition, subtraction, multiplication, division, halving, doubling, etc). After each step we find an intermediate result provided (for a technical analysis of the procedures found in the hieratic problem texts see Imhausen 2003a).
4. The indication of the solution, which usually equals the result of the last step of the instruction.
5. Verification of the solution.
6. Working of some calculations indicated in the instructions (for a recent discussion of some aspects of Egyptian arithmetic see Collier and Quirke 2004: 85–86).
7. Sometimes a drawing, indicating the object and its dimensions.

The problems teach basic mathematical techniques (e.g., how to determine an unknown quantity from a given manipulation of that quantity and its result ['a quantity, its 1/7 added to it becomes 19']) as well as applied mathematical problems, i.e., mathematical problems with a practical background. Practical problems include for example calculating distributions of rations, slopes of pyramids, work rates, exchanges of bread and/or beer and volumes of granaries.

Thus it has been concluded that Egyptian problem texts come from an educational background and were used in training junior scribes in the mathematical practices that they would need in their daily working lives (Ritter 2000). This was confirmed by administrative and economic papyri, which display the use of the same mathematical techniques (Imhausen 2003b).

Table texts comprise mathematical information in tabular format. They are often simply lists of mathematical data. Tables include those for fraction reckoning (most notably the 2/N table preserved at the beginning of the Rhind mathematical papyrus and in the Lahun fragment UC 32159), but also tables for the conversion of different metrological systems. Note that multiplication in hieratic texts was often carried out in writing, which rendered multiplication tables for natural numbers superfluous. For a description of Egyptian tables (both hieratic and Demotic) see Fowler 1999: 268–276.

Demotic Mathematical Texts

The second group of Egyptian mathematical texts dates from the Graeco Roman Period, i.e., a time when several cultures (the native Egyptian culture and the Greek and Roman cultures) coexisted in Egypt (for a description of Demotic mathematics within this cultural context see Cuomo 2001) and after Egypt had been under Persian rule twice (525–404 BCE and 343–332 BCE). Presumably during this Persian occupation (or earlier), Mesopotamian mathematical knowledge was transmitted into Egypt (see Parker 1972: 5–6 and Høyrup 2002: 405–406).

These are the extant sources consisting of several papyri (in order of their publication; for their editions see Parker 1959, 1972 and 1975):

Papyrus Griffith Institute I E.7
Papyrus Cairo JE 89127-30, 89137-43
Papyrus BM EA 10399
Papyrus BM EA 10520
Papyrus BM EA 10794
Papyrus Carlsberg 30
Papyrus Heidelberg 663

Ostraca, i.e., stone or pottery sherds were also used as writing material (for a list of Demotic mathematical ostraca see Ritter 2000 :134, note 27). It is likely that further sources will be discovered, as collections of Demotic papyri are being edited only now. Demotic (►http://www.digitalegypt.ucl.ac.uk/writing/demotic.html) is the cursive penultimate stage of ancient Egyptian.

The Demotic mathematical papyri show some similarities with their hieratic predecessors. Again, there are problem (or procedure) texts and table texts, and mathematical techniques are expressed rhetorically using specific numerical examples. On the other hand, there are distinct differences. At least within the extant Demotic mathematical papyri, we find that calculations of operations indicated in the procedures are no longer carried out in writing within the texts. Moreover there is a multiplication table within BM EA 10520, and the instructions for performing a multiplication in the same text are strikingly different from the Middle Egyptian method. The types of problems also vary, including some well-known Mesopotamian problems like that of a pole leaning against a wall.

Historiography

Earlier historiography has operated on the now outdated assumption that mathematical techniques exist and develop independently from their social and cultural context. These earlier studies focused mainly on the similarities with modern mathematics, using modern mathematical terminology and concepts to analyse the mathematical papyri. In 1989, Jim Ritter made a new beginning, setting new standards for the field (including the knowledge of Egyptian language and culture so the mathematical papyri can be studied in their original form and context). For an English translation see (Ritter 1995). A similar development has taken place for Mesopotamian mathematics pioneered by Jens Høyrup, Jim Ritter and Eleanor Robson. While older secondary literature is not to be discarded, it should be read carefully and the reader needs to keep in mind that significant progress has been made in Egyptology as well as in the History of Science (especially Gillings 1972 has to be read with this in mind) in the last 20 years.

See also: ►Mathematics in Egypt, ►Egyptian Mathematical Leather Roll

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Mathematics

George Gheverghese Joseph

A concise and meaningful definition of mathematics is virtually impossible. Mathematics has developed into a worldwide language with a particular kind of logical structure. It contains a body of knowledge relating to number and space, and prescribes a set of methods for reaching conclusions about the physical world. Also, it is an intellectual activity which calls for both intuition and imagination in deriving "proofs" and reaching conclusions. Often it rewards the creator with a strong sense of aesthetic satisfaction.

Mathematics initially arose from a need to count and record numbers. As far as we know there has never been a society without some form of counting or tallying, i.e., matching a collection of objects with some easily handled set of markers, whether it be stones, knots, or inscriptions such as notches on wood or bone. Also, it is precisely such an artifact that helps us to locate the early beginnings of mathematics.

High in the mountains of Central Equatorial Africa, on the borders of Uganda and Zaire, lies Lake Edward, one of the furthest sources of the River Nile. Though this area, Ishango, is remote and sparsely populated today, about 20,000 years ago a small community lived by the shores of the lake that fished, gathered food or grew crops depending on the season of the year. The settlement had a relatively short lifespan of a few hundred years before being buried in a volcanic eruption. Archeological excavations at Ishango unearthed a bone tool handle which is now on display at the Musée d'Histoire Naturelle in Brussels. The original bone may have petrified or undergone chemical change through the action of water and other elements. What remains is a dark brown object on which some markings are clearly visible. At one end is a sharp, firmly fixed piece of quartz which may have been used for engraving, tattooing, or even writing of some kind. Along the Ishango Bone, as it is now called, is a series of notches arranged in three distinct columns: first column contains four groups of notches with 9, 19, 21, and 11 markings; second column contains four groups of 19, 17, 13, and 11 markings; and third column has eight groups of notches in the following order: 7, 5, 5, 10, 8, 4, 6, 3, with the last pair (6,3) being spaced together, as are (8,4) and (5,5,10), suggesting a deliberate arrangement in distinct subgroups.

Conjectures based on underlying numerical patterns of the notches are well summed up by de Heinzelin, the archeologist who helped to excavate the Ishango Bone. The bone "may represent an arithmetical game of some sort devised by a person who had a number system based on ten as well as a knowledge of duplication (or multiplying by 2) and of prime numbers." Further, from the existing evidence of the Ishango tools, notably harpoon heads, northward up to the frontiers of Egypt, de Heinzelin supports the possibility that the Ishango numeration system may have traveled as far as Egypt to influence the development of its number system, the earliest decimal-based system in the world.

There is, however, another explanation which highlights a link that has played a crucial part in the historical development of mathematics. The close link between mathematics and astronomy has a long history and is tied up with the need for societies to record the passage of time, both out of curiosity as well as practical necessity. The alternative explanation is that the bone markings constitute a system of sequential notation – a record of different phases of the moon. Whether this is a convincing explanation would depend in part on establishing the importance of lunar observations in the Ishango culture and in part on how closely the series of notches on the bone matches the number of days contained in the successive phases of the moon. Marshak attempted to do both and concluded that the Ishango Bone, with its markings of different indentations, shapes, and sizes, was a lunar calendar where the different types of engraving indicate that it was also a calendar of events, probably of a ceremonial or ritual nature. There is still a good deal of controversy and interest around this bone.

One of the most ingenious methods of recording and storing information before the emergence of the computer is a *quipu*. The *quipu* (a Quechua word from the language of the Incas of South America) is an arrangement of colored wool or cotton cords with clusters of knots tied in the cords to represent numerical magnitude. In essence, it resembles a mop which has seen better days. It was widely used as a device for storing numerical and other information before the Spanish conquest in an area which would today include all of Peru, parts of Bolivia, Chile, Ecuador, and Argentina. A vast amount of information can be kept on a *quipu* using different colored cords for summation between and within categories and relative placement of the knots for indicating different numerical magnitudes. A *quipu* has been discovered which is a record of a census taken in 1587 of the Andean population of Lupaqa disaggregated by province, ethnic groups, size, and age/sex distribution of households, using cords of different thickness, color, and configuration. Altogether 46 different items of information were kept on this recording device no larger than an ordinary kitchen mop.

For a highly centralized society such as the Inca, an essential prerequisite for maintaining good order and efficient organization was the existence of detailed and up-to-date information (or government statistics, as we would describe such information today). A whole inventory of resources which included agricultural produce, livestock, and weaponry – as well as people – was maintained and updated by a group of specially trained officials known as *quipucamayus* (*quipu*-keepers). Each village under the rule of the Inca had its own specially trained *quipucamayu* and certain larger villages had as many as 30. One of the main tasks of the *quipucamayu* was to devise efficient and economical methods of storing information. The more the *quipucamayu* considered the pattern of distribution, taking account of the relative sizes and positions of different cords, the better the logical structure of the final representation. Cord placement, color coding, and number representation were the basic design features, repeated and recombined to define a format and convey a logical structure. This search for a coherent numerical/logical structure involves mathematical thinking reminiscent of database management in a modern computer and a study of spatial configuration structures of different *quipus* is a good introduction to a field of modern mathematics known as "graph theory."

It is possible to view the appearance of a written number (or numeral) system as a culmination of earlier developments. First was the recognition of the distinction between more and less (a capacity we share with certain other animals). From this developed first simple counting, then the different methods of recording the counts as tally marks, of which the Ishango Bone is one example. This progression continued with the emergence of more and more complex means of recording information, culminating in the construction of devices such as the *quipu*. Before the appearance of such devices, there must have existed an efficient system of spoken numbers founded on the idea of a base to enable numbers to be arranged into convenient groups.

There is ample historical and anthropological evidence indicating that a variety of bases for counting systems have been used over the ages and around the world. The base of a counting system tells how numbers are grouped and constructed. Our system, a decimal or base-10 system, has words for numbers from one to ten displaying no common root. Beyond ten, the number words generally show a variation of the unit word for the multiples of ten.

To illustrate, take the case of a few counting systems with different bases chosen from round the world. For an indigenous Australian group, the Gumulgal, counting proceeds as *urapon* (1), *ukasar* (2), *ukasar-urapon* (3), *ukasar-ukasar* (4), *ukasar-ukasar-urapon* (5),… to indicate counting by twos (or a base-2 system). In a Melanesian language, Sesake, counting proceeds as *sekai* (1), *dua* (2), *dolu* (3), *pati* (4), *lima* (5), *la-tesa* (6), *la-dua* (7),…,*dua-lima* (10),…,*dua-lima-dua* (20). This suggests a base-5 counting system where words for numbers six or seven use the roots for words one and two; ten is literally two-fives and twenty is two-fives twice. In a Micronesian language, Kiribati, counting proceeds as *tenuana* (1), *uoua* (2), *tenua* (3), *aua* (4), *nimua* (5), *onoua* (6), *itiua* (7), *wanua* (8), *ruainua* (9), *tebwina* (10), *tebwina-ma-tenuana* (11),…, *vabui* (20), *vabui-ma-tenuana* (21),…,*tebubua* (100),…, *tenga* (1,000),…,*tebina-tenga* (10,000),…,*tebubuna-tenga* (100,000). Here we have a straightforward base-10 counting system. In Kiribiti, number words also vary according to the object being counted. Thus the number word for 9 is *ruaman* when counting animals, *ruakai* when counting plants, *ruai* when counting knives, *ruakora* when counting baskets, and *rauawa* when counting boats. In certain other systems, such as the Aztec number system, the choice of the bases would depend on the type of objects being counted. Cloths or tortillas would be counted in twenties, while round objects such as eggs or oranges would be counted in tens.

Counting by tens has been the most widespread system probably because it is associated with the use of fingers on both hands. The other scale (base-20) had its most celebrated development as a written number system during the first millennium of the present era among the Maya of Central America. There have also been other base-20 systems, of which the Yoruba system from Nigeria and the Welsh system from Britain are two well-known examples.

An unusual feature of the Yoruba system is its heavy reliance on subtraction. The subtraction principle operates in the following way. As in our number system, there are different names for the number one (*okan*) to ten (*eewa*), the numbers eleven (*ookanla*) to fourteen (*eerinla*) are expressed as compound words which may be translated into "one more than ten" to "four more than ten." But once fifteen (*aarundinlogun*) is reached the convention changes, so that fifteen to nineteen (*ookandinlogun*) are expressed as "twenty less five" to "twenty less one," respectively, where twenty is known as *oogun*. Similarly, the numbers twenty-one to twenty-four are expressed as additions to twenty, and twenty-five to twenty-nine as deduction from thirty (*ogbon*). At thirty-five (*aarundinglogoji*), however, there is a change in the way the first multiple to twenty is referred to: forty is expressed as "two twenties" (*ogoji*) while higher multiples are named *ogata* ("three twenties"), *ogerin* ("four twenties"), and so on to "ten twenties," for which a new word *igba* is used. It is in the naming of some of the intermediate numbers that the subtraction principle comes into its own. To take a few examples, the following numbers are given names which indicate the decomposition shown on the right:

$$45 = (20 \times 3) - 10 - 5,$$

$$108 = (20 \times 6) - 10 - 2,$$

$$300 = (20) \times (20 - 5),$$

$$318 = 400 - (20 \times 4) - 2,$$

$$525 = (200 \times 3) - (20 \times 4) + 5.$$

All the numbers from 200 to 2,000 (except those that can be directly related to 400 or *iriniwa*) are reckoned as multiples of 200. From the name *egebewa* for 2,000, compound names are constructed for number in excess of this figure, using subtraction and addition wherever appropriate similar to the above examples.

The origin of this unusual counting system is uncertain. One conjecture is that it grew out of the widespread practice of using cowrie shells for counting and computation. A description of the cowrie shell counting procedure given by Mann in 1887 is interesting. From a bag containing a large number of shells the counter draws four lots of five to make twenty. Five twenties are then combined to form a single pile of one hundred. The merging of two piles of one hundred shells gives the next important unit of Yoruba numeration, two hundred. As a direct result of counting in fives, the subtraction principle comes into operation. Take the decomposition of 525, given earlier, as an illustration. We begin with three piles of *igba* (200), remove four smaller piles of *oogun* (20), and then add five (*aarun*) cowrie shells to make up the necessary number.

This complicated system of numeration in which the expression of certain numbers involves considerable feats of arithmetical manipulation has certain advantages for computation. As an example of a calculation which exploits the strength of the Yoruba numeration to the full, consider the multiplication: 19×17.

The cowrie calculator begins with twenty piles of twenty shells each. From each pile, one shell is removed (−20). Then three of the piles now containing nineteen shells each are also removed. The three piles are adjusted by taking two shells from one of them, and adding one each to the other two piles to bring them back to twenty ($-20 \times 2 - (20 - 3)$). At the end of these operations we have

$$400 - 20 - (20 \times 2) - (20 - 3) = 323.$$

While the Yoruba system shows what is possible in arithmetic without a written number system, it is clearly impractical for more difficult multiplications.

However, there are other mechanical aids which are more versatile, such as the Chinese or Japanese abacus (*soroban*). In the speed of addition and subtraction, the abacus still holds its own against the electronic calculator. In a test problem consisting of: first, adding a column of eleven numbers and then subtracting four numbers from the result where there was no number of less than three digits and most contained four or five digits, a third-grade abacus operator in China or Japan (i.e., an operator possessing the minimum level of competence acceptable for employment in a bank or similar institution) performed this computation in 30 s. An operator using the calculator took 90 s. A first-grade abacus operator would have been expected to have finished the computation in 20 s. There is even the well-attested claim of an expert operator taking less than 15 s to add ten numbers each of ten digits!

There are two modes of performing arithmetical operations. The first arose in cultures which, either because of scarcity of writing materials or because of the limitation of their written number systems, resorted to physical devices such cowrie shells or an abacus to carry out multiplication. The second mode involves "paper-and-pencil" methods of written numbers. The origins of many of these paper-and-pencil algorithms are found in parts of the non-Western world which gave birth to different place value number systems: Babylonia during the third millennium BCE, China around the third century BCE, the Maya Empire around the beginning of the Common Era, and in India a few centuries later. And in the process of transmitting the Indian numerals westward some of the efficient algorithms, initially devised for these numerals, were lost.

To illustrate, consider multiplying 97 by 93. The method favored today involves two sets of multiplication, one requiring the "9-times table," then adding the results of the two sets of multiplication on paper to get the final answer: 90/21. Of course these days, one would use an electronic calculator but feel rather lost if the calculator was not readily at hand. But there is a startling simple yet mathematically profound method available from the distant past.

Take the problem: 97 × 93; 97 is 3 less than 100, 93 is 7 less than 100. Multiply the deficiencies 3 and 7 to get 21. Subtract from 97 the deficiency corresponding to the other number, 93, which is 7 *or* the other way round. Both subtractions will give 90. The final answer is the merging of the two parts: 90/21. This procedure can be mathematically "productive" if one then proceeds to answer the following "what ifs":

- What if both numbers to be multiplied are just over 1,000?
- Both just under 1,000?
- One just over and one just under 1,000?
- Both just over or just under 100?
- Or one just over and one just under 100?
- What about numbers near 50?
- Or near 20?
- What if they are not both within the range of the same base?

In all these cases, the procedures devised involve using the principal strength of our number system – the place value principle. An examination of why the method works leads us quite naturally to the interconnection of arithmetic, algebra, and geometry, and also a reminder that algebra is but a generalization of arithmetic. A method claimed to be as old as the Vedas (ca. 500 BCE), it is found in works of later Indian mathematicians, notably Brahmagupta (ca. AD 600) and Bhāskarāchārya (ca. AD 1100). It was known to the Arabs through whom our number system, which began in India, spread westward into Europe. Yet this method was lost and what we have in place are rather cumbersome procedures, some more suitable perhaps for multiplication with number systems without place value like the Roman numerals.

The rules devised by mathematicians for solving problems about numbers of one kind or another may be classified into three types. In the early stages of mathematical development, these rules were expressed verbally, and consisted of detailed instructions about what was to be done to obtain a solution to a problem, for which reasons this approach is referred to as *rhetorical algebra*. In time, the prose form of rhetorical algebra gave way to the use of abbreviations for recurring quantities and operations, heralding the appearance of syncopated algebra. Traces of such algebra are to be found in the works of the Alexandrian mathematician Diophantus (ca. AD 250), but it achieved its fullest development in the work of Indian and Arab mathematicians during the first millennium AD. During the past 500 years symbolic algebra has developed so that, with the aid of letters and signs of operation and relation $(+, -, \times, /, =)$, problems are stated in such a form that the rules of solution may be applied consistently and systematically. The transformation from rhetorical to symbolic algebra has been a long one and marks one of the most important advances in mathematics. It had to await the development of a positional number system (i.e., the Indian numerals) which allowed numbers to be expressed concisely and with which operations could be carried out efficiently.

As early as 1800 BCE, the Babylonians had developed sophisticated methods of solving equations, building on their invention of a positional number system. A 4,000-year-old Babylonian clay tablet, now kept in a Berlin museum, gives the value of $n^3 + n^2$ for $n = 1, 2,\ldots,10, 20, 30, 40, 50$, from which it is deduced that the Babylonians may have used these values in solving cubic equations after reducing them to the form $x^3 + x^2 = c$. Linear and nonlinear equations in two and three unknowns were also solved correctly within the framework of a rhetorical algebra.

Early Indian algebra also contained solutions of linear, simultaneous, and even indeterminate equations. An example of an indeterminate equation in two unknowns (x and y) is $3x + 4y = 50$, which has a number of positive whole-number solutions for (x, y). For example $x = 14$, $y = 2$ satisfies the equation, as do the solution sets (10,5), (6,8), and (2,11). But it is only from AD 500 that there emerged a distinctive feature – the use of symbols, such as a dot or the letters of the alphabet, to denote unknown quantities. In fact it is this very feature of algebra that one immediately associates with the subject today. A general term in Indian algebra for any unknown was *yāvat tāvat*, which was shortened to the algebraic symbol *yā*, In Brahmagupta's work, Sanskrit letters appear, which are the abbreviations of names of different colors which he used to represent several unknown quantities. Thus the letter *kā* stood for *kālaka*, meaning "black," and the letter *nū* for *nūlaka* meaning "blue."

The word *al-jabr* appears frequently in Arab mathematical texts that followed al-Khwārizmū's influential *Ḥisāb al-jabr w'al-muqābala* written in the first half of the ninth century AD. There were two meanings associated with *al-jabr*. The more common one was "restoration" as applied to the operation of adding equal terms to both sides of an equation, so as to remove quantities, or to restore a quantity which is subtracted from one side by adding it to the other. Thus an operation on the equation $2x + 5 = 8 - 3x$ which leads to $5x - 5 = 8$ would be an illustration of *al-jabr*. There was also another, less common meaning: multiplying both sides of an equation by a certain number to eliminate fractions. Thus, if both sides of the equation $9/4x + 1/8 = 3 + 5/8x$ were multiplied by 8 to give the new equation $18x + 1 = 24 + 5x$, this too would be an instance of *al-jabr*. The common meaning of *al-muqābala* is the "reduction" of positive quantities in an equation by subtracting equal quantities from both sides. For the second equation above, applying *al-muqābala* would give $18x - 5x + 1 - 1 = 24 - 1 + 5x - 5x$ or $13x = 23$. The words *al-jabr* and *al-muqābala*, linked by *wa* (and), came to be used for any algebraic operation, and eventually for the subject itself. Since the algebra of the time was almost wholly confined to the solution of equations the phrase meant exactly that.

Apart from giving the name to the subject, the great contribution of the Arabs to algebra was to devise an efficient system of classifying equations. Starting with al-Khwārizmū, they reduced all equations to six main types. For each type they offered solutions and when possible a geometric rationale. Their work culminated in ʿUmar al-Khāyyam's geometric solution of the cubic equation in the middle of the eleventh century AD. The Arab work on equations is one illustration of their ability to bring together two strands of mathematical thinking – the geometric approach which had been carefully cultivated by the Greeks and the algebraic/algorithmic methods which had been used to such effect by the Babylonians, Indians, and Chinese.

The development of Chinese algebra was a direct result of their number system – the rod numeral system. Apart from its notational facility, the rod numeral system was helpful in suggesting new approaches to algebraic problems, notably the use of a variant of the modern matrix method for solving simultaneous equations about 1,000 live hundred years before its so-called discovery in Europe and the "method of double false" which constitutes an important algorithm for solving higher order equations in the modern subject of numerical analysis.

The Chinese work on solutions of numerical equations of higher order has its origins in the method of extracting square and cube roots found in their premier text, *Jiuzhang suanshu* (Nine Chapters on the Mathematical Arts), written around the beginning of the Common Era. The combination of the root extraction procedure with the use of what we know as the Pascal triangle (although it was already known to the Chinese about 500 years before the seventeenth-century French mathematician, Pascal) meant that the Chinese were solving equations of the ninth degree (i.e., equations involving the term x^9) around AD 1250, using a variant of the Horner–Ruffini method which only came into modern mathematics at the beginning of the nineteenth century.

Any definition of the subject matter of mathematics would include activities that relate to spatial configurations or geometry. There are two theories regarding the origins of geometry. Herodotus, the Greek historian who lived in the fifth century BCE, wrote that geometry arose in ancient Egypt from the need to parcel out, in an equitable fashion, precious agricultural land whose boundaries were annually obliterated by the overflow of the River Nile. The ideas of the Egyptian surveyors (or "rope-stretchers") were eventually passed on to the Greeks who proceeded to build that most impressive edifice known as "Greek geometry." However, Egyptian geometry had shown the way, for in the Moscow Papyrus, an important source of Egyptian mathematics from about 1850 BCE, the correct rule for calculating the volume of a truncated pyramid appears.

An alternative explanation sees the origins of geometry in religion and ritual. A good illustration would be a class of ritual literature from ancient India, known as the *Śulbasūtras* dealing with the measurement and construction of various sacrificial altars. They also happen to be the earliest text of Indian geometry dated around 800–500 BCE. They provided instructions for two types of rituals, one for worship at home and the other for communal worship. Square and circular altars were sufficient for household rituals while more elaborate altars involved combinations of rectangles, triangles, and trapezia for public worship. The geometry of the *Śulbasūtras* grew out of the need to ensure strict conformation of the orientation, shape, and area of altars to the prescriptions laid down in the scriptures. They include a general statement of the so-called "Pythagorean theorem," an approximation procedure for obtaining the square root of 2 correct to five decimal places and a number of accurate geometric constructions including ones for "squaring the circle" (approximately) and constructing rectilinear shapes whose area was equal to the sum or difference of areas of other shapes. The earliest known demonstration of Pythagoras' theorem is found in an ancient Chinese text, *Zhoubi suanjing*, at least 300 years before Pythagoras (ca. 500 BCE). Over 1,000 years before Pythagoras, the Babylonians knew and used the result now known under his name.

To most of us geometry deals with lines, angles, circles, and polygons. These are the central concepts that appeared in the best-known text in geometry, Euclid's *Elements* (ca. 300 BCE). To these were subsequently added subjects such as symmetry, coordinates, vectors, and other curves. Many of these concepts appear in different cultures in a variety of contexts: in architecture, drawings, decorations, etc. Do such examples constitute mathematics or can they at best be used as no more than peripheral illustrations of certain geometrical notions? In 1986, Paulus Gerdes posed the following "nonstandard" problems to a workshop of mathematics educators who had some difficulty working them out, although artisans in Mozambique, some of them illiterate, solved them as a matter of course:

- Construct a circle given only its circumference: a problem in laying out a circular floor for a traditional Mozambican house.
- Construct angles that measure 90°, 60°, or 45° with only strips of straw: a problem in basket weaving.
- Fold an equilateral triangle out of a square: a problem in making a straw hat.
- Construct a regular hexagon out of straw: a problem in making a fish trap.

Does solving these problems involve mathematical thinking? It could be argued that the artisans who first discovered the optimal solutions to these problems were engaged in "creative" geometrical thinking. Mary Harris has extended this argument to tasks which are usually seen as women's work.

> Many of the male teachers are so unfamiliar with the construction and shape and size of their own garments that they cannot at first perceive that all you need to make a sweater (apart from technology and tools) is an understanding of ratio and all you need to make a shirt is an understanding of right-angled and parallel lines, the idea of area, some symmetry, some optimisation, and the ability to work from 2-dimensional plans to 3-dimensional forms … It is interesting to take Gerdes' analyses … and apply them … in the different context of women's culture.

All that is needed in many non-Western cultures is to "defrost" the frozen mathematics of the cultures contained in useful objects such as baskets, mats, pots, houses, sand-drawings, sculptures, fish traps, etc.

There is, however, a major stumbling block: the wide spread acceptance of the hegemony of a Western version of mathematics, following from the assumption that mathematics is largely a European creation. Two tactics have been used to propagate this Eurocentric myth.

The first is Omission and Appropriation. Prior to the "Renaissance," European acknowledgment of the debt it owed to Arab mathematics and its antecedents was fulsome both in words and deeds. Indeed the course of European cultural history and the history of European thought are inseparably tied up with the activities of Arab scholars during the Middle Ages and their seminal contributions to mathematics, the natural sciences, medicine, and philosophy. By the seventeenth century, however, the perception concerning the origins of mathematical knowledge had begun to change, due to the workings of a number of forces. With the European expansion in the American continents, the development of the slave trade, and the imposition of colonial rule in many parts of the world, the assumption of white superiority became dominant over a wide range of social and economic activities, including the writing of the history of mathematics. Moreover, the rise of nationalism in nineteenth- and twentieth-century Europe and the consequent search for the roots of European civilization led to an obsession with Greece and the myth of Greek culture as the cradle of all knowledge and values. This was despite ample evidence of significant mathematical developments in Mesopotamia, Egypt, China, pre-Columbian America, India, and the Arab world, showing that Greek mathematics owed a significant debt to most of these cultures. In recent years a grudging recognition of the debt owed by Greece to earlier civilizations and the important contribution of Arab mathematicians has led to some revisions to a "purely" Eurocentric trajectory of the historical development of mathematics. But the modifications still ignore for the most part the routes through which Hellenistic and Arabic mathematics entered Europe and take little account of the mathematical knowledge produced by India, China, and other cultures. Even those texts which include the Indian and Chinese mathematics often confine their discussion to a single chapter which may go under the misleading title of "Oriental" or "Eastern" mathematics. That these cultures contributed to the mainstream development of mathematics is rarely recognized, and little consideration is given to the mathematical research that is currently taking place in these and other non-Western regions.

The second tactic is Exclusion by Definition. A Eurocentric approach to the history of mathematics is intimately connected with the dominant view of mathematics as a sociohistorical practice and intellectual activity. Despite the development of contrary trends in the last two centuries, the standard textbook approach sees mathematics as a deductive system, ideally proceeding from axiomatic foundations and revealing, by the "necessary" unfolding of its pure abstract forms, the eternal/universal laws of the "Mind."

The Indian and Chinese concepts of mathematics were very different. Their aim was not to build an imposing edifice on a few self-evident axioms, but to validate a result by any method. Some of the most impressive works in Indian and Chinese mathematics (the summations of complex mathematical series, the use of Pascal's triangle in solutions of higher order numerical equations, the derivations of infinite series, and the "proofs" of the Pythagorean theorem) involve the use of visual demonstrations that are not formulated with reference to any formal deductive system. The Indian view of the nature of mathematical objects, like numbers, is also based on a framework developed by Indian logicians and linguists which differs at the foundational level from the set theory universe of modern mathematics.

The view that mathematics is a system of axiomatic/deductive truths inherited by the Greeks and enthroned by Descartes has been traditionally accompanied by a cluster of values that reflect the social context in which it originated:

1. An idealist rejection of any practical, material(ist) basis for mathematics: hence the tendency to view mathematics as value-free and detached from social and political concerns.
2. An elitist perspective that sees mathematical work as the exclusive preserve of a pure, high-minded and almost priestly caste, removed from mundane preoccupations and operating in a superior intellectual sphere.

Non-Western mathematical traditions have therefore been dismissed on the grounds that they are dictated by utilitarian considerations with little notion of rigor in proof. Any attempt at excavation and restoration of non-Western mathematics is a multifaceted task: confront historical bias, question the social and political values shaping the mathematics curriculum, and search for different ways of knowing or establishing mathematical truths found in various traditions.

See also: ►Geometry, ►Gou-gu Theorem, ►*Zhoubi suanjing*, ►*Śulbasūtras*, ►Liu Hui and the *Jiuzhang suanshu*, ►al-Khwārizmū, ►ʿUmar al-Khayyām, ►Brahmagupta, ►Bhāskara, ►Abacus, ►*Quipu*

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Mathematics Communicating Across Culture and Time

Leigh N. Wood

> The truth is that history, as we commonly conceive of it, is not what happened, but what gets recorded and told. Most of what happens escapes the telling because it is too common, too repetitious to be worth recording…
>
> The business of making accessible the richness of the world we are in, of making dense and substantial our ordinary, day-to-day living in a place, is the real work of culture (Malouf 1998: 17).

Mathematics is a method for communicating ideas between people about concepts such as numbers, space and time. In any culture there is a common, structured system for such communication, whether it be in unwritten or written forms. These systems can form bridges of communication across culture and across time.

So, what is communication? Crowley and Heyer (1995: 7) describe communication as "… an exchange of information and messages. It is a process. About 100,000 years ago our early ancestors communicated through non-verbal gestures and an evolving system of spoken language. As their world became more complex, they needed more than just a shared memory"… this led to "the development of media to store and retrieve the growing volume of information." Communication is about an exchange of information and the techniques humans have developed to store and retrieve that information. It is not necessary to have writing, computer disks and so on: communication can be verbal (oral traditions), non-verbal (gestures, *quipu*), temporary (sand drawing) or more permanent (clay tablet, woven cloth).

Communicating in or about the field of mathematics involves taking part in mathematical discourse, whether by reading, writing, listening or speaking. Discourse is a broader concept than language because it also involves all the activities and practices that are used to make meaning in a particular profession. The discourse of mathematics includes all the ways that mathematics is done: through language, textbooks, mathematicians talking to each other and to a wider public, and through popularisation and application of mathematical knowledge (Wood and Perrett 1997).

Discourse does not see the terms *language* and *communication* as synonymous, although it certainly recognises language as a central resource for the communication process. This view sees language as a resource for making meanings within different situations (Halliday 1978; Kamp and Reyle 1993). Communication is seen as a complex process within which natural language supplies a major (but seldom the only) resource for making specific meanings within the framework of specific social practices or areas of knowledge. Readers who wish to know more about the complexities of natural language may consult texts such as Finegan (2003).

When we speak of making meaning within different areas of knowledge we are referring to different discourse practices. The language used in mathematical discourse is natural language but it is a language that has evolved in specialised ways to deal with the demands of expressing mathematical concepts. The most striking difference between mathematical writing and most other types of writing is the extensive use that mathematics makes of symbols and numbers. These are sometimes seen as alternatives to natural language, alternatives that mathematicians value as being more precise and more elegant than natural language. However the symbolic language of mathematics is an extension of natural language as much as a replacement for it, just as a pile of cowrie shells or a gesture can represent a number word. Natural language is used to complement the symbolic language of mathematics when mathematicians talk and write to each other and it has to replace the symbolic language when mathematicians communicate with non-mathematicians. Thus we would argue that natural language plays an essential part in doing mathematics.

All cultures are mathematised, in that people within any culture use ideas of mathematics in their everyday life. For this I will take a wide definition of mathematics to include concepts of number, space, chance, and time. A report of the Australian Academy of Sciences *Mathematical Sciences: Adding to Australia* (1996: ix) gives this description of modern mathematics:

> Mathematics is the study of measurements, forms, patterns, variability and change. It evolved from our efforts to understand the natural world…
>
> Over the course of time, the mathematical sciences have developed a rich and intrinsic culture that feeds back into the natural sciences and technology, often in unexpected ways. The mathematical sciences now reach far beyond the physical sciences and engineering; they reach into medicine, commerce, industry, the life sciences, the social sciences and to every other application that needs quantitative analysis.

This description takes mathematics back to its roots. Mathematics has been part of all societies, a part of every profession as well as being used in everyday life. Western mathematics became narrower with the insistence that only deductive mathematics from a set of axioms, following the Greek tradition, was *real* mathematics. The broader view of mathematics, especially with the consideration of computing, validates the work of non-European mathematicians. A majority of mathematicians today are working much closer to the way that Indian, Chinese and Arab mathematicians worked, as they focus on real applications and better computing algorithms (Horgan 1993).

Culture too can be viewed broadly. Asher (1991: 2) says "In any culture people share a language; a place; traditions; and ways of organising, interpreting, conceptualising and giving meaning to their physical and social worlds." David Malouf (1998: 17) describes the process of acculturation as, "The business of making accessible the richness of the world we are in, of making dense and substantial our ordinary, day-to-day living in a place, is the real work of culture." The description of mathematics above states that "The mathematical sciences have developed a rich and intrinsic culture".

Mathematics has often worked on many levels, as part of everyday culture and also as used by subgroups within the main culture. In the Inca culture only a small group would have been able to construct and interpret the *quipus* (knotted cords used by the Inca to convey data, Asher 1991). In the Babylonian culture of 3000 BCE few people would have been skilled in the algebraic and computational techniques required for commerce, as is evidenced by the many clay tablets which can be interpreted as instructional textbooks. In

Egypt, the Ahmes papyrus consists of instructional material for a mathematical subculture that would calculate the land areas after the annual floods and document commercial transactions. Indeed in many cultures, the mathematics of calendars and astronomy was in the hands of the priestly classes.

The mathematical subcultures communicated their knowledge to future mathematicians in a similar way to classes or apprentices today. Students worked through sets of paradigm problems designed to develop the calculating skills, ideas and language necessary for their future careers. Some of the ways that mathematics has been taught is remarkably similar across the cultures and centuries. The drill and practice examples on the Ahmes papyrus and some Babylonian clay tablets are close to the way mathematics is taught in many classrooms today (Fowler and Robson 1998: 369). Teachers wrote commentaries and extensions from previous texts. They improved algorithms and compared methods. Høyrup (1994) concluded that mathematics as a discipline began to be systematically organised with the need to teach it to professional scribes in about 3000 BCE.

Communication Without Written Language

We will examine some examples of mathematical discourse in cultures with no written language. We are dealing with speaking and listening, but also with art, artefacts and gesture. It is possible to consider the *quipu* (Asher 1991) for example, as a "written" number system, but for this essay I do not wish to include such artefacts as written language.

How were mathematics and mathematical ideas communicated within cultures without writing? Here we make the assumption that cultures that do not have written language (95% of cultures, Asher 1991: 2) communicate mathematics by methods that have been documented by outside observers. The reliability of the documentation varies greatly with the biases and the mathematical knowledge of the observer. These snapshots can nonetheless help to extrapolate back into history for cultures that have lived in isolation for some time. For example the counting system of the Gomileroi in South-Eastern Australia (Table 1) has been documented and I suggest that this number system has been in situ for thousands of years prior to the arrival of Europeans in Australia in 1788. Similarly the counting systems in Papua New Guinea, documented by Glendon Lean (summarised in Phythian 1997), would have been used for centuries before the arrival of Europeans and European mathematics. Richard Pankhurst (as cited in Zaslavsky 1973: 89) has made an extensive study of the measures, weights and values in use among the various Ethiopian peoples throughout their history.

Between the years 1968 and 1988, Lean collected and recorded data on the counting systems of Papua New Guinea and Oceania. There are 1,200 languages in the region and Lean collected data on nearly 900. He also discussed how the number systems were communicated through migration, wars and marriage. As these languages are not written, he made use of diagrams to show gesture counting and used phonetics to write down number words. His awareness of mathematics has meant that he was conscious of the 2, 5, 10 and

Mathematics Communicating Across Culture and Time. Table 1 Gomileroi counting system (as quoted in Petocz et al. 1992: 164 after consultation with elders)

Gomileroi words	English translation	
mal	Finger	1
bular	Two fingers	2
guliba	Three fingers	3
bularbular	Two fingers and two fingers	4
mulanbu	Belonging to one hand	5
malmulanbu mummi	One finger and one hand added on	6
bularmulanbu mummi	Two fingers and one hand added on	7
gulibamulanbu mummi	Three fingers and one hand added on	8
bularbularmulanbu mummi	Two and two fingers and one hand added on	9
bulariu murra	Belonging to two hands	10
maldinna mummi	One toe added (to two hands)	11
bulardinna mummi	Two toes added on	12
gulibadinna mummi	Three toes added on	13
bularbulardinna mummi	Two and two toes added on	14
mulanbudinna mummi	One foot added on	15
maldinna mulanbu	One toe and a foot added on	16

More examples and teaching materials can be found at ►http://www.science.uts.edu.au/msc/AborCount.pdf.

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20 cycles that occur in counting systems and gathered enough data to be able to classify each system. From his study, Lean concluded that the counting and tally systems in Papua New Guinea could have covered a period of thousands of years. Due to the fact that many neighbouring languages have few number words in common, he concludes that there has been little contact. An extreme example of this is two languages Baruya (6,000 speakers) and Yagwoia (5,000 speakers). Baruya is spoken by people who live north of Marawaka in the Eastern Highlands and Yagwoia is spoken to the south. Table 2 gives a few examples of differences (Phythian 1997). Should these two groups meet, they would need to have a good gesture system or concrete materials to come to a mathematical understanding, despite living next to each other. The work of Glendon Lean is collected and available at ▶www.uog.ac.pg/glec/index.htm.

The detailed work in Papua New Guinea contrasts with the work of linguists in the 1800s who recorded Tasmanian aboriginal languages before they (the aboriginals and the languages) died out. Perhaps due to a lack of mathematical awareness they did not record details of the counting systems. Some words for numbers are recorded but not in a systematic fashion. For example, one Tasmanian aboriginal group use the word *karde* for 5 and *karde karde* for 10 (Roth 1899: Appendix B, xi, xvii) but only a few other numbers are recorded. So we have a tantalising suggestion of a base five systems but insufficient evidence to come to a conclusion. This lack of evidence for numbers contrasts with the detailed coverage of words for the male and female genital areas (Roth 1899). I think we can make some conjectures about these Victorian scientists and their cultural proclivities.

In *Hidden in Plain View*, Jacqueline Tobin (1999) records the oral history of several African American quilt makers. They described the meanings and detailed communication that could be passed on by the combination of colours, beads and knots. They could give routes, times, maps and instructions all through quilting. Thus they passed on their African history and made plans to escape from slavery, all under the noses of their masters. The following quote (Tobin 1999: 78) discusses the *lukasa*, the memory boards of the Central African Luba people.

> The use of stitches and knots, as a kind of Morse code in thread, along with fabric colour and quilt patterns, made it possible to design a visual language.
>
> The *lukasa*, or memory board is a mnemonic device used by the highest level of the Luba royal association. The lusaka contains secret mythical, historical, genealogical and medical knowledge. Beads on the front…Engraved geometric patterns on the back…All these serve to recall aspects of Luba history.

There are mathematical implications. The quilts are like computer programs displaying information graphically and can be read by those who understand the code. Fortunately the code in this case has been recorded. It is an example of how mathematical (and other) ideas can be hidden in plain view.

Aboriginal art is another area where mathematics has been overlooked by Western eyes. Michael Cooke (1991) spent 10 years in the Yolngu community in northern Australia and his principal sources were Yolngu teachers. He acknowledges that by taking some of the Yolngu world and fitting it with a Western idea of mathematics, he has lost the full significance of the meanings and some of the intricacy of the Yolngu world. His paper covers many mathematical aspects including how kinship relationships are depicted in song and painting (Cooke 1991: 38).

> For the Yolngu artist, painting is a means of schematising Yolngu world order in a way parallel to the Western mathematical theorist who constructs graphs and diagrams. Just as the Western mathematician seeks elegance, symmetry and aesthetic satisfaction in such work, so does the Yolngu artist. Both rely on extensive use of systems of symbolic representation in their abstract modelling of order…
>
> For the Yolngu it is the system of song cycles which provides the theoretical basis and rationale for the Yolngu system of order and relationship.

There are many other examples of mathematical discourse in cultures without a written language:

- *Finger reckoning*. Hand signals for numbers and number operations are used in many cultures. Examples in Africa are given in Zaslavsky (1973: 239–253) and for Papua New Guinea in Phythian (1997).

Mathematics Communicating Across Culture and Time. Table 2 Examples of Baruya and Yagwoia numbers (Phythian 1997: 66)

Baruya	Yagwoia	
da-`	ungwonangi	1
da-waai	huwlaqu	2
da-waai-da	huwlaqungwa	3
da-waai da-waai	hyaqu-hyaqu	4
at-i	hwolyem pu	5
at-iraai	hwolye kaplaqu	10

- *Weaving or patterns*. Northern Australian aboriginals use painting to illustrate kinship patterns (Cooke 1991; Harris 1987; Harris 1991).
- *Cowrie shells* for currency. Again there are many examples in Zaslavsky 1973.
- *Knotting, quipu of the Incas*. Much has been written on the quipu (such as Asher 1991: 16–27; Smith 1925: 196; Joseph 2000: 28–37) and it remains an important example of how mathematics and mathematical ideas can be communicated effectively without a written language or number system.
- *Classification*. For example, Yolngu Aboriginal culture divides the world into two parts, Yirritja and Dhuwa (Cooke 1991).

All these cultures communicated mathematical ideas without written language. Some of the ideas would have been accessible to all people within the culture, such as the counting systems in Papua New Guinea, and some of the ideas would be restricted to a privileged group, such as the *quipu* makers in South America.

Making meaning from artefacts left to us presents a difficult task. What meaning can a modern observer make of the Tasmanian Aboriginal rock carvings in Figs. 1 and 2? Is this a number system, a pattern of moon phases, a written language? Even the arrangement by the modern artist may influence our ideas. We are using our western-trained minds to classify and order the images to fit with our concepts of logic and pattern. Unfortunately there are no Rosetta stones or living speakers to assist with translation.

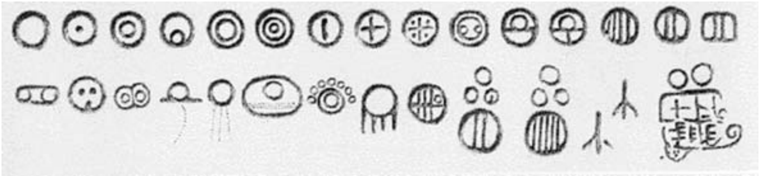
Cultures with Written Language

Making meaning from history involves examining the discourse of cultures from the information that is recorded and passed on. Written forms of mathematical discourse have largely formed the basis of modern mathematics: thus mathematical ideas have communicated across time. However, even with written records there are hazards to successful communication.

It is in part good management and mostly luck that written materials are available to modern readers, even though writers, such as Rashīd al Dīn (1971 translation) in thirteen century Persia went to great lengths to increase the probability that his work would not be lost. He made two complete copies of each work; each was translated into Persian and Arabic. Only the best quality paper and only scribes with the best handwriting were used. Even so, not all of his works exist today, but those that do give an insight into the mathematics in the lives of everyday people of that era. New materials, such as a letter of al-Kāshī on scientific life in Samarkand, described and translated in Bagheri (1997), are being added to our collection of records of mathematics. Translations, for example al Dīn (1971) make original works accessible to readers who are unable to read ancient languages.

Significant communication of mathematical ideas and techniques occurred between cultures in the past. An example of how commentaries and improved algorithms occurred between Arabic and Indian mathematicians is explained in Rashed (1994: 143–148) who showed that al-Bīrūnī (tenth century AD) was aware of

Mathematics Communicating Across Culture and Time. Fig. 2 Tasmanian Aboriginal rock carvings in situ (Clark 1986: 33).



Mathematics Communicating Across Culture and Time. Fig. 1 Symbols used in Tasmanian Aboriginal art (Clark 1986: 32).

Brahmagupta's methods of quadratic interpolation, used for trigonometry and astronomy.

However, as David Malouf (1988) states, much of what really happened is not recorded, and therefore must be inferred in the same way as for cultures with non-written languages. The information that is recorded is filtered through the eyes of the observer, who has his or her own cultural prejudices. Such cultural prejudices have caused criticism of non-European mathematics, in particular with the idea of proof. Modern mathematicians are in considerable conflict about the status and usefulness of proof (Horgan 1993) but some commentators feel free to criticise other cultures for not fitting within their own narrow definition.

Much has been made of the Greek concept of proof as the basis of modern mathematics to the extent that many writers (for example Kline 1972: 190, quoted in Joseph 1994: 194) have disparaged the Indians for their supposed haphazard ideas of proof. But as Joseph (1994) demonstrates, Indian mathematics does prove theorems though not in the same way as Greek deductions from axioms – in fact the Indian demonstrations are very similar to the way proofs are presented to students studying secondary and early tertiary mathematics. A broader idea of proof, such as that advocated by Mason et al. (1985) amongst others would include the demonstrations of Indian and Chinese mathematicians.

Another reason for miscommunication is error of interpretation. We mainly rely on translations of ancient texts. Translations are open to interpretation, compounded by time and cultural differences. Added to this, many translators are not mathematicians and so may miss subtle points which may be critical mathematically. This is not a criticism of translators but a criticism of commentators who do not take these difficulties into account when interpreting discourse over time and culture.

The mistranslation of one word can have critical effects. For example, the mistranslation of the word *asanna* in the translation of an Indian text has led to considerable misrepresentation of Indian mathematics. In verse 10 of the section entitled *Ganitapāda* from Āryabhata's *Āryabhatīya* (AD 499) appears the following: "100 plus 4, multiplied by 8, and added to 62,000: this will be the 'asanna' value of the circumference of a circle of diameter 2000." The Sanskrit word *asanna* has been translated as approximate, inexact, rough, crude and so on. On the basis of this translation, some Western historians of mathematics have concluded that Indian mathematicians did not realise the irrational nature of π.

George Gheverghese Joseph believes that the word *asanna* has a more fruitful meaning. It incorporates two different meanings that overlap with one another: "inexact" and "unattainable". The second meaning which is closer to the idea of irrationality is what Joseph thinks Āryabhata had in mind, and it was an extremely creative concept that gave the motivation to Kerala mathematicians to work on infinite series (Joseph, personal communication).

Reza Hatami, an Arab-speaking scholar working in Sweden, has translated sections of the work of al-Khwārizmī and ʿUmar Khayyām and has found similar difficulties with some of the standard English and Swedish translations (Hatami 1999).

Many translations are written in the modern discourse of mathematics and include use of symbols and algebra. The clarity of the symbolism in use today can cause us to underestimate the difficulties that mathematicians faced in the past. There is a good example of a theorem from Cardano (1545) that shows how mathematical writing has changed in the last 400 years. A comparison of this theorem with its modern equivalent shows how useful symbolic notation can be, and also illustrates the relationship of such notation to ordinary language (Smith 1997: 6). Cardano's intention was to provide a solution to the equation $x^3 + mx = n$, where m and n were implicitly assumed to be positive. However, even the *statement* of the theorem was different to modern language. Renaissance Italians referred to this equation as *a cube plus a first power equal to a number*. Cardano gave the solution as:

> Cube one-third of the coefficient of the unknown; add to it the square of one half the constant of the equation; and take the square root of the whole. You will duplicate this, and to one of the two you add one half the number you have already squared and from the other you subtract one half the same. Then, subtracting the cube root of the first from the cube root of the second, the remainder which is left is the value of the unknown.

Today we would write something like the following:

Theorem. *A solution of the equation* $x^3 + mx = n$ *is given by*

$$x = \sqrt[3]{\frac{n}{2} + \sqrt{\frac{n^2}{4} + \frac{m^3}{27}}} - \sqrt[3]{-\frac{n}{2} + \sqrt{\frac{n^2}{4} + \frac{m^3}{27}}}.$$

These examples show some of the difficulties of interpreting works from other cultures and times. The observer brings his or her knowledge and culture into the equation. I take issue with commentators, such as Kline (1980: 111), who make strident assertions about the mathematics of another culture.

> It is fairly certain that the Hindus did not appreciate the significance of their own contribution. The few good ideas they had, such as separate symbols for the numbers 1–9, the conversion from positional notation in base 60 to base 10, negative numbers, and the recognition

> of 0 as a number, were introduced casually with no apparent realisation that they were valuable innovations. They were not sensitive to mathematical values.

This is based on flimsy evidence and a very narrow view of mathematics. Notice the use of "mathematical values". Whose values? It may be that future commentators claim that strictly holding to the Greek view of deductive proof has seriously curtailed the mathematics of the twentieth century.

A Tenuous Link

> This art originated with Mahomet the son of Moses the Arab (al-Khowarizmi). Leonardo of Pisa (Fibonacci) is a trustworthy source for this statement (Cardano 1545, translation Whitmer 1968).

This is a lovely example of communication. Cardano has acknowledged the originator of his work, al-Khwārizmī, and the conduit of this knowledge, Leonardo Fibonacci.

The work of al-Khwārizmī (*ca*. 780–*ca*. 850), through the channel of *Liber abaci* (1202) by Leonardo Fibonacci became well known in Europe and became the basis of Cardano's work in 1545. This is just one example of how European mathematics was influenced by Arab mathematics, but it also shows how the European mathematicians readily acknowledged the prior work of non-European mathematicians.

Leonardo Fibonacci made considerable contributions to mathematics himself, notably in solving cubic equations, but it is his 1202 *Liber abaci* that was the most influential. Fibonacci travelled widely through Egypt, Syria, Sicily and Greece and came into contact with Arabic mathematics. He was convinced that the Indian–Arabic numerals and methods of calculation were vastly superior to the current methods in Italy (Eves 1983). *Liber abaci* can be considered the main reason why Indian–Arabic numerals and the achievements of Arabic mathematicians spread through Europe by the start of the Renaissance. How much would Cardano and others have achieved without al-Khwārizmī and Indian–Arabic numerals?

Making Meaning

Making meaning from the sources available to us leaves most unsaid and unwritten. Many of the ordinary day-to-day practices of mathematics are not recorded. The mathematical contributions of women, artisans and many workers are not represented. Many records have been lost. Of those discovered, there are risks of mistranslation, misinterpretation, or, in the case of the Tasmanian Aboriginal rock carvings, no basis for interpretation.

It is reasonable to expect difficulties with communication across time and cultures. Even within the same culture, recorders and observers often disagree. However there have been triumphs of communication across time and culture – Fibonacci's *Liber abaci* brought the ideas of algebra and Indian–Arabic numerals to Europe giving an excellent starting point for the work of Cardano and others.

Fibonacci displayed what many commentators have not: he displayed an open mind. Fibonacci was open to the work of other cultures and actively disseminated their ideas. Glendon Lean and Richard Parkhurst are more modern observers who have shown cultural sensitivity as well as keen mathematical knowledge.

As Zeilberger (1993) stated during a lively debate in the American Mathematical Society,

> Although there will always be a small group of "rigorous" old-style mathematicians... who will insist that the true religion is theirs and that the computer is a false Messiah, they may be viewed by future mainstream mathematicians as a fringe sect of harmless eccentrics...

Mathematics itself is not one culture with one discourse. The dominant paradigm in Western mathematics is shifting from Greek deductive proof to a more experimental and applied mathematics and with this comes a new discourse. A reappraisal of the contributions of non-European mathematics under the new paradigm will see a better valuing of their mathematical achievements and consequent changes in forms of mathematical discourse.

Let us look forward to a time when we can appreciate the mathematics of all cultures and the contribution of mathematical ideas to the "business of making accessible the richness of the world we are in, of making dense and substantial our ordinary, day-to-day living in a place – the real work of culture".

See also: ►Quipu, ►Mathematics of Australian Aboriginals

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Mathematics, Practical and Recreational

Jens Høyrup

The geographical distribution of so-called "recreational" mathematical problems does not respect ideas about distinct mathematical cultures. The familiar conclusion is that they reflect "age-old cultural relations between Eastern and Western civilizations" (Hermelink 1978). This inference is indubitably true but does not exhaust the matter. The reasons that these kinds of problems reflect relations between civilizations that are less visible in other mathematical sources are informative, both regarding the conditions and nature of mathematical activity in different civilizations and about the sense (or nonsense) of the concept of distinct mathematical cultures.

"Recreational problems" are pure in the sense that they do not deal with real applications, however much they speak in the idiom of everyday (some examples will be cited later). Nonetheless, their social basis is in the world of know-how, not that of know-why (the world of "productive," not that of "theoretical" knowledge, in Aristotle's terminology). The distinction between these two orientations of knowledge is of general validity but has particular implications for mathematics.

Beyond this distinction between orientations, it is also useful to distinguish two main ways in which "productive knowledge" can be transmitted. One is through master-apprentice networks and on-the-job training. This type of knowledge, whose results may be labeled "subscientific," is explained later. The other is through institutionalized schools, where training is separated from actual practice and taken care of by teachers whose own connection to the practice for which they prepare is reduced; the outcome may be labeled "scholasticized knowledge."

It is important not to identify practitioners' knowledge (whether subscientific or scholasticized) with practical knowledge alone. The difference has to do precisely with the influence of the social systems which carry the knowledge in question.

The larger part of the practitioners' fund of knowledge is evidently applicable in practice, at least according to the convictions of the social totality within which they function (whether *we* regard the knowledge of seventeenth century physicians as medically useless is irrelevant to the seventeenth century existence and prestige of their profession). As far as this part is concerned, problems – the problems which the craft or profession is supposed to confront – are fundamental, and appropriate techniques have been developed which allow it to deal with these problems. But the training of future practitioners, even when done on the job, will have to start from simpler tasks than those taken care of by the master, in part from tasks which have been prepared with the special purpose of training the techniques which the apprentice should learn but which have no direct practical relevance. Here, techniques and methods are by necessity primary, and problems are secondary, derived from the techniques which are to be trained. Anybody familiar with schoolbooks on arithmetic will recognize the situation, and scholasticized systems are indeed those where problems constructed for training purposes dominate. Apprenticeship-based systems, for their part, tend to train as much as possible on real, albeit simple tasks.

Scholasticized systems often make some use of recreational problems as a means to create variation. However, the genuine basis for the invention and spread of these problems – problems that distort everyday settings so as to create a striking or even absurd situation – is what we can call the subscientific knowledge system. This system is oral in character, while scholasticized systems have always been geared to writing. Recreational problems are riddles for specialists, sharing with other riddles that eristic (given to dispute or argument) character which distinguishes oral cultures in general. Often, when they enter written problem collections or manuals, they contain phrases like "if you are an accomplished calculator, tell me..." – or they are presented as a way to impress the nonspecialists who do not understand. In the premodern world, this type of knowledge was neither "folk" nor "popular," but a possession of the few to a significantly higher degree than scientific knowledge today.

Phrases of this kind indicate how we are to understand the function of the "recreational" problems, which were not primarily recreational (whence the quotes) – no more recreational, indeed, than the potentially lethal riddle of the sphinx. They served as a means to display virtuosity, and thus, on one hand, to demonstrate the status of the profession as a whole as consisting of expert specialist, and, on the other, to let the single members of the profession stand out, and discover themselves, as accomplished calculators, surveyors, etc.

This function puts some constraints on the problems, which explains their character. They must arouse immediate interest, which explains the "recreational surface": if a camel is to transport grain from one place to another, being able to carry only one third of the grain in one turn, and seems as a consequence to devour exactly everything in the process, then the expert solution allowing a net transfer is impressive. A less striking formulation might provoke the reaction "so what?" The problems, furthermore, must appear to belong to the domain of the profession – skill in singing does not enhance the professional prestige of an accountant, since it does not demonstrate professional valor; according to their form, the problems have to be practical. But they must also be more difficult than the tasks that any average bungler in the profession performs without difficulty. This, together with the quest for the striking or absurd, is the reason that the problems are pure in substance, i.e., separated from real practice – and more truly so than the simplified problems of school teaching.

Like school problems, however, recreational problems are determined from methods, namely from the characteristic methods of the profession. Often they come from a peculiar trick (in the case of the camel, an intermediate stop and return) that will be known within the subculture of the profession but not outside.

Such tricks will often not be generalizable; moreover, as several mathematicians from the Islamic Middle Ages tell, the practitioners using them would often be ignorant of why their tricks worked. The purpose of posing and solving the problems is not to provide insight but to show off. The pure level of knowledge is thus neither a direct nor an indirect underpinning of practice, nor is it a critical reflection on the principles underlying practice. In this respect, it differs fundamentally from what Aristotle and al-Fārābī would speak of as theoretical knowledge and from what we call scientific knowledge.

But there is another point in the term "subscientific", namely that all levels of the subscientific knowledge system, the pure or recreational no less than the applied, have served as inspiration in the development of scientific mathematics. This process can be followed in the Greco-Islamic area (and its European offspring), in India, and in China; Japanese *wasan* may even offer an instance of direct transformation of a subscientific into a scientific system.

In the Greco-Islamic-premodern-European area (the most sensible delimitation of "Western" culture if the long historical run is considered), in contrast, the theoretical knowledge system may have been socially segregated from the subscientific systems to an extent which in other cultural areas was reserved for different domains, as courtly music in Japan, or poetry as bound up with the writing system in China. While the distinction between different orientations of knowledge systems and the effect of scholastization versus apprenticeship learning hold in general, the social segregation and the high social prestige falling to philosophical and scientific knowledge in this broadly defined Western culture have tended to make the rupture between scientific and practitioners' mathematics more visible than elsewhere and to hide the whole subscientific complex from view. Another reason for its invisibility in the contemporary European orbit is evidently that the originally autonomous subscientific traditions were displaced from the late Renaissance onwards by methods that were ultimately derived from scientific mathematics. Increasingly since the late nineteenth century, this process has occurred globally.

Few sources survive that tell how practical computation was performed in former times, in particular by practitioners not trained from school books. Moreover, most practical computations and geometrical constructions have relied on such simple techniques that questions of diffusion versus independent invention cannot be decided; this simplicity is precisely the reason that they could not serve as a basis for professional self-esteem. Even "wrong" formulae can be so intuitively near at hand that independent invention demonstrably happens time and again. For instance, Isabel Soto Cornejos observed when teaching illiterate peasants in Chile during the Allende era that they reinvented the "surveyors' formula" for approximately rectangular areas (average length × average width) spontaneously after having been taught how to calculate the area of true rectangles. Only problems that are complex enough to serve as display are by the very fact also so characteristic that they may function as index fossils. This is why the recreational problems are crucial for the understanding of the subscientific knowledge system and its relations to the scholasticized and scientific systems.

Often the recreational problems go together in clusters which, although some exchange takes place, are relatively closed. As an example we may look at a cluster – better documented than most others – which appears to be connected to communities of merchants interacting either along the Silk Road trading network or in the sea trade between China, India, the Near East, and the Mediterranean but which certainly also had an impact on local communities of accountants and calculators (whatever their social status and organization) wherever they were in contact with the merchants' communities.

One favorite problem from this cluster was the doubling of unity, repeated either 30 or 64 times and ending by a summation. The first occurrence is in a text from Mari (Northern Babylonia) from the eighteenth century BCE. Then it turns up in a papyrus from Roman Egypt, and next in a Carolingian problem collection (*Propositiones ad acuendos iuvenes*) based on material which had circulated since late antiquity in the Gallic region – all of these instances deal with 30 doublings. In the early ninth century, al-Khwārizmī wrote a treatise on the other (chessboard) variant, which appears to have passed via India, even though actual Indian attestations are later. In the following centuries, both versions are found in India, in the Islamic world, and from around 1200 even in Latin Europe.

Another problem from the cluster that was highly popular in the Islamic and European Middle Ages was the "purchase of a horse": three men go to the market in order to buy a horse. The first says that if he may have half the money belonging to the others he will be able to buy the horse; the second needs only one third, and the third only one fourth (the number of purchasers and the fractions may vary, but invariably they exhibit a striking pattern). Sometimes the price of the horse is told; sometimes the problem is left indeterminate and thus is not only striking but outright absurd (in the present case, any multiple of the set [10,22,26] will do for an answer). The earliest Western source to state the problem (without the equestrian dress) is Diophantos' *Arithmetic*; slightly earlier is an occurrence with a different dress in the Chinese *Shushu jiuzhang* (Nine Chapters on the Arithmetic Art, first century AD). A passage in Book I of Plato's *Republic*, however, reveals that the problem could be expected to be familiar for the Athenian public of the fourth (and probably the fifth) century BCE ("buying a horse collectively" is said to be a situation where one needs an expert).

A third problem from the cluster is "the hundred fowls": Somebody is to buy 100 fowls for 100 monetary units, given that (e.g.,) a rooster costs 5 units, and a hen 3, while chicks are sold 3 for 1 unit. It occurs in a Chinese fifth century source, as well as the Carolingian *Propositiones*, and Abū Kāmil describes it as widespread in his environment among people who do not understand the mathematical principles involved but just give one answer without adequate reasoning. A variant has been located by Jean Christianides in a Greco-Egyptian papyrus.

It is thus true that the distribution of these (and other) problems from the cluster bear witness of "age-old cultural relations between…Civilizations" (in Hermelink's words as quoted initially). It is no less true, however, that they highlight the absence of cultural relations at other levels. The *Nine Chapters* as well as Plato's remark and the reflections of the subscientific corpus in Diophantos' *Arithmetic* demonstrate that the literate cultures of China and of the Mediterranean world (to take these as the paradigm) knew about the anonymous tradition, and would take over appropriate material without credit. The wholly different methods applied by the Chinese mathematicians and by Diophantos to solve the same problems also show that what they took over was inspiration, in particular problems, and not full mathematical structures. The high cultures did not really communicate with the low oral culture (no more in mathematics than in other cultural domains); they drew on them and exploited them. Nor did they communicate with each other through the low cultures. Moreover, what happened at the level of oral culture may not be adequately described as cultural relations. The very possibility of distinguishing particular clusters shows that even oral cultures had their sharp boundaries across which only limited communication took place. But these boundaries did not coincide with the geographical boundaries between high cultures, and only in part were they at all geographical in nature. It was, so it seems, a common subscientific merchants' culture which inspired the Chinese and the Alexandrian mathematicians, and which thereby creates the illusion of general cultural relations (similarly, jugglers might move between China and ancient Rome; neither Roman nor Chinese gentlemen ever did).

The cluster just used as an example belonged with a calculators' and caravan merchants' culture. A cluster dealt with elsewhere in this volume, surveyors' "algebra", was carried by practical geometers from the Syro-Irano-Iraqi region. Even in this case, just enough evidence from the Greco-Roman world has survived to show directly that the tradition was known (one Greek papyrus, a problem in one agrimensor [surveyor] treatise). Indirect evidence shows that Diophantos drew inspiration even from this source, and that Book II of Euclid's *Elements* is closely connected to the tradition. For the present argument, however, the relation between surveyors' algebra and Babylonian scribe school algebra is more important, as an unusually articulate instance of the relation between subscientific and scholasticized mathematics.

According to what can be concluded from combination of the evidence presented by the various written traditions that it inspired, the stock of quasialgebraic recreational which problems that were current among the practical geometers of the region was quite restricted:

- to find the side of a square when the area; the diagonal; the sum of the area and the side; or the sum of the area and all four sides was known;
- to find the sides of a rectangle when the sum of its sides was known together with the area or the area augmented by the difference between the sides;
- when the difference between the sides together with the area or the area augmented by both or by all four sides; or
- when the diagonal together with the sum of or difference between the sides.

Each problem type was presented by only one or at most two examples, which would permit even those who did not understand to learn them by heart, and everything concerns the entities really present in the geometrical configuration – *the* area, not some multiple; the side, or the sides; etc. From indirect evidence, we may assume that the diagonal of the 10 × 10 square was taken to be 14.

The technique was taken over by the Old Babylonian scribe school and developed into its central discipline – a quasialgebra based on geometric cut-and-paste procedures. It still appears to have served professional self-esteem on the part of the scribes. But becoming a discipline (etymologically: a subject which is to be learned) it was systematized. We find texts which vary the coefficients of both the area and the sides systematically, others which replace the length of a rectangle with the product of the length and the ratio between length and width, and the width with the product of the width and the ratio between width and length (formally the outcome is a problem of the sixth degree; the solution combines a second-degree and a homogeneous third-degree equation, that is, well-known stuff), and still others where the geometrical entities represent prices in artificial commercial problems. Mathematical irregularities like the diagonal of 14 have been eliminated.

Beyond professional pride, this systematically drilled technique served the purpose of normal school mathematics: through the introduction of coefficients and other complications, the discipline could function as a training ground for the use of the sexagesimal place value system, which was fundamental for the daily engineering and accounting practice of scribes (while all second-degree problems were completely artificial and pure). On the same occasion, the problems lost most of their recreational character.

But the introduction of systematic drills and the elimination of mathematical irregularities were not the only changes. The sixth-degree problems, however much they constitute a trivial extension, and the use of the geometrical technique as a representation of nongeometrical entities, have to be understood as systematic attempts to test the carrying capacity of the professional tools, including the trick of the quadratic completion that was the basis even of the surveyors' algebra. The outcome may be claimed to be really an algebra, while the "surveyors' algebra" was not – an algebra being understood as the application of a functionally abstract standard representation (in terms of *x* and *y,* Greek *arithmós,* or Arabic *šay*' [thing] and *māl* [possession]) in the analysis of complex relationships involving entities of any kind. If the scribe school had possessed the intellectual drive for that, a transformation into scientific mathematics might have occurred, as it appears to have occurred in the case of *wasan,* and as it occurred – but then in interaction with already-present scientific mathematics – in the Islamic Middle Ages.

Lest anybody believe that the process of scholastization, with all its tediously repetitive drills, should be a characteristic of non-Western civilizations (or of some of them), one may point out that it reached a high point in the Humanist schools of the Renaissance and Early Modern period – the very cradle of the Western ideology.

See also: ►Mathematics in Japan, ►Sexagesimal System

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The transcultural nature of recreational mathematics is discussed in:

Hermelink, H. Arabic Recreational Mathematics as a Mirror of Age-Old Cultural Relations Between Eastern and Western Civilizations. *Proceedings of the First International Symposium for the History of Arabic Science, April 5–12, 1976.* Vol. II, Papers in European Languages. Ed. A. Y. al-Hassan Aleppo: Institute for the History of Arabic Science, Aleppo University, 1978. 44–92.

A highly useful (though by necessity incomplete) survey of the occurrence of single recreational (and other) problem types will be found in:

Tropfke, Johannes. *Geschichte der Elementarmathematik.* 4. Auflage. Band 1: *Arithmetik und Algebra.* Vollständig neu bearbeitet von Kurt Vogel, Karin Reich, Helmuth Gericke. Berlin and New York: W. de Gruyter, 1980.

A broad treatment of the relation between oral and literate culture types is

Ong, Walter J. *Orality and Literacy. The Technologizing of the Word.* London and New York: Methuen, 1982.

A general discussion of the concept of subscientific mathematics (yet without a clear distinction between subscientific and scholasticized traditions), with extensive bibliography and source quotations, is

Høyrup, Jens. Sub-Scientific Mathematics. Observations on a Pre-Modern Phenomenon. *History of Science* 28 (1990): 63–86.

The scholastization process in Babylonian algebra is investigated in:

Høyrup, Jens. Algebra in the Scribal School–Schools in Babylonian Algebra? *NTM. Schriftenreihe für Geschichte der Naturwissenschaften, Technik und Medizin,* N. S. 4 (1993): 201–18.

Mathematics in Africa South of the Sahara

Paulus Gerdes

Most books on the history of mathematics devote only a few pages to Africa, and even then only to Ancient Egypt and to northern Africa during the Middle Ages. Generally they ignore the existence of mathematics in Africa south of the Sahara. They often deny that Egyptian mathematics is African. With the publication of Claudia Zaslavsky's *Africa Counts: Number and Pattern in African Culture* in 1973 this dominant Eurocentric view of the history of mathematics in Africa became challenged. When one uses a broad definition of mathematics – including counting, locating, measuring, designing, playing, explaining, classifying, sorting, etc. – it becomes clear that mathematics is a pan-cultural phenomenon manifesting itself in many ways. In African history, we have evidence of counting and numeration systems, games and puzzles, geometry, graphs, record-keeping, money, weights, and measures, etc. Mathematics in Africa may not be considered in isolation either from the development of culture and economy in general, or from the evolution of art, cosmology, education, philosophy, natural sciences, medicine, logic and language, graphic systems, and technology in particular. The application of historical and ethnomathematical research methods in recent years has contributed to a better knowledge and understanding of the history of mathematics in Africa.

In this article evidence for early mathematical activity in Africa will be given, followed by examples from geometry, games, riddles, and puzzles with mathematical "ingredients." Some topics for future research will be indicated and some comments about the development of mathematics south of the Sahara and in other regions, in particular northern Africa, will be presented.

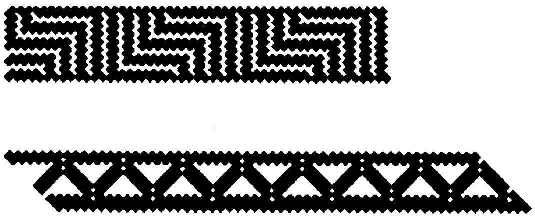
A small piece of the fibula of a baboon, marked with 29 clearly defined notches, may be one of the oldest mathematical artifacts known in the world. Discovered in the early seventies during an excavation of a cave in the Lebombo Mountains between South Africa and Swaziland, the bone has been dated to approximately 35,000 BCE. This bone resembles calendar sticks still in use today by the San (Bushmen) in Namibia. The San hunters developed very good visual discrimination and visual memory for survival in the harsh environment of the Kalahari desert. From the San in Botswana, information has been collected on their counting, measurement, time-reckoning, classification, and tracking. Well known as early evidence for mathematical activity in Africa is a bone now dated from about 8000 BCE to 20,000 BCE, dug up at Ishango (Zaire). The bone has what appear to be tallying marks on it, notches carved in groups that have been explained as early lunar phase count or as an arithmetical game of some sort.

Georges Njock has characterized the relationship between African art and mathematics as follows: "Pure mathematics is the art of creating and imagining. In this sense black art is mathematics."

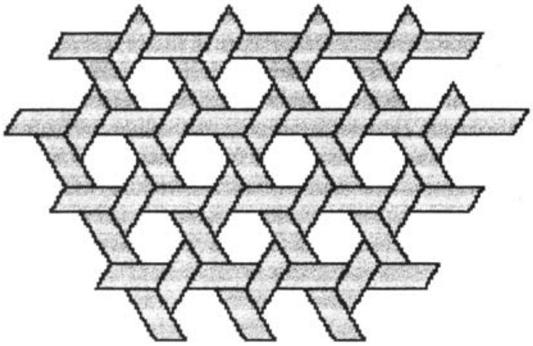
Mathematicians have primarily analyzed symmetries in African art. Symmetries of repeated patterns may be classified on the basis of the 24 different possible types of patterns which can be used to cover a plane surface (these are the 24 plane groups attributed to Federov). Of these, seven admit translations in only one direction and are called strip patterns. This classification has been applied to decorative patterns that appear on the raffia pile cloths of the Bakuba (Zaire), on Benin bronzes, and on Yoruba adire cloths (Nigeria), showing that all seven strip patterns and many of the plane patterns occur. The use of group theory in the analysis of symmetries in African art attests to and underlines the creative imagination of the artists and artisans involved and their capacity for abstraction. These studies do not focus, however, on how and why the artists and artisans themselves classify and analyze their symmetries. This is a field open for further research.

Why do symmetries appear in human culture in general, and in African craftwork and art, in particular? Paulus Gerdes analyzed the origin of axial, double axial, and rotational symmetry in African basketry. He showed how six and fivefold symmetry emerged quite naturally when artisans were solving some problems in (basket) weaving (see Figs. 1 and 2).

Beehive, conical, cylindrical, and rectangular shapes are common in African architecture. In West Africa the mathematician-scholar and the architectural designer–builder was often the same person. An example of geometrical know-how used in laying out the rectangular house plans in Mozambique is the following. Two ropes of equal length are tied together at their midpoints.



Mathematics in Africa South of the Sahara. Fig. 1 Two examples of woven strip patterns on baskets (Mozambique).



Mathematics in Africa South of the Sahara. Fig. 2 Hexagonal weaving pattern (Congo, Kenya, Madagascar, Mozambique).

A bamboo stick, whose length is equal to the desired breadth of the house, is laid down on the floor, and at its endpoints pins are hit into the ground. An endpoint of each of the ropes is tied to one of the pins. Then the ropes are stretched and at the remaining two endpoints of the ropes, new pins are hit into the ground. These four pins determine the four vertices of the house to be built.

The geometric shapes of pots, baskets, fishtraps, houses, etc. generally represent many practical advantages and are frequently the only possible or the optimal solutions of a production problem. Some scholarly research has been undertaken concerning knowledge about the properties and relations of circles, angles, rectangles, squares, regular pentagons and hexagons, cones, pyramids, cylinders, symmetry, etc. probably involved in the invention of the techniques (Gerdes 1992a,b). Themes for further research are the geometry of string figures, the geometry of settlement patterns in Africa, and the geometry involved in the ornamentation of the walls of buildings all over Africa (e.g., the attractive colorful patterns of the Ndebele in South Africa and the *litema* patterns drawn by Basotho women in Lesotho) (Fig. 3).

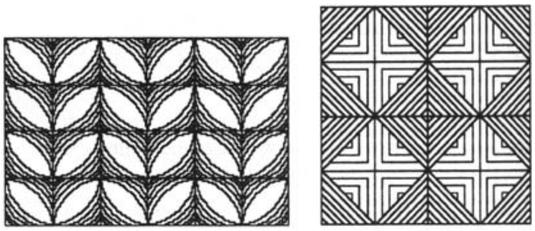
Games

Among the games with mathematical ingredients are counting rhymes and rhythms, arrangements, three-in-a-row-games like *Shisima* (Kenya), *Achi* (Ghana), *Murabaraba* (Lesotho), *Muravarava* (Mozambique), and games of chance. Board games like Mancala games, both two-row versions such as *Oware* (Ghana), *Awélé* (Côte d'Ivoire), *Ayo* and *Okwe* (Nigeria), and four-row versions such as *Omweso* (Uganda), *Tshisolo* (Zaire), and *Ntchuva* (Mozambique) also exhibit use of mathematical knowledge.

Recent research in Côte d'Ivoire showed that the rules of some games, like *Nigbé Alladian*, reveal a traditional and empirical knowledge of probabilities.

Riddles and Puzzles

From the Kpelle (Liberia) a riddle has been reported about a man who has a leopard, a goat, and a pile of cassava leaves to be transported across a river, whereby



Mathematics in Africa South of the Sahara. Fig. 3 Examples of *litema* wall patterns (Lesotho).

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certain conditions have to be satisfied: the boat can carry no more than one at a time, besides the man himself; the goat cannot be left alone with the leopard, and the goat will eat the cassava leaves if it is not guarded. How can he take them across the river? This type of problem is also known from Ethiopia, Liberia, Tanzania, Uganda, and Zambia. More difficult to solve is the following puzzle from the Valuchazi (eastern Angola and northwestern Zambia) about three women and three men who want to cross a river in order to attend a dance on the other side. With the river between them there is a boat with the capacity for taking only two people at one time. However, each of the men wishes to be the only husband of all the three women. Regarding the crossing, they would like to cross in pairs, each man with his female partner, but failing that any of the other men could claim all the women for himself. How can they cross? In order to solve the problem or to explain the solution, the Valuchazi make auxiliary drawings in the sand.

The relationships between the development of mathematics in Africa south of the Sahara and the development of mathematics in Ancient Egypt, in both Hellenistic and Islamic northern Africa, and across the Indian and Atlantic Oceans, deserve further study.

Throughout history there have been many and varied contacts between Africa south of the Sahara and North Africa. Since the birth and spread of Islam, relations have been intensified and/or extended. *ᶜIlm al-isāb* (arithmetic), as part of the Islamic sciences was introduced some time after the eleventh century in Nigeria, first in Kanem–Borno and later, probably in the fifteenth century in Hausaland. Arithmetic was taught in both secular and Islamiyya schools, was used in the courts for the calculation of inheritance, and for collecting and distributing poor dues, business, and land surveying. A famous mathematician was Muammed ibn Muammed from Katsina (now northern Nigeria), who worked on chronograms and magic squares. He had been a pupil of Muammed Alwali of Bagirmi. He made a pilgrimage to Mecca in 1730, and he died in Cairo in 1741. Recently a manuscript of his was found in Marrakesh, Morocco. Magic squares were used in amulets among the Fulbe, and in Niger, Benin and Timbuktu (Mali). Formal logic was one of the fields of study in the economic and educational-scientific centre of Timbuktu, where recently three Arabic mathematical manuscripts were found in the Amad Baba Library. One of the three manuscripts, whose calligraphy is typical for Africa south of the Sahara, seems to have been written by a mathematician from Mali, al-Arwani. The other two contain references to medieval mathematicians from the Maghreb. Systematic research in libraries and archives will probably lead to the discovery of more mathematical manuscripts from Muslim scholars south of the Sahara.

What mathematics was brought to the Americas by the slaves? Which mathematical ideas have survived in one way or another? Mancala, and maybe other games with mathematical components, are played in the Caribbean and may be compared with their African "ancestors." In Africa the slave trade was extremely destructive of the existing mathematical traditions. This is because of breaking professional continuity and depriving Africa of bearers of mathematical knowledge and skills such as that of the drawing experts from Angola and Zambia and that of calculators like Thomas Fuller (1719–1790). Recent ethnomathematical research in Nigeria and Mozambique shows the survival, nonetheless, of a rich tradition of mental calculations among illiterate people.

The destructive impact of colonialism and the slave trade on Africa is one of the principal reasons Georges Njock gives to explain why mathematics in Africa has had a slower development in the last five centuries than in Europe. Other reasons he gives deal with the geography of the continent (migratory movement) and wars. This also constitutes an important research area that deserves further study.

See also: ►Number Systems in Africa, ►Geometry in Africa: Sona Geometry

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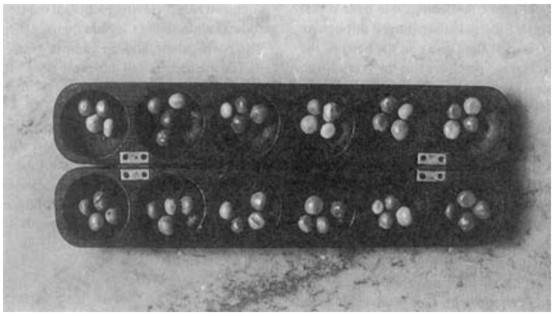

Mathematics in Africa: West African Games.
Fig. 1 Game of the Sorcerer. Photograph by the author.

Mathematics in Africa: West African Games

Salimata Doumbia

Exploring the sociocultural environment of Africa is an interesting way of learning about concrete mathematics. Games, always a popular childhood activity, should be studied with care in as much as they are a reflection of the society and its fundamental values. Today we are witnessing the introduction of “educational games” to the African continent, as if African games did not exist. In this article, we will describe several African games and the mathematics behind them.

Exhibition Games

In Africa there are games which have hidden underlying algorithms. The person who knows the algorithm is assured of winning, which makes him a “magician” or “sorcerer” to those who do not know it. The “sorcerer” often chants incantations or performs other magic tricks to show his power. We will study two of these games.

a. *The game of the sorcerer.* The game of the sorcerer is very old. Sorcerers perform it to demonstrate their supernatural powers. Forms of the game are played throughout Africa – in Senegal (Game of the Devil), in the bend of the Niger River (the Sorcerer’s Apprentice), in the Ivory Coast (*Lokoto*), and in Mali (*Gamma*) (Fig. 1)

There are two players: the sorcerer and his victim. The game is played on a board of 12 compartments set up in two rows of 6 and 48 beads.

Before beginning play, the players place four beads in each compartment. The sorcerer and the victim each take two stones from 11 compartments. From the 12th, the sorcerer takes three beads, the victim one (the sorcerer thus has two extra beads). He must now “magically” pass the two extra beads to the victim. He rubs the beads, chants incantations, blows on his thumbs, and then instructs the victim to fill the compartments with four beads each as he does the same. When the beads are redistributed, three beads are left in the victim’s hand, one in the sorcerer’s, and the trick is done.

If we analyze the mathematical aspects of the game, we see that it has two parts:

1. The taking of the stones (beads)
   The sorcerer: $2 \times 11 + 3 = 25$
   The victim: $2 \times 11 + 1 = 23$
2. The replacing of the stones
   Each player must put four beads in each of the compartments, filling as many as he can with the beads in his hand.
   The sorcerer: $25 = 4 \times 6 + 1$
   The victim: $23 = 4 \times 5 + 3$

After redistributing the beads, the victim has three beads in his hand and the sorcerer, one. The game works whenever the number of compartments is even.

b. *The game of the unknown stone.* The player asks a spectator to select in his mind one of 16 different stones. The player must discover the unknown, selected stone. First, he arranges the stones in two rows of eight. Then he asks the spectator to indicate the row that the unknown stone is in. Mentally the player makes two groups of four stones each from the stones in the indicated row. He rearranges them (or distributes each group on different lines) and asks the spectator again to indicate which row has the unknown stone. Upon the indication of the row he makes two groups of two stones each from one of the groups of four stones. Then he rearranges them again.

Again, the spectator indicates the row with the unknown stone. The player then redistributes the only two stones left, which could possibly be the unknown stone, into two different rows. The spectator again indicates the row with the unknown stone. Having identified the stone, the

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player then collects all the stones together, mixes them up, pulls out the “unknown” stone, and the game is over.

The mathematics of this game shows that the player must divide the stones into two rows in order to locate the unknown stone.

$16 = 2^4$ where 4 is the number of times that the player must divide the 16 stones, two being the number of rows. More generally, if n is the total number of stones, and k is the number of times the player must divide the stones into two rows, then the following equation holds true: $n = 2^k$. Inversely, if one knows n, one can calculate k from the formula $k = \log_2 n$.

Games of Chance

Men have always played games of chance. In Africa, there are many situations in which chance is called into play: when one needs to make a hard choice (heads or tails, the short straw), or when one needs to be sure of winning. Games of chance are based on theories of probability.

The cowrie is a sea shell with two sides: a front and a back. In Africa, cowries were considered rare and valuable, and so played an important role in African life. Its form, similar to an aura according to the mystics, makes it an instrument of divination. Cowries also play a role in initiations, funerals, and engagements, and in certain regions of Africa, they were – and still are – used as a medium of exchange.

All the cowrie games are collective games. The number of players is two or more. The principle of the game is simple. Two players (or two representatives of two teams) throw the cowries at the same time. The cowries fall on the ground, landing on one of two sides. There are usually four shells. The configurations formed by the cowries are examined so that the results can be read. The results are interpreted according to pre-established rules: heads is given a +; tails is given a –.

Thus, when the four stones are thrown, there are five possible configurations:

Heads (+)	**Tails (–)**			
+ + + +	– – – –	10 points	– – – –	win
+ + + –	+ + + +	5 points	+ + + +	win
+ + – –	+ + – –	2 points	+ + – –	win
+ – – –	+ + + –	0 points	+ + + –	lose
– – – –	+ – – –	0 points	+ – – –	lose
Configurations	Example 1		Example 2	

The calculation of points varies. There are two ways to compute points, either numerically (Example 1) or not (Example 2). Generally, if points are calculated numerically, the winner is declared when a player reaches a certain total number of points, that number being fixed before play begins.

Word Games and Traditional Learning in Africa

In many African countries, traditional learning is oral. Information and wisdom are transmitted from generation to generation in the form of proverbs, stories, chants, riddles, and games. This provides real lessons in language, history, geography, natural science, arithmetic, measurement, cosmography, etc. Teaching is seen as the natural and traditional way of communicating the secrets of the adult world to a child. Following are some examples of counting games.

Cumulative Chants

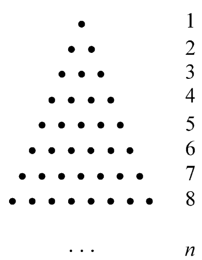
Memory Games: The Yé Gonan. The Yé Gonan is a children’s game from the Ivory Coast. There are two players, one who asks questions and one who answers. The players use eight stones and eight holes dug in a line in the sand, each one containing a stone. The player who is answering looks at the game and makes himself/herself acquainted with the rules. One of the rules is to retain correctly the sense of the course imposed by the questioning player. Then the answering player turns his back on the game. For each turn, the questioner taps on the hole and always asks the same question: “Am I taking a stone?” The answerer, who has his back to the game, can only answer “Yes” or “No, it’s empty.” Each time that he has taken a stone, the questioner comes back to the first hole. The answerer who reaches the eighth hole without making a mistake, wins the game. The players then change roles (Fig. 2).

The mathematical problem posed by the game is the following: when the questioner is at hole number n, which contains a stone, which is the total number Z_n of questions posed from the beginning of the game to the taking of that stone?

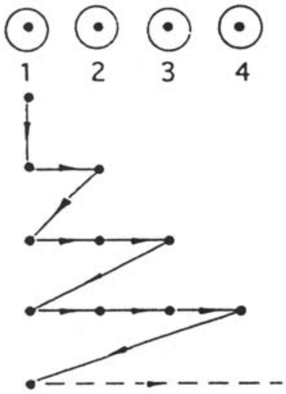
The answer is $Z_n = n(n+1)/2$.

It is a triangular number. For $n = 8$, one finds that: $Z_8 = 9 \times 8/2 = 36 = 6^2$. The number Z_8 is therefore a squared number: it is the smallest number that is, at the same time, both triangular and squared. The Pythagorean tradition considered the number $n(n + 1)/2$ as a secret value. It is interesting to find this same representation in the Pythagorean tradition both among the moors in Mauritania and the Wolofs in Senegal.

$Z_1 = 1$
$Z_2 = Z_1 + 2 = 1 + 2$
$Z_3 = Z_2 + 3 = 1 + 2 + 3$



$$Z_n = Z_{n-1} + n = 1 + 2 + \cdots + (n-1) + n$$



Mathematics in Africa: West African Games. Fig. 2 Cumulative chants diagram.

Riddle problems. In The Vultures, a shepherd, spending the night under a baobab tree, heard an old vulture pose the following riddle to some children: "There are 33 baobab trees; on each baobab there are 33 vultures; each vulture had laid 33 eggs; each egg yields 33 chicks; and each chick has 33 barbed feathers – How many barbed feathers are there altogether?" The shepherd, wanting to answer, fell dead. This is why, they say, the Fulani do not want to answer.

The solution to the problem lies in the calculation of powers. There are 33^6 vultures: $33^6 = 1{,}291{,}467{,}969$.

Magic squares. The Fulani are familiar with simple magic squares. They appear drawn with Arabic numerals as amulets. They are also used as a kind of game. Someone who knows the magic square proposes it to a group of people who then try to figure it out by putting stones, pebbles, or pieces of dung in a square drawn on the ground.

2	9	4
7	5	3
6	1	8

Saturn square (sum = 15).

21	26	19
20	22	24
25	18	23

Number of Allah (sum = 66).

23134	23137	23143	23127
23142	23128	23133	23138
23129	23145	23135	23132
23136	23131	23130	23144

The Four Angles (sum = 92541).

In a magic square, the sum of the numbers in each line, horizontal, vertical or diagonal, is the same. The number of Allah is 5 + 30 + 30 + 1 = 66. In the Square of Saturn, the total is 15, and in the Four Angels, the total is 92,541. Magic squares are well known in Muslim countries, as they are in China and Japan.

See also: ►Mathematics, ►Recreational

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Mathematics and Astronomies of the Ancient Berbers

José Barrios García

Northwest Africa is an immense territory extending from the Mediterranean shores to the Niger River and from Libya to the Canary Islands. It is here where Berber culture began to develop about 10,000 years ago, and where it has continued to develop until the present.

Despite the antiquity and widespread diffusion of Berber culture, North African studies have traditionally understated its contribution to human history. Camps (1980) aptly summarized the situation in the title of his book: *Berbères: aux marges de l'Histoire* (Berbers: On the Margins of History). Although the overall situation has improved in the last decades thanks to the efforts of a new generation of scholars – one main outcome being the ongoing publication of the *Encyclopédie Berbère*, of which 27 volumes have already appeared – actual research on the mathematics and astronomies of the ancient Berbers remains scarce.

A faithful exposition of the situation must take into account two main areas of research, each one of them with its own scope, achievements and methodological problems: continental Berbers on the one hand, and Canary Islands Berbers on the other. While both areas are certainly unbalanced from many points of views, for our purposes they complement one another.

Continental studies are part of the ethnographic fieldwork performed in the nineteenth to twentieth centuries by European researchers, so they mainly provide information on modern Berbers. Most of these notices are related to astronomy through religion, calendar, and folklore, while those few dealing with mathematics mainly focus on numeral systems and their grammar. While some of the reported traditions are important and thought-provoking, little has been said on the technical aspects underlying them, nor on their supposed origin and extent. Besides that, some preliminary work has also been done on the astral aspects of the religion of the ancient Berbers, as well as on the astronomical orientation of a few archaeological sites.

Canarian studies deal with the Berber populations inhabiting the archipelago before the Spanish conquest of the Islands on the late fifteenth century. They mainly draw on a collection of written sources originating with the European rediscovery of the Islands in the early fourteenth century, complemented with archaeological, ethnographic, and linguistic data. Since written sources mostly apply to Grand Canary and Tenerife in the fourteenth to fifteenth century, I must restrict the evidence to both islands and this period of time.

Numeral Systems

Our knowledge of ancient Berber numerals comes from different sources, and all of them point to a pure 10-base system. The three oldest numeral lists are from the Canary Islands and are summarized in Table 1. The first one appears in a letter describing a Portuguese expedition to the islands in 1341, and seems to have been first studied by Costa de Macedo (1841). The second one appears in a play written in 1582. The third one appears in a chronicle of the conquest of Grand Canary preserved in a very problematic manuscript from 1682–1687; it is most probably a late compilation that dislocates the original list by erroneously introducing two Arabian numerals (*arba* and *canza*) and false forms for the tens.

Continental lists are considerably younger than the Canarian ones. The first one I can document was made by Domingo Badía in 1804 near Marrakech, and published under a pseudonym in Abassi (1814).

Mathematics and Astronomies of the Ancient Berbers. Table 1 The three known lists of Canarian numerals

	Recco 1341	Cairasco 1582			Cedeño 1687
		Hypothesis 1	Hypothesis 2	Hypothesis 3	
1	nait/vait	be	be	be	ben
2	smetti	smi	smi	smi	liin
3	amelotti	amat	amat	amat	amiet/amiat
4	acodetti	aco	aco[s]	aco[s]	arba
5	simusetti	somuset	somu[s]	somu[s]	canza
6	sesetti	–	–	[ses]	sumus
7	satti	–	set	set	set
8	tamatti	tamo	tamo	tamo	set
9	alda morana	–	–	benir ?	acot
10	marava	[marago]	[marago]	marago	marago
11	nait/vait marava	ben-ir-marago	ben-ir-marago	–	venir marago
12	smatta marava	–	–	–	linir marago
13	amierat marava	–	–	–	–
14	acodat marava	–	–	–	–
15	simusat marava	–	–	–	–
16	sesatti marava	–	–	–	–
20	–	–	–	–	linago
30	–	–	–	–	amiago
40	–	–	–	–	arbago
50	–	–	–	–	cansago
60	–	–	–	–	sumago
70	–	–	–	–	satago
80	–	–	–	–	setago
90	–	–	–	–	acotago
100	–	–	–	–	bemaraguin
200	–	–	–	–	limar...in

Generally speaking, the continental data show that the intense Arabisation process suffered by continental Berber speaking groups from the seventh century on led to three types of situations, summarized in Table 2:

a. Certain groups preserved a purely Berber numeral system (Tuaregs, Mzabits, etc.).
b. Certain groups completely lost the Berber numeral system, and counted with some dialectal variant of the Arab system.
c. Certain groups preserved the Berber numerals until a certain point and after that they counted with some dialectal variant of the Arab system. Among them were Kabylians (counting in Berber up to two) and Shilhs (counting in Berber up to nineteen).

Prasse (1974) undertook the reconstruction of the proto-Berber language. A comparison of his reconstruction with other relevant members of the Afro-Asiatic family can be seen in Table 3.

Mathematics and Astronomies of the Ancient Berbers. Table 2 Tuareg, Kabylian, and Arabian numeral systems

	Tuareg 1859		**Kabylian 1858**		**Classic Arabian**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
1	iien	iiet	iiun, iiedj	iiuth, iiechth	’aḥad^{un}, wāḥid^{un}	’iḥdâ, wāḥidat^{un}
2	sin, essin	senatet	sin	senath	’iṯnāni	’iṯnatāni
3	keradh	keradhet	thletha	id.	ṯalāṯ^{un}	ṯalāṯat^{un}
4	okkoz	okkozet	arbâa	id.	’arba‘^{un}	’arba‘at^{un}
5	semmus	semmuset	khamsa	id.	ẖams^{un}	ẖamsat^{un}
6	sedis	sediset	settsa	id.	sitt^{un}	sittat^{un}
7	essaa	essahat	sebâa	id.	sab‘^{un}	sab‘at^{un}
8	ettam	ettamet	themania	id.	ṯamān^{in}	ṯamāniyat^{un}
9	tezzaa	tezzahat	tsâa	id.	tis‘^{un}	tis‘at^{un}
10	merau	meraut	âchera	id.	‘ašr^{un}	‘ašarat^{un}
11	merau d iien	meraut d iiet	ah’dach	id.	’aḥada ‘ašara	’iḥdâ ‘ašrata
12	merau d sin	meraut de senatet	ethnach	id.	’iṯnā ‘ašara	’iṯnatā ‘ašrata
20	id.	senatet temeruin	âcherin	id.	‘išrūna	id.
30	id.	keradhet temeruin	thlathin	id.	ṯalāṯūna	id.
40	id.	okkozet temeruin	arbâin	id.	’arba‘ūna	id.
50	id.	semmuset temeruin	khamsin	id.	ẖamsūna	id.
60	id.	sediset temeruin	settsin	id.	sittūna	id.
70	id.	essahat temeruin	sebâin	id.	sab‘ūna	id.
80	id.	ettamet temeruin	themaniin	id.	ṯamānūna	id.
90	id.	tezzaat temeruin	tesâin	id.	tis’ūna	id.
100	id.	timidhi	miia	id.	mi’at^{un}	id.
200	id.	senatet temadh	miithain	id.	mi’atāny	id.
1000	id.	agim	elef	id.	‘ělf	id.

Mathematics and Astronomies of the Ancient Berbers. Table 3 General comparative table of numeral systems

	Proto-Berber	**Canarian**	**Egyptian**	**Acadian**	**Arabian**
1	yīwan	nai/vai, be, ben	w’jw	ištēn	wāḥid^{un}
2	sīn	sme, smi	snwj	ši/ena	’iṯnāni
3	karāḍ	amel, amat	ẖmtw	šalaš	ṯalāṯ^{un}
4	hakkūẓ	acod, aco[s]	jfdw	erba	’arba‘^{un}
5	sammūs	simus, somu[s]	djw	ẖamiš	ẖams^{un}
6	saḍīs	ses	jsw	(ši/eššum)	sitt^{un}
7	sāh	sa, se	sfẖw	sebe	sab‘^{un}
8	tām	tama, tamo	ẖmnw	samāne	ṯamān^{in}
9	tiẓāh	alda [marava]	psḏw	tiše	tis‘^{un}
10	marāw	marava, marago	mḏw	ešer	‘ašr^{un}

Astronomy, Calendars and Social Organization

The fieldwork of nineteenth to twentieth century ethnographers shows that northwest African peasants actually used several concurrent calendars. While the Julian calendar was the most used for agricultural purposes and the Hegira was mainly used in religious circumstances, the Gregorian calendar served to interact with administration and modern life, and was a common reference between the different systems.

Since these three calendars are non-Berber in origin and a summary of their local characteristics can be seen in EB–Gast–Delheure (1992), it is only necessary here to make a brief remark on their respective dates of introduction. Certainly, the Hegira was introduced after the Arab invasion in the seventh century and the Gregorian calendar after its inception in 1582, but there are good reasons to think that the Julian calendar is not a remnant of Roman domination, as is usually said. It seems to have been introduced by Coptic communities well after the Arab invasion and before the adoption of the Gregorian calendar (Servier 1985).

Besides the three mentioned calendars, a less evident but more profound and extensive astronomical tradition has been posed by two different and exhaustive studies carried out in the middle twentieth century by the French ethnologists Jean Servier and Viviana Pâques.

The Doors of the Year

Jean Servier travelled in North Algeria from 1949 to 1961 compiling information about the traditional thinking of Berber speaking peasants. His work (Servier 1962, 1985) describes a complex symbolic world superposed on an apparently simple material culture. He found that northern Algerian peasants mix a visible world with an invisible world. The invisible world would be related to their ancestors and the rhythms of nature as marked by the *tibburin ussegwass* (doors of the year). The doors of the year are the solstices and the equinoxes. In his opinion, this was part of an ancient system, which has disappeared in other parts of the circum-Mediterranean area, but is well preserved by traditional Berber peasants.

Canopus and the Cosmic Tree

From 1953 on Viviana Pâques researched in Fezzan, Sahara, Mali, Algeria and Tunis. She studied the spiritual world which enslaved Black people would have brought with them into these lands. Her results were presented in Pâques (1964). To her surprise, what she found was a conception of the world common to all peoples of North and West Africa, a conception as characteristic for an anthropologist as a typical biface would be for an archaeologist (Pâques 1964: 10).

Everywhere she found one or another variant of the following cosmogony:

1. God created the world by exploding Canopus, the primeval star. From Canopus exited the triple serpent it held in its matrix, which commands all divisions of the world by three. The explosion of Canopus gave birth to six other stars, which command all divisions of the world by seven.
2. The world turned back when a hero (sometimes a smith) decapitated the serpent, which was the prelude to all circumcisions.
3. The hero descended to the Earth through the triple cosmic tree formed by the body of the decapitated serpent.
4. The hero ascended the cosmic tree later, on the occasion of a second sacrifice of the serpent, which was the prelude to all marriages.
5. These mystic events occurred at a determinate point of the sky, at a moment when the sun was in a particular relation with Canopus, for the explosion, and with the Pleiades for the sacrifices. (On the planets' layout, the Pleiades are assimilated with Venus).

This myth defined the rules that organise every aspect of traditional North and West African life. From political, territorial and social structures to the division and rhythms of the heavenly movements, from the division of the agricultural year by means of certain constellations, to the design of clothes, shoes, coiffures and everything that could reflect this system in daily life.

The myth is deeply associated with three colours – white, red and black – respectively related to the triple serpent inside Canopus. Number 3 (and 60-based counts) is associated with women, while 4 (and 80-based counts) are associated with men. Number 7 (=3 + 4) represents the union of a man and a woman.

As to the origin of this African cosmogony, different opinions have been posed, ranging from a Mediterranean to an Oriental or Indian one. Nevertheless, the internal coherence, originality and distribution map of this myth make Pâques suggest that it originated at a very ancient date in some agricultural community living in a subdesert territory, perhaps around some of the Saharan oases where these conceptions are most fully preserved (Pâques 1964: 676).

What can be said about the astronomical and mathematical implications carried by the antiquity, originality and complexity of this cosmogonical system? This is probably one of the most interesting open problems for the history of ancient sciences, and the Canary Islands have something to say here.

The Canarian Evidence

In the fourteenth to fifteenth centuries AD, Grand Canary and Tenerife were inhabited by Berber populations – called Canarians and Guanches – coming from the nearby continent on different occasions between the first millennium BCE and the first millennium AD. These populations remained relatively isolated until the European rediscovery of the Islands in the late thirteenth century. At that time the population of each island was about 40–60,000, sustaining a developed agricultural (barley, wheat) and stock raising (goats, sheep, pigs) economy. The written sources point out the presence in both islands of a powerful priestly class, in whose religious system the sun, moon and stars played a very important role.

Grand Canary Island

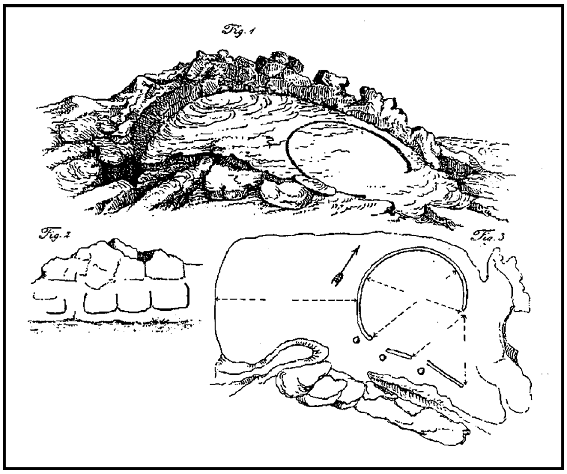
The Canarians used a synodic lunar calendar for daily life. The lunar year was adjusted to the solar year at the summer solstice. Although nobody mentions an intercalary moon, the first new moon after the summer solstice marked a new year and was feasted. Actual calendrical figures are very scarce but they mention a lunar synodic month of 29 days, a lunar year of 12 months, and a certain period of 520 days, which is an exact measure of one and a half eclipse years or three passes of the Sun by the lunar nodes (incidentally, this is the reason why eclipses are located in three fixed zones of the 260-day Mesoamerican sacred calendar). There are also notices about observation of rising and setting of stars. Sirius is the only explicitly mentioned star but there is a clear reference to Afarakrak, a Berber name of Canis Maior, in Facaracas, the preserved name of an important site where the nobility of the island used to meet.

Archaeoastronomical research undertaken from 1985 at the mountain of Cuatro Puertas (Four Doors) has revealed several methods for observing the solstices and other astronomical dates.

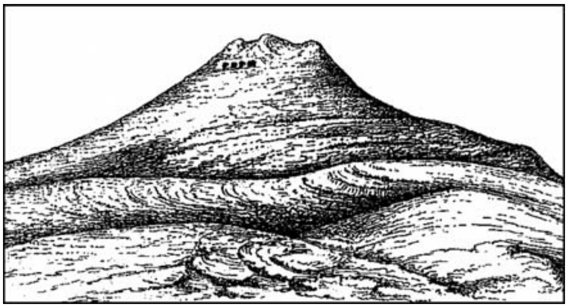
The mountain is an isolated arid volcanic semicone oriented east–west with an elevation of 319 m. above sea level. Seen from the north (Fig. 1) its slopes are smooth and rounded. All that stands out is the big artificial cave with four entries located near the top, which gives its name to the mountain. The precise orientation of these doors assures that sunlight only enters the cave at sunrise (Fig. 3) and sunset (Fig. 4) on a few days around the summer solstice.

Seen from south its appearance is diametrically opposed, plunging abruptly from its top to the bottom of a ravine. On this slope there is a group of spacious and sophisticated artificial caves excavated in the rock, among which stands out the Cave of the Pillars. This cave is fully illuminated by the rising sun on winter solstice days (Figs. 5 and 6).

At the top of the mountain there is a little ritual esplanade of some 10 × 5 m. partially excavated on the rock (Fig. 2). Open to the east and south, on the wall facing the east there is a carved sign about 2.4 m. long with JUUU form (Fig. 8).



Mathematics and Astronomies of the Ancient Berbers. Fig. 2 Ritual esplaaade at the top of Cuatro Puertas after Berthelot (1879).



Mathematics and Astronomies of the Ancient Berbers. Fig. 1 The mountain of Cuatro Puertas after Berthelot (1879).

Mathematics and Astronomies of the Ancient Berbers. Fig. 3 Summer solstice sunrise at Cuatro Puertas cave. Photo by José Barrios García.

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Mathematics and Astronomies of the Ancient Berbers. Fig. 4 Summer solstice sunset at Cuatro Puertas Cave. Photo by Jose Barrios Garcia.

Mathematics and Astronomies of the Ancient Berbers. Fig. 5 Winter solstice sunrise from the Cave of the Pillars. Photo by José Barrios García.

Mathematics and Astronomies of the Ancient Berbers. Fig. 6 Winter solstice sunrise illuminating the cave of the Pillars. Photo by José Barrios García.

Mathematics and Astronomies of the Ancient Berbers. Fig. 7 Summer solstice sunrise from the sign of Cuatro Puertas. Photo by José Barrios García.

Every day at sunrise the silhouette of the rock located in front of the sign casts a certain shadow that changes its position day by day, reflecting the azimuthal change of the sunrise. The left edge of the shadow reaches the different strokes on determined dates, while the whole shadow fits the sign just on the summer solstice days (Figs. 7 and 8).

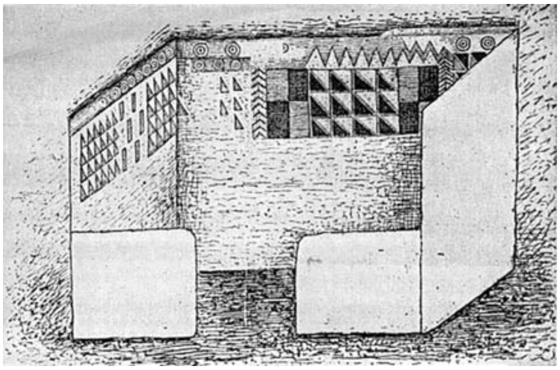
The Canarians used certain characters to record numerical, astronomical and calendrical data systematically. These figures were triangles, squares and circles painted in white, red and black on wood planks and on the walls of certain caves. The modern reconstruction of the decoration of the Painted Cave of Gáldar strongly suggests the use of a 3 × 4 chessboard, named *acano*, to represent 12 moons (Figs. 9 and 10).

A systematic analysis of the *acano* as a lunar calendar shows how the vertical numeration of its squares forces the solstitial, equinoctial and eclipse Moons to move across the board in very simple and stable patterns. These patterns provide a safe and clear mnemonic guide for performing on the *acano* an easy arithmetical calculus of seasonal and eclipse moons over extended periods of time. This calculus establishes the *octaeteris* and the 135-Moon eclipse cycle as basic periods of the *acano*.

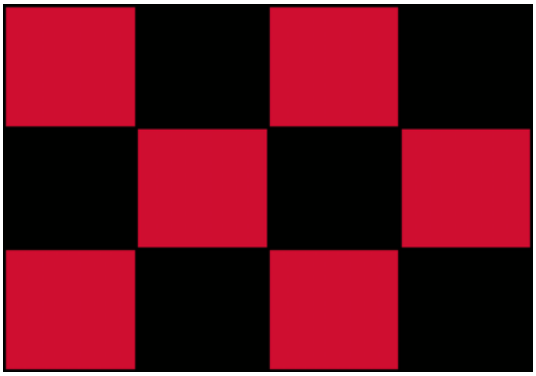
Tenerife Island

The Guanches, as the Canarians, used a synodic lunar calendar for daily life, adjusting it to the solar year at the summer solstice. Also mentioned is the use of tally boards and small necklaces of clay beads for recordkeeping, although the absence of well-preserved examples in a reliable archaeological context impedes testing these accounts. Nobody mentions an intercalary moon, but the first moon of the year occurred towards the middle of August and was celebrated. This festival exists today in the traditions of the Virgin of Candelaria, patron of the island, whose apparition to

Mathematics and Astronomies of the Ancient Berbers. Fig. 8 The shadow at Summer solstice sunrise fitting the sign of Cuatro Puertas. Photo by José Barrios García.



Mathematics and Astronomies of the Ancient Berbers. Fig. 9 The Painted Cave of Gáldar after Verneau (1889).



Mathematics and Astronomies of the Ancient Berbers. Fig. 10 The acano chessboard.

the Guanches is reported to have occurred about 100 years before the Spanish conquest in the late fifteenth century. A close analysis of these traditions shows that they match a Guanche cult to a stellar deity considered the "mother of the sun" as well as the "mother of the one who sustains the world."

Besides the main festival that occurred about the middle of August, there were two other important ones occurring in early February and late April, respectively. These three periods can be readily correlated with the heliacal rise, acronical rise and heliacal set of Canopus. On the whole the gathered evidence proves the presence in Tenerife of the Canopian cosmogonical system described by Pâques (1964).

Further evidence concerning the determination of the year of apparition of the Virgin to the Guanches supports the idea that the Guanches used a commensurability period of 19 solar years ≈21 sidereal lunar years in their calendrical reckonings.

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Mathematics: Aztec Mathematics

Michael P. Closs

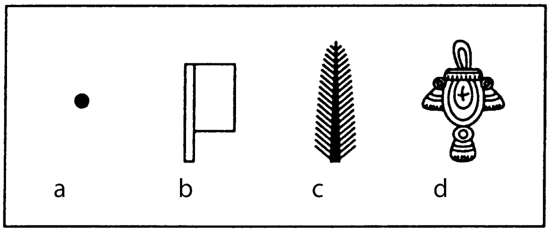
The tribal records of the Aztecs indicate that they left their legendary homeland in AD 1168 and founded their capital Tenochtitlan (present day Mexico City) in 1325. By the fifteenth century, their capital had become the center of an expansionist empire. When Cortés arrived in 1519, Tenochtitlan dominated all other cities and had reached the height of its power and magnificence. The language of the Aztecs, Nahuatl, is still spoken today in Central Mexico. An overview of the Nahuatl number sequence is given in Table 1.

Mathematics: Aztec Mathematics. Table 1 The Nahuatl number sequence

1	ce	
2	ome	
3	ei, yei	
4	nahui	
5	macuilli	
6	chicuace	(5) + 1
7	chicome	(5) + 2
8	chicuei	(5) + 3
9	chiconahui	(5) + 4
10	matlactli	
11	matlactli once	10 + 1
12	matlactli omome	10 + 2
13	matlactli omei	10 + 3
14	matlactli onnahui	10 + 4
15	caxtolli	
16	caxtolli once	15 + 1
17	caxtolli omome	15 + 2
18	caxtolli omei	15 + 3
19	caxtolli onnahui	15 + 4
20	cempoalli	one score
30	cempoalli ommatlactli	20 + 10
37	cempoalli oncaxtolli omome	20 + 15 + 2
40	ompoalli	2 × 20
60	eipoalli	3 × 20
100	macuilpoalli	5 × 20
400	tzontli	
401	centzontli once	(1 × 400) + 1
405	centzontli onmacuilli	(1 × 400) + 5
500	centzontli ipan macuilpoalli	(1 × 400) + (5 × 20)
8,000	cenxiquipilli	1 × 8,000

The term for five, *macuilli*, derives from *maitl* "hand", *cui* "to take" and *pilli* "fingers". It means something like "fingers taken with the hand". The term for ten, *matlactli*, comes from *maitl* "hand" and *tlactli* "torso". The term for 15 is a new basic word for which there is no known etymology. The vigesimal nature of the number system clearly shows up in the introduction of new basic terms for 400 and 8,000. The word for 400, *tzontli*, means "hair" or "growth of garden herbs". In either case, it signifies multitude or abundance. The word for 8,000, *xiquipilli*, refers to a "bag of cacao beans".

The Aztec had written numerals for the first four vigesimal powers: $20^0 = 1$, $20^1 = 20$, $20^2 = 400$ and $20^3 = 8{,}000$. These symbols are shown in Fig. 1: (a) a dot represents the unit 1; (b) a flag represents 20; (c) a hank of hair or garden herb represents 400; (d) a bag of cacao beans is used for 8,000. It can be seen that the symbol for 400 reflects the word for that number, *tzontli*, "hair" or "growth of garden herbs". Similarly, the sign for 8,000 reflects the word for that number, *xiquipilli*, "bag of cacao beans".



Mathematics: Aztec Mathematics. Fig. 1 Aztec numerals: (**a**) 1; (**b**) 20; (**c**) 400; (**d**) 8,000 (Drawing by Closs).

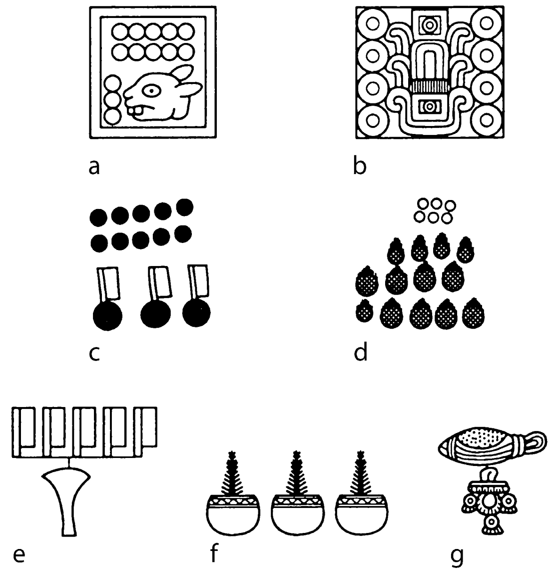
A tally of these four numerals was used to represent other numbers. Thus, quantities from 1 to 19 were represented by the appropriate number of dots or circles. In the same way, multiples of 20 less than 400 were represented by repeating the sign for 20 as many times as necessary. Similarly, the symbols for 400 and 8,000 were repeated to form multiples of 400 and multiples of 8,000, respectively. The largest number I have seen recorded with these numerals occurs in the Vatican Codex. It is composed of two signs for 8,000 and 9 signs for 400 yielding (2 × 8,000) + (9 × 400) = 19,600.

Numerals are found in a variety of contexts. One of the most common of these is as numerical coefficients in calendar dates. The Aztecs, along with other Mesoamerican cultures, employed two major calendrical cycles, a sacred almanac of 260 days called the *tonalpohualli* and an annual calendar of 365 days. The *tonalpohualli* was constructed from a sequence of numbers from 1 to 13 paired with a sequence of 20 day names. The 260-day and the 365-day calendars were combined so that each day could be specified by both a sacred date and an annual date. Since the least common multiple of 260 and 365 is 18,980 (= 52 × 365), the combined cycle of the two calendars repeats after 52 years of 365 days each. This 52-year period, known as the *xiuhmolpilli* "sacred bundle," played a significant role in Aztec religious life.

A given 365-day year was designated by the sacred almanac name of its 360th day. We refer to this name day of the year as the year bearer. Because of the structure of the calendar, only four day names could function as year bearers. The 13 numerical coefficients with the 4 day names yield 52 year bearers, one for each year in the 52 year period. In the Aztec codices and stone monuments, such years are frequently named. In these cases, the numerical coefficients are represented by a tally of from 1 to 13 small circles. Examples of the year bearer dates, 13 Rabbit and eight Reed, are shown in Fig. 2a and 2b.

The Aztecs also used numerals in chronological counts which varied from a few days to thousands of years. One section of the Mendocino Codex gives the different stages in the education that a boy or girl receives from its parents. The tasks which children must learn are depicted and their daily food ration is shown by a tally of tortillas that appears over their heads. The ages are indicated by a simple tally of blue disks representing the number of years. These run from three up to 14 as one progresses through the manuscript. The corresponding daily ration rises from half a maize cake to two per day. The largest chronological interval of this type is depicted in another portion of the Mendocino Codex where an elderly male and female are shown drinking a fermented beverage denied to those who are younger. Both persons are seventy years old and their age is indicated by a tally of ten blue disks together with three disks marked with the flag symbol for 20 as shown in Fig. 2c.

The Vatican Codex contains other chronological counts which measure far larger intervals. A count which refers to the years of the second age of the world is shown in Fig. 2d. Each of the cross-hatched disks with hair on top is blue in the original and represents a period of 400 years, being a conflation of the standard blue disk for the 365-day period and the numeral for 400. (In this regard, recall that the Aztec term for 400 is *tzontli*, "hair".) In the upper row is a tally of six smaller disks marking 6 years. The total count measures a period of (13 × 400) + 6 = 5,206 years.



Mathematics: Aztec Mathematics. Fig. 2 Contexts of Aztec numeral usage. *Calendar dates (year bearers):* (**a**) 13 Rabbit; (**b**) eight Reed. *Chronological counts:* (**c**) 70 years; (**d**) 5,206 years. *Tribute records:* (**e**) 100 copper hatchets; (**f**) 1,200 coarse clay pots; (**g**) 8,000 balls of unrefined copal (incense) wrapped in palm leaves (Drawing by Closs).

Some of the Aztec codices contain lists in which the quantities of the various tribute items to be received from conquered towns are recorded. In these documents, the towns are represented by hieroglyphic toponyms, the tribute items by hieroglyphic signs, and the quantities by numerals or by a simple tally of the items. If the total is less than 20, the item is often represented by a simple tally of the sign for the object itself or by a single depiction of the tribute item with an attached tally of numerals. For larger totals, a combination of the two types of tallies is often used. Some examples of tribute records are shown in Fig. 2e–g.

In the land documents of the Texcocan Aztecs a more concise and sophisticated system of numerical notation was employed. It was used for recording the measurements of perimeters and areas of land holdings in at least two locations in the Valley of Mexico. The system made use of only four symbols – a vertical tally stroke, a bundle of five strokes linked at the top, a dot and a corn glyph (*cintli*) – and position to indicate the value of measurements (Harvey and Williams 1980, 1986).

An example from the Códice de Santa Maria Asunción, dating from around 1545, is illustrated in

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Fig. 3. The land record is divided into three parts. The first section (*tlacatlacuiloli, tlacanyotl*) contains a census by household. The name for each head of household is written in glyphic form beside a conventional symbol for household head. In the present example, the tlacatlacuiloli shows the head Pedro, his wife Juana, their two young daughters Ana and Martha, and the head's younger brother, Juan Pantli, his wife Maria and their son Balthasar. The shaded heads indicate that the individual is deceased.

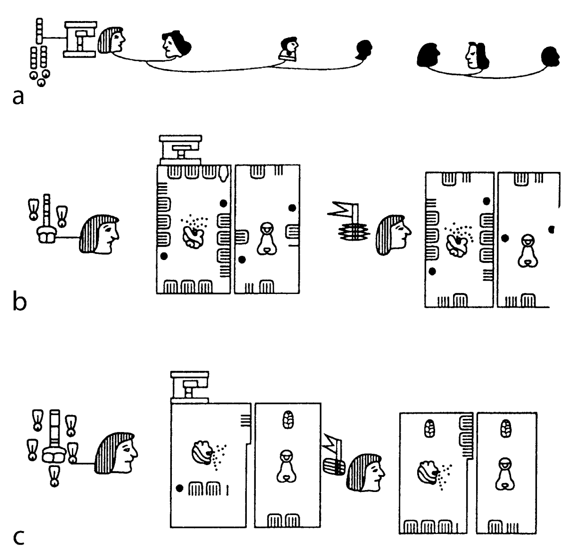
The second section (*milcocoli*) consists of a record of land parcels associated with each household. In this section, the scribe drew the approximate shape of each field. The measurement of each side was recorded using lines and dots, a line equal to one linear unit and a dot equal to 20. In the Texcocan area, the usual unit of linear measure was the *quahuitl* of approximately 2.5 m. Units less than one quahuitl were indicated by symbols such as a hand, an arrow, or a heart. The modern equivalents of these signs can only be estimated at present. In addition to recording linear measurements around the field perimeters, each field contains a hieroglyph in the center which indicates the type of soil. In particular, the milcocoli section for our example records the approximate shape, perimeter measurements, and soil type of four fields belonging to the household, two to the household head and two to his brother. The hand glyph in the first field indicates a fraction of a quahuitl.

The third section (*tlahuelmantli*) is a second record of the same lands as in the milcocoli section. However, in this case, the lands are shown in a stylized form as rectangles of the same size. Interestingly, the Nahuatl term *tlahuelmantli* literally means "smoothed, leveled, equalized." The majority of these fields have a protuberance in the upper right-hand corner. In addition to the standardized field shapes, the placement of numbers in the tlahuelmantli is different from in the milcocoli. The numerical quantities using lines and dots are entered either in the center or on the bottom line of the rectangle and in the protuberance. When numbers, never exceeding 19, are entered on the bottom line, a cintli glyph occurs near the top border of the rectangle. In addition, most fields contain a number ranging from 1 to 19 in the upper right corner of the protuberance. It has been determined that these numbers report the area of the field in square quahuitl by use of positional notation.

The system of recording area is dependent on three separate registers. The first register is located in the upper right protuberance and is used to record a unit count from 0 to 19. When the value of this register is 0, the protuberance is left empty or is not drawn. Otherwise, 1 to 19 strokes are recorded with groups of five being bundled together by a connecting line. The second register is the bottom line of the rectangle. It is used to record from 1 to 19 multiples of 20 (the vigesimal numbers from 20 to 380) by using a simple tally of 1 to 19 strokes. The third register is in the central portion of the rectangle. It is used to express higher multiples of 20, that is multiples of 20 which are greater than or equal to 400. In this register, a dot has value 400 and a stroke has value 20. The second and third registers are never used concurrently. If there is no entry in the third register, the cintli glyph is drawn toward the top of the rectangle. This may signify 0 in that register. In order to compute the area, the number in the second or third register is multiplied by 20 and added to the number in the first register.

In the example under consideration, the length of the sides, in quahuitl, of the four fields in the milcocoli section and the area, in square quahuitl, of the corresponding fields in the tlahuelmantli section is shown in Table 2.

The problem of how the areas in the tlahuelmantli were determined remains to be resolved. In general, the area of a quadrilateral cannot be determined from the



Mathematics: Aztec Mathematics. Fig. 3 A land record from the Codice de Santa Maria Asuncion (Drawing by Close from Harvey and Williams 1986).

Mathematics: Aztec Mathematics. Table 2 The length of the sides, in *quahuitl*, of the four fields in the *milcocoli* section and the area, in square *quahuitl*, of the corresponding fields in the *tlahuelmantli* section

	Sides	Area
Field 1	39, 15, 39, 15+	$(31 \times 20) + 4 = 624$
Field 2	25, 8, 26, 8	$(10 \times 20) + 0 = 200$
Field 3	38, 9, 39, 8	$(16 \times 20) + 13 = 333$
Field 4	20, 9, 20, 8	$(9 \times 20) + 0 = 180$

lengths of its sides. As a result, the information in the milcocoli section is not sufficient to obtain the true areas of the fields.

See also: ►Calendars

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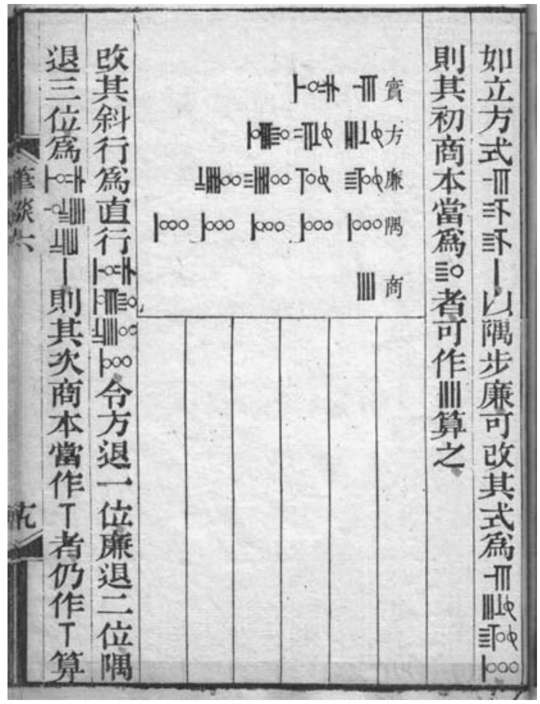
Mathematics in China

ANDREA EBERHARD-BRÉARD

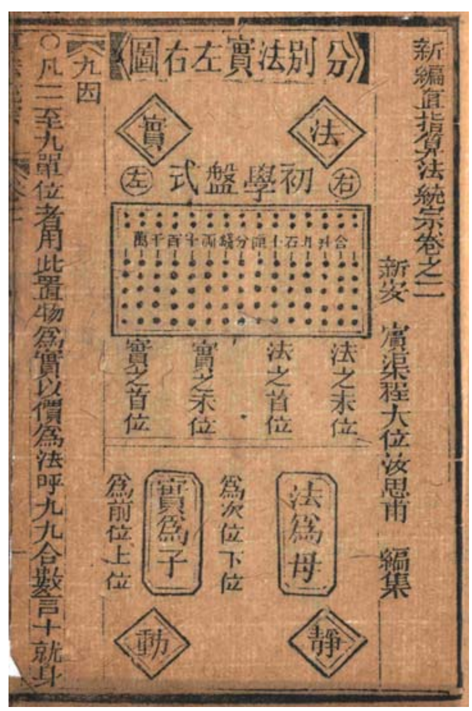
Number System and Calculation Tools

Archaeologic finds from the Shang dynasty (fourteenth to eleventh century BCE) show the earliest number symbols inscribed on bones and tortoise shells. By then, different decimal and sexagesimal systems were in use. The use of rod-numerals is also attested on coins as early as from the Wang Mang period (9–23 AD). These are related to the instruments in use. For calculations, numbers were represented on a calculation surface by counting rods. The representation follows a decimal positional notation, where nine different signs for the numbers from 1 to 10 consist of either vertical or horizontal bars used to mark units, hundreds, myriads, etc. or tens, thousands, and other odd powers of ten. Three hundred twenty-six for example was thus put down in the following way: III = T. For negative numbers, black instead of red counting rods were used. In printed records (from the eleventh century onwards) they were marked by an oblique bar (Fig. 1).

"Brush calculations" written on paper and the abacus were widely spread by the sixteenth century, but the latter may have existed one or two centuries earlier. Procedures linked to abacus calculation are mostly written in versified form for easy memorization, and historians have shown how these evolved out of earlier procedures for counting rods (Fig. 2).



Mathematics in China. Fig. 1 Solving a cubic equation with counting rods as shown in Hua Hengfang, Xue suan bitan, 1885.



Mathematics in China. Fig. 2 An abacus as represented in Cheng Dawei, *Suanfa tongzong*, 1592.

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Textual Sources

The scope of research into the history of mathematics in China today is determined by the available source material transmitted to us. The early beginnings of mathematics are closely connected to astronomy. With its non-geometric formal methodology, astronomy in China was oriented towards calendrical calculations and numerical lists, but less concerned with the design of geometric models. The positions of the celestial bodies could be determined by a system of numerical constants derived from observation, interpolation algorithms and cyclical theories. But their choice was also influenced by numerological considerations and political events.

One of the earliest texts that has been preserved is the *Zhoubi suanjing* (*Mathematical Classic of the Gnomon of Zhou*) compiled towards the end of the first century AC. It is closely related to the cosmographic doctrine of the "Heaven as a chariot-cover" (*Gaitian shuo*), which was popular during the Han dynasty (206 BCE–220 AC). Among historians, it is mainly known for its proof of a statement analogous to the Pythagorean theorem (Fig. 3).

When the court astro loger Li Chunfeng (602–670) and his staff included the *Zhoubi* and its commentaries in a compilation of *Suanjing shi shu* (*Ten Books of Mathematical Classics*) for the government academy of the Tang dynasty, the text was elevated to the status of a mathematical canon as were the other nine contemporary or earlier treatises. The collection was first printed by the imperial library of the Northern Song in 1084, which is partly still extant from a 1231 reprint.

Mathematics in China. Fig. 3 Proof of Pythagorean theorem from the *Zhoubi suanjing*.

But there is another context in which mathematics played an important role and which shaped its methods of calculation and notation in China. The administrative tradition of registering numbers in the form of tables involved the calculation of the totals of sums or provided multiplication tables for fiscal purposes. Archaeologists found six manuscript sources, which attest of such mathematical activities, at the beginning of the twentieth century in the Buddhist Dunhuang Caves in Northwest China. They date from the 6th to the tenth century and are now stored in the National libraries of France and Great Britain. One of the manuscripts for example, which gives the date of the second year of the Guangshun era (952), tabulates the products in *mu* for the surfaces of all rectangular fields with the lengths of a side less or equal than 60 *bu* (1 *mu* = 240 square *bu*).

Equally important for our understanding of mathematical activities in early China is the recent excavation of a manuscript on 190 bamboo strips in a Chinese nobleman's tomb that was closed no later than 186 BCE. It represents the earliest document that has survived and provides us with a text outside the government sanctioned *Ten Books*. The stated problems and procedures show a certain connection to the foundational *Jiu zhang suan shu* (*Nine Chapters on Mathematical Procedures*) and its commentary by Liu Hui (263 AC), which were part of the *Ten Books*, yet this connection still needs to be explored.

The commentaries to the now still extant Song dynasty edition of the *Nine Chapters* also contain fragments ascribed to other mathematicians. Zu Geng (late fifth century to early sixth century), son of the famous Tang mathematician and astronomer, Zu Chongzhi (429–500), obviously knew Liu Hui's commentary, when he wrote his "sub"-commentary on the calculation of the volume of a sphere. Later editions contain commentaries by Jia Xian (first half of the eleventh century), which are based on the now lost *Huangdi jiu zhang suanjing xicao* (*Detailed [calculation] sketches for the Yellow Emperor's Mathematical Classic in Nine Chapters*).

Among other preserved Song dynasty commentaries on the *Nine Chapters*, we find Yang Hui's *Xiangjie jiu zhang suanfa* (*Detailed Explanations of the Nine Chapters on Mathematical Methods*) printed in 1261 and in 1408 for the copies of the Ming dynasty imperial library named the *Yongle dadian* (*Great Encyclopedia of Yongle reign*). The evidential research scholar Dai Zhen (1724–1777) compiled *Supplements of Diagrams and Errata to the Nine Chapters on Mathematical Procedures* when he worked on the edition of traditional Chinese mathematical sources to be included in the imperially commissioned *Siku quanshu* (*Complete Library of the Four Treasuries*). Since Dai Zhen's compilation project of the *Ten Books of*

Mathematical Classics, more than ten other editions of the *Nine Chapters* have been discovered.

The Foundational Mathematical Content of the Ten Books

Wang Xiaotong's *Ji gu suanjing* (*Mathematical Classic in Continuation of the Ancients*, compiled earlier than 626) played an important role in the development of numerical procedures for the solution of algebraic equations. It contains 20 problems, the first one of which concerns a calendrical calculation; problems 2–5 concern the construction of a geometric solid; problems 6–16 consider the construction of different types of granaries, and the (partially incomplete) problems 17–20 deal with right-angled triangles. All the procedures to solve problems 2–20 involve the solution of a quadratic or a cubic equation, which gives the treatise a certain coherence. Given the daily motion of the sun and the moon, the position of the sun on the ecliptic at the time of the new moon, and the time lapse between new year and new moon, Wang Xiaotong's first problem asks for the position of the moon on the ecliptic at the time of the New Year's new moon which should have ideally happened at midnight of the first day of the 11th month.

Commentaries by Chen Luan (fl. 566) and Li Chunfeng on *Sunzi suanjing* (*Master Sun's Mathematical Classic*, late fourth century) mentioned in the Tang dynastic annals are unfortunately lost. But *Master Sun's Mathematical Classic* itself is the earliest document on arithmetical procedures in China. It describes the positional arrangement of numbers represented by bamboo sticks, and gives detailed multiplication and division algorithms for these tools laid out on the positions of a counting board. The textual structure of the first part of the treatise is distinct from the usual arrangement in problem, answer and solution procedure. In sequential order, measures, weights, large numbers, and standard measure vessels are defined, before expounding the methods and positions for calculations with counting rods. The texts state in general terms, procedures for multiplication, and as its inverse counterpart, the procedure for division, followed by an ordered numerical list of multiplications, division, and summations.

Zhang Qiujian suanjing (*Zhang Qiujian's Mathematical Classic*), probably written between 466 and 485, can – taken in a large sense – be interpreted as a commentary to the *Nine Chapters*, since it recycles certain problems, for which the numerical solution is described through "detailed calculation sketches" by the Sui dynasty astronomer Liu Xiaosun (mid-sixth century). But *Zhang Qiujian's Mathematical Classic* also contains problem types which in later texts become themselves canonical models. For example, there is the "one hundred fowls" problem, in which somebody is to buy one hundred fowls for one hundred monetary units of several kinds. This requires the solution of an indeterminate system of equations. What is characteristic for this text is that problems from the *Nine Chapters* are often given in inverse formulation, which leads to inverse algorithms. In many cases this requires the solution of a cubic equation, which Zhang Qiujian solves with an extended procedure to the algorithm for root extraction found in the *Nine Chapters*. From the preface one can deduce, that Zhang Qiujian was familiar with other treatises from the *Ten Classics* and that his main mathematical activity was to rewrite their procedures. His textual work on Antiquity was thus not only limited to commenting on earlier writings, as he also combined and rewrote many of the problems found in the *Nine Chapters*, which gave rise to new mathematical objects.

The Song Yuan Period: Apogee of Mathematical Tradition in China

Judging from the available sources, the thirteenth century was a highly creative period for the development of mathematics in China. Numerous references to now lost treatises show that it was also one of the most productive periods as concerns the publication of mathematical treatises, although now only eight works by four mathematicians in all survive from the late Song to the early Yuan period in China. These are:

1. Qin Jiushao. *Shushu jiuzhang* (*A Mathematical Book in Nine Chapters*), 1247
2. Li Ye. *Ceyuan haijing* (*Sea Mirror of Circle Measurements*), 1248
3. Li Ye. *Yigu yanduan* (*Calculating with Segments in Extension of the Ancients*), 1259
4. Yang Hui. *Xiangjie jiuzhang suanfa* (*Detailed Explanations to the Mathematical Methods of the Nine Chapters*), 1261
5. Yang Hui. *Riyong suanfa* (*Mathematical Methods for Daily Use*), 1262
6. Yang Hui. *Yang Hui suanfa* (*Yang Hui's Mathematical Methods*), 1274/1275
7. Zhu Shijie. *Suanxue qimeng* (*Introduction to Mathematical Learning*), 1299
8. Zhu Shijie. *Siyuan yujian* (*Jade Mirror of Four Elements*), 1303

Yang Hui's writings record the traces of a geometric method that is at the basis of the algebraic method of the "heavenly element" (*tian yuan*), a method which circulated among authors in Northwest China. The latter allowed Li Ye to solve equations of higher degree in one unknown. To do so, the numerical coefficients were laid out in (ascending or descending) order on a calculation surface with counting rods. The position of

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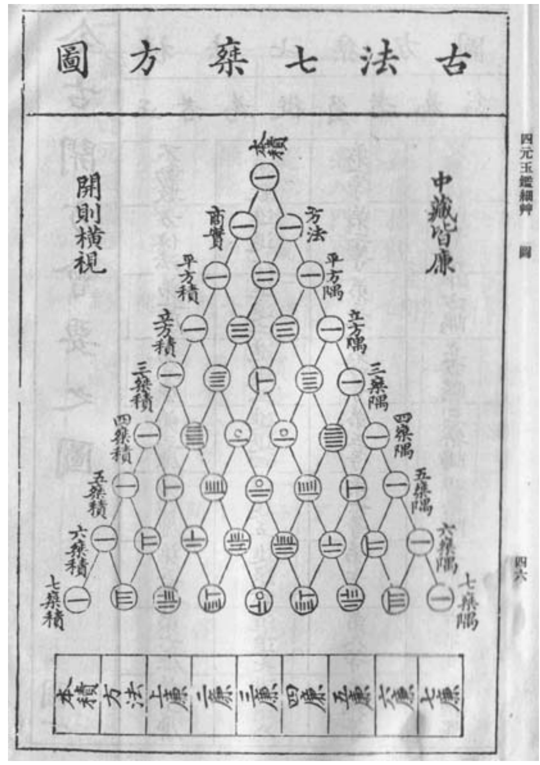
the constant term was either marked with the character *yuan* (element), or the coefficient of the linear term was marked with the character *tai* (supreme). In that way, the significance of each position was determined and the solution procedure could be performed.

According to the solution procedures cited in one of Yang Hui's texts, the *Tian mu bi lei cheng chu jie fa* (*Simple Methods for Multiplication and Division with Analogous Examples to the Categories of Field Measurement*, 1275), the algebraic *tian yuan* method evolved out of considerations of planes whose surfaces are known. In the related problem solutions, these surfaces are thought of as composed of segments, which are constructed with the given magnitudes of the problem and are in argumenative relation with the coefficients of the quadratic equation that needs to be solved.

In 1299 Zhu Shijie uses the *tian yuan* method systematically in the last chapter of his *Suanxue qimeng* (*Introduction to Mathematical Learning*) in diverse problems for plane surfaces and also for the first time for volumes. Only the first seven problems of that chapter do not require the layout of the coefficients for a polynomial equation in one unknown. These problems deal with the "opening of the square" that is the extraction of the square root of a given surface, volume, or high-dimensional surface-product. In problem 5 this requires the "opening of the triple multiplied side of a square," i.e., the extraction of the fourth square root of 1129458 511/625.

In the *Jade Mirror of Four Elements* (1303), famous for its earliest known drawing of the arithmetic triangle (or Pascal Triangle), Zhu Shijie uses in more than 200 problems the *tian yuan method* to solve equations in one unknown (Fig. 4). These problems were not limited only to applications on lengths of the sides or circumferences, and surfaces or volumes of geometric figures, but they also explored discrete cuts and accumulations that gave rise to investigations into arithmetical series. Zhu Shijie's solution procedures, however, do not contain any longer step-by-step deduction of the layout of coefficients. He merely indicates the choice of the unknown and the numerical values of the coefficients, which one obtains by an elimination method, related to the searching of "equal [surface-] products" (*ru ji*).

The *tian yuan method* had a great impact on the development of mathematics in other East Asian countries like Korea and Japan and gave rise to a large number of commentaries due to the transmission of Zhu Shijie's earlier book, the *Introduction to Mathematical Learning*. In Korea it was reprinted in 1433 under the reign of King Sejong (r. 1418–1450), and further transmitted into Japan by the end of the sixteenth century. Commentators then also started to see the limits of the *tian yuan* method, in particular for problems with two unknowns that could not be



Mathematics in China. Fig. 4 The arithmetic triangle as shown in Zhu Shijie's *Siyuan yujian*, 1303.

formulated by two independent equations in one unknown each. In China, Zhu Shijie and his precursors were already able to solve such problems (at least partially) with a method for up to four unknowns, but these writings had not made their way into Korea or Japan.

Zhu Shijie's *Jade Mirror* is now the only preserved witness of a solution procedure for higher degree equation systems with up to four unknowns. The first unknown remains the "heavenly unknown" (*tian yuan*), the other three are the "earthly" (*di yuan*), "human" (*ren yuan*), and "material unknown" (*wu yuan*). The coefficients of these unknowns are then laid out on a counting board as shown in the following illustration:

$$\begin{array}{ccccccccc}
d^m\cdot w^k & \cdots & d^2\cdot w^k & d\cdot w^k & w^k & w^k\cdot r & w^k\cdot r^2 & \cdots & w^k\cdot r^l \\
\vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots & \iddots & \vdots \\
d^m\cdot w^2 & \cdots & d^2\cdot w^2 & d\cdot w^2 & w^2 & w^2\cdot r & w^2\cdot r^2 & \cdots & w^2\cdot r^l \\
d^m\cdot w & \cdots & d^2\cdot w & d\cdot w & w & w\cdot r & w\cdot r^2 & \cdots & w\cdot r^l \\
d^m & \cdots & d^2 & d & {}_{t\cdot w}tai^{d\cdot r} & r & r^2 & \cdots & r^l \\
t\cdot d^m & \cdots & t\cdot d^2 & t\cdot d & t & t\cdot r & t\cdot r^2 & \cdots & t\cdot r^l \\
t^2\cdot d^m & \cdots & t^2\cdot d^2 & t^2\cdot d & t^2 & t^2\cdot r & t^2\cdot r^2 & \cdots & t^2\cdot r^l \\
\vdots & \iddots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\
t^n\cdot d^m & \cdots & t^n\cdot d^2 & t^n\cdot d & t^n & t^n\cdot r & t^n\cdot r^2 & \cdots & t^2\cdot r^l
\end{array}$$

This way of representation naturally limited the possibilities of solving certain types of equations. On the one hand, this is because not all theoretically possible products of unknowns could be represented;

on the other hand, a spatial extension was impossible. The possibilities of a two-dimensional layout were restricted to the four cardinal directions and thus to no more than four unknowns. Besides socio-political factors that influenced the transmission of mathematical knowledge and writings in Chinese society this was probably a structural reason for the end of the development of the *tian yuan method* after Zhu Shijie.

"Minor Traditions" as reflected in Printed Sources on Arithmetic

The commercialization of print since the Song dynasty brought about several other texts that were not printed under official auspices. The most widely circulating book was Cheng Dawei's *Suanfa tongzong* (*Systematic Treatise on Arithmetical Methods*, 1592), which was reprinted and very influential in Japan in the seventeenth century. It is structured into chapters according to the canonical categories of the *Nine Chapters* and three chapters on "difficult problems" (Fig. 5).

At the very end of Cheng Dawei's bestseller, we find a list of books of the time, but unfortunately nearly all of them are lost. But we learn from one comment and from a preface to Ding Ju's *Ding Ju suanfa* (*Arithmetical Methods*, 1355) that they might have been part of what was considered a "low" arithmetical tradition that coexisted in parallel with the tradition of the *Nine Chapters*. This parallels the historiographic trend to portray the Ming dynasty as a time of decline in scientific activity. Since the tradition was characterized by arithmetical procedures for abacus calculations, and often put in versified form, historians have paid little attention to Ming dynasty treatises and interpreted their content as folklore mathematics of little originality. Only Roger Hart has so far taken an opposite position on Ming dynasty trends. By analyzing Zhu Zaiyu's (1536–1611) *Yuelü quan shu* (*Complete Compendium of Music and Pitch*) and in particular the mathematics presented in his *New Explanation of the Theory of Calculation* (*Suanxue xinshuo*, engraved in 1604), he claims that Zhu's mathematics is perhaps some of the most sophisticated found in extant texts from the Ming dynasty. There the equal temperament of the musical scale is calculated to 25 decimal places using nine abacuses.

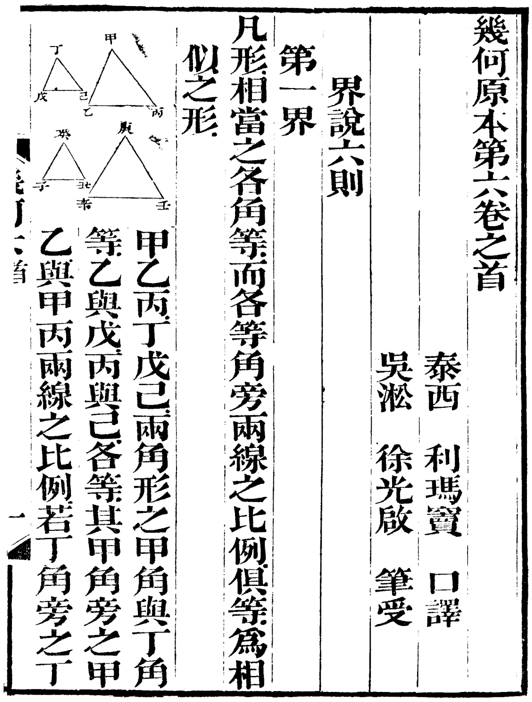
Mathematics in China. Fig. 5 Difficult problems in the *Suanfa Tongzong*, 1592.

Foreign Influence in the late Imperial Era

The first wave of transmission of some elements of the European sciences to China, which started in the late sixteenth century, was a systematic enterprise of the Jesuit mission, who sought the support of the elite to evangelize from the top down. Matteo Ricci (1552–1610), the founder of the mission, identified the mathematical sciences as a field in which Chinese literati circles were interested. He translated, together with one of his convert students in mathematics, astronomy, hydraulics, and geography Xu Guangqi (1562–1633), the first six books of Euclid's *Elements* (*Jihe yuanben*, 1607). The translation was based on Christoph Clavius' (1538–1612) Latin edition and commentary (Rome, 1574) and aroused Chinese mathematicians and even the Emperor Kangxi's (r. 1662–1722) interest in Euclidean geometry (Fig. 6).

Several other treatises on geometry, trigonometry and methods of root extraction were then written in syncretistic style by Chinese literati, who attempted creatively to come to grips with the new learning. A series of mathematical textbooks was also translated into Chinese and eventually formed the basis of an imperially commissioned compilation on mathematics, the *Shuli jingyun* (*Essential Principles of Mathematics*, 1723), which played an important role into the mid-nineteenth century.

A second wave of translations of mathematical books related to foreign presence in China following the treaties concluding the Opium Wars. Protestant missionaries, foreign employees of the Imperial Maritime Customs Service connected to its Foreign Language Institute (*Tongwenguan*) in Beijing and private foreign enterprises to promulgate Western sciences in China were the driving agents in that movement in the second half of the nineteenth century (Fig. 7).



幾何原本第六卷之首

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凡形相當之各角等而各等角旁兩線之比例俱等為相似之形

甲乙丙丁戊己兩角形之甲角與丁角等乙與戊丙與己各等其甲角旁之甲乙與甲丙兩線之比例若丁角旁之丁

Mathematics in China. Fig. 6 Book 6 of the *Jihe yuanben*, 1607.

It was during that time that Chinese mathematicians started to introduce symbolic algebra into a renewed mathematical discourse. In the assimilation and translation of works on algebra, the late Qing mathematician Li Shanlan (1811–1882) played a key role. Not only he did derive new summation formulas for finite series based on traditional procedures (known as Li Jen-Shu's formula) and write commentaries on traditional algebraic methods, but also he was instrumental in the transmission of differential and integral calculus. In 1859 he translated, together with the British missionary Alexander Wylie (1815–1887), Elias Loomis' (1811–1889) *Elements of Analytical Geometry and of Differential and Integral Calculus* (1851) and Augustus De Morgan's (1806–1871) *The Elements of Algebra Preliminary to the Differential Calculus* (1835) which were reprinted in Japan in 1872 (Fig. 8).

Both algebra and calculus quickly found their way into late Qing curricula of mathematical education, in contrast to probability theory and statistics, which remained two applied fields of mathematics that had to wait for the 1930s – and for returned students educated abroad – to be fully understood. By then, the Chinese algorithmic traditional style closely related to the written classical language was abandoned. Texts were written in vernacular language and algebraic

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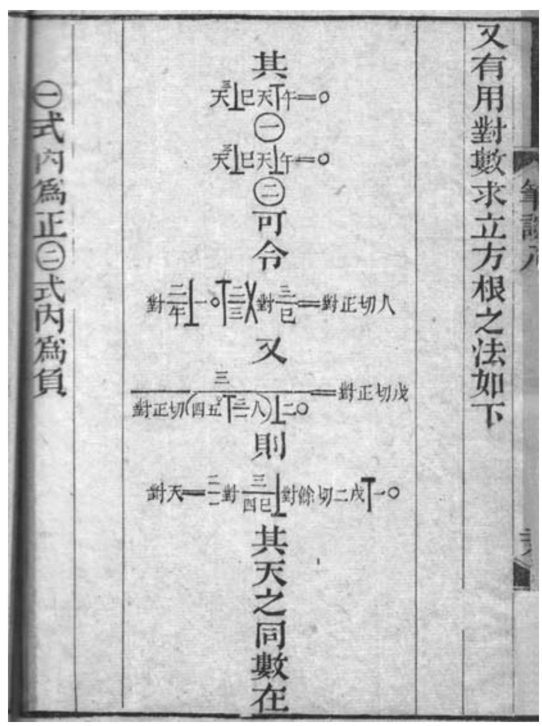
Mathematics in China. Fig. 7 Biography of Blaise Pascal in the Scientific and Industrial Magazine *Gezhi huibian*, 1880.



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Mathematics in China. Fig. 8 Syncretistic symbolism in Hua Hengfang, *Xue suan bitan*, 1885.

symbolism was adopted as the universal scientific language. China's mathematicians for the first time had an institutional base, the Academy of Science's (*Zhongguo kexue yuan*) Mathematical Institute and several research centers in universities, where the emphasis was on number theory, operations research and closely related to it statistics and probability. The antirightist campaign of 1957 and the Cultural Revolution at its peak in 1966 involved a major disruption of intellectual activities in China. At the 1978 National Science Conference, Deng Xiaoping again allowed for the progress of all aspects of mathematical research by emphasizing science as one of the "four modernizations."

Mathematics Education in China

Mathematics, together with rites, music, archery, charioteering, and calligraphy, formed the *Six Arts* as defined by traditional Confucian learning. We know that Li Chunfeng's compilation project, the *Ten Books of Mathematical Classics*, was used as a textbook for the Mathematical Academy (*Suanxue guan*) founded by the Emperor Gaozong in 656. This academy was part of the "directorate of education" (*Guo zi jian*) responsible for the training of government officials. A "School of mathematics for the national youth" (*Suan li guozi xue*) had already existed since the Sui dynasty. It was taken over by the Tang, but we do not know about its curriculum and the manuals that were used. In Imperial China, there was no such profession as a mathematician; knowledge was mainly transmitted orally from teacher to pupil in private academies. We have little or no biographical information on those who wrote mathematical books except for court astronomers or those who held a government position, like Qin Jiushao in the Song administration. It was only during the late nineteenth century educational reforms that mathematics became part of the standard curriculum in schools and the first universities in China. By then, some government supported students returned from Japan, Europe, or the United States and served as teachers for Western sciences. But it was really only in the 1930s that effective schools were built up and that mathematical research started to be systematically institutionalized.

See also: ►*Pi* in Chinese Mathematics, ►Algebra in Chinese Mathematics, ►Computation: Chinese Counting Rods, ►Liu Hui and the *Jiuzhang Suanshu*, ►Sundials, ►Li Shanlan, ►Guo Shoujing, ►*Zhoubi suanjing*, ►Li Zhi, ►Yang Hui, ►Decimal System, ►Gou-Gu Theorem, ►Shen Gua, ►Zhu Shijie, ►Calendar, ►Geomancy in China, ►Divination in China, ►Qin Jiushao, ►Abacus

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Mathematics in Egypt

James Ritter

By "Egyptian mathematics," we understand the mathematics developed in Ancient Egypt between the end of the fourth millennium BCE, when a centralized state came into being in the Nile Valley and a system of writing was invented, and 332 BCE, when Egypt was conquered by Alexander the Great and Greek cultural elements entered into the hitherto fairly autonomous development of Egyptian civilization. During these 3,000 years, the role of mathematics remained of central importance; the Egyptian educational system was geared principally to produce scribes who could count and calculate the work, rations, land, and grain of the State and the private landowner.

The judgments of Egyptian mathematics ordinarily to be found in histories of science fall into two main schools: either they are dismissive, claiming that mathematics in Egypt was merely of a "practical" or "trial and error" nature; or they are laudatory in the extreme, the Egyptians being seen as the precursors and inventors of all important concepts in mathematics. In fact, these two judgments share an identical misconception about mathematics itself, namely that it really exists only insofar as it corresponds to a particular Western image of theorem and proof. However recent interest in alternative (algorithmic and effective) methods in mathematics, as well as a better understanding of the complex and sophisticated nature of Egyptian civilization, has opened the way for a deeper comprehension of mathematics in the Nile Valley.

The real question is what mathematics represented for the Egyptians themselves, what they aimed at, what structural, intellectual, and sociological activities were connected with their mathematics. The Egyptians left us no philosophical or self-reflexive works commenting on their own activity; the nature and role of Egyptian mathematics must be pieced together from such texts as administrative and accounting documents, historical annals, and, above all, school texts.

We have, in fact, astonishingly few sources: the choice of excavation sites and the fragility of papyrus under humid conditions means that most written documents come, almost exclusively, from cemeteries and temples in the desert fringe along the Nile valley and only rarely from towns or cities in the fertile band around the Nile and its Delta. In addition, mathematical texts are particularly rare – some five papyri, mostly fragmentary, a pair of wooden exercise tablets, and a small inscribed stone flake. Moreover, with the exception of the last, all the texts are originals or copies dating from the same period, the Middle Kingdom between 2000 and 1700 BCE. The accounting documents are a little more plentiful and from a more balanced time span, but not all have been published and those that have still await a study of the mathematical techniques used in their fabrication.

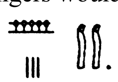
But there are some things that we do know. In Egypt, there were no centers of mathematical research in the modern sense, no journals or books exposing new results. There is not even an Egyptian word for "mathematics" in our sense: the only two Egyptian titles of mathematical school books that have come down to us are "The right method for entering into things, for knowing everything that is, every obscurity, …, every secret" (Rhind Mathematical Papyrus) and "The right method in matters of writing (?)" (Kahun Papyrus LV.4).

However, Egypt, like almost all societies, needed to create computational skills, to count and keep track of the collection and distribution of material wealth. Indeed, writing in Egypt was created precisely to make permanent records of these numerical data; the earliest signs were used to indicate metrological values along with the titles and proper names of those from whom came and to whom were to be delivered this wealth; mathematics and writing were linked from the very start and were the staple of Egyptian educational training. In particular, the mathematical texts we possess – including the Rhind Mathematical Papyrus – are school textbooks. So it is to the world of apprentice scribes and their teachers that we must look for an understanding of Egyptian mathematics.

Numbers

The third millennium had seen the development of some eight or nine distinct metrological systems – a discrete system, used for counting individual objects; a length system; an area system, used for measuring field surfaces; a distinct system for surfaces of linen; a capacity system for grain, and a weight system for measuring precious metals. The signs used to write the units of each system differed among themselves, as did the ratio between successive units in each system. In all cases though the Egyptians used an additive system of notation, in which a unit was repeated as many times as necessary to express the value desired.

For example, the discrete system is decimal in structure while the length system has four fingers to the palm and seven palms to the cubit. Thus whereas 14 goats would be written with 1 ten and 4 ones – written – a length of 14 fingers would have three palms and two fingers:



By the time of the Middle Kingdom, there is a distinct rationalization of these systems. Some, such as that for linen, simply disappear; some, such as that for lengths, are simplified. In the mathematical texts, all arithmetical operations are performed in the discrete system, now employed as a universal calculational system; an abstract concept of number is born. The discrete system being decimal, the base 10 became the standard. A significant part of mathematical training was devoted not only to learning how to perform mathematical calculations in the decimal system but also to mastering the conversions into and out of the surviving, nondecimal metrological systems.

The Mathematical Texts

The careful organization of the mathematical papyri reflect their pedagogic nature. They are constituted of numerical tables (to which we shall return) and solved problems: each problem is expressed in ordinary language with no symbols aside from the numbers themselves. The data and the results are given as concrete numerical values, and the solutions presented in the form of algorithms, that is a specific sequence of steps leading to the solution, generally followed by a numerical verification of the result obtained.

The subjects of the problems in the mathematical papyri touch on arithmetic calculations involving distribution of rations, work assignments, and the conversion of quantities of grain into beer and bread; mensuration problems involving the determination of volumes of circular and rectangular containers, areas of triangular, rectangular, and circular fields, slopes of pyramidal and conic constructions, and parts of ships, as well as others. The problems are roughly grouped by subject but, more precisely, by the type of algorithm used in their solution. Each group of problems is a series of exercises in the learning and use of an algorithm.

A typical example is given by the following Problem 26 of the Rhind Mathematical Papyrus; the words in red ink in the original are given in bold-face; the numbering of the steps of the algorithm and phrases in square brackets are my additions:

A quantity; its 1/4 is added to it. It becomes 15.

1. Calculate starting from 4; you will make its 1/4: 1.
2. [Add them together.] Total: 5.
3. Calculate starting from 5, to find 15.

   \1 5
   \2 10
   3 is the result.

4. Calculate starting from 3, 4 times.

   1 3
   2 6
   \4 12
   12 is the result.

The quantity: 12. Its 1/4: 3. Total: 15.
[Verification]

1 12
[1/2 6]
1/4 3
Total: 15.

It is important, in order to understand Egyptian mathematics, that each problem in a mathematical text operates on three distinct levels. The first is the global strategy used, embodied by the *algorithm* and is the same for all problems in a group. In our example it is the common Egyptian method, now called "false position." A (false) solution is supposed, in our example 4; the result of calculation with this value (steps 1 and 2) is compared to the true answer (step 3) and the original choice corrected by the necessary factor (step 4).

The second level is that of arithmetical *operations:* addition, subtraction, multiplication, division, square root extraction, etc., each of which corresponds to one step of the algorithm. It is introduced by a standardized formulation and includes a numerical computation. In our example, step (4) is a multiplication: as always indicated by "Calculate starting from *N*, *M* times"; likewise, step (3) is a division.

The third level is that of *techniques*, that is the set of means for carrying out the operation. Here the Egyptian scribe had a wide range of choices. For the simple operations of addition and subtraction (see step 2 in the example), no details were shown; the scribe was presumed to be able to do these without such aids. In the case of multiplication and division, the computations show what was done.

The multiplication of step (4), in our example, 3 × 4, is carried out in the following manner: starting with the first multiplicand, 3, in the right-hand column and 1 in the left, the scribe seeks the value of the second multiplicand, 4, in the left-hand column (since this is multiplication); in this case, the scribe obtains the columns directly by two successive uses of the same technique, namely *doubling*. The 4 is marked and the answer, 12, read off in the opposite column.

The division of step (3), 15 + 5, is carried out by putting the divisor 5 in the right-hand column, facing 1, and then, after a single doubling, finding the dividend, 15, in the right-hand column (since this is division), the sum of the two entries. Both are checked and the answer, 3 = 1 + 2, read off as the sum of the corresponding entries in the left-hand column.

Note that though the two operations, in the particular case treated here, are the inverse of each other, the only technique used to effect both of them is doubling. However, the Egyptian scribe was not limited to this single technique; others, such as halving (illustrated in the verification step of our problem), multiplying or dividing by 10, multiplying by 2/3, inversing, etc. were equally available. Given a particular arithmetic operation, the scribe chose the set of techniques appropriate to the numerical values in play.

Tables and Fractions

Fractions played a particular role in Egyptian mathematics. A fraction was viewed as the inverse of an integer; there could thus be only one fraction associated with a given integer *N:* namely, what we call the "unit fraction" 1/*N* – there being a single exception, the fraction 2/3. These fractions were manipulated in precisely the same way as integers, using the same panoply of techniques.

Only one fraction of a given kind could be used in the writing of a given number. Thus, for example, the double of the number 1 + 1/5 was not written 2 + 1/5 + 1/5 but rather 2 + 1/3 + 1/15. Finding such expressions is a centrally difficult problem: it occurs each time it is necessary to double an "odd" fraction, calculate two-thirds of a fraction, or add fractions together. It constitutes the core area of Egyptian mathematics, and furnishes the content of Egyptian mathematical *tables*. Such difficult calculations could be done once and for all and the results simply copied and looked up when the need arose in the solution of a specific problem.

The problems in Egyptian mathematical texts were chosen in order to cover the domain of the possible by a *network of typical examples*, a process which permitted the student (and later the practicing scribe) to place any new problem in this framework. The Egyptian approach to the question of generalization was not the discovery and application of a "general formula" in which each case might be enveloped, but rather through interpolation in a pattern of known results – a method equally used in some branches of mathematics today.

If Egyptian mathematics is viewed not as a poor simulacrum of proof-oriented mathematics, but on its own ground, it will be seen as an adequate and rational response to the socioeconomic and educational needs of Egyptian society. Mathematics even provided a model of a rational practice, equally applicable to other domains, wherever an efficient mode of action on the world was needed. Egyptian medical texts, for instance, were constructed in the same manner, with tables of remedies and a systematic network of procedural prescriptions.

This approach was not unique to Egypt; one finds analogous underlying principles at work in the mathematics of other civilizations, such as Mesopotamia, China, and India. It is not a question of borrowing; the mathematical traditions in question developed too early and were too widely geographically spread for this. Rather it shows the success of this algorithmic approach to the solutions of the problems posed by sufficiently advanced societies.

These different civilizations differed in their choices of number system, of modes of writing, of arithmetical operations, as well as the techniques used to carry these out. And the differences determined in turn the very different paths of development that mathematics knew in each society. If similar needs led to similar responses on the fundamental level, the different ways of implementing them created very different mathematics.

See also: ►Weights and Measures in Egypt

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Mathematics in Egypt: Egyptian Mathematics and African Predecessors – New Insights from Work Sites

Beatrice Lumpkin

Recent archaeological digs have uncovered Middle Stone Age (MSA) artifacts that root the origin of modern behavior in Africa. The MSA dates from 200,000 BP to 40,000 BP (Before the Present). These recent finds upset the textbook theory that places the origin of modern behavior in Southern France and Spain, only 30,000–40,000 years ago. Modern behavior includes abstract thinking and symbolic representation, essential features of mathematical thinking. It also includes designing sophisticated tools and making plans for the future.

Reports of these MSA finds include stone blades from Kenya by McBrearty (1995), basalt tools from Tanzania by Adelsberger (2002), barbed harpoon points from the Democratic Republic of the Congo by Yellen, Brooks et al. (1995) and engraved designs from South Africa by Henshilwood et al. (2002). The Kenyan stone blades came from a formation over 200,000 years old and were shaped before they were knocked off the rock core (Gutin 1995). This required planning by toolmakers who had an abstract picture in their minds of the desired tools. If the toolmakers were anatomically modern *Homo sapiens*, they were among the earliest of their species. Modern humans are believed to have evolved in Africa about 150,000–200,000 BP and migrated to Australia and possibly East Asia by 50,000 BP.

In about 200,000 BP at Laetoli, Tanzania, raw material used by "archaic" *Homo sapiens* was transported from sources at least 20–30 km distant. The ancient toolmakers made a round trip to obtain the stone or some type of trade took place. The basalt from the more distant sites provided a better cutting edge than the local finer-grained rock. The author of the study wrote, "…apparently the archaic Homo sapiens of the Laetoli region comprehended these attributes as early as 200,000 years ago" (Adelsberger 2002).

At the somewhat later MSA site of Katanda in the Democratic Republic of the Congo, archaeologist Yellen was disappointed when he found a barbed harpoon point. He had hoped the site dated back as far as 70,000 BP. But the bone point was so finely crafted that it resembled European harpoon points that were only 14,000 years old. Disappointment changed to joy when the bone point was dated to ca. 90,000 BP. The Katanda materials included barbed bone points, unbarbed points, and a flat dagger, products of a formal bone industry. Although the Yellen team used three different techniques to date their finds, some archaeologists continue to dispute the date (Yellen et al. 1995) (Fig. 1).

However, sophisticated tools may not be enough to identify modern human behavior. The record was missing what Christopher Henshilwood et al. described as "evidence of abstract or depictional images" (Henshilwood et al. 2002). In 2002, they recovered two engraved pieces of ochre from MSA layers in Blombos Cave in South Africa, dated to 77,000 BP. One piece is inscribed with a design, a row of cross hatches, framed by two horizontal lines and bisected by a third. The second piece has fewer lines but indicates that the design on the first piece is not unique.

Why was the African evidence for sophisticated tool technology in the MSA not discovered sooner? Archaeologists now working in Africa have a simple explanation:

Mathematics in Egypt: Egyptian Mathematics and African Predecessors – New Insights from Work Sites. Fig. 1 A barbed harpoon point from Democratic Republic of Congo. After Chip Clark. *Science* 268, 28 April 1965: 495.

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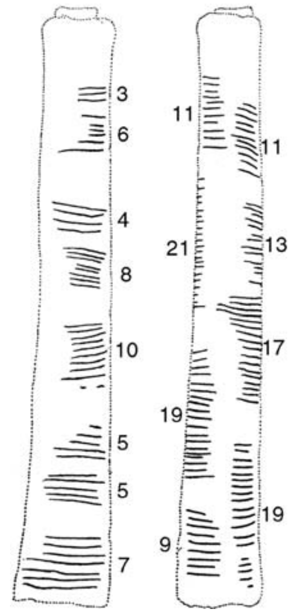
nobody had really bothered to look for it. "In France alone there must be three hundred well-excavated sites dating from the period we call the Middle Paleolithic," archaeologist Alison Brooks said. "In Africa there are barely two dozen on the whole continent" (Shreeve 1992).

Language is also a factor in the development of mathematics. The logical concepts needed for mathematics are built into all languages, as Karl Menger pointed out in his lectures. For example, all known languages have words for "or," for "and," and for counting numbers. By its nature, the development of language has left no records for archaeologists to excavate. However, numerical records have been found from soon after the MSA. The oldest known to date was found in Border Cave in Southern Africa and has been dated to ca. 37,000 BP. It is a fossilized baboon bone inscribed with 29 tally marks. Similar records are still made by San peoples of Southern Africa to record the lunar cycle (Bogoshi et al. 1987). Alexander Marshack gives examples of this type of tally record from many parts of the world (Marshack 1991). By the time anatomically modern humans left Africa, they may have been counting as well as making relatively sophisticated tools.

Trade played a very important role in the development of early mathematics. No direct evidence is known for a trade in chert, a flint-like quartz that was mined in large quantities in Southern Egypt ca. 33,000 BP. However, the quantities mined appear greater than the needs of local consumption. The miners used complex techniques not known in other parts of the world before 10,000 BP. Also, a grave at the mine site contained the remains of a young miner, buried with his mining tool. Burial goods and advanced mining techniques suggest cultural development at 33,000 BP (Vermeersch et al. 1984).

A Central African fossilized tally record, known as the "Ishango Bone," has excited discussion because it is more complex than the Border Cave fossil. First studied in 1950, the bone was recently redated back to 20,000–25,000 BP. The Ishango bone shows tallies on one edge for 3, 6, space; 4, 8, space; 10, space; 5, 5, space; 7. The other side is marked on one edge, 11, 13, 17, 19, and on the other edge, 11, 21, 19, and 9 (Zaslavsky 1999: 18). A number of hypotheses suggested that these number sequences were more than a simple count. Many harpoon points were also found at the site. This harpoon point technology spread to other parts of Africa, including the Nile Valley. Although not proof, it is suggestive of an Ishango input to the later Nile Valley civilizations (De Heinzelin 1962) (Fig. 2).

Some 15,000–20,000 years passed between the time of the Ishango bone and the first pharaohs who ruled all of Egypt. Although the record is sketchy, there were many advances made in the period before the pharaohs. Rock drawings from Nubia and Southern Egypt show ships with large crews, implying extensive trade. Evidence of early measurement systems predates writing and embodies a whole corps of mathematical knowledge. For example, Flinders Petrie reported a red limestone balance beam and sets of graduated weights from Southern Egypt, dated to Naqada I, 4500–4000 BCE. The weights are multiples of a base weight, showing that the concept of ratios was already well developed (Petrie 1920: 28, also 1926: 18).



Mathematics in Egypt: Egyptian Mathematics and African Predecessors – New Insights from Work Sites. Fig. 2 Ishango Bone, diagram (DeHeinzelin 1962: 114).

In 1998, archaeologists reported a 6,000-year old Stonehenge-type arrangement of large stones at Nabta Playa in Southwestern Egypt. They described a "calendar" circle with stones that align with the summer solstice of 6,000 years ago (Wendorf and Schild 2000). By 3200 BCE, hieroglyphic numerals were in use. An engraving on a knife handle clearly shows a numeral for 3,000 and other numerals are indicated (Williams and Logan 1987). The prehistory of Egyptian mathematics was coming to an end and the dawn of literacy had begun.

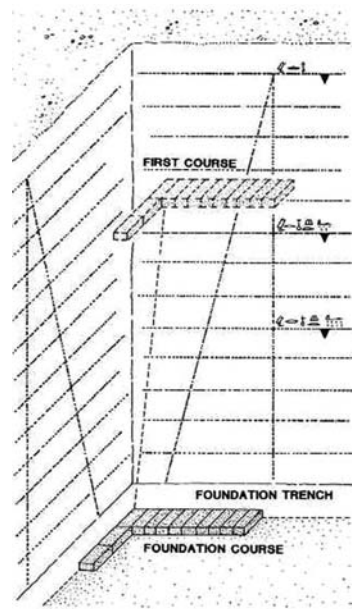
Egypt of the Pharaohs

The mathematical insights, discussed below, were gleaned from artifacts found at pyramid and temple work sites. They have not yet appeared in the textbooks on the history of mathematics. These insights include the use of rectangular coordinates and construction lines labeled with integers and a zero reference point. The same symbol used to label the zero reference point was later used to show zero remainders in a bookkeeping papyrus.

The period of building great pyramids began in Egypt ca. 2700 BCE. Thanks to the findings of Egyptologists such as Dr. Zahi Hawass and Mark Lehner, the Hollywood image of slave labor building the pyramids has been discredited. It is now known that the pyramid builders were well fed and were paid wages. There was a demand for mathematical and engineering skills. Scribes trained in mathematics kept accounts for thousands of workers, maintained the Egyptian calendar, and used a canon of proportions for paintings and statues of kings and nobles.

No mathematical texts are among the surviving papyri from that period. So we must study the pyramids, themselves, to learn about the mathematics used in pyramid design. Because they were so massive, pyramids and the large tombs called *mastabas* required careful leveling to prevent collapse. They also used deep foundations. For leveling purposes, the Ancient Egyptian architects created a system of guidelines with horizontal lines spaced one cubit apart. To locate exact distances below and above ground level, they placed a vertical line on the grid of horizontal lines. A zero reference level was used, often near pavement level, and labeled *nfrw*. (Egyptian hieroglyphic writing omitted vowels so the vowel sounds are not known.) Other points on this vertical line were labeled with the number of cubits above nfrw or below nfrw. In effect, these architects created a number line with a zero reference point and directed, or signed integers.

An example of these number lines appears to the right. These lines can still be seen in a foundation trench at Mastaba 17 in Meydum, Egypt. Horizontal, leveling lines were drawn on the wall of the trench, spaced 1 cubit apart. A vertical line intersected the horizontal lines. Some points of intersection were labeled with “nfrw” for ground or zero level, “5 cubits below nfrw” and “8 cubits below nfrw.” No labels are seen for “above nfrw” because the higher lines were not preserved. But at the nearby Meydum pyramid, there are leveling lines marked “6 cubits above “nfrw” and “8 cubits above “nfrw.” Dieter Arnold believes the vertical lines were “used not only for horizontal measuring, but also for marking directions” (Arnold 1991: 17, 18) (Fig. 3).



Mathematics in Egypt: Egyptian Mathematics and African Predecessors – New Insights from Work Sites. Fig. 3 Construction lines with zero reference (Arnold 1991: 12).

These findings contradict the oft-repeated statement that, “The Egyptians did not have a zero” (Bunt et al. 1976: 7). It is true that Egyptian numerals were additive, without place value. There was no need of a zero placeholder. But nfrw for zero level was noted by Egyptologists 100 years ago. Also, the related Egyptian word, *nfr*, was used for the zero remainder on the balance sheets of a bookkeeping papyrus. That papyrus is now known as Bulaq 18, written by the scribe Neferhotep, ca. 1700 BCE.

Neferhotep and his assistants recorded each day’s receipts and disbursements of supplies for the Pharaoh and his traveling court. For each type of goods, the sum of the disbursements was subtracted from the sum of the receipts to get the balances. On Day 1, Month 3 of this account, disbursements equaled receipts in four of the eight columns. Subtraction left zero remainders. The scribe wrote the zero quantity as nfr. Nfr had several meanings. In notes collected by Egyptologist Aayko Eyma, he writes:

> This nfr particle means ‘be at an end,’ ‘finished,’ ‘be zero(?),’ and occurs in constructions like nfr n (+ verbal form) ‘not,’ r-nfr n ‘so that not,’ and nfr pw ‘there is not.’ Some think the word nfr, ‘beautiful,’ ‘good,’ is unrelated but others believe that it may be related, in the sense of ‘perfect,’ ‘ultimate’ or ‘final state’ (Lumpkin 2003).

Scharff, the first European to publish Bulaq 18 (in 1922), translated the Egyptian numerals as Indo-Arabic numerals. Naturally, he knew that 52–52 left a remainder of 0 and that 7–7 = 0. But instead of writing zero, he wrote nfr, with no translation. In his comments, he described these remainders as “*das glatte Aufgehen*,” the flat or even outcome (Scharff 1922). Perhaps he did not want to challenge the established belief that “the Egyptians did not have a zero.” The great Egyptologist, A. Gardiner, in 1927 gave “zero” as the meaning of nfr(w) and “perhaps” zero as a meaning of nfr (Gardiner 1978: 266, 574). A later writer, Spalinger, had no problem with translating the nfr balances as “0” in his 1985 translation of Bulaq 18 (Spalinger 1985: 12). It appears that the Egyptians had a zero, after all.[1]

Few construction plans have survived the thousands of years since the time King Djoser’s step pyramid was built at Saqqara ca. 2700 BCE. Fortunately, an architect’s detail was found next to a domed structure inside the pyramid complex. The plan, inscribed in red ink on a limestone flake, shows a curve. Evenly spaced vertical lines, a cubit apart, give horizontal coordinates while hieroglyphic numerals state the vertical coordinates for points on the curve. Archaeologist Gunn plotted these points and connected them with a smooth curve. He reported in 1927 that the curve matched the curvature of the domed structure nearby (Gunn 1926). Somers Clarke and Engelbach, in their classic on Ancient Egyptian construction, called this early use of coordinates “of great importance” (Clarke and Engelbach 1930: 52–3). To date, this achievement remains little known, perhaps because it does not appear in the surviving papyri (Lumpkin 2002).

Pairs of construction guidelines may have provided axes for rectangular coordinates to locate points on pyramid walls. As early as 1865, Richard Lepsius recorded such systems of horizontal and vertical guidelines. The horizontal guidelines were labeled with the number of cubits from “a foundation line,” much as at Mastaba 17, shown in Fig. 3. In a chamber at Khufu’s great pyramid, Lepsius noted a pair of vertical lines intersecting a horizontal line. The line to the left was marked “3.” In fact, that line measured 3 cubits from the vertical line to the right (Lepsius Trans. 2000: 11–13). Since there were both horizontal and vertical reference lines, it is possible that rectangular coordinates were used to locate points of interest during the construction.

Khufu’s pyramid at Giza presents a special challenge in the study of the mathematics and technology used in construction. It is best know for its massive size, covering an area as large as eight football fields. The pyramid measured over 230 m each side and stood 146 m high. Many wonder how these pyramid builders, without modern machines, moved more than two million stones, some weighing 50 tons. But the greater challenge is to explain the extreme accuracy of the 90° angles that varied less than 1/15 of 1°. And what technology did they use to level the foundation platform to within 2.1 cm? How were the walls so closely aligned to the cardinal points?

Egyptologists are divided about how the builders found true North, whether they used star light or sun shadows. Either method required an accurate circle and bisection of an angle. Writers have suggested that leveling was accomplished by flooding the area inside a closed wall. But the pyramid was built on a sloping plateau with a rocky massif that became part of the pyramid. Leveling by water was not an option, Lehner concluded. He studied a double line of holes parallel to the sides of Khufu’s pyramid. It is possible, Lehner writes, that stakes were placed in these holes to support a cord used as a reference level (Lehner 997: 214–219).

Many have tried to explain how the Egyptians achieved such accurate square corners. Some Mozambicans and the Kpelle of Liberia compare the length of the diagonals of the base to check square corners for their traditional homes. But the rocky massif precluded this method at Khufu’s pyramid. It is possible that the pyramid builders used the right-triangle theorem to set nearly perfect square corners. There are reports of 3–4–5 triangles in the design of Old Kingdom temples but Lehner finds the evidence inconclusive.

Some have suggested that intersecting arcs were used to construct a perpendicular, using a cord as a compass. The accuracy of this method has also been questioned. Another method relies on tools invented by Ancient Egyptians. These included square levels, set squares and plumb bobs. A rough perpendicular line could be drawn with the set square. Flipping the square around that line would give a slightly different perpendicular. A more accurate perpendicular would be the line halfway between the two rough perpendiculars. Again, many believe that this method could not produce the accuracy achieved by the Ancient Egyptians.

Another difficult problem solved by Egyptian pyramid builders is less obvious. How did they manage to bring the four sides to a central point at the top? Knowledge of the slope of a pyramid is well attested in the *Rhind Mathematical Papyrus*, Problems 56–60. Actually, they used inverse slope, the ratio of run to rise. For Khufu’s pyramid, it was 14–11. This ratio must be kept constant to achieve the smooth sides of the pyramid. Lehner writes, “There is evidence that guidelines marking the plane of the pyramid face were cut into each casing block...” Also, Lehner has found possible postholes for markers to serve as backlights to align the pyramid axes and diagonals. This followed an earlier suggestion by Clarke and Engelbach. Further mapping of holes and marks around the pyramid may supply more insight into the Egyptian method of controlling the run to rise ratio (Lehner). It is hoped that continued exploration of African work sites will yield other exciting discoveries about our mathematical forerunners.

[1] Bulaq 18 is discussed in more detail in Lumpkin 2002. I thank Frank Yurco for his kind help with Bulaq 18 and other sources for the zero concept in Ancient Egypt.

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Mathematics in Egypt: Mathematical Leather Roll

Milo Gardner

Henry Rhind purchased the 10″ × 17″ leather roll in 1858. It was sent to the British Museum in 1864, but was not chemically softened and unrolled until 1927 (Scott and Hall 1927).

Middle Kingdom hieratic characters were written right to left. There are 26 rational numbers listed. Each rational number is followed by a series of equivalent unit fractions.

There are ten binary rational numbers: 1/2, 1/4 (twice), 1/8 (thrice), 1/16 (twice), 1/32, and 1/64. There are seven other even rational numbers: 1/6 (twice – but wrong once), 1/10, 1/12, 1/14, 1/20, and 1/30. Finally, there are nine odd rational numbers: 2/3, 1/3 (twice), 1/5, 1/7, 1/9, 1/11, 1/13, and 1/15.

The British Museum examiners found no introduction or description of how and why the equivalent unit fraction series were computed (Gillings 1981: 456–457). A series of equivalent unit fractions is associated with the fractions 1/3, 1/4, 1/8, and 1/16. There is a trivial error associated with the unit fraction series total of 1/15. It is listed as 1/6. A serious error is associated with the rational number 1/13, a problem that the examiners did not resolve.

The *British Museum Quarterly* (1927) naively reported the chemical analysis to be more interesting than the Egyptian mathematical leather roll's (EMLR's) additive contents.

The binary fractions are now seen to be restatements and improvements to the older Horus-Eye numeration system. Horus-Eye arithmetic employed an infinite series numeration system that used "decimal fractions" similar to our present decimals (Ore 1948: 311–325). Note the Horus-Eye definition for the number 1

$$1 = \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + \frac{1}{64} + \cdots,$$

with the last term 1/64th being thrown away (Gillings 1972: 210).

Another Middle Kingdom text, the *Rhind Mathematical Papyrus* (RMP), mentioned the use of six additional significant digit fractions, called *ro*. Ro units were used in volume calculations reducing the Horus-Eye error to 1/4,096.

Note that Babylonian scribes wrote in an expanded base 60 system before the Egyptian hieratic system appeared. Babylonian numeration also used properties of "decimal fractions." Babylonian numeration was written within a positional notation similar to the modern decimal system. Babylonians attempted high accuracy, minimizing error to 1/3,600 for two terms and 1/216,000 for three terms. However, for inverse prime numbers, Babylonians rounded off when writing their equivalent unit fraction series, thereby seriously degrading their system's accuracy (Robson et al. 2003).

Because the Middle Kingdom arithmetic was written in an unusual exact series context, modern researchers frequently minimized the EMLR's significance. One minimal aspect is that the older Horus-Eye system's accuracy may at first have been superseded in only special situations. Several ancient texts, the Akhmim Wooden Tablets, Berlin, Kahun, Moscow, and Reisner papyri, are read in this low content manner. However, the EMLR and RMP demonstrate generalized ways to convert any rational number to a concise unit fraction series. Therefore, the EMLR and RMP abstract arithmetic could have been seen in 1927 as having been standardized, thereby superseding both its additive Horus-Eye parent and its nearby competitor Babylonian base 60. Arguably the more accurate system provided more than "bragging rights" to Egyptian science and trade.

Restating the problem of fairly reading the EMLR, a process that took over 75 years, the majority of its early examiners strongly suggested that it contained only simple additive information. Over 60 years would pass before a higher systemized form of arithmetic began to be parsed from the EMLR and RMP data (Gardner 1995, 2002).

The following chronology shows several of the events along the road to understanding Egyptian abstract arithmetic.

For example, Ahmes, the RMP scribe, mentally computed:

$$
\begin{aligned}
&2/(pq) = 2/21, \text{where } p = 3,\ q = 7,\ A = (3+1)\\
&\text{such that}: 2/21 = 2/(3+1) \times (3+1)/21\\
&\qquad = 1/2 \times (3/21 + 1/21)\\
&\qquad = 1/2 \times (1/7 + 1/21)\\
&\qquad = 1/14 + 1/42
\end{aligned}
$$

Cryptanalysis has parsed five categories (a–e) from the EMLR's 26 equivalent unit fraction series. Three are identities (a–c) and one (d) is a remainder. The first four categories have been basically understood since 1927. However, one (e) is an algebraic identity. The algebraic identity form had escaped detection and confirmation for over 75 years. The five methods are explained below (Gardner 2002).

For example, the EMLR student set $p = 1$, $q = 8$, $A = 25$ such that

$$
\begin{aligned}
1/8 &= 1/25 \times 25/8\\
&= 1/5 \times 25/40\\
&= 1/5 \times 5/8, \text{ with}\\
5/8 &= 1/5 + 1/3 + 1/15 + 1/40
\end{aligned}
$$

may have been mentally computed by:

$$
\begin{aligned}
5/8 - 1/5 &= (25 - 8)/40\\
17/40 - 1/3 &= (51 - 40)/120\\
11/120 &= (8 + 3)/120\\
&= 1/5 \times (1/5 + 1/3 + 1/15 + 1/40)\\
&= 1/25 + 1/15 + 1/75 + 1/200
\end{aligned}
$$

Interestingly, the EMLR's four values for A (4, 5, 7, and 25) did not optimize its fraction series in a manner comparable to the RMP 2/*n*th table's entries. The EMLR's partitioning *A*s are therefore considered to be a RMP training technique. The serious error 1/13th could have been resolved by methods (c), (d), or (e). The error was related to a failed attempt to apply method (e). Math historians have titled a closely related "pick a number" method, found in the RMP, as "false position" (Eves 1961: 40).

The EMLR has been proven to be a student's introduction to an innovative numeration system. The improved Middle Kingdom arithmetic easily converted any rational number, after employing a factoring process, to a concise, optimal and exact series of unit fraction statements. This subtle conclusion was difficult to reach for a number of reasons, the greatest one being the small collection of surviving fragments of Middle Kingdom texts. Seen in its most basic terms, the EMLR was the most elementary of the 2000–1650 BCE abstract arithmetic texts.

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M

Mathematics of the Hebrew People

TONY LÉVY

A "Hebrew mathematical text" is any text or work whose language is Hebrew (usually written in Hebrew characters), and whose content is mathematical in a narrow sense, that is, does not include astronomy (apart from relevant mathematical sections), astrology, or calendar calculations.

Apart from a few passages that are to be found in biblical and postbiblical (rabbinical) literature and which are relevant to the history of mathematics (number words and fraction words, practical rules of geometry), the oldest mathematical tract in Hebrew is the *Mishnat ha-Middot,* by an unknown author. This tract gives practical rules for the measurement of areas and volumes, and then deals with the measurements (*middot*) of the Tabernacle erected by the Jews in the desert. It has been recently shown that its composition was probably influenced by the geometrical part of al-Khwārizmī's *Algebra.* This tract remained unknown to most medieval Jewish scholars and its Hebrew mathematical terminology was of no consequence.

Two famous scholars are central in the eleventh and twelfth centuries in Spain: Abraham bar Hiyya (ca. 1065–ca. 1145) and Abraham ibn Ezra (1092–1167). This period saw the actual birth of Hebrew mathematics.

Abraham bar Hiyya, also called Savasorda (latinized from the Arabic *Ṣāḥib al-shurta*), flourished in Barcelona in Christian Spain, but was probably educated in the Arabic kingdom of Saragossa. Bar Hiyya wrote books in Hebrew on mathematics, astronomy, astrology, and philosophy. He clearly indicated that his Hebrew compositions were written for Jews living in southern France (in Hebrew, *EreṣSarfat*) who were unacquainted with Arabic scientific culture and unable to read Arabic texts. Bar Ḥiyya can thus rightly be considered the founder of Hebrew scientific culture and language, and specifically the father of Hebrew mathematics. We know of two mathematical compositions by Bar Ḥiyya: the extant parts of a scientific encyclopedia and a geometrical compilation.

The first of these books, *Yesodey ha-Tevuna u-Migdal ha-Emuna* (The Foundations of Science and the Tower of Faith), is presumably an adaptation from some unknown Arabic composition; the geometrical and arithmetical parts are extant. The study of its content sheds some light on eleventh century mathematical literature in Western Islamic lands and its diffusion.

The *Ḥibbur ha-Meshiḥa we ha-Tishboret* (The Composition on Geometrical Measures) enjoyed a very large diffusion as the *Liber embadorum* in its Latin translation by Plato of Tivoli (1145). Much has been said by ancient and modern scholars concerning the importance of this text for traditions of practical geometry in Europe.

Abraham ibn Ezra was born in Tudela in Aragon. Raised in Arabic culture, and probably knowing Latin, Ibn ᶜEzra spent the last part of his life traveling over Europe. He was a poet, a grammarian, an astronomer–astrologer, and a biblical commentator of great reputation. Ibn Ezra, one generation after Bar Ḥiyya, also created a new scientific language, different from that of his predecessor, closer to biblical Hebrew and less influenced by Arabic. His mathematical work consists essentially of the important book *Sefer ha-Mispar* (The Book of Number), but numerous arithmetical and numerological remarks are scattered in his others works, including his biblical commentaries.

His *Book of Number,* written probably before 1160, expounds for the first time the decimal positional notation including zero. The foundations of arithmetic are then discussed in the following order: multiplication, division, addition, substraction, fractions, proportions, and square roots.

In the thirteenth and fourteenth centuries, the works of both Abrahams opened up to the Jewish communities unfamiliar with Arabic access to basic mathematical knowledge. They obviously mention the names of classical authors, Greek or Arabic, and of their works, but these works themselves only became partly available in Hebrew during the thirteenth century. This first major period of translations continued until the first third of the fourteenth century.

Several of the translators were members of a single family of scholars. The first, Yehuda ibn Tibbon, left Granada in the middle of the twelfth century, at the time of the arrival of the Almohads in al-Andalus, and settled in Lunel in the south of France. There, he undertook the translation into Hebrew of ethical and philosophical works written in Arabic by Jewish scholars from Spain. His son, Samuel ben Yehuda, translated the famous *Guide for the Perplexed* of Maimonides from Arabic into Hebrew. The third and fourth generations of this family include translators of scientific works.

Thus, Jacob Anatoli (ca. 1194–1256), working in Italy under the patronage of Frederic II of Sicily, translated Ptolemy's *Almagest* and Ibn Rushd (Averroes)' *Compendium on Astronomy,* lost in the Arabic original. According to recent findings, he is perhaps the first translator into Hebrew of Euclid's *Elements.* Moses ben Samuel ben Yehuda of Montpellier (active between 1240 and 1283) translated, among others things, works by Euclid (*The Elements*), Theodosius (*Sphaerics*), al-Fārābī (The Commentary on *The Elements*), Ibn al-Haytham (The Commentary on *The Elements*), and al-Ḥaṣṣār (The so-called *Arithmetic*) Lastly, Jacob ben Makhir of Montpellier (ca. 1236–1305) also translated works by Euclid (*The Elements,* the *Data,* and perhaps the *Optics*), Autolycus of Pitane (*On the Moving Sphere*), Menelaus (*Sphaerics*), Jābir ibn Aflah (*Astronomy*), and Ibn al-Haytham (*Astronomy*).

To this period belongs a Jewish scholar from Toledo, who also had contacts with Frederic II of Sicily during the first half of the thirteenth century. Yehuda ben Solomon ha-Kohen (probably b. 1215) wrote in Arabic a (lost) encyclopedia of sciences, which he translated himself into Hebrew, *Midrash ha-ḥokhma* (The Learning of Wisdom). This book includes a redaction, or free translation, of Euclid's *Elements* (Books I–VI and XI–XIII).

A generation after Jacob ben Makhir, Qalonymos ben Qalonymos (Maestro Calo) of Arles (b. 1287) translated Archimedes (*The Sphere and the Cylinder* and the commentary upon it by Eutocius, perhaps also *The Measurement of the Circle*), Nicomachus of Gerasa (a lost Arabic paraphrase of the *Introduction to Arithmetics*), Thābit ibn Qurra (on the *Figura Sector* of Menelaus), Jabir ibn Aflaḥ (on the same problem, a text apparently lost in Arabic), and Ibn al-Haytham (a part of the commentary on *The Elements,* already translated in part by Moses ibn Tibbon). Qalonymos also translated several texts for which the original Arabic has not yet been identified, or is now lost: thus we have important fragments of a *Treatise on Cylinders and Cones* by Ibn al-Samḥ of Granada (eleventh century), perhaps extracted from a larger book of this Andalusian scholar. Qalonymos is also probably the author of an important mathematical and philosophical composition on the nature of numbers, the *Sefer ha- Melakhim* (The Book of Kings).

Thus, we possess more or less complete Hebrew versions of the treatises of the following classical authors: Euclid, Archimedes, Autolycus, Theodosius Menelaus, Ptolemy, Nichomacus. The conspicuous absence of the name of Apollonius does not mean that he was not known to the Jewish scholars.

The diffusion of the Hebrew versions of important mathematical works created the conditions for the composition of original works by Jewish scholars who were also excellent astronomers. This, at least, is the case of two scholars that we will mention here, as much for the depth of their talent as for the importance of their works. Levi ben Gershon, also called Gersonides (1288–1344) is the author of an important mathematical work. His writings on harmonic numbers (extant only in a Latin translation), on arithmetic and combinatorics (*Ma'aseh Ḥoshev,* Work of the Reckoner), and on the geometry of Euclid have been recently studied from the point of view of their contents, of their Arabic and perhaps Latin sources, and their possible influence on later works.

Immanuel ben Jacob Bonfils of Tarascon, one generation after Gersonides, must be mentioned in connection with two mathematical areas: that of the introduction of decimal fractions, and that of calculations related to the measurement of the circle. The sources and the scope of his developments in both areas have not yet been fully investigated.

In fifteenth-century Italy, there were a number of translators and commentators of note. The movement toward Italy is not only geographical: the Hebrew texts which we possess, and which have been only partially studied, show an increasing influence of Latin and also the vernacular languages.

Mordekhai (Angelo) Finzi of Mantua (active between 1441 and 1473) is without a doubt the best known of these translator–scholars. He translated several compositions of Abū Kamīl (a tenth-century Arabic scholar); he seems also to have been the translator (or perhaps the author) of a compendium on geometry in eleven chapters. Finzi is the author of a *Ma'amar be-Ḥeshbon Medidut ha-Gigiyyot we ha-Ḥaviyyot* (Treatise on the Measurement of Buckets and Barrels) in which he quotes Bar Ḥiyya and "the masters of the abacus," and whose analysis should yield useful clues on the history of stereometry before Kepler. Finally, we must emphasize Finzi's role in the diffusion of algebraic knowledge: in addition to Abū Kamīl's *Algebra,* Finzi translated from Italian or Latin into Hebrew the noteworthy algebraic composition of a certain Maestro Dardi of Pisa (who wrote in the fourteenth century), dealing with complex equations involving powers up to the twelfth degree.

The contacts of Jewish scholars in Italy with those in Constantinople, especially after the arrival of the Ottomans, constitute perhaps one of the channels by which ideas or texts of the Arabic East diffused.

There is also some mathematics of note in the Judeo–Byzantine scholarly world of the fifteenth to sixteenth centuries. The specific interest in studying this scholarly milieu – besides the talents of its representatives – lies in the use made therein of a triple heritage: that of texts available in Hebrew (Bar Ḥiyya, Ibn ʿEzra, the Greek and Arabic classics in translation, Gersonides, etc.), Arabic texts (sometimes not extant in Arabic) not translated into Hebrew but quoted in Hebrew compositions, and finally the Greek–Byzantine texts.

From this point of view, attention of scholars must be drawn to the mathematical works of Mordekhai Komtino (1402–1482) and of his two students Kalev Afendopulo (1460–1525) and Eliahu Mizraḥi (1455–1526).

The *Sefer ha-Ḥeshbon we-ha-Middot* (Book on Reckoning and Measurements) of Komtino shows a direct knowledge of ancient Greek sources such as Hero, and probably also of Byzantine–Greek texts. The *Sefer ha-Mispar* (The Book of Number) by Mizraḥi of which extracts were published in Latin in the sixteenth century, should be analyzed in the light of recent studies on the history of Arabic and Greek–Byzantine arithmetic. Finally, the commentary by Afendopulo of the Hebrew version of Nicomachus' *Introduction to Arithmetics* is a long text which includes several excursuses on philosophy, astronomy, and astrology.

In this very brief – and far from exhaustive – survey of Hebrew mathematics, an attempt has been made to indicate the importance of these texts and to describe their transmission as a general set of mathematical ideas of Hellenistic origin between the eleventh and the sixteenth centuries, that is, before the rediscovery of Greek original texts and the relaunching of activity in the Renaissance.

See also: ▶al-Khwārizmī, ▶Ibn Tibbon, ▶Moses Maimonides

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Mathematics in India

George Gheverghese Joseph

A widely held view is that Indian mathematics originated in the service of religion. Support for this view is sought in the complexity of motives behind the recording of the *Śulbasūtras,* the first written mathematical source dated around 800–500 BCE, dealing with the measurement and construction of sacrificial altars. This view ignores the skills in mensuration and practical arithmetic that existed in the Harappan (or Indus Valley) culture which dates back to 3000 BCE. Archaeological remains indicate a long established centralized system of weights and measures. A number of different plumb-bobs of uniform size and weights have been found that could be classified as decimal, i.e., if we take a plumb-bob weighing approximately 27.534 g as a standard representing 1 unit, the other weights form a series with values of 0.05, 0.1, 0.2, 0.5, 2, 5, 10, 20, 50, 100, 200, and 500 units. Also, scales and instruments for measuring length have been discovered, including one from Mohenjo-Daro, one of the two largest urban centers, consisting of a fragment of shell 66.2 mm long, with nine carefully sawn, equally spaced parallel lines, on average 6.7056 mm apart. The accuracy of the graduation is remarkably high, with a mean error of only 0.075 mm.

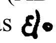
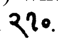
A notable feature of the Harappan culture was its extensive use of kiln-fired bricks and the advanced level of its brickmaking technology. While 15 different sizes of Harappan bricks have been identified, the standard ratio of the three dimensions – the length, breadth, and thickness – is always 4:2:1, considered even today as the optimal ratio for efficient bonding. A close correspondence exists between the standard unit of measurement (the "Indus inch" (33.5 mm) and brick sizes, in that the latter are integral multiples of the former. (An Indus inch is exactly twice a Sumerian unit of length (*sushi*). Twenty-five Indus inches make a Megalithic yard, a measure probably in use north-west Europe around 2000 BCE. These links have led to the conjecture that a decimal scale of measurement originated somewhere in western Asia and then spread as far as Britain, Egypt, Mesopotamia, and the Indus Valley.)

This relationship between brickmaking technology and metrology was to reappear 1,500 years later during the Vedic period in the construction of sacrificial altars of bricks. However, a most intriguing suggestion of Subbarayappa is that the Harappan numeration system contains certain similarities with the Kharoṣṭhī and the "Aśhokan" variant of the *Brāhmi* numeration systems which emerged in India about 2,000 years later. He notes the following similarities:

There are identical symbols for the numbers 1–4 and for a 100 in all three numeration systems.

All three were ciphered systems employing a decimal base.

He suggests that deciphering the inscriptions on the large number of excavated seals and other artifacts require that they be recognized as numerical records rather than as literary passages. Given the failure so far to decipher the Harappan script, this approach is certainly worth further examination.

The earliest written evidence in India of a recognizable antecedent of our numeral system is found in an inscription from Gwalior dated "Samvat 933" (AD 876) where the numbers 50 and 270 are given as  and . Notice the close similarity with our notation for 270 showing in both an understanding of the place value principle as well as the use of zero. There is earlier evidence of the use of Indian system of numeration in South East Asia in areas covered by present-day countries such as Malaysia, Cambodia and Indonesia, all of whom were under the cultural influence of India. Also, as early as AD 662, a Syrian bishop, Severus Sebokt, comments on the Indians carrying out computations by means of nine signs by methods which "surpass description" (Joseph 1993).

The spread of these numerals westwards is a fascinating story. The Arabs were the leading actors in this drama. Indian numerals probably arrived at Baghdad in 773 AD with the diplomatic mission from Sind to the court of Caliph al-Manṣūr. In about 820, al-Khwārizmī wrote his famous *Kitāb ḥisāb al-adad al-hindī* (Book of Addition and Subtraction According to the Hindu Calculation, also called just Arithmetic), the first Arab text to deal with the new numerals. The text contains a detailed expositioṇ of both the representation of numbers and operations using Indian numerals. Al-Khwārizmī was at pains to point out the usefulness of a place-value system incorporating zero, particularly for writing large numbers. Texts on Indian reckoning continued to be written, and by the end of the eleventh century this method of representation and computation was widespread from the borders of Central Asia to the southern reaches of the Islamic world in North Africa and Egypt.

In the transmission of Indian numerals to Europe, as with almost all knowledge from the Islamic world, Spain and (to a lesser extent) Sicily played the role of intermediaries, being the areas in Europe which had been under Muslim rule for many years. Documents from Spain and coins from Sicily show the spread and the slow evolution of the numerals, with a landmark for its spread being its appearance in an influential mathematical text of medieval Europe, *Liber Abaci* (Book of Computation), written by Fibonacci (1170–1250), who learnt to work with Indian numerals during his extensive travels in North Africa, Egypt, Syria, and Sicily. The spread westwards continued slowly, displacing Roman numerals, and eventually, once the contest between the abacists (those in favor of the use of the abacus or some mechanical device for calculation) and the algorists (those who favored the use of the new numerals) had been won by the latter, it was only a matter of time before the final triumph of the new numerals occurred, with bankers, traders, and merchants adopting the system for their daily calculations.

The beginnings of Indian algebra may be traced to the *Śulbasūtras* and later Bakhshālī Manuscript, for both contain simple examples involving the solution of linear, simultaneous and even indeterminate equations. An example of an indeterminate equation in two unknowns (x and y) is $3x + 4y = 50$, which has a number of positive whole-number (or integer) solutions for (xy). For example, $x = 14$, $y = 12$ satisfies the equation as do the solution sets (10, 5), (6, 8) and (2, 11).

But it was only from the time of Āryabhaṭa I (b. AD 476) that algebra grew into a distinct branch of mathematics. Brahmagupta (b. AD 598) called it *kuṭṭaka gaṇitā,* or simply *kuṭṭaka,* which later came to refer to a particular branch of algebra dealing with methods of solving indeterminate equations to which the Indians made significant contributions.

An important feature of early Indian algebra which distinguishes it from other mathematical traditions was the use of symbols such as the letters of the alphabet to denote unknown quantities. It is this very feature of algebra that one immediately associates with the subject today. The Indians were probably the first to make systematic use of this method of representing unknown quantities. A general term for the unknown was *yāvat tāvat,* shortened to the algebraic symbol *yā.* In Brahmaguptas's work Sanskrit letters appear, which are the abbreviations of names of different colors, which he used to represent several unknown quantities. The letter *kā* stood for *kālaka,* meaning "black," and the letter *nī* for *nīlaka* meaning "blue." With an efficient numeral system and the beginnings of symbolic algebra, the Indians solved determinate and indeterminate equations of first and second degrees and involving in certain cases more than one unknown. It is likely that a number of these methods reached the Islamic world before being transmitted further westwards by a similar process and often involving the same actors as the ones that we discussed earlier in the spread of Indian numerals.

The beginnings of a systematic study of trigonometry are found in the works of the Alexandrians, Hipparchus (ca. 150 BCE), Menelaus (ca. AD 100) and Ptolemy (ca. AD 150). However, from about the time of Āryabhaṭa I, the character of the subject changed to resemble its modern form. Later, it was transmitted to the Arabs who introduced further refinements. The knowledge then spread to Europe, where the first detailed account of trigonometry is contained in a book entitled *De triangulis omni modis* (On All Classes of Triangles), by Regiomontanus (1464).

In early Indian mathematics, trigonometry formed an integral part of astronomy. References to trigonometric concepts and relations are found in astronomical texts such as *Sūryasiddhānta* (ca. AD 400), Varāhamihira's *Pancha Siddhfāntạ* (ca. AD 500), Brahmagupta's *Brāhma Spuṭa Siddhānta* (AD 628) and the great work of Bhāskara II called *Siddhānta Śiromaṇi* (AD 1150). Infinite expansion of trigonometric functions, building on Bhāskara's work, formed the basis of the development of mathematical analysis – a precursor to modern calculus to be discussed later.

Basic to modern trigonometry is the sine function. It was introduced into the Islamic world from India, probably through the astronomical text, *Sūryasiddhānta,* brought to Baghdad during the eighth century. There were two types of trigonometry available then: one based on the geometry of chords and best exemplified in Ptolemy's *Almagest,* and the other based on the geometry of semichords which was an Indian invention. The Arabs chose the Indian version which prevailed in the development of the subject. It is quite likely that two other trigonometric functions – the cosine and versine functions – were also obtained from the Indians.

One of the most important problems of ancient astronomy was the accurate prediction of eclipses. In India, as in many other countries, the occasion of an eclipse had great religious significance, and rites and sacrifices were performed. It was a matter of considerable prestige for an astronomer to demonstrate his skills dramatically by predicting precisely when the eclipse would occur.

In order to find the precise time at which a lunar eclipse occurs, it is necessary first to determine the true instantaneous motion of the moon at a particular point in time. The concept of instantaneous motion and the method of measuring that quantity is found in the works of Āryabhaṭa I, Brahmagupta and Muñjāla (ca. AD 930). However, it was in Bhāskara II's attempt to work out the position angle of the ecliptic, a quantity required for predicting the time of an eclipse, that we have early notions of differential calculus. He mentions the concept of an "infinitesimal" unit of time, an awareness that when a variable attains the maximum value its differential vanishes, and also traces of the "mean value theorem" of differential calculus, the last of which was explicitly stated by Parameśvara (1360–1455) in his commentary on Bhāskara's *Līlāvatī.* Others from Kerala (South India) continued this work with Nīlakaṇṭha (1443–1543) deriving an expression for the differential of an inverse sine function and Acyuta Piṣāraṭi (ca. 1550–1621) giving the rule for finding the differential of the ratio of two cosine functions.

However, the main contribution of the Kerala school of mathematician–astronomers was in the study of infinite-series expansions of trigonometric and circular functions and finite approximations for some of these functions. The motivation for this work was the necessity for accuracy in astronomical calculations. The Kerala discoveries include the Gregory and Liebniz series for the inverse tangent, the Liebniz power series for π, the Newton power series for the sine and cosine, as well as certain remarkable rational approximations of trigonometric functions, including the well-known Taylor series approximations for the sine and cosine functions. And these results had been obtained about 300 years earlier than the mathematicians after whom they are now named. Referring to the most notable mathematician of this group, Mādhava (ca. 1340–1425); Rajagopal and Rangachari (1978) wrote: "(It was Mādhava who) took the decisive step onwards from the finite procedures of ancient mathematics to treat their limit-passage to infinity, which is the kernel of modern classical analysis." The growing volume of research into medieval Indian mathematics, particularly from Kerala, has refuted a common perception that mathematics in India after Bhāskara II made "only spotty progress until modern times" (Eves 1983).

See also: ►*Śulbasūtras*, ►Weights and Measures in India, ►Surveying, ►Technology and Culture, ►Geometry in India, ►Arithmetic in India, ►*Bakhshālī* Manuscript, ►*Almagest*, ►Eclipses, ►al-Khwārizmī, ►Brahmagupta, ►Āryabhaṭa, ►Bhāskara, ►Parameśvara, ►Nīlakaṇṭha Somayāji, ►Acyuta PiṣāraṭI, ►Mādhava

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Mathematics in Islam

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Roughly speaking, one can distinguish two types of mathematics in Antiquity and the Middle Ages: one is "practical" (or subscientific) mathematics, concerned with practical calculation, administration, trade, land measurement, tax collecting, etc. The other is "theoretical" mathematics, studied either for its own sake, or connected with astronomy, philosophy, or religion.

The following survey of the history of mathematics in Islamic civilization will concentrate on "theoretical" mathematics. "Practical" mathematics in Islamic civilization is of great historical interest, but until recently the subject has received less attention than it deserves, perhaps because this kind of mathematics is less exciting from an intellectual point of view. Therefore it is not yet possible to give an adequate survey of its history.

The history of theoretical mathematics in Islamic civilization is intimately connected with astronomy. In Iran there was a pre-Islamic astronomical tradition which simply continued after the country was conquered by the Muslims. When the Abbasids came to power in 750, an interest in astronomy, and hence mathematics, developed in the new capital Baghdad. Iranian astronomy was influenced by Indian astronomy, and around 775 Indian astronomers and mathematicians were received at the court of the Caliph, and Sanskrit astronomical works were translated into Arabic. After 800, the Greek mathematicial and astronomical works became increasingly popular, and many of these works were translated into Arabic, including the *Elements* of Euclid and the *Almagest* of Ptolemy, an astronomical compendium full of very complicated mathematics. In the rest of this article, the term "Arabic" will be used in a linguistic sense, referring to Arabic as a scientific language. Thus "Arabic mathematics" is mathematics written in the Arabic language; an "Arabic mathematician" is a mathematician writing in Arabic. The reader should bear in mind that a large number of these "Arabic mathematicians" were actually Persians.

The most important traces of the Indian heritage in the Arabic tradition were the system of numbers and the sine function (which replaced the Greek chord in trigonometry). It is possible that early Arabic algebra was influenced by India to a much greater extent than is recognized today by most modern historians, many of whom assume a Babylonian influence, transmitted in some unknown way. However, the Greek influence was predominant in Arabic mathematics. It was a living continuation of Greek mathematics. New areas of mathematics were developed (algebra, trigonometry), new problems were solved (such as the *qibla* problem, determining the direction of Mecca), and a lot of creative work was done. However, there was no "revolution" in Arabic mathematics comparable with, for example, the development of analytic geometry and calculus in seventeenth-century Europe.

Arithmetic

Various systems of numeration were used by the Arabic mathematicians and astronomers. Many mathematicians and astronomers used the *abjad* (alphabetical) numeration. In this system, the letters of the alphabet have numerical values 1, 2, …, 9, 10, 20, …, 90, 100, 200, …, 900, 1,000. Almost all astronomical calculations were performed in a sexagesimal system in which the sexagesimals were denoted in the abjad system. The Hindu–Arabic system, consisting of nine symbols and a zero, was introduced into the Arabic world by al-Khwārizmī around AD 830, but it was not received with much enthusiasm. It was only used for large numbers, for example the tangents of angles near 90°. In algebraical works, al-Khwārizmī and others did not use numbers but words, for example "three squares and four is equal to seven things" (meaning: $3x^2 + 4 = 7x$ in modern notation). Fractions were denoted in various complicated ways, often without any symbolism. In the tenth century, al-Uqlīdisī used decimal fractions and a symbol equivalent to our decimal point.

Algebra

The name of this part of mathematics is derived from al-Khwārizmī's *Kitāb fī'l-jabr wa'l-muqābala* (Book on Restoration and Confrontation). In this treatise al-Khwārizmī gives a systematic treatment of linear and quadratic equations. The contents were not new, because the Babylonians in Iraq were able to solve quadratic equations 2,000 years before al-Khwārizmī. However, the treatise is very well written and al-Khwārizmī gives many worked examples. He treats the reduction of any linear or quadratic equation to one of six standard forms $ax = b$, $ax^2 = c$, $ax^2 = bx$, $ax^2 + bx = c$, $ax^2 + c = bx$, $ax^2 = bx + c$, and he then gives the solution of each of these forms: first the procedure for finding x, and in the case of the last three forms, also a geometrical motivation using rectangles and squares. The operation *al-jabr,* which gave its name to the whole field of solving equations, means the "restoration" of a negative term (example: $3x^2 - 7x = 4$ is "restored" to $3x^2 = 4 + 7x$). After al-Khwārizmī, Abū Kāmil solved complicated quadratic equations with irrational coefficients. In the tenth century, al-Karajī treated various properties of quadratic irrationals, which Euclid had proved geometrically. Al-Karajī also discussed cubic irrationalities, and he explained the extraction of the root of a polynomial (which is assumed to be a perfect square). In the tenth and eleventh centuries, cubic equations were solved geometrically by the intersection of conic sections, for example by ʿUmar al-Khayyām, and the theory was perfected by Sharaf al-Dīn al-Ṭūsī. A few mathematicians worked on equations of degree higher than three, but most of this work seems to be lost.

Theory of Numbers

Some Arabic mathematicians were interested in indeterminate equations, i.e., equations with an infinite number of solutions. The solutions had to be rational numbers (in the way of Diophantus of Alexandria, whose *Arithmetica* was translated into Arabic) or integers. Examples of the last kind are: find integers x, y, and z such that $x^2 + y^2 = z^2$ (such numbers x, y, and z are the sides of a right-angled triangle); or the famous problem of "congruent numbers": find numbers which are the surface area of a right-angled triangle whose sides are all integers. In the tenth century it was believed that no numbers x, y, and z such that $x^3 + x^3 = z^3$ existed, but it seems that this fact could not be proven by means of the mathematical methods then available.

Some progress was made in the theory of perfect and amicable numbers. A number is perfect if it is equal to the sum of its own divisors. Euclid had proved a formula for even perfect numbers, and four such numbers were known in antiquity: 6, 28, 496, and 8,128. In or before the thirteenth century, three more were found by Arabic mathematicians: 33,500,336; 8,589,869,056, and 137,438,691,328. Two numbers are called amicable if they are the sum of the divisors of each other. The example 220, 284 was known from antiquity. Thābit ibn Qurra discovered and proved that if p, q, and r are three prime numbers of the form $P = 3 \cdot 2^{n-1} - 1$, $q = 3 \cdot 2^n - 1$, $r = 9 \cdot 2^{2n-1} - 1$, then the numbers $2^n \ldots pq$ and $2^n \ldots r$ are amicable. Examples are the pairs 200, 284 ($n = 2$) and 17,296, 18,416 ($n = 4$). Perhaps the subject of amicable numbers was popular because of its magical applications, and such applications may also explain the interest in magic squares, which continued throughout the Arabic tradition.

The reader should bear in mind that the ancient and medieval concept of "number" is not necessarily the same as the modern one. In ancient Greek mathematics, a "number" was always a positive integer number, or a fraction (i.e., a ratio between two positive integer numbers). The Greeks knew that there were proportions in geometry which could not be expressed by this limited concept of number (such as the ratio between the side and diagonal of a square, that is $1 : \sqrt{2}$). Nevertheless, they did not extend their concept of number to include the modern idea of an irrational or real number. The reason is that this involves difficulties with the infinite, which they would have avoided (and which are carefully hidden in naïve presentations of the concept of real number in school mathematics). Instead of working with real numbers, the Greeks developed a theory of proportions of geometrical magnitudes (for example, line segments). This theory is found in Book V of Euclid's *Elements*, which was widely studied by the Arabic mathematicians. In astronomy, one has to calculate the (approximate) length of segments, which cannot be represented as a number according to the orthodox view. Thus it is understandable that the Arabic mathematicians, most of whom were also astronomers, came closer to the naive concept of real number, as it is nowadays taught in schools. Many mathematicians, such as Sharaf al-Dīn al-Ṭūsī, continued to believe that any rigorous treatment of numbers and algebra had to be based on the Euclidean theory of proportions.

Geometry

The basic geometrical work in Arabic mathematics was the *Elements* of Euclid (ca. 300 BCE). This work was very thoroughly studied, and more than fifty commentaries in Arabic were written, most of which have not been studied in modern times. Euclid's parallel postulate was one of the main points of attention. Most Arabic mathematicians found this unsatisfactory, and attempts were made, by Ibn al-Haytham, Naṣīr al-Dīn al-Ṭūsī, and others, to replace it by a more appropriate axiom. Many other Greek geometrical works were translated into Arabic, so the Arabic literature is an important source of new information on Greek geometrical works which are now lost.

The Arabic mathematicians were very interested in geometrical constructions. Such constructions should preferably be made by ruler and compass, that is to say, by successive intersections of straight lines through two known points and circles with known centers and radii (the intersection of such known figures produces new known points). The most interesting problems from Greek geometry (trisection of the angle, construction of two mean proportionals, etc.) cannot be constructed in this way. The Arabic mathematicians also used conic sections as means of construction.

Some of the mathematicians were clearly aware that they progressed beyond the ancient Greeks, and there was a feeling that the authorship of a geometrical construction added to one's prestige as a mathematician. Some mathematicians even plagiarized others' works, as in the case of the regular heptagon. This figure cannot be constructed by means of ruler and compass, but the Arabic geometers knew an ancient construction (attributed to Archimedes) by means of a straight line which had to be moved in an unclear way until two triangles are equal. Around 968 Abū'l-Jūd proposed a ruler- and compass construction of the heptagon. The elementary error in this construction was soon discovered by al-Sijzī. The missing link was filled by al-ᶜAlā' ibn Sahl by means of conic sections, and this was then plagiarized by al-Sijzī (who repented later) and also by Abū'l-Jūd. Other constructions of the heptagon were found by al-Qūhī (ca. 970) and Ibn al-Haytham (ca. 1000), who were both very proud of their achievement. Most mathematicians felt that the heptagon had not really been constructed by the ancients, and thus the "moderns" had gone beyond the level reached by the Greeks. A similar problem was the inscription of an equilateral pentagon in a given square. This was solved by al-Qūhī, who stressed that this problem had not been solved by the ancient geometers.

An important branch of geometry was spherical trigonometry. In the eighth and ninth centuries, spherical trigonometry developed rather chaotically, in the context of astronomy and on the basis of a mixture of Indian and Greek methods. In the tenth century the field became an independent subject of study, and special treatises were devoted to it. The Arabic mathematicians studied the spherical triangle, that is a triangle on a sphere, such that the "sides" of the triangle are arcs of great circles (i.e., circles whose center is the center of the sphere). In the tenth century, "angles" were also defined in a spherical triangle, so that a spherical triangle has six elements, three angles and three sides, like a plane triangle. The main problem of spherical trigonometry could now be phrased thus: if three elements are given, how do we compute the rest? Treatises on this problem were written by Naṣīr al-Dīn al-Ṭūsī and the eleventh century Spanish mathematician Ibn Muᶜādh.

The determination of the *qibla* (direction of Mecca) from a locality with given geographical coordinates can also be regarded as a problem of spherical trigonometry. In the eighth and ninth centuries only approximate solutions of the problem were known, but exact solutions were found in the ninth century, and tables were computed in the twelfth century and later.

The Arabic mathematicians devoted much time and energy to the computation of trigonometrical tables (sines and tangents) with ever increasing accuracy. The main difficulty is the determination of the sine of one degree; since this quantity cannot be expressed in square roots of rational numbers, the standard approximation methods fail. Around 1420, al-Kāshī found a method to approximate the sine of 1° with any degree of accuracy, using algebra. Al-Kāshī was able to express this as a root of a cubic equation with known coefficients, and he developed a very fast algorithm to approximate the root. He also computed the number π to 16 decimals.

Mathematics and Astronomy

It is historically impossible to separate Arabic mathematics from Arabic astronomy. Astronomy was the main field of application of mathematics, and calculations that were done by the astronomers vastly surpassed those of "practical mathematics" (commerce, administration, etc.). Many people studied mathematics in order to become astronomers (or astrologers). One finds a lot of very interesting mathematics in astronomical handbooks (*zījes*). The astronomical problems were sometimes too difficult to be solved by the methods of medieval mathematics, or, in cases where the problems could be solved, the computations were sometimes too complicated to be performed in a reasonable amount of time. Therefore, such computations were often simplified by clever approximation devices, which presuppose considerable numerical insight.

Mathematics was also important for astronomy on a more philosophical level. The philosophical foundation of Ptolemy's astronomical models was unacceptable for some Arabic mathematicians (such as Naṣīr al-Dīn al-Ṭūsī) because some of the circular motions in his theories of the moon and the planets were nonuniform.

The later Arabic mathematicians sought to remove these flaws by adding one or more circles to these models, producing the same effects as Ptolemy in a philosophically acceptable way. The most famous device is the so-called Ṭūsī couple, consisting of a circle of radius *r,* which rolls along the interior of a second circle with the double radius 2*r*. As a result of this motion, any point on the first circle oscillates on a fixed straight line.

Transmission

Arabic mathematics influenced the development of mathematics in medieval Europe in various ways. In the twelfth century, some Arabic mathematical works (such as the *Arithmetic* and the *Algebra* of al-Khwārizmī) and Arabic versions of Greek mathematical and astronomical works (such as Euclid's *Elements* and Ptolemy's *Almagest*) were translated into Latin, mainly in Spain. These translations were the beginning of the development of mathematics in Christian Europe. The thirteenth century European mathematician Leonardo Fibonacci learned mathematics in the city of Bougie in Algeria and during his travels to other Islamic countries, and he then wrote various influential mathematical works. The transmission of mathematics from Arabic to Latin was far from complete, and until 1450 the level of mathematics in Europe was below that in the Islamic world.

See also: ►al-Khwārizmī, ►al-Uqlīdisī, ►ʿUmar al-Khayyām, ►al-Karajī, ►Sharaf al-Dīn al-Ṭūsī, ►Thābit ibn Qurra, ►Ibn al-Haytham, ►Naṣīr al-Dīn al-Ṭūsī, ►al-Sijzī, ►Ibn Sahl, ►al-Qūhī, ►Ibn Muʿādh, ►al-Kāshī, ►*Qibla*, ►Astronomy in Islam, ►Geometry in Islam

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Mathematics in Japan

Jean-Claude Martzloff

At various stages of Japanese history, mathematics developed as a direct consequence of contacts with foreign cultures, both Chinese and Western. Five successive waves of cultural influx may be delineated (1) Chinese wave I, from the seventh to the end of the ninth century; (2) Chinese wave II, from the end of the sixteenth to the mid-nineteenth century; (3) Western wave I, 1543–1639; (4) Western wave II, 1720–1854, and (5) Western wave III, from 1854 onwards.[1]

As far as may be surmised, the two Chinese waves developed independently and were separated by an interim period of semi-seclusion from continental influences during which Japanese mathematical activity subsided.

During Chinese wave I, Japanese mathematics did not depart significantly from that developed in China during the same period. This was also the case in Sui (589–618)[2] and Tang (618–907)[3] China. Japanese imperial authorities are said to have founded an elite school for training future accountants, fiscal officers, surveyors, calendar makers, and other such practitioners. The teaching of mathematics was based on the Chinese *Suanjing shishu* (The Ten Computational Canons) and not on Japanese autochthonous manuals. During that period and the following centuries, mathematics never developed beyond the rudiments. Fragmentary records such as those of a priest from the Kenninji temple show that ca. 1311, the Chinese *Jiuzhang suanshu* (Computational Prescriptions in Nine Chapters) from the Han dynasty was studied in Kyoto. Certain texts known as *oraimono* (didactic exchanges of letters) contain, nonetheless, a number of mathematical recreations such as the problem of *mamakodate* (lit., the standing stepchildren). In this problem, a mother has 15 true children and 15 stepchildren; she must eliminate the latter by placing them in a circle in such a way that starting from some child and counting clockwise she eliminates every tenth child until at last only the true children are still

[1] This mode of periodization is borrowed from Sugimoto and Swain (1978).

[2] The short-lived Sui dynasty inaugurates a period of relative stability characterized by the unification of China after several centuries of disunion.

[3] The Tang dynasty is one of the most brilliant in Chinese history where the Chinese were able to extend their influence all over Asia, from Iran, Central Asia, India, and of course Japan.

standing. This problem is reminiscent of the Josephus puzzle, where children are replaced by Turks – to be eliminated – and Christians.

During Chinese wave II, a number of Chinese mathematical texts were imported into Japan on the occasion of the Japanese military expeditions in Korea of the 1590s.

One of them, the *Suanfa tongzong* (Comprehensive Treatise on Arithmetic), was a compendium of commercial arithmetic. First published in China in 1592, this manual was mostly intended for abacus calculations and was very often reprinted in China and Japan until the twentieth century. However, although strongly influenced by its Chinese model, Japanese arithmetic began to develop on its own. In particular, arithmeticians devised a new type of abacus (*soroban*). It was composed of five balls for the representation of the decimal digits of each order of units, instead of seven in the Chinese case. There were four balls valued at one unit each and one ball valued at five units, instead of five balls valued at one unit and two balls valued at five units. For the first time, the Japanese also wrote arithmetical books in their own language. One of them, the *Jingōki* (Treatise on Numbers Ti and Huge) of Yoshida Mitsuyoshi (1578–1672), first published in 1627, became so popular that hundreds of plagiarized versions were published. In its 1641 version, the author included 12 problems left unsolved and bequeathed to posterity (*idai keishō*). Subsequently, this kind of challenge was often issued and played an important role in the development of Japanese mathematics. At first, the custom was limited to more or less trivial arithmetical problems, but gradually amateur mathematicians imagined complex problems relating, for example, to the volume of intricate solids (such as those defined by the intersection of two other solids), or to chains of circles or spheres tangent to other circles, spheres, ellipses, or ellipsoids, respectively. When solutions were found, the solvers published them and in their turn propounded new enigmas.

A development in mathematics more sophisticated than arithmetic, however, was triggered by the introduction into Japan of the *Suanxue qimeng* (Introduction to Computational Science), a Chinese algebraic textbook by Zhu Shijie published in 1299 in Yuan China. Subsequently forgotten in China for five centuries, but universally considered by present historians of Chinese mathematics as representative of the golden age of Chinese mathematics, this manual was first reprinted in Korea during the fifteenth century and in Japan in 1658. At first, the part of this text devoted to *tianyuan* (celestial origin) algebra was not well understood.

This Chinese medieval technique was presented using a series of artificial problems, with some intermediary computations and a few cryptic and terse sentences apparently having more to do with magic than mathematics. Moreover, known and unknown quantities were not distinguished from each other by special symbols but only by the relative position of numbers on the counting board, so that mere numbers in all cases equally represented both kinds of quantities. Yet, 20 years later, certain scholars began to crack the code and realized that Zhu Shijie's algebra was in fact a powerful weapon capable of mechanically solving all sorts of intricate problems and particularly those of the *idai* new tradition. What is more, these efforts at last enabled Seki Takakazu, also called Seki Kowa[4] (ca. 1742–1708), the son of a samurai who became a chief Palace accountant, to develop algebra well beyond the state he had found it in Zhu Shijie's manual.

Seki was so successful as a mathematician that he was retrospectively considered the father of a national tradition called *wasan*. Wasan is literally Japanese (*wa*) and mathematics (*san*). That is in contrast with *yōsan*, Western (*yô*) mathematics; these two terms were coined ca. 1870. Although strongly influenced by Zhu Shijie, and more generally by Chinese models, Seki's work marks a certain rupture with mathematics conceived as collections of isolated problems. Concerning the elimination of unknowns between polynomial equations, he imagined a general method which resulted in an invention of determinants independently of Leibnitz. He also systematized the Chinese Hornerian methods for the numerical evaluation of the roots of polynomials, computed the decimals of π, and used what we now call the Bernoulli numbers. Last, but not least, he created a kind of notational algebra whose symbols consisted of dissections of Chinese characters which enabled mathematicians to perform literal (and not merely numerical) computations in writing rather than by using counting-rods as the Chinese did. In fact, Seki's algebra was not so different from that of Vieta. Seki Takakazu's collected works were published in 1974 (Hirayama et al. 1974).

Later mathematicians improved all this. In addition, questions relating to the precise evaluation of the circumference, arcs, and chord lengths became so important that they were conceived as a single domain called *enri* (circular principles). Later, this domain was generalized to the computation of all sorts of infinite series and to various curves in a way which more or less evokes Western calculus.

However, Chinese mathematics was not the sole source out of which Japanese mathematicians developed their own mathematics. During Western wave I, a very limited amount of mathematical knowledge of Western origin (consisting perhaps only of some mathematical recreations) was introduced into Japan as a consequence of the diffusion of Catholicism by Jesuit missionaries. But edicts against Christianity were issued as early as 1612, and in 1630 a ban on the

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importation of Western books was decreed. During Western wave II, the ban was progressively removed and Western mathematical knowledge gradually permeated into Japan. In the period from 1720 to 1730, elementary geometry, plane and spherical trigonometry, and even logarithms became accessible through the medium of Chinese adaptations of European works such as the *Chongzhen lishu* (Chongzhen Reign-Period Compendium of Mathematical Astronomy), an encyclopaedic work which marked the start of the reform of Chinese astronomy in 1644 on the basis of European knowledge. Later, the Japanese also came into contact with Western works written not in Chinese but in Dutch, the language of the Dutch merchants, the sole Westerners who had relations with Japan. This initiated the development of a new branch of knowledge called *Rangaku* (Dutch learning). A consequence for mathematics of this new learning was the importation of the Dutch version of John Keill's (1671–1721) commentary on Newton's *Principia*.

Consequently, elements of European mathematics were integrated into wasan and new results were discovered. For example, Takebe Katahiro (1664–1734) developed an infinite series of the square of the arcsine. Takebe was a disciple of Seki and a Shogunal advisor also responsible for new developments in geography and astronomy. Ajima Naonobu, another distinguished wasan scholar, independently solved celebrated geometrical problems such as those of Steiner's chains of circles (circles mutually tangent inserted between two non-concentric circles situated one inside the other) or the so-called *Malfatti's problem* about three circles mutually tangent and inscribed in a triangle. Less anecdotally, Ajima and later Wada Yasushi (1787–1840) also elaborated methods for calculating areas and volumes as limits of infinitesimal rectangles or parallelepipeds in a way which is reminiscent of the construction of definite integrals. The achievements of Japanese autochthonous mathematics were thus quite high. A fundamental difference between Western and Japanese mathematics stems from the fact that the latter was essentially algebraic and developed independently of axiomatic–deductive reasoning.

While the search for general and systematic methods concerned more and more mathematicians, an opposite trend towards solving highly artificial problems conceived as isolated puzzles became still more prominent. In fact, mathematics was mainly practiced by 'hobbyists', members of rival schools or even mathematical sects. Works of wasanists were thus not much diffused. Original manuscripts were often copied by the disciples of some master (like Seki) and kept secret. Consequently, no consensus towards uniforming mathematical notations and concepts ever emerged, even though towards the end of the eighteenth century some mathematical works were eventually printed. More importantly, wasan studies were often condemned by Confucian elites who judged them 'mental acrobatics' and thus futile and socially useless. No official schools devoted to the study of wasan were ever created. During the whole Edo period (1698–1868), wasan was often practiced by *rōnin* (lordless samurai) who travelled all over Japan and earned their living by teaching wasan in private academies or becoming private tutors at the service of rich merchants. Unexpectedly, owing to a surprising alliance between mathematics and religion, wasan became more and more visible even in the Japanese countryside. From the end of the seventeenth century, wasan adepts advertised the achievements of the groups they belonged to by means of votive tablets (*sangaku*). Hung in public view in Buddhist temples and Shinto shrines, these wooden tablets generally displayed problems and beautifully engraved geometric figures (often consisting of mutually tangent figures, especially circles and triangles) with numerical solutions but no intermediary calculations. Hundreds of tablets have survived, and it is still possible to admire them everywhere in Japan. Moreover, printed anthologies of such tablets have been published. Such a practice is unattested anywhere else in the world outside Japan.

Until 1853, despite the importation of a certain amount of knowledge from China and Europe, Japan essentially remained isolated. But the partisans of isolation did not succeed in imposing their policy after Commodore Matthew C. Perry of the United States had forced open Japan's ports. As early as 1855, an Office for Occidental Learning (*Yōgakusho*) was created; one year later, this office was renamed Office for Investigating Barbarian Documents (*Bansho shirabesho*). There, government-appointed students learned to apply mathematics to navigation, shipbuilding, armaments, and other military matters. But radical changes had to wait the Meiji restoration of 1868. With the advent of this utterly new era, Western learning was no longer confined to military affairs and other utilitarian goals. Wasan was completely abandoned to Western mathematics. In 1877, the University of Tokyo was founded. At first, four out of five professors were foreigners (one American and three French). The Japanese professor was Kikuchi Dairoku (1885–1917) who later became Minister of Education. Kikuchi was an outstanding student who had been trained at the *Bansho shirabesho* and sent to Cambridge University; he gave his mathematical lectures in English. A few years later, however, the best students of mathematics were appointed professors in their turn. In 1877, the Tokyo Mathematical Society was founded. Japanese mathematicians rapidly attained the same level as that of Western researchers. Many mathematicians, such as Takagi Teigi (1875–1960) who contributed to class-field theory and gained worldwide fame, were trained during this period.

Extra: Seki Takakazu's Works

Seki Takakazu's collected works were published in 1974 (Hirayama, A., K. Shimodaira, and H. Hirose. *Takakazu Seki's Collected Works Edited with Explanations*. Osaka: Osaka Kyoiku Tosho, 1974). This thick volume has 871 pages comprising (1) various preliminary data concerning Seki Takakazu: a chronology, his biography, his disciples, a critical note on his portrait, the location of his tomb, his mathematical achievements; (2) the main text of his original works, printed or manuscripts (most often) (576 p); (3) a presentation of the main text in Japanese (216 p); and (4) a presentation of the main text in English (83 p). Given the seminal importance of Seki Takakazu for Japanese mathematics, it is worthwhile to describe his collected works briefly here.

The collection contains the following 29 original works:

1. *Kiku yōmei sampo* (1683) [Essential Methods of Calculation with the Compass and T-Square]. This is his earliest work. It gives simple calculations concerning the circle, arc of circles and the sphere; it has only ten pages and contains the first known Japanese proof of the Pythagorean theorem, in the form of a Chinese-like dissection.
2. *Ketsugishō tōjutsu* [Solutions *Tō* (in the form of *jutsu*, i.e. 'prescriptions') – the Japanese *jutsu* is the same as the Chinese *shu* – [of the 100 unsolved problems] from the *Ketsugishō*]. Here, the *Ketsugishō* is the title of a previous work, published in 1659; the expression *ketsugi* means 'omitted', i.e. the original solutions were not given. *Shō* = manuscript. For example, the fourth problem asked for the dimensions of a right-angled triangle given the sum of its three sides and the difference between the hypotenuse and the shorter side. Other problems are more complex and involve square and inscribed circles in a triangle and solid figures such as wedges, pyramids, or trunks of a cone. The last problem is about the construction of a 19 × 19 magic square. Most are solved using the algebraic technique known as *tengenjutsu*, a variant of the Chinese *tianyuanshu*.
3. *Futsudankai tōjutsu*. *Futsudankai* is the title of a previous manuscript (1673) containing unsolved problems. The expression *Futsudankai* means 'do not be afraid to change (the answers)'. This is again a collection of specific problems but they are much more complex than the two preceding ones. Sometimes, dissections of plane or solid figures into several pieces of unknown dimensions are given. Again, Seki provides algebraic solutions depending on the establishment of a polynomial, often of high degree, with coefficients composed of ten or more digits.
4. *Hatsubi sampō*. Once again, this work is based on a previous collection of problems. Here, *Hatsubi* means something like 'disclosing subtle [elements]' and *sampō* is exactly the same as the Chinese *suanfa*, 'computational methods' or 'mathematics'. Here the problems have several unknowns and the solutions involve their elimination.
5. *Kaihendai no hō* [Method of Solving 'Transparent' Problems]. This covers the area and volumes of simple plane figures and solids.
6. *Kaindai no hō* [Method of Solving 'Opaque' Problems]. This work is more theoretical than the previous ones. It does not consist of a list of problems but explains how to set and manipulate algebraic equations. A technique of solving polynomial equations analogous to Horner's method is also given.
7. *Kaifuku dai no hō* [Method of Solving Dissimulated Problems]. Here the expansion of determinants in relation to the process of elimination of polynomial equations is given.
8. *Kaihō honhen no hō* [Method of Solving Various Cases of Root Extractions]. This covers the tentative classification of polynomial equations and the study of elimination procedures.
9. *Daijutsu bengi no hō* [Method for Differentiating Problem Statements and Solutions]. This contains a method of successive approximations.
10. *Byōdai meichi no hō* [Method for Clarifying Flawed Problems]. Here one problem has an imaginary root and its statement is modified in order to let it having a computable root.
11. *Hōjin no hō*, *ensan no hō* [Methods for Magic Squares and Circles].
12. *Sandatsu no hō*, *Kempu no hō*. These two titles refer to the Japanese equivalent of Josephus's problem (called here *sandatsu*, i.e. enumerating a series of elements, *san*, while skipping some of them in the count, *datsu*) and another mathematical game consisting of remembering letters written on cards.
13. *Kyûseki* [Finding Volumes and Areas]. These include the area of an ellipse, analogous to the theorem of Pappus–Guldin. It also contains a problem concerning the intersection of a torus and a cylinder.
14. *Kyûketsu henkei sō*. A draft (*sō*) concerning the intersection of solids.
15. *Kaihō sanshiki* [Computational Configurations for Root Extractions]. This describes a technique for obtaining several roots of an equation with an approximation technique equivalent to Newton's method of approximation.
16. –19. *Katsuyō sampō*, 4 vols. [A Compendium of Mathematical Methods]. This contains a finite summation formula for the sum of powers with the discovery of the coefficients usually known as *Bernouilli's numbers*. A method for solving simultaneous congruences of the first degree (Chinese remainder theorem) is also included, as well as a systematic derivation of polynomial equations for calculating the length of the side of regular polygons, from the equilateral triangle to the 20-sided polygon. The compendium also offers inter alia a derivation of the result $\pi = 3.14159265358$.
20. *Happō ryakuketsu* [Abbreviated Mnemotechnical Tricks Concerning Eight Methods]. The content of this book is simpler than the preceding ones; it deals with the equivalence and conversion of units of length, weight, and volume.

The following seven treatises concern astronomical calculations:

21. *Juji hatsumei* [An Elucidation of the *Shoushi li*]. Here, the *Shoushi li* is a set of calendrical and astronomical official techniques, adopted in China from 1281 to 1368, and from 1368 to 1644 with some minor modifications. Seki explains the Chinese approximation method for the mutual expression of the arc and sagitta, by means of special approximation techniques.
22. *Juji rekikei rissei no hō* [Methods for Astronomical Tables in the *Shoushi li* Canon]. Introduction to the question of the tables for the motion of the sun and the five classical planets.
23. *Juji rekikei rissei* [The Astronomical Tables of the *Shoushi li* Canon]. Here the tables are fully reproduced.
24. *Seiki teisho* [Chinese Texts Corrected by Seki]. The text in question is the *Tianwen dacheng jiyao* (An Abridgment of the Great Sum of Astrology), a Chinese astrological treatise published in 1659.
25. *Siyō sampō* [Methods of Calculation of the Four *Yō*]. The 'four *yō*' are four invisible and imaginary celestial bodies used in Chinese astrology.
26. *Shukuyō sampō* [Calculation of the Astrological Chinese Mansions].
27. *Temmon sûgaku zatcho* [Various Mathematical and Astronomical Works]. Various notes, mainly on eclipses, with numerous geometrical drawings.

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Lastly, the collection also contains the following:

28. *Sampō kyojō* (Mathematical Diploma). This is an attestation awarded by Seki to one of his disciples, in 1704. The document gives a list of all the subjects mastered by him.
29. *Hatsubi sampō endan genkai* [Explanation of the *Endan* Methods of Solution Concerning Subtle Computational Methods]. Here, the *endan* is a special algebraic notation borrowing its name from Chinese mathematics, but it is more complex than the original since the unknowns are denoted by special expressions (Chinese characters) and not only by the relative positions of numbers.

The reader will find many more details in the aforementioned book, with some examples of problems and mathematical techniques fully worked out.

See also: ►Takebe Katahiro, ►Ajima Naonobu, ►Magic and Science, ►Seki Kowa, ►Magic Squares in Japan

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Mathematics in Korea

Kim Yong-Woon

During the Shilla dynasty (59 BCE–AD 935), in AD 682, Korea established its official mathematical system under the influence of the mathematics of China (Tang dynasty) whose primary structure was algebra (theory of equations) and whose philosophical background was *yin-yang* theory. It was an educational program designed to train professional mathematicians, and it prescribed the number of mathematicians to be trained and the length of study and curricula, and it remained the official mathematical system to the end of the Chosun dynasty in 1910.

The system soon died out in China. It was revived in the Song dynasty, but failed to become an official system again. Meanwhile, Japan set up its mathematics system under the influence of the Paekche and Shilla dynasties in Korea. The Taihorei of 710 clearly defined its contents, but this too soon became extinct. In China and Japan official mathematics ceased to exist, but civilian mathematics prospered. Korea, on the contrary, was fundamentally different from these two countries (see Table 1).

The arrangement of the Shilla curriculum here is hypothetical; originally only the names of the four subjects were given. The length of study for Korea, 9 years, is for classical studies; whether this applied to mathematics and other technical fields is yet to be explored.

In China during the Tang, there were different qualifications for the *guozixue* (National Academy) in mathematics and other fields. In Korea and Japan, qualifications also differed by field.

The Koryo dynasty (918–1392) continued using the Shilla mathematical system in a slightly changed version. Whereas the Koryo continued to use Nine Chapter Arithmetic, the Continuation Technique, and Three Opening Arithmetic, they discontinued Six Chapter Arithmetic and began to use Saga.

The Chosun dynasty (1392–1907) strengthened the system of its predecessors and the standard text books were completely changed. The texts include Sanmyon arithmetic, Yonghui arithmetic, Sanhak Kaemong arithmetic for bureaucrats, and arithmetic for surveying.

In the Chosun dynasty, the study of mathematics was encouraged to fill administrative needs and was incorporated into the official system. During the reign of King Sejong (AD 1419–50), a Bureau of Mathematics and an Agency for Calendars were created, and mathematics was revived to match the level of the Koryo dynasty (936–1392). The positions of *Sanhak*

Mathematics in Korea. Table 1 Mathematics education systems in Korea, China, and Japan around the seventh century AD

Country	Enrollment age	Admission qualifications	Subjects	Length of study
Korea (Shilla) AD 682	15–30	Taesa (grade 12 in a hierarchy of 17 grades) and those who had no official positions	Six-chapter arithmetic, nine-chapter arithmetic, three opening arithmetic, continuation technique	9 years or longer
China (Tang) AD 624	14–19	Children of grade 8, and lower-grade public officials	Nine-chapter arithmetic, calculation of distance to a far-off island, Sun Zi's arithmetic for five government bureaus, Zhang Guijian's arithmetic calculation and gnomon continuation technique, topics in number three standard mathematics	7 years
Japan AD 710	13–15	Children of grade 8, and higher-grade public and local officials	Nine-chapter arithmetic, calculation of distance to a far-off island, Sun Zi's arithmetic, three opening arithmetic, continuation technique, six-chapter arithmetic	7 years

paksa (Doctor of Mathematics), *Sanhak Kyosu* (Professor of Mathematics), and *Sansa* (mathematician) were created.

The Chosun dynasty attached great importance to mathematics from the beginning, and the bureaucrats in charge of the technical civil service examinations in 10 fields began to play a greater role, ultimately forming the new social class of *chungin* (middle men). The *chungin* class is considered unique in the history of the world. (The term began to be used officially during the reign of King Sukchong (1675–1720)). As technocrats, they were recruited through comparatively low-level civil service examinations. Most of them came from the *chungin* class. It does not mean that a son inherited his father's position; rather it seems that intermarriage among the *chungin* contributed to the preservation of the tradition. Among them, mathematicians showed an especially strong tendency toward preserving this hereditary tradition. The roster of successful candidates in the tests for mathematicians and the position of *Sanhak Sonsaeng* (mathematics teachers) list a total of 1,627 during 300 years from the fifteenth to the seventeenth centuries. Their fathers' occupations were as follows: 124 herbalists, 75 translators, and 6 astronomers; the rest were mathematicians.

The mathematicians of the *chungin* class lived in a very closed society. As many of the books they wrote have been lost, and only fragmentary information is available, it is difficult to evaluate their achievements, either as a group or as individuals. A typical mathematician of the *chungin* is Hong Chong-ha, a professor of mathematics, who wrote an eight-volume (plus a supplement) *Kuilchip* (Nine Chapters on Arithmetic in One) which is still extant today. He was born in 1684 into a typical *chungin* family of mathematicians; his father, grandfather, great-grandfather, and his wife's father were all mathematicians.

From his book, we find the following. First, mathematicians of the day were quite unfamiliar with the course of events in China, whereas the literati of the *yangban* class maintained direct contact with Chinese culture and with European culture through China. The mathematicians were bound by the old system and continued using only the traditionally handed-down manuals; they had no access to Chinese translations of Western mathematics books. Second, *tianyuan shu* (Horner's approximation theorem for an equation with real coefficients) and the calculation rod thrived in Korea throughout the Chosun dynasty, long after they had ceased to be used and had been replaced by the abacus in China after the establishment of the Ming dynasty. Japanese mathematics in the Edo period (1603–1867) is called *wasan*. The origin of *wasan* is Chinese mathematics, but the Japanese replaced the calculation rod with handwriting and eventually developed it into symbolic algebra. Korean mathematicians were then isolated from the outside world and from European mathematics which had already found its way into China, but they preserved traditional mathematics using the calculation rod.

One of the other mathematical trends in the Chosun dynasty was *yangbans* (nobles). Ch'oe Sok-chong was a mathematician of noble birth who was a great admirer of classical Chinese philosophy. As the author of *Kusuryak* (Concise Nine Chapter Arithmetic), similar in its style of description to that of early European monastic mathematics books, he was a "Boethius (480–525) of the Orient." Boethius's mathematics was theological, metaphysical, and number-theory centered. Both gave a touch of mysticism to numbers, and Ch'oe studied magic squares of various types: circle, square, hexagon, etc. The hexagon denotes "water" in Chinese traditional philosophy, and Korean mathematicians attempted to indicate some philosophical meanings by means of mathematics.

Culture and Mathematics

King Sejong wanted all the branches of Asian learning – Confucianism, linguistics, music, astronomy, herbal medicine, and agriculture – to be in the service of his country. Unlike the Greek system of learning that branched off into mathematics, natural sciences, and metaphysics, the Eastern system tended to integrate all fields of learning into a whole. This was typified by classical Chinese studies (compare this with the Western trivium and quadrivium). For example, in the reform of music and the creation of the Korean alphabet, King Sejong remained true to the orthodox Asian view of learning and was content with being a true inheritor of Eastern culture. His policy for the promotion of mathematics did not seek any new paradigm.

Sirak

Sirak is the Korean version of the neo-Confucian concept of "practical learning," similar in nature to *jitsugaku* in Japan and *shixue* in China. It was active for about 300 years, from the mid-sixteenth to the mid-nineteenth centuries. Descriptions of some of the prominent mathematicians and their works follow. Yi Sugwang (1563–1628) wrote *Chibong yusol* (Chibong's Miscellany) which treats astronomy, geography, bureaucracy, belles-lettres, human behavior, technology, and even birds, animals, and insects.

Typical of this encyclopedic coverage is *Ojuyon mun-jangjon san'go* (An Oju's Multitude of Articles and Essays) by Yi Kyu-gyong (b. 1788) in 60 volumes, which contained 1,400 entries relating to the problems of all ages and countries. He had a very practical outlook, and in a commentary on the original text of a geometry book, he regarded surveying as the primary purpose of its study.

Ch'oe Han-gi (1803–79) is said to have broken with the traditional position of neo-Confucianism and become an activist philosopher, adhering to thoroughgoing empiricism. But he too remained orthodox in his attitude to arithmetic, as is evident in his comment, "By the degree of knowledge one has acquired in arithmetic, we can judge one's insight; we can see whether one's attitude is reasonable or not by judging if one's reasoning is arithmetical."

In 1765 Hong Tae-yong (1731–83) visited a Catholic church in Beijing, China, and acquired first-hand knowledge of Western culture. He conversed with Hallerstein, the Chief Astronomer, and his deputy Gogeisl at a Chinese astronomical observatory, thereby broadening his knowledge of astronomy. His work *Tamhonso* (Tamhon's Writings) treats mathematics and astronomy in Vols. 4–6 of Book II. Hong consciously discussed the infinite; he was the first Korean to discuss an infinite Universe, and he also mentioned infinite decimals in discussing the value of π.

At the end of the Chosun dynasty a new movement in mathematics arose. Nam Pyong-gil (1820–1859) and Yi Sang-hyok (1810–), perhaps the two greatest arithmeticians at the time, did not belong to the *Sirak* school. None of the *sirak* scholars specialized in arithmetic. But Nam was born into a *yangban* family, and Yi was a professional arithmetician of the *chungin* lineage. They joined hands in the study of arithmetic.

Nam's works include many arithmetic books, but he made them look new by adding illustrated explanations. There is no trace of metaphysical view, a dominant characteristic of the works of other *yangban* scholars.

Yi Sang-hyok was a typical *chungin* arithmetician. After passing the national test, he was assigned to an astronomical observatory as a budget officer. Among his works are some astronomical books and the following books on arithmetic: *Iksan: Ch'agunbop monggu* (Winged Mathematics: Hypothetical Method for the Theory of Roots) and *Sanhak Kwan-gyon* (A Brief Survey of Arithmetic). The first title probably implies "mathematics of two wings," one wing referring to traditional arithmetic, and the other to modern arithmetic. *Ch'agunbop monggu* is an explanatory book on European algebraic equations, while *Sanhak Kwan-gyon* presents Yi's creative study of mathematics. Yi's single-minded devotion to higher mathematics, ignoring the traditional patterns of thought when classic arithmetic was reviving, leads us to assume that this type of mathematical research may have prevailed among *chungin* scholars at that time.

Classical official Korean mathematics maintained its continuity without any fundamental changes from the seventh century (Shilla dynasty) to the beginning of the twentieth (the end of the Chosun dynasty).

The Chosun dynasty had three groups of mathematicians: the *chungin*, the *yangban*, and the *sirak*. The *sirak* school searched for new mathematics as seen in collaboration between *yangban* and *chungin* mathematicians. But their study of European mathematics was limited to algebraic equations and geometry at best, and they never went much beyond the traditional Chosun dynasty mathematics even when they accepted European mathematics. The works of Hong Tae-yong, allegedly the most progressive of all *Sirak* mathematicians, differ from other classical manuals only in that they dealt with practical applications of old principles.

At the end of the Chosun dynasty, some of the *chungin* mathematicians attempted an original study in mathematics, breaking with the old traditions. But they too were limited by the prevailing intellectual climate, which hindered understanding and assimilation of modern mathematics.

Korean mathematicians made little effort to change fundamentally the mathematics which originated in China, they did not yield to foreign influence, and they maintained the classical mathematics of the East to the last (to the end of the Chosun dynasty) even when Chinese and Japanese mathematics underwent drastic changes.

See also: ►*Yinyang*, ►Sun Zi, ►Zhang Qiujian, ►Computation: Chinese Counting Rods, ►Surveying

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Mathematics of the Maghreb (North Africa)

Ahmed Djebbar

In discussing the mathematical activity which occurred within the framework of Arab-Islamic civilization, it is not possible to speak of one specific tradition from the medieval Maghreb, nor still less of specific traditions from each of the three regions of the Maghreb-Ifrīqyā, the central Maghreb, and the far Maghreb. Indeed, there has been one Arab mathematical tradition, born and developed in the East, partially transmitted to the Muslim cities of the west of Central Asia and then, later, to southern Europe by the intermediary of Latin and Hebrew translations. This tradition was assimilated, revived, and enriched by different scientific milieux.

Mathematics in the Maghreb from the Ninth to the Eleventh Centuries

Considering the close economic, political, and cultural ties which linked the Maghreb with the Andalus, it is not possible to separate the mathematical activities which took place in these two regions of the Muslim West. Indeed, the period which extends from the end of the eighth century to the end of the eleventh was characterized by the development of two scientific traditions linked to each other and brought to life by scholars who, apart from social divisions and differences in laws and religion, were united by the cultural and scientific environment which was made up of exchanges between the Andalus and the Maghreb, and of frequent contacts with the cities of the east – Baghdad, Damascus, and, later, Cairo.

That being said, the beginnings of scientific activities in the Andalus and the Maghreb are not well known. Indeed, information on the earliest mathematical activities of the region is rare and not very specific. But it is reasonable to state that, during the period of installation and consolidation of Arab-Islamic power, the development of the study and teaching of the Arabic language and of the different religious sciences of the period probably favored the teaching of sciences like medicine and arithmetic, which answered the needs of certain fringes of urban society (in particular, caring for the wealthy and administrating the distribution of inheritances).

In the Andalus, it is likely that from the beginning of the ninth century, the first translations of Greek and Indian works appeared in Cordoba from the centers of the empire and served to bring scientific learning to everyone from children to rulers. This was the case, for example, for ʿAbd ar-Raḥmān II (822–852) who benefited from this education and, in turn, actively supported further scientific activity by financing the establishment of an important library with works bought in the East. But it was not until the middle of the ninth century that scientific centers began to exist independently, outside the walls of palaces and princely mansions, in Cordoba, Toledo, Seville, and Saragossa.

During the last third of the ninth century and throughout the tenth the activities of teaching and research in the different branches of mathematics were greatly stimulated by the patronage of two great

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Umayyad caliphs, ᶜAbd ar-Raḥmān III (912–961) and his son al-Ḥakam II (961–976). These activities continued in the eleventh century with the blossoming of important scientific centers in capital cities of principal states which, in turn, stemmed from the brilliance of the caliphate of Cordoba.

The information which exists today about scientific activities in the Maghreb leads one to believe that the beginnings of mathematics, on the scale of all of the Maghreb, occurred in Ifrīqyā (present day Tunisia) as early as the end of the eighth century. Among the scholars whose names are still known is Yaḥyā al-Kḥarrāz, who had as a student Yaḥyā al-Kinānī (828–901), the author of the first book of *ḥis'* (control of weights and measures) written in the Maghreb.

From the ninth century, the name of only one mathematician remains, Abū Sahl al-Qayrawānī, of Iraqi origin. He is also the first Maghrebian mathematician whose book is known: *Kitāb fi al-ḥisāb al-hindī* (Book of Indian Mathematics). As the title indicates, the book was in the new Arabic arithmetical tradition, of Indian origin, which had been inaugurated by mathematicians in Baghdad at the end of the eighth century and the beginning of the ninth.

As in other regions of the Islamic world, patronage of scientific activity was prevalent in the Maghreb and functioned as it did in the great cities of the East, with the purchase of books, the financing of manuscript copies, grants to scholars, and the construction of schools and institutions. The only precise information we have is on the *Bayt al-ḥikma* (House of Wisdom) founded by Ibrāhīm II (875–902) in Raqqāda. This institution, which survived as a scientific center until the Fatimid dynasty, welcomed mathematicians, astronomers, and astrologers.

Maghrebian mathematical activity of the tenth century is not well known. It seems that the patronage initiated by the Aghlabids in the ninth century continued and that the study of mathematics and astronomy flourished, particularly in the course of the first two decades of the reign of the Fatimid Caliph al-Muᶜizz (953–975). But biographers have given us only a few names of people who were known for their mathematical activities or their interest in the discipline, such as Yaᶜqūb ibn Killīs (d. 990) and al-Huwarī (d. 1023). To these names must be added the names of scholars who came under the influence of the intellectual centers of the Umayyad Andalus or of Fatimid Egypt, like Ibn Yāsīn and al-ᶜUtaqī.

We are somewhat better informed about mathematical activity in the eleventh century, but information is still fragmentary. Some scholars of this period are well known, for example Ibn Abir-Rijāl (d. 1034–1035) and Abū'1-Ṣalt (1067–1134). They wrote on mathematics, astronomy, and astrology, but only certain of their works in the latter two disciplines survive.

Mathematics in the Maghreb in the Almohad Period (Twelfth to Thirteenth Centuries)

Much is known about the importance of the twelfth century in the political and economic history of the Maghreb. But the cultural and scientific history of that period remains a vast, unexplored field. For example, in the field of mathematics, only three scholars of this period have been the subject of research studies. They are Abū Bakr al-Ḥaṣṣār (twelfth century), Ibn al-Yāsamīn (d. 1204), and Ibn Munᶜim (d. 1228). These three scholars are important because of several factors. The first is that they were the first mathematicians in the Maghreb whose writings have survived.

The full name of al-Ḥaṣṣār is Abū Bakr Muḥammad ibn ᶜAbdallāh ibn ᶜAyyāsh al-Ḥaṣṣār. It appears that in addition to his mathematical activities, he was also a reader of the *Quʾrān* and a specialist in inheritances. It is also probable that he lived a long time and that he taught in Sebta, since he seems to have had ties with other mathematicians in that city. Only two of his writings have survived. The first, entitled *Kitāb al-bayān wat-tadhkār* (Book of Demonstration and Memorization) is a manual of calculation dealing basically with arithmetical operations on whole numbers and fractions. His second book is entitled *Kitāb al-kāmil fī ṣināᶜat al-ᶜadad* (Complete Book on the Art of Numbers). It was in two volumes, but only the first volume is extant. It takes up the themes of the first book, with new chapters on the breakdown of a number into prime factors, on common divisors, and on common multiples.

Reference to al-Ḥaṣṣār in two Andalusian works which are now lost leads us to the conclusion that, in one way or another, the Andalusian arithmetical tradition was present in the Maghreb in the twelfth century. This presence was reinforced, moreover, both by the direct diffusion of Andalusian works on algebra, geometry, and astronomy and by the utilization of the contents of the works of al-Ḥaṣṣār by later Maghrebian mathematicians like Ibn Munᶜim, Ibn al-Bannāʾ (d. 1321), and Ibn Ghāzī (d. 1513).

It appears that al-Ḥaṣṣār lived before Ibn al-Yāsamīn, but there is no way to verify that fact. However, the contents of their mathematical writings are quite similar insofar as they are written in the Andalusian tradition of the twelfth century, and they expand that tradition by the introduction of symbolism for certain objects and certain arithmetical operations and by the important development of a chapter on fractions.

We can say nothing about the works of Ibn Munᶜim on geometry or on the construction of magic squares, as they have not yet been discovered. But we are better informed about his writings on combinatory analysis, arithmetic, and number theory. The *Fiqh al-ḥisāb* (Science of Calculation), his only surviving text, contains the usual chapters of calculation manuals, dealing with the four arithmetic operations applied to whole numbers and to fractions, but also chapters at a higher level which deal with extraction of the exact or approximate root of a number, the properties of figurative numbers, the sum of series of whole numbers, and the determination of amicable numbers.

It is not known what the importance of mathematical activity in Marrakesh was at the time that Ibn Munʿim settled there. He himself is not specific about the Maghrebian mathematicians of his time or their predecessors. On the other hand, he refers very specifically to Andalusian scholars, citing their names, titles of their works, and even passages of their writings. This only serves to confirm the important scientific ties between the Maghreb and the Andalus, ties which were considerably strengthened in the fields of science and philosophy during the reigns of the first four Almohād caliphs, from 1130 to 1213.

It is important to note that the writings of al-Ḥaṣṣār, Ibn al-Yāsimīn, and Ibn Munʿim were not the only writings which were studied. Indeed, one can cite the names of several whose work may have been just as important: Abū'l Qāsim al-Qurashī (d. 1184) who taught algebra in Bougie, al-Qāḍī al-Sharīf (d. 1283) who was a student of Ibn Munʿim in Marrakesh, al-Qalʿī (d. 1271) who also lived in Bougie and who taught the science of inheritances, and Ibn Isḥaq al-Tūnusī (d. after 1218), who was known for important work in astronomy. Unfortunately, none of the mathematical writings of these scholars remains, and we cannot even speculate on their contents.

The Mathematics of Ibn al-Bannāʾ and Commentaries on His Work (Fourteenth to Fifteenth Centuries)

In the history of scientific activity in the Maghreb, the fourteenth century is a special time, not only because of the quantity of mathematical work, but also because of the content of that work and its influence on the teaching of mathematics in the Maghreb in the centuries to follow.

The majority of mathematical work done in this century was reviews, in the form of commentaries and summaries of work which had already been discovered or assimilated in the course of previous centuries. New contributions were the exception. The work of the mathematician Ibn al-Bannāʾ (1256–1321) becomes even more important in this light, since he was both one of the last innovators in the great Arab mathematical tradition and also one of the initiators of a new tradition in the teaching of mathematics.

Ibn al-Bannāʾ was born and raised in Marrakesh where he also died, but he also lived and taught in Fez for a period. He seems to have been one of the last scholars to have engaged in research activity in that he grappled with problems which were new at that time and to which he found original solutions, for example in combinatory analysis. He also introduced original ideas or processes in algebra (on the existence of solutions to a second degree equation) and in calculus (on nondecimal bases).

Ibn al-Bannāʾ was also notable for the richness and diversity of his work. In the inventory which Ibn Haydūr (d. 1413) made of his writings, he records 98 titles, 32 of which deal with mathematics and astronomy. This may have been the reason for the high social status he enjoyed, being honored by the highest authorities in the far Maghreb, which led him to leave Marrakesh and settle in Fez for a period of time.

Ibn al-Bannāʾ wrote on geometry and an important work on algebra which was used as a teaching text in the Maghreb until the fifteenth century. But it is his writings on the science of calculation which have made him famous. Three of them remain in existence: the *Talkhīṣ aʿmāl al-ḥisāb* (Summary of the Operations of Computation), *al-Qānūn fi l-ḥisāb* (Canon of Mathematics), and the *Rafʿ al-ḥijāb* (Lifting of the Veil).

While the third title is the most important in mathematical terms, it is the first which is best known. A manual on the operations of calculation, it is characterized by great conciseness, rigor in its formulation, and especially, by a total absence of mathematical symbolism. For these reasons, many mathematicians after Ibn al-Bannā have published commentaries on this manual.

A comparative study of the most important chapters of these commentaries leads to the following observations on their content and on the general level of mathematics at that time. First, that the level of mathematics was not lower than that of earlier periods but that certain themes which had been taught since the tenth century no longer appear. Second, there are no new contributions in the commentaries, neither on the theoretical level nor on the level of the applications of ideas or earlier techniques. The most significant innovation in the commentaries is in the progressive utilization of a relatively elaborate symbolism. This symbolism had already appeared in the writings of al-Ḥaṣṣār and Ibn al-Yāsamīn, but its use seems to have taken hold throughout the thirteenth century and the beginning of the fourteenth. It reappeared in certain commentaries in the fourteenth and fifteenth centuries, both in arithmetic and in algebra.

Mathematics in the Maghreb After the Fifteenth Century

The activities of mathematicians from the Maghreb who lived between the sixteenth and nineteenth centuries are not clearly known, but it is possible to get an idea of their contributions from the titles of

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writings which still exist. The mathematical disciplines which were taught or treated in the writings are metric geometry and calculation. It is possible to affirm that the content of these works differs from that of earlier mathematical writing both in form and level. There are poems, for example, those of al-Akhḍarī (d. 1575) and al-Wansharīsī (d. 1548), glosses and commentaries like those of Ibn al-Qāḍī (d. 1616) and Muḥammad Bannīs (d. 1798), and summaries like those of Ibrāhīm al-Ribāṭī (d. 1926). But the level of these works is inferior to those of the fifteenth century, which are themselves much poorer than works of the thirteenth and fourteenth centuries, both in ideas and techniques. The same is true in other sectors of intellectual activity in the Maghreb which were characterized by a narrowing of the respective domains of investigation and an impoverishment of their contents. This situation, the result of a long process of decline, had an indirect effect in mathematics in a gradual reduction both of content and in the field of application. Thus, the only activities left to mathematicians, aside from teaching and editing manuals, were mathematical practices linked directly to activities or preoccupations of a religious nature, like the distribution of inheritance, and donations to rightful claimants, the determination of times for fixing moments of prayer, or the construction and use of astronomical instruments.

See also: ►Ibn al-Yāsimin, ►Ibn Munʿim, ►Ibn al-Bannāʾ

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Mathematics: Maya Mathematics

Michael P. Closs

The common numerical notation of the Maya employed combinations of "bars", having value 5, and "dots", having value 1, to represent the vigesimal digits from 1 to 19. For example, the kneeling scribe in Fig. 1 appears on a Classic Maya vase dating from around AD 750. From his armpit emanates a vegetative

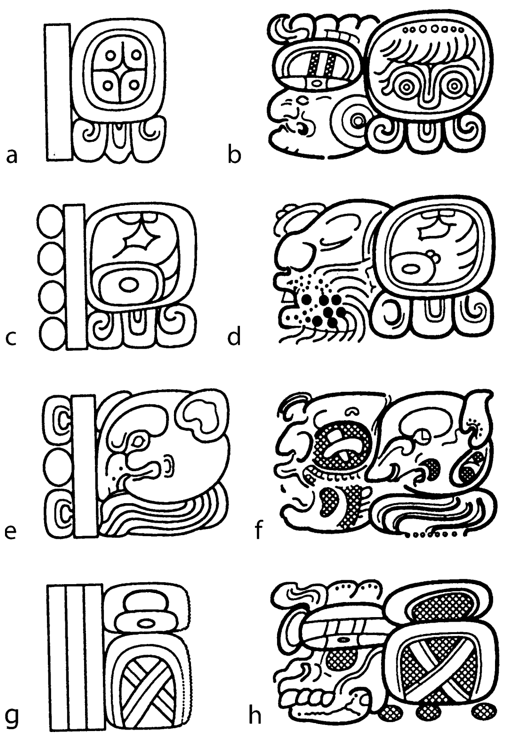
Mathematics: Maya Mathematics. Fig. 1 A kneeling Maya scribe (drawing by Closs after Clarkson, 1978).

scroll containing bar and dot numerals. Beginning at the armpit, the sequence of numerals runs 13, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Often, non-numerical crescents or other fillers were used to create a more aesthetic balance for the numeral.

In some records, these simple numerals are used to count objects, in particular to specify the quantity of offerings of a particular type. However, the overwhelming usage occurs in calendrical and chronological contexts. In the former, the numerals appear as coefficients in the Maya calendars of 260 and 365 days. The former consisted of the cycle of numbers from 1 to 13 paired with a cycle of 20 day names. As the days went by, both the number and the day name would simultaneously advance in their respective cycles, thus generating a sequence of 260 distinct dates. The second calendar was a civil year composed of 18 "months" of 20 days each and a residual "month" of 5 days. The days within a given month were numbered consecutively from the first to the penultimate by prefixing the proper numeral to the appropriate month name. The last day was sometimes indicated by prefixing a special sign having the sense of "end" to the month name. However, the more common practice was to prefix a sign signifying "seating" to the following month and thereby identify the last day of one month as the seating day of the following month. Frequently, the Maya would describe a day by giving its dates in both the 260 and 365 day calendars. This generated a cycle of 18,980 paired dates known as the "calendar round".

A characteristic of Maya writing is that it often uses many distinct signs to represent the same linguistic value. This is the case with numerical terms where, in addition to bar and dot numerals, the Maya represented numbers by head forms and even full body figures. Some examples of bar and dot numerals in calendrical contexts, with alternative representations of the same dates using head variant numerals, are illustrated in Fig. 2. All of these examples come from the same ancient Maya city of Palenque and demonstrate the scribal variation to be found in Maya writing even at the same location. For a more extensive description and additional examples of Maya numeral forms, see Closs (1986).

The Maya frequently recorded the chronological interval separating two calendar dates. For this purpose they employed a vigesimal count of *tuns* (360 day periods) and separate counts of *winals* (20 day periods) and *k'ins* (days). A given interval would be expressed as a count of the respective time periods into which it could be minimally decomposed. Each of the time periods was represented by a characteristic sign and the appropriate count was indicated by a numerical prefix. In recording such chronological counts, it is necessary to have a symbol for zero so as to indicate an empty count of a particular period if this occurs. The Maya did have a zero symbol for that purpose. In fact, as with other signs employed in Maya writing, there are several variants of the zero symbol.



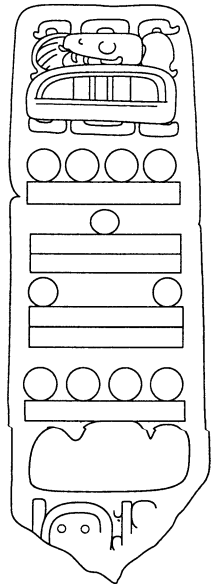
Mathematics: Maya Mathematics. Fig. 2 Maya numerals in a calendrical context. Dates in the 260-day calendar: (a) 5 Lamat, Palenque, Palace Table, R4; (b) 5 Lamat, Palenque, Tablet of the 96 Glyphs, D4; (c) 9 Manik, Palenque, Dumbarton Oaks Panel 2, J; (d) 9 Manik, Palenque, Tablet of the 96 Glyphs, H1. Dates in the 365-day calendar: (e) 6 Xul, Palenque, Palace Tablet, N15; (f) 6 Xul, Palenque. Tablet of the 96 Glyphs, C5; (g) 15 Uo, Palenque, Tablet of the Slaves, H5a; (h) 15 Uo, Palenque, Tablet of the 96 glyphs, G2 (drawing by Closs).

In many cases, and typically in the codices, Maya scribes would represent chronological counts using a system of positional notation. In this system, counts were written vertically with the lowest position being occupied by the count of *k'ins*, the next higher position by the count of *winals*, the next higher position by the count of *tuns*, and successively higher positions by the corresponding count of successively larger vigesimal multiples of the *tun*. Any chronological count could be recorded in this system by using the 19 vigesimal bar and dot digits and a symbol for zero.

In the monumental inscriptions, it was customary to indicate the interval between two successive dates of the text by recording the chronological interval separating them. Such chronological counts are referred to as "distance numbers" and might be added or subtracted to a given date to reach the following date. The initial date in an inscription is often anchored in an absolute chronology by recording the chronological count separating it from a common base date far in the past. These chronological records are referred to as Initial Series and have a characteristic format. An example of an Initial Series on Stela 1 at Pestac, employing positional notation and incorporating a zero, is illustrated in Fig. 3. It shows a count of 9 baktuns (=3,600 tuns), 11 k'atuns (=220 tuns), 12 tuns, 9 winals, and 0 k'ins (a total of 1,379,700 days or approximately 3,777 years) and leads to a date in AD 665. This is the oldest securely dated Maya text incorporating the system of positional notation with a zero sign.

In nonpositional contexts, the zero sign is found in Initial Series at a much earlier time. For example, the zero sign occurs on Stela 18 and 19 at Uaxactun, dating from AD 357. The most ancient nonpositional chronological count of this type, but without a zero, is found on Stela 29 at Tikal, dedicated in AD 292. It is interesting to note that the system of positional notation is very ancient in Mesoamerica and is found on monuments that predate those of undisputed Maya origin. However, none of them exhibit a zero sign. The oldest of these monuments goes back to 36 BCE.

In several instances, the Maya worked with negative chronological counts. These are used when counting backward from the zero point (base date) of the absolute chronology. They are distinguished from positive counts by a peculiar notation that has engendered the term "ring number". An example of a ring number from the Dresden Codex, one of the few surviving Maya



Mathematics: Maya Mathematics. Fig. 3 The front of Pestac, Stela 1, with an Initial Series of 9.11.12.9.0 employing positional notation and a zero sign (drawing by Closs).

Mathematics: Maya Mathematics. Fig. 4 A Maya ring number of 1.7.11 from the Dresden Codex, p. 58 (drawing by Closs).

hieroglyphic books, is illustrated in Fig. 4. The ring number of 1.7.11 is a negative chronological count with reference to the zero point of Maya chronology and leads to a mythological date.

Among the mathematical problems faced by the Maya were those of determining the calendar round date when a chronological interval is added to or subtracted from a given date and of determining the chronological interval between two given calendar round dates. The Maya also used other calendrical cycles of 4 days, 9 days, and 819 days. This led to other problems such as determining the station in the 819 day cycle closest to a given calendar round date. It is clear from artifactual evidence that the Maya performed their calculations using residue arithmetic.

The most sophisticated accomplishments in Maya mathematics are found in their arithmetically based astronomy. Here I will touch on three areas.

1. From the earliest days, the Maya scribes kept track of the moon through a lunar calendar. We have a large number of moon age records giving the current age of the moon within a cycle of 29 or 30 days. If a moon age was greater than 19 days, a special symbol for 20 was employed along with a regular bar and dot numeral to make up the balance of the count. Occasionally, a similar notation was used in the chronological counts discussed above. Since a lunation is around 29.5 days, the Maya used varying proportions of 29-day and 30-day months to keep their moon age records in agreement with astronomical reality. This gives an idea as to how the Maya avoided the necessity of fractions in their integer-based arithmetic. We have a few examples of moon age calculations from contemporaneous dates into mythological time, thousands of years earlier, from which it has been possible to recover the moon-age formulas that were used. These are formulas of the type "x moons = y days" where x and y are integers. Dividing through by x, one can say that a particular Maya formula is equivalent to estimating an average lunation as y/x days. This can then be compared with modern estimates and the precision of the Maya results can be recognized. Nevertheless, it can be misleading because the Maya did not look at things in this way.
2. The Dresden Codex contains a Venus table that permits the prediction of first appearance of the planet as morning star and as evening star over a period of about 104 years. The introductory page to the table has several features of mathematical interest. It has a mythological base date marked by a ring number. To this is added a companion number leading to a canonical base date of the table in the historic era. The companion number spans a period of 1,366,560 days (more than 3,741 years). It has the prime factorization $2^5 \cdot 3^2 \cdot 5 \cdot 13 \cdot 73$ and so is highly divisible into a product of relatively small prime numbers. This is fairly typical of other companion numbers associated with ring numbers in the Dresden Codex. It is a contrived number constructed using a knowledge of residue classes. The page also includes a table of multiples of 2,920 days. The importance of this number stems from the formula "5 Venus years of 584 days = 8 solar years of 365 days" commensurating the Venus and solar cycles. The existence of tables of multiples is

habitual in the Dresden Codex and indicates that the Maya worked from such tables rather than depending on algorithms for multiplication. The table of multiples and other calculation factors provide a mechanism for advancing from the canonical base date of the Venus table into the Venus table proper at a contemporaneous date. Still other calculating factors on the same page permit the Venus table to be recycled over time so that it maintains its astronomical integrity over several hundreds of years, much longer than the actual span of the table.

3. The Dresden Codex also contains an eclipse table that identifies dates of potential solar and lunar eclipses. It records a commensuration of the eclipse cycle with the sacred calendar of 260 days. This table also has mechanisms for recycling so that it can remain useful over many runs of the table. It is one of the great mathematical and astronomical achievements of the ancient Maya.

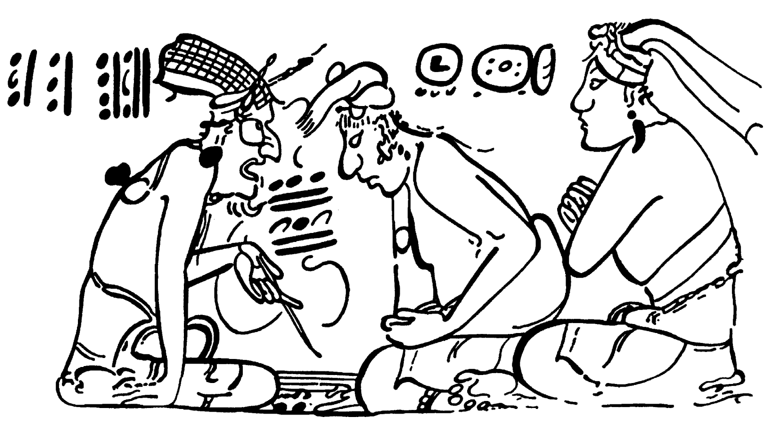
We also have some indications of geometrical knowledge among the Maya but nothing derived from written texts. Information that has been obtained comes from the study of architecture and site plans. For example, there are reasons to believe that an arrangement of three major temples at Tikal – at the vertices of an isosceles right triangle – is not coincidental. Many other alignments suggesting intentional geometrical concerns have been proposed at various Maya sites, but no adequate synthesis of the geometry involved has yet been achieved.

The idea of mathematics was sufficiently concrete in Maya thought that it has a presence in Maya art and iconography. In a number of almanacs in the Madrid Codex, deities are shown holding a vessel of black paint in one hand and a brush for painting or writing in the other. This type of scene is now known to depict the deity in the act of writing or painting. In at least two instances, an extra feature has been added to the scene. This consists of a scroll containing numbers issuing from the mouth of the deity. The added element indicates that the writing which is being performed is of a mathematical nature. By using this device, the Maya artist testifies to the visibility of mathematics as a discipline in Maya society.

The notion that mathematics was also considered a distinct discipline within the scribal curriculum is demonstrated on a Classic Maya vase (ca. AD 750). The scene on one side of the vase, illustrated in Fig. 5, shows a classroom scene in which Pauahtun, an aged god with a characteristic netted headdress, instructs two disciples in the mathematical art. Pauahtun, who is known to be a patron of scribes, is seated with a codex in front of him and a brush pen in his left hand. From his mouth issues a speech scroll containing the bar and dot numbers 11, 13, 12, 9, 8, and 7. The hieroglyphic caption behind the head of the first student is a name glyph. On the other side of this vase, there is a near identical classroom scene in which hieroglyphs are recorded in the speech scroll. In that case, the spoken text begins with a verb indicating "to teach."

A pair of deities in a detail from another Classic Maya vase is shown in Fig. 6. The god on the right has the facial features of a monkey and carries a codex in his right hand. An effigy head rests on top of the opened codex. The god on the left rests one hand on the back of the previous figure and holds a conch shell ink-pot in the other. Of special interest is a vegetative scroll, containing bar and dot numerals, which emanates from his armpit. There is also a curl, with single digits, running down from his cheek. Coe has suggested that these deities are patrons of mathematics and writing. The pairing of the two deities in this manner distinguishes between mathematics and writing in Maya thought. It reinforces the idea that mathematics was recognized as a separate discipline.

It is apparent that a scribe who was a mathematical specialist must have mastered calendrical and chronological calculations. The most detailed information on Maya civilization at the time of the Spanish conquest is



Mathematics: Maya Mathematics. Fig. 5 An ancient Maya mathematics lecture (drawing by Closs from Kerr, 1989).

Mathematics: Maya Mathematics. Fig. 6 Maya gods of mathematics and writing (drawing by Closs from Coe, 1978).

found in Bishop Landa's *Relacion de las Cosas de Yucatan*. This work was written shortly after the conquest and draws heavily on data provided by educated native informants, members of the former scribal class. Landa refers to the mathematical techniques of the Maya scribes as the computation of the katuns. He writes that this "was the science to which they gave the most credit, and that which they valued most and not all the priests knew how to describe it" (Tozzer 1941). This informs us that not all scribes were mathematical specialists and that those who were had greater prestige. It supports the idea that mathematical specialists were recognized as a specialized subgroup of the scribal class. In this regard, the situation at the time of the conquest seems to have been no different than it was during the Classic period.

See also: ►Calendars, ►Astronomy, ►Eclipses

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Mathematics in Mesopotamia

SEMA'AN I. SALEM

"A mind that does not know accounting, is it a mind that has intelligence?" This ancient Mesopotamian proverb equates mathematical dexterity, to the exclusion of all other disciplines, with mental capability, and portrays the reverence the ancient Mesopotamians had for the field of mathematics. It is certainly true that the study of mathematics is an intellectual activity that requires both imagination and intuition.

Mathematics arose from the need to count and to record numbers. Many ancient societies had methods for tallying and counting. Thus, they developed a variety of counting systems used over the millennia around the world. Our base-10 system, the most common of all systems because of its association with the number of fingers on both hands, is but one of many.

A concise and meaningful definition of the field of mathematics is virtually impossible. The word was originally used to mean arithmetic. Then simple algebra was introduced, followed by plane geometry and other related concepts. At present, the word mathematics is defined as a language with a particular kind of logic. It contains a large body of knowledge often beautifully expressed in terms of equations, numbers, and symbols.

In this article, the word mathematics is used in its most general meaning.

Mesopotamia is a land that nurtured many civilizations – Sumerian, Akkadian, Babylonian, Chaldean, and later on Abbasid. It has a long list of achievements in astronomy and mathematics as well as other disciplines. The Mesopotamians' love for and interest in the study of astronomy led to their development of mathematics. The two fields, being interdependent, grew and prospered side by side.

Originally, mathematical calculations were used to count herds, livestock, produce, and people; later, they were used to help understand astronomical observations. Mesopotamian stargazers had a motto, "When it is clear, observe, when it is cloudy, compute." They observed for long periods of time; the longest uninterrupted period of astronomical observation, and this includes modern day observations, was carried out in Mesopotamia. To understand these observations, they performed very complex mathematical computations.

In this article we present some of the simple mathematical operations that were performed by early Mesopotamians. We will avoid the more complex calculations more suitable only to the experts.

The ancient Mesopotamians worshipped celestial objects as gods, and they believed that they were created for the purpose of serving these gods. To perform this function properly and to interpret the wishes of these gods, they studied their every move, chartered their paths, and calculated their positions as a function of time, thus creating a strong link between the study of mathematics and astronomy. This link played an important role in the development of both fields and later gave rise to the formulation of the Mesopotamian early calendars.

For our knowledge of Mesopotamian mathematics we are indebted primarily to the work of the Otto Neugebauer, who, between 1935 and 1937, studied all the known mathematical cuneiform tablets and published their contents in three volumes entitled *Mathematische Keilschrift-texte*. In these, he included photographs of original texts, transcripts, and translations into German. He also wrote a comprehensive commentary. A later publication by F. Thureau Dangin contains new transcriptions and French translations of most of the material published by Neugebauer, and a new and valuable commentary. For an extended period after 1937, Neugebauer continued his study of Mesopotamian mathematics; he kept translating and publishing articles about the subject, indicating what type of mathematics the Mesopotamians were interested in and how they solved some of the difficult and involved problems. And in 1945, he and Sachs published another collection – a supplement to Neugebauer's early work. In 1961, E. M. Bruins and M. Rutten produced a volume entitled *Textes Mathématiques de Susi* (Susa). The works of Otto Neugebauer, F. Thureau Dangin, and E. M. Bruins and M. Rutten are our main sources and best references to Mesopotamian mathematics.

The oldest mathematical symbols uncovered in Mesopotamia are Sumerian; they go back to ca. 3000 BCE. They are a short straight line, which stands for unity; a small circle darkened at the top which corresponds to 10; and a half-moon which represents 60. To add numbers, they wrote them next to one another; to multiply two numbers, they wrote one inside the other. For subtraction they had symbols that stood for the minus sign; to write 8, they wrote $10 - 2$.

With the advent of cuneiform, wedge-shaped signs replaced the old Sumerian symbols. A one wedge-sign by itself stood for unity, and two such signs placed next to each others meant two, and so on. The symbol for 10 was a small arc inscribed in an angle, and 60 was represented by a triangle. This retained the decimal/sexagesimal system.

Numerous clay tablets uncovered in Mesopotamia reveal that by 2000 BCE the Mesopotamians had a fully developed number system, which is partly decimal and partly sexagesimal. It has a symbol for 10, but instead of clumping together six such symbols to form 60, they had a unique symbol for 60. Although the ancient Egyptians are usually credited with the development of the decimal system, the Mesopotamians made partial use of such a system. These various notations were in use until the advent of the elegant, place-value system, a great leap in the advancement of mathematics. To differentiate between their numerous gods, the Mesopotamians assigned numerical values to these gods. Anu, the god of heaven, was allotted the number 60, and thus in their calculations, they used the sexagesimal system. That is, they used 60 the same way we use 10 in our decimal system. The influence Mesopotamian mathematics had on the Western civilization and mathematics is clear, as remnants of their sexagesimal system are still apparent in our method of measuring time (60 min to an hour and 60 s to minute) and in measuring angles (360°, 6×60, in a complete circle, and there are 60′ to a degree).

True to their sexagesimal system, they wrote all their fractions out of 60, the way we write our fractions out of 10. Thus, to write one half, they wrote a symbol that meant 0.30, the way we write 0.50 to mean a half.

Place-Value Numeration System

In our decimal system, if we desire to write eleven, we do not need to write 11 straight line scratches next to one another, we simply write 11 – the one in the first column to the right stands for unity, and the one in the second column stands for ten, and when they are placed together they represent 11. Similarly if we write one hundred and eleven starting from right to left, we have

M

1, 10, and then 10^2 giving the desired number of 111. Every time we move one column to the left we multiply by 10. In the sexagesimal system, the second column is 60, the third is 60^2, and every time we move one column to the left we multiply by 60. With the advent of cuneiform and the place-value numeration system, there was no further need for a symbol for 60. It was dropped, but the symbol for 10 was retained.

This system, which was conceived by the mathematicians and astronomers of Mesopotamia toward the beginning of the second millennium BCE, was a giant step in the annals of mathematics. To comprehend the importance of this giant step and how much simpler it is to perform mathematical operations using the place-value system, one ought to try to multiply two numbers using present-day Roman Numerals. The following table illustrates the use of place-value in the sexagesimal system (Table 1).

As the Mesopotamians had only two symbols to work with, the separations between successive symbols indicate different columns and a multiplication by 60 of the left column, instead of a simple addition of the two symbols. In solving one problem, another was created. The scribes had to determine how wide or how narrow the spaces between the columns ought to be. According to Mesopotamian understanding, if the spacing was too narrow, the two numbers must be added instead of multiplying the one to the left by 60 then adding. Thus making a symbol for zero became a necessity.

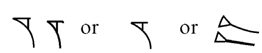
The astronomers and mathematicians of Mesopotamia had to contend with this difficulty for some 1,500 years, before they introduced a sign for zero. It took that long because it is difficult to think of "nothing" and even more difficult to find a symbol that represents "nothing." But in spite of the shortcomings of their numerical system, they were able to perform sophisticated calculations.

A Symbol for Zero

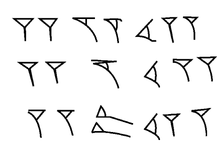
The history of the development and use of zero played a crucial role in mathematics and was the subject of several scientific publications, papers, and books. In a recently published book, *The Nothing That Is: A Natural History of Zero*, Robert Kaplan wrote that the earliest evidence of the use of zero was found on Sumerian clay tablets uncovered in southern Mesopotamia. The Sumerians, around 3000 BCE, inserted a slanted double wedge between numerical symbols to indicate the absence of a number. This date, if true, corresponds to the earliest use of mathematical notations by the Sumerians, and it comes only a couple of hundred years after the Sumerians invented writing.

It is possible that a symbol for zero was used by one civilization, got lost then rediscovered by another. Kaplan adds that the zero made its way into the Babylonian Empire and from there to India. In the Greek culture, the zero appears only occasionally, and there is no trace of its use during the Roman Empire. Arab scholars and merchants introduced the zero to the West, providing the earliest steps in the crucial role the zero plays in the world of mathematics. Note that the English word "cipher," meaning zero, has its origin in the Arabic word *sifr*, meaning empty. Finally, at a date not precisely determined, but either late in the sixth century BCE or early in the fifth century BCE, the Babylonian mathematicians, to indicate the absence of a sexagesimal unit, used a true sign for zero and spread its use over their vast empire and into the Indian subcontinent.

To avoid the difficulty encountered by leaving spaces to indicate zero or the absence of a number, they inserted between the columns one of the following signs:

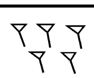
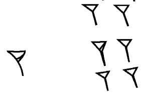
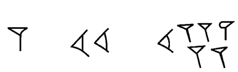


For example 132 was written in one of the following ways:



That is $2 \times 60 + 12 = 132$.

Mathematics: Maya Mathematics. Table 1 The place-value numeration system

	is 5
	is 64
	is $60 \times 60 + 60 + 1 = 3661$
	is $60 \times 60 + 20 \times 60 + 15 = 4815$

When cuneiform writing became obsolete in the first half of the first century AD, the Babylonian signs for zero were lost with it. But the great mathematician, Muḥammed ibn Mūsā al-Kwārizmī (ca. 800–847), working in Baghdad, reestablished a sign for zero and introduced it into his mathematical computations (Fig. 1).

Recreational Mathematics

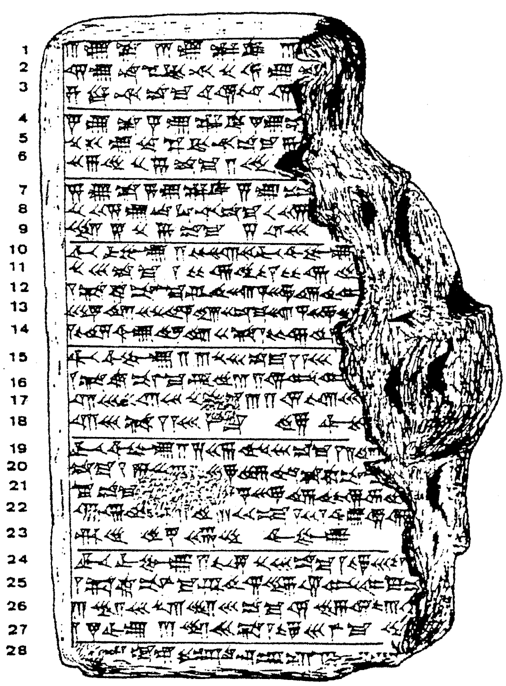
Most ancient mathematicians were interested in the solution of practical problems such as dividing geometrical figures into two or more equal parts, or multiplying two numbers to determine the area of a field. Such knowledge was used to divide properties among inheritors. For similar practical reasons they worked out the volumes of various solids to measure and store grains and other crops.

The Mesopotamians' interest in mathematics took them beyond its practical aspect and into its recreational, or what we call today pure mathematics. They worked out equations with two and three unknowns, they found solutions for quadratic equations, and they worked on problems such as, "Given the product of two numbers and either their sum or their difference, find the numbers." For most of their mathematical operations, the Mesopotamians constructed tables; they had tables of multiplication, division, squaring, and extracting square and cube roots. They also had tables of reciprocals, i.e., sexagesimal fractions. They went beyond all that and constructed tables for the summation of geometrical progression, such as

$$1 + 2 + 4 + \cdots + 2^9 = 2^9 + (2^9 - 1).$$

They also calculated the time required for the alignment of the sun–earth–moon to determine the time of lunar and solar eclipses. They were able to predict these eclipses with great precision.

A truly dramatic clay tablet, written in 568 BCE during the reign of Nebuchadnessar, states that a lunar eclipse predicted to take place on the 4th July 568 BCE (the date was recently calculated from an ancient Babylonian calendar) "failed to occur." Modern astronomers have verified that a lunar eclipse did take place on that date, but during the day, when the moon was not visible in Mesopotamia.



Mathematics: Maya Mathematics. Fig. 1 This mathematical clay tablet was uncovered in Uruk. It dates from either the late third or early second century BCE. It contains the earliest known signs of the Babylonian zero (Musée du Louvre, Paris). Used with the author's permission, from his article in *Dahesh Voice* 8.4 (2003): 14–9.

Influence on Greek and Western Mathematics

The first known Ionian astronomer, Thales of Miletus (ca. 625–545 BCE) was a statesman fond of traveling. While in Babylon, he obtained lists of observations of the heavenly bodies. From these lists, Babylonian astronomers had already deduced the periodicity of eclipses, and had accurately predicted several solar and many lunar eclipses. With these lists in his possession, Thales returned to his hometown of Miletus. It was reported there that he predicted a solar eclipse that took place in 585 BCE. But Thomas Martin, in his book *Ancient Greece, from Prehistoric to Hellenistic Times*, writes, "Modern astronomers doubt that Thales could actually have predicted an eclipse" (Martin 1969: 91).

Greek tradition indicates that it was customary for young Greek scientists to visit Mesopotamia in search of knowledge. One of the famous Greek scientists, who made the journey, probably after being deported from Egypt, was Pythagoras of Samos (d. ca. 497 BCE). He may have become acquainted with Mesopotamian mathematics, and most certainly with the theorem that bares his name, and which states that in a right triangle, the square of the hypotenuse is equal to the sum of the squares of the two other sides.

Neugebauer (vol. II, p 53 and vol. III, p 22) states that a cuneiform tablet, also belonging to the Old Babylonian period, contains extensive values of the sides of right triangles that satisfy the above-mentioned theorem. And Neugebauer and Sachs collection (pp 38–41) contains an extensive table of "Pythagorean Triplets." In addition to the theorem itself, right triangles, which obey the theorem, are also known as "Pythagorean Triangles" and the sets of numbers such as 3, 4, 5 and 6, 8, 10 and 12, 16, 20, etc. which satisfy the theorem are known as "Pythagorean Triplets or Pythagorean Triads." The theorem, the triangles that obey the theorem, and the sets of numbers that satisfy the theorem should be named Babylonian instead of Pythagorean.

This is not an isolated case. Through the work of Neugebauer, it became clear that the work of the mathematicians and astronomers of ancient Mesopotamia greatly influenced the mathematics of the Greeks, and through them that of the Western world.

In Babylonian algebra, quadratic equations of the four standard types occur frequently:

$$X + Y = A, \quad XY = B,$$
$$X - Y = A, \quad XY = B,$$
$$X + Y = A, \quad X^2 + Y^2 = B,$$
$$X - Y = A, \quad X^2 + Y^2 = B.$$

They also appear in Euclid's *Elements*: Theorem 5–6 and 9–10 of Book II without reference to their origin, and Neugebauer pointed out that the Greek geometrical solutions of these equations were exactly the same as the Babylonian algebraic solutions; for example, whenever the Babylonians wrote, "Take the square root of A." The Greeks changed it to read, "Take the side of the square of area equal to A."

The great interest the Mesopotamians showed in the solutions of pure mathematical problems – recreational mathematics, which has no practical applications – indicates that they viewed this endeavor as a mental exercise. This kind of mathematical intelligence greatly benefited both the Mesopotamians and the civilizations which followed them.

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Mathematics in Native North America

Michael P. Closs

The mathematical development of the Native American peoples is highly variable among different cultural groups. In this article, I will treat two areas of interest: the wonderful diversity in the formation of number words and the use of tally systems to record information. Other articles in this volume give more explicit details on the mathematics of two particular indigenous groups, the Aztec and the Maya.

Number Words

Often numbers have a digital origin, indicating that counting began, or at least was remembered, by finger counting or by counting on the hands and feet. Here, I look at only a few examples. For a more extensive treatment, see Closs (1986a, b).

The relationship between the method of finger counting used and the creation of number words may be very explicit. The Bacairi of Mato Grosso in Brazil have the number sequence shown below:

1	*tokale*	
2	*ahage*	
3	*ahage tokale*; *ahewao*	2 + 1; 3
4	*ahage ahage*	2 + 2
5	*ahage ahage tokale*	2 + 2 + 1
6	*ahage ahage ahage*	2 + 2 + 2

The second of the number words for 3 is not used more often than the form made up of 2 and 1, nor is it used in the formation of any of the higher number words. The word for 1 comes from the word for bow. It has been suggested that since each man has only one bow but many arrows, the bow came to exemplify 'oneness'. The word for 2 and the word for 'many' derive from the same source. Thus, the two basic terms in the number vocabulary have a non-digital origin. The number sequence is an example of an additive 2-system, i.e. a system in which the terms are formed by using addition (implicitly) and groups of twos.

In finger counting, a Bacairi starts with the little finger of the left hand and says *tokale*, grasps the adjacent finger and joins it with the little finger and says *ahage*, goes to the middle finger and, holding it separately beside the little finger and the ring finger, says *ahage tokale*, goes to the index finger and joining it to the middle finger says *ahage ahage*, grasps the thumb and says *ahage ahage tokale*, places the little finger of the right hand along side it and says *ahage ahage ahage*. He then goes to the remaining fingers of the right hand and touches each finger in turn while saying *mera* 'this one'. He continues by touching the toes of the left and right foot and each time says *mera*. If he is still not finished he grasps his hair and pulls it apart in all directions. The number 6 marks the end of the use of 2-groups in finger counting. Nevertheless, the finger counting still continues on to 20 by a straight one-to-one correspondence without the use of number words.

Number words are not always derived from words associated with counting on the fingers. Frequently, the meaning of even relatively small number words is transparent. In some languages the word for 1 is related to the first person pronoun. Often the word for 2 comes from roots denoting separation or pairs. Moreover, not only large numbers but also small ones may be formed by using arithmetical principles. In the simplest case, this takes the form of doubling but there are instances in which addition, subtraction, multiplication, and division are used. Number words may also be created in more exotic ways (see Table 1).

Larger number words may be formed by using superlatives or other expressions which are indefinite (see Table 2).

There are many number systems developed in the New World that follow unusual principles of grouping. The number sequence of the Coahuiltecan of Texas shown in Table 3 exhibits an extensive use of additive and multiplicative principles early in its development. It is also very unusual in the heavy reliance it places on 3-groups.

The word for 3 is an additive composite of the words for 2 and 1. That pattern, seen in the earlier 2-system, is not continued and new words are introduced for 4 and 5. The number 6 is expressed in two ways, either as a composite of 3 and 2 or by a new word. The next new term introduced is for 20. The number sequence rises from 6 to 20 by a regular use of 3-groups and the use of the arithmetic operations of addition and multiplication. Below 12 the development of the

Mathematics in Native North America. Table 1 Creation of number words

Apache	2	naki	from *ki-e* 'feet'
Micmac	2	tabu	'equal'
Omaha	2	nomba	'hands'
Micmac	3	tchicht	cognate with Delaware *tchicht* 'still more'
Abipones	4	geyenknute	'the ostrich's toes'
Yana	4	daumi	from *dau* 'to count'
Pawnee	5	sihuks	from *ishu* 'hand' and *huks* 'half'
Kutchin	6	neckh-kiethei	from *nackhai* '2' and *kiethei* '3'
(NW) Maidu	6	sai-tsoko	from *sapu* '3' and *tsoko* 'double'
(E) Pomo	7	kula-xotc	from *kula* and *xotc* '2'
(NW) Maidu	7	matsan-pene	from *ma-tsani* '5' and *pene* '2'
Crow	8	nupa-pik	from *upa* '2' and *pirake* '10'
Kansas	8	kiya-tuba	from *kiya* 'again' and *tuba* '4'
(NW) Maidu	8	tsoye-tsoko	from *tsoye* '4' and *tsoko* 'double'
(E) Pomo	8	koka-dol	from *ko* '2' and *dol* '4'
(NW) Maidu	9	tsoye-ni-masoko	'4 with 10' (i.e. 4 towards 10)
(E) Pomo	9	hadagal-com	from *hadagal* '10' and *com* 'less'
Gabrieleño	10	wehes-mahar	from *wehe* '2' and *mahar* '5'
(NW) Maidu	10	ma-tsoko	from *ma* 'hand' and *tsoko* 'double'
(E) Pomo	10	hadagal-com	from *hadagal* '10' and *com* 'full'
Unalit	10	kolin	'upper half of the body'
(E) Pomo	11	hadagal-na-kali	from *hadagal* '10' and *kali* '1'
Cehiga	12	cape-nanba	from *cape* '6' and *nanba* '2'
(E) Pomo	12	hadagal-na-xotc	from *hadagal* '10' and *xotc* '2'
(NW) Maidu	13	sapwi-ni-hiwali	'3 with 15'

Mathematics in Native North America. Table 2 Larger number words

Biloxi	1,000	tsipitcya	'old man hundred'
Choctaw	1,000	tahlepa siponki	'old hundred'
Delaware	1,000	ngutti kittapachki	'great hundred'
Wiyot	1,000	kucerawagaatoril piswak	'the counting runs out entirely once'
Kwakiutl	1,000,000	tlinhi	'number which cannot be counted'
Ojibway	1,000,000	ke-che me-das-wac	'great thousand'

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Mathematics in Native North America. Table 3 The number sequence of the Coahuiltecan of Texas

1	pil	
2	ajte	
3	ajte c pil	2 + 1
4	puguantzan	
5	juyopamáuj	
6	ajti c pil ajte; chicuas	3 × 2
7	puguantzan co ajti c pil	4 + 3
8	puguantzan ajte	4 × 2
9	puguantzan co juyopamauj	4 + 5
10	juyopamauj ajte	5 × 2
11	juyopamauj ajte co pil	(5 × 2) + 1
12	puguantzan ajti c pil	4 × 3
13	puguantzan ajti c pil co pil	4 × 3 + 1
14	puguantzan ajti c pil co ajte	4 × 3 + 2
15	juyopamauj ajti c pil	5 × 3
16	juyopamauj ajti c pil co pil	5 × 3 + 1
17	juyopamauj ajti c pil co ajte	5 × 3 + 2
18	chicuas ajti c pil	6 × 3
19	chicuas ajti c pil co pil	6 × 3 + 1
20	taiguaco	
30	taiguaco co juyopamauj ajte	20 + 10
40	taiguaco ajte	20 × 2
50	taiguaco ajte co juyopamauj ajte	20 × 2 + 10

Mathematics in Native North America. Table 4 The number sequence of the Yuki (Round Valley dialect)

1	pa-wi	
2	op-i	
3	molm-i	
4	o-mahat, op-mahat	'two forks'
5	hui-ko	'middle-in'
6	mikas-tcil-ki	'even-*tcilki*'
7	mikas-ko	'even-in'
8	paum-pat	'one-flat'
9	hutcam-pawi-pan	'beyond-one-hang'
10	hutcam-opi-sul	'beyond-two-body'
11	molmi-sul	'three-body'
12	omahat-sul	'four-body'
13	huiko-sul	'five-body'
14	mikastcilki-sul	'six-body'
15	mikasko-sul	'seven-body'
16	hui-co(t), '8'	'middle-none', '8'
17	pawi-hui-luk, '9'	'one-middle-project', '9'
18	opi-hui-luk, '10'	'two-middle-project', '10'
19	molmi-hui-poi, '11'	'three-middle-project', '11'
20	omahat-hui-poi, '12'	'four-middle-project', '12'
24	'8'	'8'
26	'10'	'10'
35	'19'	'19'
51	'19'	'19'
64	omahat-tc-am-op	'four-pile-at'

number system is not consistent. The Coahuiltecan sequence might be classified as a 2–3–20-system.

The number systems employed within closely related linguistic groups may also exhibit considerable variation. For example, the four Yukian languages of California belong to the same family but have very different number systems. In three of the four, the numbers up to 3 are related. However, from 4 on all the languages employ composite number terms whose meanings are completely different. Moreover, the methods of forming the numerals also differ since one of the four is an 8-system, two others are 5–10-systems, and the fourth is a 5–20-system.

The number sequence of the Round Valley, or Yuki proper, dialect is shown in Table 4, together with an analysis of the numerals.

The Yuki number sequence is inextricably linked to their method of finger counting. Rather than counting the fingers themselves, the Yuki count the spaces between the fingers, in each of which, when the manipulation is possible, two twigs are laid. Except for the words for 1 and 2, common to all the Yukian languages, and the word for 3, common to all but one of the Yukian languages, the number words are descriptive of this method of counting. The number words have no relation to those used in the other related languages. From 9 to 15 the number words are formed by addition to a base of 8. Those from 10 to 15 include the term *sul* 'body', suggesting that 'body' represents the full count of 8 spaces between the fingers.

Many of the terms given for the larger numbers are residue representations as can be seen below:

$$16 = (8) + 8, \quad 24 = (16) + 8,$$

$$17 = (8) + 9, \quad 26 = (16) + 10,$$

$$18 = (8) + 10, \quad 35 = (16) + 19,$$

$$19 = (8) + 11, \quad 51 = (2 \times 16) + 19,$$

$$20 = (8) + 12.$$

The above terms suggest that 16, as well as 8, may be used as a base for constructing the higher numbers. Indeed, the term for 64 is literally '4-pile-at' and 64 would be 4 piles of 16. It has been reported that 64 is also used as a higher unit in the Yuki count. This has been taken as evidence that the Yuki had evolved a pure 8-system. Nevertheless, because of the term for 64, it seems better to classify it as an 8–16-system.

The Yuki number sequence illustrates that one may employ the fingers and hands in counting and not end up with a decimal or vigesimal system. This lesson could also have been drawn from the finger counting of the Bacairi who evolved a 2-system. It can also be seen that the Yuki had precise concepts of number and counting which went far beyond their formal number sequence. The existence of variant terms for the same number and the use of residue expressions for larger numbers attest to this.

The facility with which different indigenous peoples dealt with large numbers also shows considerable variability across the Americas. The Pomo of California have a deserved reputation as great counters. Large counts were commonly performed by them at the times of deaths and peace treaties. An example of such a count is related in a Pomo tale about the first bear shaman who gave 40,000 beads in pretended sympathy for the victim whose death he had caused. One investigator reports that his informant has observed counting in excess of 20,000.

Although the Pomo were able to express numbers reaching into the tens of thousands, the published lists of Dixon and Kroeber contain numbers which do not exceed 200. From these lists, I present the number sequence of the Eastern Pomo which is shown in Table 5. The second last column gives a simple analysis of the number words while the last column gives a second-order arithmetical analysis so as to exhibit the structure of the numerals more simply.

It can be seen from the above number list that the Eastern Pomo employed a 5–(10)–20-system. The term '1-stick' is used to represent 20. The phenomenon of overcounting (i.e. referring a count upwards to the next higher level) is also employed. For example, 50 is expressed as 10 towards 60, and 70 is expressed as 10 towards 80. Fortunately, the absence of higher numbers in the list has been remedied by Edwin Loeb. He provides the sequence for large counts among the Eastern Pomo in Table 6.

The Pomo number words are closely connected with the method of counting. For example, in counting small amounts, the word for 20 is *xai-di-lema-tek*, 'full stick', and when that number is reached a stick is laid out for this primary unit. When 20 such sticks were accumulated they formed a larger unit of 400 that also was represented by a stick.

There is evidence that 1-stick represents counts of 20, 40, 80, or 100 in different Pomo number sequences. This simply indicates that variant grouping practices prevailed in different Pomo areas at different times. Using different sizes of groups to represent 1-stick would yield different number sequences even though

Mathematics in Native North America. Table 5 The number sequence of the Eastern Pomo

1	kali		
2	xotc		
3	xomka		
4	dol		
5	lema		
6	tsadi	1-di	(5) + 1
7	kula-xotc	kula-2	(5) + 2
8	koka-dol	2-ka-4	2 × 4
9	hadagal-com	10-less	10 − (1)
10	hadagal-tek	10-full	10
11	hadagal-na-kali	10 + 1	10 + 1
12	hadagal-na-xotc	10 + 2	10 + 2
13	hadagal-na-xomka	10 + 3	10 + 3
14	xomka-mar-com	3-mar-less	(3 × 5) − (1)
15	xomka-mar-tek	3-mar-full	(3 × 5)
16	xomka-mar-na-kali	3-mar + 1	(3 × 5) + 1
17	xomka-mar-na-xotc	3-mar + 2	(3 × 5) + 2
18	xomka-mar-na-xomka	3-mar + 3	(3 × 5) +3
19	xai-di-lema-com	stick-di-5-less	20 − (1)
20	xai-di-lema-tek	stick-di-5-full	20
21	xai-di-lema-na-kali	stick-di-5 + 1	20 + 1
30	na-hadagal	na-10	(20) + 10
40	xotsa-xai	2 sticks	2 × 20
50	hadagal-e-xomka-xai	10-e-3-sticks	10 towards (3 × 20)
60	xomka-xai	3 sticks	3 × 20
70	hadagal-ai-dola-xai	10-ai-4-sticks	10 towards (4 × 20)
80	dol-a-xai	4 sticks	4 × 20
90	hadagal-ai-lema-xai	10-ai-5-sticks	10 towards (5 × 20)
100	lema-xai	5 sticks	5 × 20
200	hadagal-a-xai	10 sticks	10 × 20

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Mathematics in Native North America. Table 6 The number sequence of the Eastern Pomo for large counts

80	dol-a-xai	4 sticks	4 × 20
100	lema-xai	5 sticks	5 × 20
200	hadagal-a-xai	10 sticks	10 × 20
300	xomka-mar-a-xai	15 sticks	15 × 20
400	kali-xai	1 (big) stick	400
500	kali-xai-wina-lema-xai	1 (big) stick + 5 sticks	400 + (5 × 20)
800	xote-guma-wal	2 (big sticks)	2 × 400
2,400	tsadi	6 (big sticks)	6 × 400
3,600	hadagal-com	9 (big sticks)	9 × 400
4,000	hadagal	10 (big sticks)	10 × 400

the same techniques of stick counting were applied. There is evidence for distinct Pomo systems which may be classified as 5–20–400, 5–40–400, (5)–80–400, and (10)–100–400.

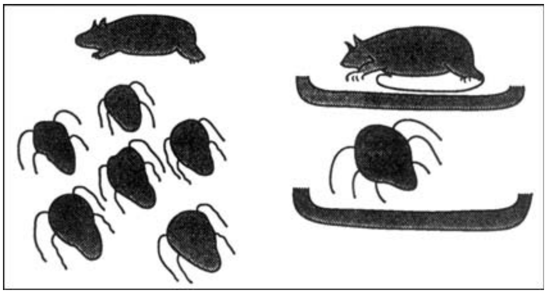
Tally Records

A tally is a simple method of representing the cardinal number of a group of objects by making a one-to-one correspondence between the objects being counted and special marks made by a counter. Today, many tallies are made by using automated counted devices. However, throughout history, tallies were made by more personalized methods such as marking vertical strokes on a flat surface, cutting notches on a stick, tying knots on a string, or placing pebbles in a bowl. It is the most ancient form of record keeping used by humans.

Biographical and chronological records formed of strings with simple knots tied in them existed among the interior Salish and neighbouring tribes of southern British Columbia and the region about Yakima, Washington. More sophisticated knotted string records, *quipus*, were used by the Inca.

For this discussion, I consider three types of tally records employed by the Ojibway:

1. The pictograph in Fig. 1 was transcribed from the sides of a blazed pine tree found on the banks of a tributary of the Upper Mississippi in 1831. On the upper right is the totem of an Ojibway hunter who had encamped at that spot. It represents a fabulous animal called the *copper-tailed bear*. The two parallel lines beneath it, curved at each end, represent the hunter's canoe. The next sign, on the same side, below, is the totem of his companion, the cat-fish, and below that a representation of his canoe. The upper figure on the left represents the common black bear, the six figures below it denote six fish of the cat-fish species. The interpretation is this: the two hunters, whose totems were cat-fish and copper-tailed bear, while encamped at the spot, killed a bear, and captured six cat-fish in the river.

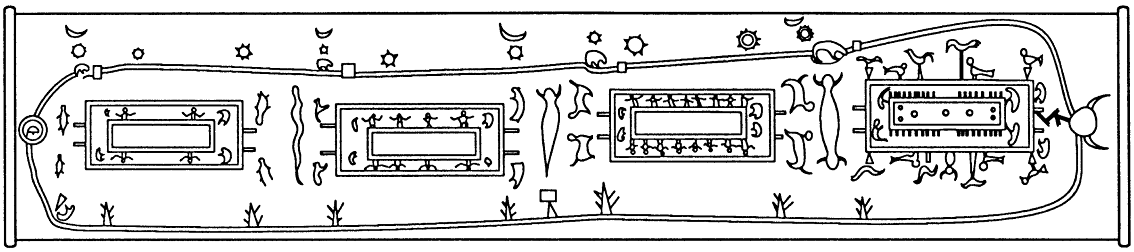


Mathematics in Native North America. Fig. 1 An Ojibway pictographic record (drawing by M. P. Closs from Schoolcraft 1851).

The record was designed to convey this piece of information to any of their people who should pass the locality.

2. Tally records were also carved on Ojibway grave posts. Babesakundiba, or Man with Curled Hair, was the ruling chief of the Sandy Lake band of the Ojibway on the Upper Mississippi. He died in the late 1840s, after a long life of usefulness and honour, and was buried on a prominent elevation, on the east bank of the river, where his grave and an ensign which waved over it were visible to all who navigated the stream. A drawing of his inscribed grave post is shown in Fig. 2.

The upside down bird denotes his family name, or clan, the crane. Four transverse lines above it signify that he had killed four of his enemies in battle. This fact was declared by the funeral orator at the time of the deceased's interment. At the same time, the orator dedicated the ghosts of the four men, whom the departed had killed in battle, and presented them to the dead chief, to accompany him to the land of the spirits. The four lines to the right and also the four corresponding lines to the left of the central marks denote eight eagle feathers and are commemorative of his bravery. Eight marks made across the edge of the inscription board signify that he had been a member of eight war parties. The nine other transverse marks



Mathematics in Native North America. Fig. 2 The grave post of Babesakundiba (drawing by M. P. Closs from Schoolcraft 1851).

below the sign of the crane signify that the orator who officiated at the funeral and drew the inscription had himself participated in nine war parties.

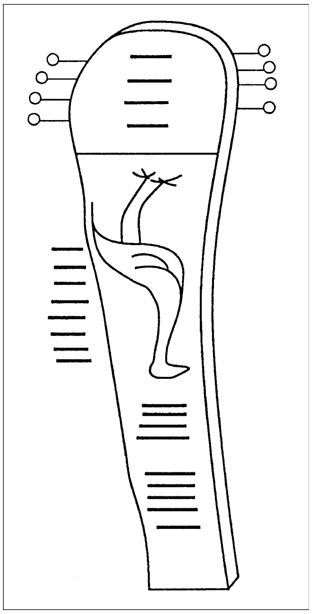
3. The Midéwewin was a set of ceremonials conducted by an organized group of men and women among the Ojibway people who had occult knowledge of ‘killing’ and ‘curing’ by the use of herbs, missiles, medicine bundles, and other objects which possessed medicinal properties. The records and teaching of the Midéwewin were inscribed on birchbark scrolls. These form a body of pictographic material in which one can find various tallies and graphic notations exhibiting a ritual use of number among the Ojibway.

The scroll depicted in Fig. 3 was used for instruction in the lore and rites of the Midéwewin. It is characterized by four rectangular floor plans corresponding to four lodges (and degrees of initiation) which a candidate had to pass through before achieving the status of a Midé master.

The inner rectangle in each lodge represents the path that is followed when processions are made around the interior of the lodge. There are four bear *manitos* (archetypal spirits) in each lodge, two guarding each entrance. In addition, there are 4 officials shown in the first lodge, 8 in the second, 16 in the third, and 36 in the fourth.

Lurking between the lodges are evil manitos that block the entrances. The first three lodges are each blocked by four manitos, two near each entrance. The fourth lodge is uniquely surrounded by 12 bird-like figures, possibly sky manitos, with an additional horned figure and two bear figures. These seem to be beneficent entities.

The network of lodges is bordered by the Ojibway universe. It begins with a small circle containing Bear and terminates with the horned symbol of Everlasting Life. Along the upper border, close to the upper left-hand corner of each lodge, is a figure of Bear seated before his sacred drum. Outside of this border are lunar and solar symbols. Along the lower border is a sequence of trees which represents a forest.



Mathematics in Native North America. Fig. 3 The Midé master scroll kp-1 (drawing by M. P. Closs from Dewdney 1975).

The scroll emphasizes the number 4, sacred to the Ojibway, in many ways. It is the number of lodges, the number of bears in each lodge, the number of evil manitos adjacent to the entrance of the first three lodges, the number of bear and drum figures on the boundary, and the number of lunar signs. Also, the 12 bird manitos about the fourth lodge and the series of officials in the sequence 4, 8, 16, and 36 are based on multiples of 4.

See also: ►*Quipu*

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Mathematics in Oceania

Nicholas J. Goetzfridt

The historical and contemporary practice of mathematical concepts in Oceania and their intentional and unintentional expression in various fields of written literatures negates, from the start, the possibility of pinning down their elements entirely. This is to be expected since a bibliographic tour is not only limited to what writers have thought relevant or important enough to mention since the start of anthropological inquiries into Pacific societies. It is also limited to depictions of real life, culture, and society in written words. But the available representation of these concepts throughout the past several decades nevertheless allows one to grasp ethnomathematical essences in their indigenous contexts – such as the application of knotted plants or leaves for mnemonic purposes or for the determination of one's fate using a system of 256 possible results originating from the sky god *Supwunumen* who bore the destiny faces of *pwee* before allowing them to emerge into 16 human forms. They then descended in a heavenly constructed canoe to teach the art of knot divination to a few select men in the Caroline Islands. The two major schools of the art of the *pweewunus* were distinguished by whether one conceived of the celestial canoe as having been a sailing canoe or a paddling canoe (Goodenough 2002).

Knots for memorization or recall take several forms throughout the Pacific, although none of the forms serves as a society's definitive method of memorization. They instead reflect environmental needs and practices, such as the tying and untying of knots to mark the passage of days before a particular event in Papua New Guinea (Blackwood 1935) or, in "former times," the tying and untying of knots on various types of leaves and strands for deaths and the successful revenge for each death among the Parevavo people of Papua New Guinea (Hallpike 1979 and Wolfers 1971). In 1832, Typerman and Bennett described the practice of a Hawaiian "tax-gatherer" in the district of Waerua who kept "very exact accounts" of each inhabitant's tax debt on a line of cordage of four to five hundred fathoms in length and which were individually distinguished with "knots, loops, tufts, of different shapes, sizes, and colors" (p.71). While knotted cords were used in the Marquesas Islands to measure time, record genealogies, and as mnemonics for the singing of religious songs (Barthel 1971), one women in Papua New Guinea kept track of the number of times her husband beat her by tying knots in a leaf cord and eventually presented it to authorities as concrete proof of his treatment of her (Hallpike 1979).

Of course people count objects using base systems, terms, objects, and even themselves (most extensively practiced in Papua New Guinea) for transaction and gifting practices (each society having particularly prominent objects to enumerate – pigs and yams, for example, in Papua New Guinea), for the distribution of food and objects in accordance with statuses or roles, and for the counting of material objects and people for other reasons. Objects themselves can take on quantifying terminology separate or derived from words that form base systems unique to societies as well as those acculturated through time from neighboring villages and islands. Among Elsdon Best's condescending though detailed work on Maori society in the 1920s is a reference to a system used by the Maori people in the Waikato district for counting eels (Best 1921) (44 eels forming the smallest unit for tallying large numbers of eels (Best 1929)), and the encapsulating of four birds in a single brace or *pu* (Best 1924). Koch (1983) notes terms used in Tuvalu for bundles of 10 coconuts (*fui*) and a larger bundle ranging from 10 to 70 coconuts (*fikau*) while MacGregor (1937) cites use of terms for units of ten recently harvested coconuts in counting coconuts to 1000. Fox (1931) observed that among the Arosi people, Solomon Islands, counting was sometimes done "by ones, sometimes by pairs, sometimes by fours, sometimes by fives; the pair, or four or five being reckoned as a unit and given a distinct name" with numerous object centered variations and terms existent for yams, coconuts, banana-shoots for planting, pigs, dogs, fish, breadfruit, dogs' teeth, and shell currency.

These distinctions evolved in the context of counting systems and their bases that, as Lean (1991) demonstrated primarily in Papua New Guinea, extend from a vast array of counting systems in numerous languages. Lean classified these systems into several distinct types with a particular emphasis on a number system's expression of its "frame pattern" and "cyclic pattern" although others before and after Lean used other organizational standards. (See for example Berndt 1954, Joseph 2000, Philip and Kelly 1977, and Laycock 1975.) Descriptions (sometimes with illustrations) of body-part counting systems of indigenous peoples of Papua New Guinea, based on the extent of numbers before an extension beyond that number is employed, sometimes note a reversal in counting direction (characterized further by descending or ascending directions) or the use of another body in this relatively unorganized literature.

These descriptions appear to be characterizing these societies in an ethnomathematical context, as does a perhaps peculiar concern with indigenous Pacific peoples' abilities to count to large quantities and with their concepts of infinity. Although Clark maintained in 1839 that Hawaiians "seldom had occasion for any complex combination of numbers" (a perception usually tossed at atoll inhabitants in Micronesia as well), he still intermittently listed Hawaiian words for 4 (considered to be "the lowest class or collection of numbers") to 400,000 as well as a word for four million. He maintains however that this number "is not often brought into practice as their minds become confused with so great a number as is implied by the meaning of the word [*nalowale*]. A great but indefinite number is expressed by the repetition of the word *kini*, or *lehu*, as *kinikini*, *lehulehu*." Other, at least partial, depictions of the numerical extent of counting systems usually have indigenous counters falling off at a certain numbers (the highest numbers usually thought to be employed infrequently) and into a shout of the greatness of quantities that are like sands of the beach, stars in the sky, etc. (See for example Beaglehole and Beaglehole 1938, Elbert and Pukui 1979, Taylor 1957, Kaleva 1995, Seidenberg 1962). The Beagleholes (1938: 354) maintained in their study of the ethnology of Pukapuka that it was "a little hard to see the function of high numerical concepts in an atoll culture" although such large numbers "indicate not so much a definite number as a progression of increased greatness that is more sensed or felt than definitely apprehended." Drawing from his own experiences in learning mathematics in Papua New Guinea schools and his knowledge of the Wisai language from the Buin district of Bougainville, Kaleva (1995) also notes that while the word for a chicken represents 1000, and for 2 chickens 2000, and so on, there comes a point at which this numerical progression ceases and people say that "the chicken went into the bush and never came back" (Beaglehole 1938: 144) – a phrase Kaleva also identifies as an expression of infinity.

Numerical, spatial, and linear elements common to the western assigned cultural boundaries of Melanesia, Polynesia, and Micronesia vary in accordance with both the demands and the nurturing characteristics of the distinctive environments and social and cultural histories embodied in these boundaries. Arguing that the counting systems and their bases have developed and changed from indigenous environments and not from some Babylonian or other Western source (as Pospisil and Price (1966) suggested but which Bowers (1977) strongly rejected), Lean's extensive study of these systems throughout Papua New Guinea and into the Pacific islands demonstrates the depth to which functionality in an environment characterizes the individual elements of ethnomathematical concepts and practices in these three vast regions of the Pacific. While the existent literature (scattered with unintended and sometimes unindexed mathematical references) might enable one to identify Melanesia with the presence of counting systems, linguistic structures and principles of terminology, measurement, agricultural and lunar based calendars, and methods of conveying currency values for exchange (buoyed in particular by studies done in Papua New Guinea), ethnomathematical practices in the far flung atolls of Micronesia are much more distant and spatial in nature. Most aspects of counting, measuring, astronomical methods of determining time and creating the calendar, the intentional expression of geometric forms, determination of distance and numerous other elements of ethnomathematical practices span across Oceania. But each of these three Pacific regions originally created by European cartographers has its own physical circumstances and historical connectedness to make, for example, Papua New Guinea the central area for expanded enumeration concepts but Polynesia (and particularly Hawai'i and Easter Island) for past practices of aligning stone structures with stars to mark the occurrence of the equinox and solstice. Meanwhile in Micronesia, linear concepts in voyage dead reckoning, using what is often considered to be a dividing of a voyage into segments via linear associations of stars with an out-of-sight reference island en route through the *etak* concept, are generally lacking in Polynesia. While this *etak* concept is absent in Papua New Guinea (where some interesting topographical associations with ancestors and directions are reminiscent of Australian Aboriginal practices), it is also absent in island Melanesia.

Here we are again dealing also with the limitations not only of what has been of interest to writers – and particularly the earliest writers in the case of Polynesia – but what was accessible to them. Perhaps Captain Winker's tenacious but sidetracked attempts (1901) to comprehend the then secret essences of Marshallese stick charts and their use for interpreting swells refracted by atolls is somewhat demonstrative of this now incurable problem. Centuries of interaction between Papua New Guinea tribal peoples and the centrality of exchanges and gift protocols, the impacts of indigenous diffusion where it occurred, as well as the contemporary acculturation of contact with Europeans has its passages and forms in the many enumeration systems Lean examined. Enumeration descriptions occur elsewhere in this literature but not anywhere to the degree that it has in regards to Papua New Guinea. There are nevertheless a few examples available for Micronesia. Alkire (1970), for example, describes how Woleai's enumeration bases of four and eight not only reflect dualism in Woleai (central Caroline Islands) concepts of enumeration but also emphasizes their importance in the knot diviner's interpretation of 256 knot combinations (ultimate destinies) formed by knots representing those 16 traditional divination spirits whose two pairs of leaflet knot quantities do not each exceed four. In a somewhat sensationalized note, Ballinger (1978) discusses the recording by the 1908 Thilenius South Seas Expedition of a "mysterious" counting system on the atoll of Faraulep in the central Caroline Islands with its "regular, stepped, series of 'characters'" representing numbers from 100,000 to 60,000,000 (again noted as being unpractical for an atoll environment) and symbols being used with no apparent derivations from other Pacific islands. And while noting that the "ethnonavigators" of the Caroline Islands, in contrast to Western navigational practices, employ rigid spatial concepts that close off the potential for new information to be introduced into this nongeometrical or nonalgebraic system, Freedman (1980) still pointed out the Pukapuka system of numerals running from 1 to 12 and extending by 100s to 2,000 along with its quantitative class names for the counting of specific objects.

The presence of Polynesian enumeration in the literature (comparably marginal when referenced against the literature on enumeration in Papua New Guinea) in Polynesia either reflects a lack of attention by European writers, the long and early impact of European acculturation on enumeration systems, or both. We have Conant's 1893 survey of "primitive number systems" (including Polynesia) whose origins of numbers among "the savage languages of the human race" are unknowable as well as Thomas' attempt to link the Marquesas Islands to India via Malaysia through the presence of vigesimal systems of enumeration.

Even so, mathematical characteristics in each of these three giant regions of Oceania were and are expressible on the basis of the environments that have prompted and sustained them. It is clear, for example, that the large ocean areas separating small atolls and higher level islands, the relatively recent scholarly interest paid to the prehistoric exploration and settlement of the Pacific, and the remaining availability of indigenous, noninstrumental navigational techniques on the Caroline atolls of Polowat and Satawal in a larger context of the importance of such exploration and techniques to contemporary Pacific cultures, all make distance and linear associations prominent in Micronesian ethnomathematics. These distances are inherently linear in a forward moving fashion. A universal kind of fascination with the capacity of indigenous navigators to maintain and essentially harness distance in movements from one point to another is energized by both scholarship and cultural pride. The concept of *etak* as a technique for segmenting these voyages into manageable parts (as well as at least one alternative explanation that dismisses this segmentation (Hutchins 1983) and the expression and explanation of wave refraction and interpretation in the linear expressions of the Marshallese stick charts remain prominent parts to this literature on Micronesian mathematical ideas and practices.

On the other hand, spiritual, material, and societal needs have also encouraged recognition and study of land-based uses of mathematical concepts. The knot divination practices passed on by the sky-god *Supwunumen* to determine the outcomes of certain events and the 256 possible fates of people for days and years to come probably registers as the most unique mathematical element in Micronesia. However, measurement concepts that may employ a small variation of lengths by the use of the same body part but from different bodies for canoe and house construction, axis concepts, calendar development (primarily lunar and somewhat stellar referenced in Polynesia and Micronesia but more agriculturally based in Melanesia), circular displays and conceptualizations, cosmology, and geometric concepts and applications are generally found in the written literature on all of Oceania although each region has its distinctive marks. Late nineteenth and early to lower-mid twentieth century literature on Hawaiian cosmology and lunar calculations of the days and thus the months are, for example, coated with Hawaiian genesis traditions of the cosmos and the role of the Pleiades and the moon. Chauvin (2000: 116) notes that, "the Hawaiian names for the thirty nights of the moon indicate an ancient ability to make accurate naked-eye observations of lunar phases and then to record those observations in descriptive appellations. Thus the first appearance of the waxing crescent moon in the west marking the first night of the month was called Hilo – meaning 'twisted' or 'threadlike,' as a braid."

There is very little mention of base properties in Micronesia (as compared to their propensity in writings on Papua New Guinea enumeration systems), little or no recognition of any body part counting practices, no references to archaeoastronomy research (in comparison to those available for Easter Island, Hawai'i, and, to a lesser extent, Tonga), very little concern with any mathematical elements of debt calculation and payment or base properties (again, in comparison to a much stronger presence in the literature on Papua New Guinea), and no mathematical elements of birth order names. However, the presence of horizontal concepts and their role in dealing with ocean distances are far more present in the literatures on Polynesia and Micronesia than for Melanesia and specifically Papua New Guinea. Horizontal lines on the tattoos of an elder Marshallese man in Barclay's novel (2002) on the Marshall Islands have numerous horizontal elements which themselves are intended to reflect their conceptual presence at sea. The earth's horizon itself often figures prominently not only in relation to stellar references to cardinal points (see Brower (1983), Finney (1998), and Babayan (1987) for examples) but it also has a crucial role in traditional Hawaiian and Chuukese conceptualizations of a series of domed heavens. (See Chauvin 2000 also for their Hawaiian expression in a gourd.) Chuukese conceptualizations of these layered heavens involved paths for the dead where the "Singing Place" (*Neechiichi*) level or path tended to turn these voyaging souls toward irresponsible dance and song, thus distracting them from their final abode. Riesenberg (1972) focuses on the centrality of metaphor in several categories of mnemonic navigational knowledge on Polowat and the expression of relationships between real and mythical geographic elements and star courses. Riesenberg also examines the importance of the horizon in stellar courses that are thought of in terms of navigators pursuing a reef fish from one island to another with their associated stellar alignments. The Breadfruit Picker (*fééyah*) category of courses, Riesenberg notes, "are not necessarily on a straight line under the star named in the directions but include one star to each side of it, thus covering a sector of the horizon three stars wide" (Riesenberg 1972: 24).

The ethnographic and anthropological literatures of Melanesia, Polynesia, and Micronesia all have seemingly inevitable references to the triangular or rectangular or square joining of cross beams, weaving threads, planks, and canoe pieces that emerge from practical applications but which would not only be difficult to isolate entirely (and what would be the point?) but would probably also be difficult to align with conscious ethnomathematical concepts. The appearance of squares, circles, and triangles in the numerous available descriptions of string figure practices in the Pacific are likewise natural consequences of string designs with a few exceptions of figures named after geometric shapes and the direct intent to convey these figures in the end result of the dexterity of string and fingers. One might point to these natural consequences of material needs as being indicative of the ultimate weakness with which bibliographic overviews of subjects are not only guided by the literature that is actually available but more importantly, by the human dynamics of history that will always defy anything resembling a complete inventory.

Thus environmental factors and geographic realities (linear spaces associated with stellar concepts in Micronesia, enumeration systems for social traditions of exchange and possession in Papua New Guinea) serve to define and stress the kinds of mathematical concepts employed in different Pacific societies. The piecemeal fashion with which these concepts have been identified and extended in both scholarly and contextual terms actually underlines the intricate place of ethnomathematical practices in individual cultures. Their emergence comes and came over the past several decades through their sometimes chance recognition in other ethnographical terms, the scholarly concerns that happen to be prevalent for given societies, and of course the extent to which access was allowed to outside observers. At times it was the particular practice wrapped up in ethnomathematical principles that was the primary reason for an ethnographic focus – such as Bernard A. Deacon's detailed descriptions (1934) of the geometrical sand drawings from Malekula (Vanuatu) and most notably that which the *Temes Savsap* ghost half erased and expected the dead souls traveling to the afterlife to reconstruct before passing on or face being devoured – for a particular society. The same was true for selected other works on mathematical principles. Price and Pospisil's theory (1966) of a Babylonian influence on enumeration structures among the Kapauku people in Papua New Guinea was strongly rejected by Bowers (1977) while conjectures by Ross (1936) and Heyerdahl (1961) that an apparent presence of two distinct counting systems on Easter Island at the time of early European contact was indicative of outside, non-Polynesian influences were challenged by Métraux (1936). Works on Papua New Guinea enumeration systems sometimes draw from previous works while scholarship on the challenges Papua New Guinea students face in successfully comprehending and using Western enumeration and mathematical principles – particularly in the acknowledged context of their social and environmental origins – represent the pocket of literature on the presence of Pacific ethnomathematical principles that is most responsive to the works of others.

While arguing that a predominant belief in Western worlds of the universality of mathematical principles underlines the ongoing use of these principles "as one of the most powerful weapons in the imposition of western culture," Bishop (1990: 60) also recognizes the nebulousness of the term "ethnomathematics" itself. Perhaps, he suggests, "it would be better not to use that term but rather to be more precise about which, and whose, mathematics one is referring to in any context." This issue of the foremost inclusion of contextual realities stresses the "humanly constructed" nature of mathematics – a nature that Bishop maintained can be imperialistically manipulated as reflected for example in the fact that the 180° sum of the angles of a "perfect triangle" was predetermined by a dominant western epistemology. In extending linear and horizontal concepts to a Micronesian concept such as *etak*, to the practice of backsighting against prominent points of an island as it sinks below the horizon, and even to the "linear series" of ancestral and contemporary movements that embody a "lineal segmentation" from a point of unity (Rumsey 2001), one speaks directly to the representation of cultural ideas and realities subverted by the idea of there being a universal and culturally free field of mathematics to which all can refer. The interpretations of mathematically related ideas throughout the Pacific and the anthropological and other literatures that have attempted by happenstance or intent to express them have always prompted the possibilities and appropriateness of this extension. The legitimacy that they are afforded speak not only to Bishop's concerns but to the relevancy of practices that in many cases have become more "past" through colonial hegemony as well as an acculturation that was once more indigenous in nature but of course finds its niche in the far reaching influences of western society.

This is where, however, the depiction of "real life" in specific societal and cultural dynamics resides when lineal and spatial manifestations from that life are acknowledged in their own right. In Rumsey's examination of "topographic objectification" in a landscape of totemic references in the Morehead River area of Papua New Guinea and among the Iatmul people of Sepik, the concept of spatial unity derived from ancestral tracks that emanated from a featureless pit at the beginning of the world and from which ancestral movements in space and associated phenomena designated clan properties, features linear and spatial ideas and actions of both practical and spiritual value. The difference between this kind of ancestral tracking and that of Australian aboriginal peoples is the greater abstraction of actual places from the empowering force of their names in Morehead River cosmology than is true of Aboriginal approaches to such inscriptions. However, admitting these ideas of spatial unity and ancestral tracks and property segmentation into ethnomathematical levels of describing societies bodes well for their relevance in the intricate nature that mathematical ideas in a society play in understanding social structures, values, and perceptions. Perhaps we can be reminded here of Bishop's suggestion that even a universal term such as "ethnomathematics" for indigenous contexts may not serve the Sepik and Morehead River areas (or those of Maekula or perhaps of any other area discussed above) very well. Environmentally based concepts of lines, distances, division and segmentation, topographical and oceanic references (both practical and mythical), enumeration by systems of indigenous diffusion and acculturation (and now those of an influential western world), perceptions of space and measurement, and any number of mathematical principles that have emerged from various literatures on the Pacific clearly underline the centrality of these cultural contexts.

See also: ►Quipu

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Mathematics in Vietnam

Alexei Volkov

Traditional Vietnamese mathematics has never been studied systematically. Rare mentions of Vietnamese mathematical works are either written by nonspecialists or based on second-hand information. No systematic efforts were made by modern researchers to locate, publish, or study the corpus of extant Vietnamese documents concerning mathematics. General works by colonial French scholars, such as the book by Huard and Durand (1954: 120, 144) or the paper by the modern Vietnamese author Tạ (1979) contain only scarce and sometimes unreliable information on the traditional Vietnamese mathematics (Volkov 2002: 375). Similarly, no more than a short paragraph was devoted to the topic in the recent book *A history of Chinese mathematics* by Martzloff (1997: 110).

The first attempt to study the extant materials on Vietnamese mathematics was made by the Chinese mathematician and historian of science, Zhang Yong 章用 (1911–1939). In 1938 Zhang Yong visited Hanoi and explored the collection of books of the French

School of the Far East (École française d'Extrême-orient) (Li 1954). In 1939, soon after his travel Zhang Yong passed away and his findings were not published. Only recently Han Qi provided a brief introduction to the extant Vietnamese astronomical and mathematical texts written mainly on the basis of his study of the partial copies of Vietnamese treatises made by Zhang Yong in Vietnam and preserved in Beijing (Han 1991). Recently the author of these lines published several papers (Volkov 2002, 2004, 2005, 2006) on the basis of his preliminary investigation of the original mathematical treatises preserved in Vietnam and in France.

Vietnamese Mathematics: An Outline

Vietnam gained independence from China in the tenth century AD; the country was united and proclaimed an Empire in 968. At that time the Vietnamese state took shape based upon the blueprint of its Chinese counterpart, and a State University (*Quoc tu giam* 國子監, Chinese *Guozi jian*, literally Directorate of Education for Sons of the State), an equivalent of the Chinese University of the Tang dynasty, was established early in the eleventh century. There are records about the metropolitan examinations in "counting" (*suan*, Viet. *toán* 算) that took place in 1077, 1179, 1261, 1363, 1404, 1437, 1472, 1505, 1698, 1711, 1725, 1732, 1747, 1762, 1767, and 1777. In a record of 1762 the mathematics examinations were ordered to be held every 15 years.

The official mathematics examinations were suspended in China by the end of the Tang dynasty (618–907) and reintroduced during the Song dynasty (960–1279). The mathematical textbooks were reedited and block-printed in 1084; the examinations were held in 1104, 1106, 1109, and 1113 (Hucker 1985; Martzloff 1997: 82). It may be therefore assumed that in the eleventh century the Vietnamese mathematics education and examination system functioned following the Chinese tradition of the late first millennium AD. However, the oldest mathematical textbooks supposedly used in Vietnam were lost, most likely, prior to the mid-fifteenth century. One of the possible reasons for the loss was the massive destruction of books during the war with Champa (1371) and during the Chinese occupation in the early fifteenth century (Tran 1938: 43–45; Cadière and Pelliot 1904: 619, n. 3). In 1460–1497 two successive orders of the newly established Lê 黎 dynasty prescribed to look for ancient books all over the country and to deliver them to the court, yet there is no available information concerning any mathematical or astronomical books found during these campaigns. The state of mathematics and mathematics education in Vietnam of the eleventh to fifteenth centuries thus cannot be reconstructed, at least on the basis of the available sources.

The state mathematicians and astronomers in the seventeenth century Vietnam are mentioned in the records of the Jesuit scholars, Christoforo Borri (1583–1632), Julien (Giuliano) Baldinotti (1591–1631), and Alexandre de Rhodes (1591–1660). In his book *Relation on the New Mission of the Fathers of the Company of Jesus to the Kingdom of Cochinchina* published in 1631, Borri describes in great detail his predictions of the lunar and solar eclipses on December 9, 1620 and on May 22, 1621 he used to convert Vietnamese functionaries (Borri 1631: 178–190, 1931: 372–381).[1] Borri mentions that the court astronomers of the Nguyen Lords (who at that time reigned over the Central part of the present day Vietnam) were usually calculating eclipses with the accuracy of 2–3 h (Borri 1931: 378). In his book Baldinotti mentions the discussions he had with the "King of Tonkin" (i.e., Northern Vietnam) about "the Sphere" (Baldinotti 1629: 196); most likely, he refers to the treatise *Tianwen lüe* 天問略 (Brief account on the Questions concerning the Heaven), a compendium of Ptolemaic astronomical theories compiled by Manuel Dias in 1614 (Dudink 2001: 201). In turn, A. de Rhodes visited Northern and Central Vietnam in 1624–1640 and mentioned in his book the numerous discussions of astronomical topics he had with local astronomers and geomancers (whom he indiscriminately calls "mathematicians") as well as with the rulers of the both parts of Vietnam (de Rhodes 1854: 111–113, 185). All three accounts suggest that by the early seventeenth century Vietnamese mathematical astronomers and high-rank officials were capable of conducting sophisticated astronomical calculations and were aware of contemporaneous Chinese (and, therefore, European) astronomical theories.

It appears that the state mathematics education survived in Vietnam at least until the early nineteenth century. The reign of the Emperor Minh Mệnh (Minh Mạng) 明命 (Nguyễn Phúc Đảm 1791–1841) was the time when traditional Chinese scholarship of the Ming dynasty (i.e., prior to the Manchu invasion and the rule of the Qing dynasty, 1644–1911) was highly appreciated, and even though the European mathematics and astronomy, as suggested above, may have been known to Vietnamese court astronomers beginning from the early seventeenth century, the Vietnamese treatises of the nineteenth century and even early twentieth century still looked similar to Chinese texts prior to the early seventeenth century (see below).

The list of the Chinese books on mathematics and mathematical astronomy preserved in the imperial library in Hue in the nineteenth century reconstructed

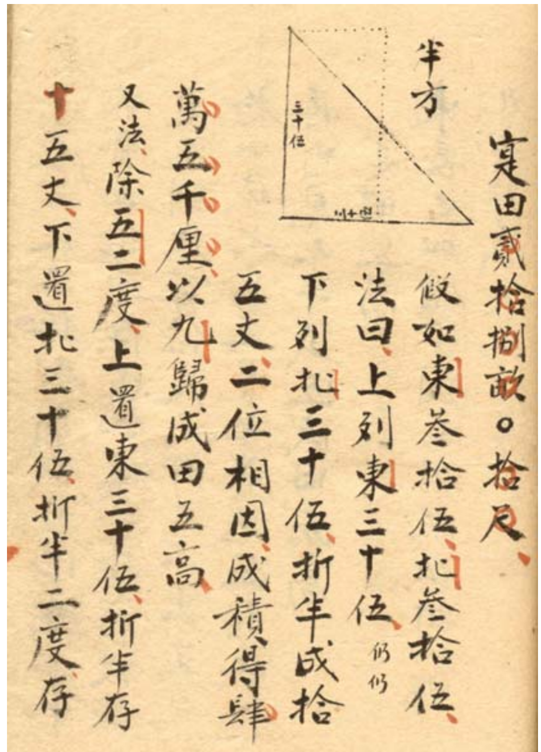
[1] It is possible that the way in which Borri used his astronomical expertise to convert the Vietnamese functionaries was known to the Jesuit Ferdinand Verbiest whose prediction of a solar eclipse in 1669 played a crucial role in the history of the Jesuit mission in China.

on the basis of the extant catalogs includes 59 titles. The list shows that the collection of mathematical books in the library (presumably accessible to the officers of the Astrological Bureau) contained mainly pre-Qing and early Qing mathematical treatises not influenced by European mathematics. It remains unknown whether this was the result of a deliberate choice of the authorities made in attempt to restore classical Chinese scholarly tradition.

The Extant Vietnamese Mathematical Treatises: A General Outline

The number of extant treatises representing Vietnamese mathematical tradition amounts to 19, yet only seven of them (nos. 1–7 below) can be dated. Their list reads as follows:

1. *Toán pháp đại thành* 算法大成 (Great Compendium of Mathematical Methods). By Lương Thế Vinh. Location: The Institute of Han-Nom Studies, Hanoi.
2. *Cửu chương lập thành toán pháp* 九章立成算法 (Ready-made Computational Methods of Nine Categories). By Phạm Hữu Chung 范有鍾, 1713. Location: The Institute of Han-Nom Studies, Hanoi; Paris, Bibliothèque Nationale de France; The National Library of Vietnam, Hanoi.
3. *Chỉ minh lập thành toán pháp* 指明立成算法 (Guide for understanding of the Ready-made Calculational Methods). By Phan Huy Khuông 潘輝框, 1820. Location: The Institute of Han-Nom Studies, Hanoi, Vietnam; The Institute of Information on Social Sciences,[2] Hanoi; Ecole française d'extrême-orient, Paris (microfilm).
4. *Ý Trai toán pháp nhất đắc lục* 意齋算法一得錄 (A Received Copy of the Computational Methods of Ý Trai). By Nguyễn Hữu Thận 阮有慎 [=Nguyễn Ý Trai], 1829. Location: The Institute of Han-Nom Studies, Hanoi.
5. *Cửu chương toán pháp* 九章算法 (Computational methods of Nine Categories); another title: *Cửu chương toán pháp lập thành* 立成 (Ready-made Computational methods of Nine Categories), 1882. Location: The Institute of Han-Nom Studies, Hanoi; The Institute of Information on Social Sciences,[3] Hanoi.
6. *Bút toán chỉ nam* 筆算指南 (Compass of Handwritten [lit. "Brush"] Computations). By Nguyễn Cẩn 阮菫, revised by Kiu Oánh Mậu 喬瑩懋, 1909. Location: The Institute of Han-Nom Studies, Hanoi; Ecole française d'extrême-orient, Paris (microfilm).



Mathematics in Vietnam. Fig. 1 Page 75 of the *Thống tông toán pháp* 統宗算法 (Systematic Treatise on Computational Methods). By Tạ Hữu Thường 謝有常. Picture coutresy of the National Library, Hanoi.

7. *Toán pháp* 算法 (Computational methods). By Nguyễn Cẩn 阮菫, revised by Kiều Oánh Mậu 喬瑩懋. Location: The Institute of Han-Nom Studies, Hanoi.
8. *Đại thành toán học chỉ minh* 大成算學指明 (Guidance and explanations for the Great Compendium of Mathematical Learning). By Phạm Gia Kỷ 范嘉紀; revised by Phạm Gia Chuyên 范嘉瑼. Location: The Institute of Han-Nom Studies, Hanoi.
9. *Lập thành toán pháp* 立成算法 (Ready-made computational methods). Location: The Institute of Han-Nom Studies, Hanoi; the Institute of Information on Social Sciences, Hanoi;[4] the Institute of History, Hanoi.
10. *Thống tông toán pháp* 統宗算法 (Systematic Treatise on Computational Methods). By Tạ Hữu Thường 謝有常. Location: The National Library, Hanoi (see Fig. 1).
11. *Toán điền trừ cửu pháp* 算田除九法 (Nine methods of division for computations [related to] fields). Location: The Institute of Han-Nom Studies, Hanoi.

[2] According to Tran and Gros (1993).
[3] According to Tran and Gros (1993).
[4] According to Tran and Gros (1993).

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12. *Toán học để uẩn* 算學底蘊 (Reaching the Depths of the Science of Computation). Location: The Institute of Han-Nom Studies, Hanoi.
13. *Toán học tâm pháp* 算學心法 (Mental Methods of the Science of Computation). Preface 1850. Location: The Institute of Information on Social Sciences, Hanoi.
14. *Toán học cách trí* 算學格致 (Exploration [of Things] and Extension [of Knowledge] in the Science of Computations).[5] Location: The Institute of Han-Nom Studies, Hanoi.
15. *Toán pháp* 算法 (Computational methods).[6] Location: The Institute of Han-Nom Studies, Hanoi; The Institute of Information on Social Sciences, Hanoi;[7] Ecole française d'extrême-orient, Paris (microfilm).
16. *Toán pháp đề cương* 算法提綱 (Presentation of the Key Points in the Computational Methods).[8] Location: The National Library, Hanoi.
17. *Toán pháp ký diệu* 算法奇妙 (Mysteries of Computational Methods). Location: The Institute of Han-Nom Studies, Hanoi.
18. *Tổng tụ chư gia toán pháp đại toàn* 總聚諸家算法大全 (Great Compendium of the Computational methods of All Schools). Location: The Institute of Information on Social Sciences, Hanoi;[9] the Institute of Han-Nom Studies, Hanoi.
19. *Trùng dính Toán học chỉ nam tân biên* 重訂算法指南新編 (New Edition of the Re-established [text of the] *Compass for Method of Computations*). Location: The Institute of History, Hanoi.

The book conventionally considered the oldest, the *Toán pháp đại thành*, is credited to the authorship of one Lương Thế Vinh 梁世榮 (1441–1496?), a high-rank official of the Lê 黎 dynasty (1428–1789), yet the authorship of Lương is problematic (see below). Another book (no. 2 in the list) was compiled in the early eighteenth century, and three (nos. 3–5), in the nineteenth century, while the last of the dated books (no. 6) was published as late as the early twentieth century. Since the compilers of the book no. 7 are the same as of the book no. 6, one can conjecture that the latter was also compiled in the late nineteenth–early twentieth century. None of the remaining 12 books are mentioned in the bibliographic chapter of the *Đại Việt thông sử* (Complete History of the Grand Viet) accomplished in 1749 by the famous Vietnamese *literatus* Lê Quý Đôn 黎貴惇 (1726–1784?), and one can be tempted to date all the books not earlier than the late eighteenth century (Gaspardone 1934: 149; Tran 1938: 97–98). On the other hand, the mathematical contents of the books are similar to that of Chinese mathematical treatises antedating the introduction of European mathematical methods to China by the Jesuits in the early seventeenth century.

The Structure of a Mathematical Treatise: The Example of the *Toán pháp đại thành*

There are two manuscript copies of the treatise *Toán pháp đại thành*, both found in the Han-Nom Institute, Hanoi; their call numbers are VHv 1152 and A 2931. When manuscript A 2931 was produced is unknown (but it certainly happened prior to 1934), while the date when the copy VHv 1152 was made (1944) is written on its front page; a comparison of the copies suggests that the MS VHv 1152 is a copy of A 2931. Neither manuscript has a preface or a postface, or any other data which would suggest the date when the treatise was compiled or would specify the identity of the author(s). The name of the presumed author ("Doctor Lương Thế Vinh") is written only on the first page of each manuscript next to the title; however, it is possible that this page was added later (see also Gaspardone 1934: 149, n. 1).

The treatise is compiled in the traditional "Chinese" way, as a collection of problems with numerical answers given along with the procedures (algorithms) for their solution. There are also several procedures that do not correspond to any particular problems; most probably this is the result of loss of parts of the text containing the corresponding problems and answers. The total number of problems in the treatise amounts to 138. Some geometric problems are not explicitly stated, but introduced with a diagram of a figure with given dimensions. In one case neither numerical data nor a problem accompanied an algorithm, yet the algorithm may well be a fragment from the famous Chinese "Sunzi remainder problem."

The text of the treatise can be subdivided into eight parts:

Part 1 (problems 1–35) contains problems devoted to partitioning, and, in particular, to division. Part 2 (problems 36–42) contains problems devoted to the calculation of the areas of plane figures: a square, a rectangle, a figure approximated by the area of a trapezium, a circle, and a segment of a circle. Part 3 (problems 43–69) contains problems devoted to proportions, the rule of three, and the rule of double false position, as well as to rather simple cases of

[5] The book is listed in Tran and Gros (1993) under the title Toán pháp 算法 (Computational methods).
[6] The original title of the book remains unknown; the title "Computational methods" was apparently given to a manuscript with missing first pages on the basis of its contents.
[7] According to Tran and Gros (1993).
[8] This is *not* the title of the book. The first page(s) of the manuscript is (are) missing and the subtitle of its first section is used as its title in the catalogue of the National Library.
[9] According to Tran and Gros (1993).

multiplication and division. This part also includes a method for calculating the height of an object when the height of another object and the length of the shadows of both objects are given. Part 4 (problems 70–85) contains problems devoted to root extraction and to an auxiliary algorithm used for the conversion of monetary units of one type into another. Part 5 (problems 86–93) is a sequel to Part 3. The reader is asked to solve problems on the calculation of interest and on multiplication and division. However, there is a problem devoted to the calculation of the volume of a solid figure and a fragment on divination. Part 6 (problems 94–131) is related to various subjects, such as calculations of the areas of various figures. Here one finds such shapes as rectangles, circular segments, a "horn of the bull," circles, "drums," ellipses, rings, an "eye-lid" (or "eye-brow," that is, the intersection of two circles), an isosceles triangle, a rectilinear figure composed of several adjacent trapezia, a trapezium, a quadrilateral with four given sides, and the figure formed by two adjacent squares. The remaining problems in this group are devoted to the extraction of square roots, calculation of the volumes of rectilinear solids, and to the conversion of metrological units. Part 7 does not contain mathematical problems; this is a large independent text devoted to land taxation. Part 8 (problems 132–138) embraces various problems devoted to "numerical divination," the calculation of the height of a tree when the length of its shadow is given, a rhymed solution to a problem of indeterminate analysis, and the calculation of the area of a quadrilateral.

Several "earmarked" mathematical problems and methods found in the *Toán pháp đại thành* studied in order to suggest the possible origins of the contents of the treatise were discussed in (Volkov 2002). The analysed topics included: (1) the counting instruments to be used; (2) the 9 × 9 multiplication table featured in the treatise; (3) the lists of the so-called "large numbers"; (4) rhymed algorithms for computation of areas; (5) problems of remote surveying; (6) problems related to numerical divination; and (7) problems on indeterminate analysis. The results of the comparison of the above-mentioned mathematical methods, problems, and instruments with their Chinese counterparts can be summarized as follows (for more details see Volkov 2002):

1. The lack of explicit references to the abacus in the treatise suggests that either the *Compendium* was compiled *before* Vietnamese mathematicians were acquainted with any Chinese books devoted to abacus calculations, or it was compiled later solely on the basis of Chinese and Vietnamese mathematical books written prior to 1573 when the first extant Chinese mathematical treatise devoted especially to the use of the abacus, Xu Xinlu's 徐心魯 *Counting procedures for Pearls on a Plate* (*Panzhu suanfa* 盤珠算法), was published.
2. The text of the treatise does not contain any information confirming that it was indeed authored by Luong Thế Vinh, the fifteenth century *literatus* and official.
3. It is not impossible, however, that the book may well have been a compilation made exclusively on the basis of mathematical treatises compiled in China prior to the late fifteenth century and later available in Vietnam. However, the compilation of the treatise involved a substantial "localization," that is the adaptation of the problems and methods to local measure units, currency, tax system, as well as to the names of specific local objects mentioned in the problems (plants, drugs, kinds of food, animals, etc.).
4. The seeming similarity between certain methods in the *Compendium* and in the Chinese treatise *Suanfa tongzong* 算法統宗 (1592) by Cheng Dawei 程大位 does not necessarily mean that the Vietnamese text was compiled on the basis of the book of Cheng. The similarity can be explained by the fact that Cheng himself based his manual on numerous mathematical texts compiled in the thirteenth to sixteenth centuries available to him, firstly and most importantly, the treatises of Yang Hui 楊輝 (fl. ca. 1275) and Wu Jing 吳敬 (fl. ca. 1450). It is not impossible that the compilers of the *Compendium* also had access to these treatises, or to other older Chinese treatises containing similar materials and later lost.

The preliminary exploration of the contents of the Vietnamese treatise *Toán pháp đại thành* presented in (Volkov 2002) thus did not permit a clear picture of its origins. The exploration of the materials related to the life and activity of its presumed author, Lương Thế Vinh, thus appeared necessary to establish the origins of the book. The obtained results of this exploration (Volkov 2005, 2006) are summarized in the following section.

Lương Thế Vinh: The Case of a "Mathematical Agiography"

The biographies of Lương can be provisionally subdivided into two categories, the "historical biographies" and the "legendary accounts." The "historical biographies" of Lương Thế Vinh are found in the collections of biographies *Đăng khoa lục* 登科錄 (*Records of successful examinees*) by Nguyễn Hoãn 阮俒 (1712–1791) et al., in the manuscript entitled 登科錄抄本 (Manuscript copy of the *Records of successful examinees*), and in the treatise *Lịch đại đại khoa lục* 歷代大科籙 (Records of Great Examinations

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Through Generations). All these texts present rather short descriptions of Lương's official career and specify his birthplace and his official duties within the Hàn lâm 翰林 Academy. Second and third treatises mention a mathematical book he wrote, yet provide different titles for the book. The second and the third biographies mention that Lương's diplomatic activities, the details of which, however, remain unspecified.

The second group of the extant Lương's biographies focus primarily on the supernatural circumstances of his life and death. The following four collections of biographies of successful examination candidates contain his biographies including "supernatural" elements that slightly differ from source to source and are sometimes placed in different order:

1. The *Đăng khoa lục* 登科錄 (Records of successful examinees) by Nguyễn Hoản.
2. The *Đăng khoa lục sưu giảng* 登科錄搜講 (Investigation and discussion of the *Records of successful examinees*), by Trần Tiến 陳瑨 (1709?–?).
3. The *Đại Việt đỉnh nguyên Phật lục* 大越鼎元佛錄 (*Records of the Successful Candidates and of those who attained Buddhahood in the Great Viet [=Vietnam]*).
4. The *Nam sử tập biên* 南史輯編 (Histories of the South [=Vietnam], collected and edited), by Vũ Văn Lập (1896).

A short description of the "supernatural" biographies is found in (Volkov 2005), and the translation of one of them is published in (Volkov 2006). The preliminary analysis of the legends suggests that the early legends of Lương were created in two nonintersecting social circles (that can be dubbed "Palace" and "Village"), yet both groups of legends portrayed him as possessing supernatural powers or divine origin. One can conjecture that the reason why he became associated with mathematics may have been related to his official duties during his lifetime such as, for example, his participation in diplomatic activities and in military operations against the Cham, his work in cartography, etc., briefly mentioned in his biographies. His legendary capacities of "counting" and "measuring" (in a broader sense) in this case would have merged with his established status of supernatural being and thus may have made him the patron saint of professional mathematicians by the early eighteenth century (Volkov 2005).

The temple devoted to Lương Thế Vinh 梁狀元祠 located in his native village Cao Hương (Nam Dinh Province, Vu Ban district) hosts the statue of Lương, his portrait, details of his official costume (boots and hat), and a number of Imperial edicts related to the establishment and functioning of the temple (Volkov 2005). The official portrait of Lương preserved in the temple (Fig. 2) depicts him as a state functionary without making any visual reference to the miraculous circumstances of his birth and life; only one inscription mentions a mathematical work he presumably authored.

Mathematics in Vietnam. Fig. 2 The portrait of Lương Thế Vinh preserved in his temple, Cao Hương village.

The *Chỉ minh lập thành toán pháp* and the Model Examination Paper

The mathematical treatise *Chỉ minh lập thành toán pháp* 指明立成算法 (Guide for Understanding of the Ready-made Calculational Methods) was compiled by Phan Huy Khuông 潘輝框 in 1820 (Tran and Gros 1993; 1: 258). The last, fourth chapter of the book contains a model examination essay that spreads over almost six pages. This unique document is particularly interesting for the history of mathematics education in Vietnam and China.

The text of the model examination work written by Phan Huy Khuông contains a rather simple problem: three categories of officials, A, B, and C have to be remunerated with $N = 5{,}292$ *lương* of silver; the ratio of the amounts of silver to be given to the functionaries of the three ranks is $a{:}b{:}c = 7{:}5{:}2$, and the numbers of functionaries of each category are A = 8, B = 20, and C = 300. The question is to find the "scaled distribution" for them, i.e., the amounts of silver x, y, z given to each functionary of the categories A, B, and C, such that $x{:}y{:}z \therefore a{:}b{:}c$, and $\mathrm{A}x + \mathrm{B}y + \mathrm{C}z = N$. The problem of this type are found as early as in the *Suanshu shu* (prior to the early second century BCE) and in the *Jiuzhang suanshu* (the first century AD), and are also found in a large number of medieval Chinese mathematical treatises. To solve the problem, the imaginary model candidate has to use the method based on the following idea: since $x:y:z \therefore a:b:c$, the ratio of the magnitudes $Ax + By + Cz$ and $Aa + Bb + Cc$ will be the same as $x:a = y:b = z:c$. This latter ratio can easily be found: since $Ax + By + Cz = N$ is given, $x:a = y:b = z:c = Ax + By + Cz:Aa + Bb + Cc = 5292:(56 + 100 + 600) = 5{,}292:756 = 7:1$, hence the solution (Volkov 2004).

The solution of this particular problem is not as important as the very form of the essay suggested by Phan Huy Khuông, most likely an instructor of an educational institution. Firstly, the candidate is supposed to check the data proposed in the problem; secondly, he has to find a solution to the problem. The basic algorithm is certainly known to the examinee, he is not supposed to invent it anew. Yet he has to apply it correctly to the given data and to make sure that it works and that the obtained solution satisfies the original conditions. This style of the "model" examination work found in the nineteenth century Vietnamese mathematical treatise thus was essentially the same as that of the mathematics examinations papers of the Tang dynasty (Siu and Volkov 1999).

Conclusions

The available materials do not suggest any reliable picture of the traditional Vietnamese mathematics prior to the fifteenth century, and no information is available concerning the transformation of the system of mathematics education that most likely resulted from the Chinese occupation of Vietnam in the early fifteenth century. However, numerous sources suggest that mathematics and mathematical astronomy occupied in Vietnamese society a position similar to that of its Chinese counterpart in the first millennium AD and remained a discipline supported by the state until the early twentieth century.

The extant Vietnamese mathematical treatises were produced, most likely, in the early eighteenth–late nineteenth centuries on the basis of older Vietnamese mathematical treatises drawing upon their Chinese counterparts of the Ming dynasty. Their preliminary investigation suggests that the Vietnamese mathematicians were not willing to include the elements of the contemporaneous Western mathematics introduced by Western missionaries in China in the early seventeenth century. The Vietnamese mathematical treatises appear rather similar to the Yuan and Ming dynasty corpus of the "practical" or "popular" Chinese mathematical treatises (dramatically different from the high-level mathematical texts devoted to the higher degree polynomial algebra of the late Song–early Yuan dynasties). In the Ming dynasty China (1368–1644), the traditional mathematics was transformed into an applied discipline used for practical ends by low-level state officials, merchants, artisans, etc., while remaining the subject of the research conducted by isolated scholars without the ideological or material support of the state who were interested in what would be called nowadays intellectual history; it was no longer one of the subjects of the state examinations, as it used to be during the Tang (618–907) and Song (960–1279) periods. In Vietnam, on the contrary, the discipline remained embedded in the framework of the old Chinese-style state education, employed traditional didactic practices, and was linked to the bureaucratic hierarchy via the institution of mathematics examinations.

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Mathematics of Yolngu Aboriginal Australians

Helen Verran

Yolngu Aboriginal Australians live as members of around 20 different clan groups in northeast Arnhem Land in Australia's Northern Territory. They organise their collective and individual lives through a mathematics system very different to the modern system of abstracting through number and quantification. The modern system is incorporated as a subsidiary to their indigenous mathematical system. The Yolngu form of indigenous mathematics can be understood as exemplifying the many similar systems that have life in hundreds of Aboriginal Australian communities.

To consider notions of Aboriginal mathematics usefully in a short space we need to avoid the academic controversies over what mathematics is about and how we know it, while still demonstrating something held in common between the two arenas we identify as Western and Yolngu Aboriginal mathematics. Before we can say anything about mathematics in the life of Aboriginal Australian communities it will help to look briefly at the cluster of meanings associated with the term 'mathematics' in Western life.

Bowing to the antiquity of the notion of mathematics we can note the Greek origins of the words mathematics and mathesis/mathetic. This cluster of words coming to us in English through Latin carries original ideas of learning, seeing and mental discipline. To these are added overtones of systematicity: arithmetic, geometry and reasoning. Western mathematics involves rigorous and systematic ways of seeing and working things out, and is intimately tied up with the constitution of the social order at both the macro- and micro-level. That much is uncontroversial. But asking about the objects which constitute mathematics brings us to less solid ground. Most people want to answer that mathematics is constituted of abstract objects. But constrained to ask what abstract objects are, we find ourselves amongst the disagreeing philosophers and mathematicians and in the realm of metaphysics.

The objects of Western mathematics are forms that inhabit an arena seen as somehow beyond the concrete here-and-now. Those mathematical forms, glimpsed through material objects and arrangements, are usually taken as representations of mathematical objects. In contrast the objects of Yolngu Aboriginal mathematics have life in the concrete here-and-now in that they are performed or enacted. In their being performed or collectively enacted, 'The Dreaming' or *Wangarr*, which is the origin of Yolngu mathematical objects, is remade in the present. There are significant differences between Western mathematics and Yolngu Aboriginal mathematics at the metaphysical level. I will not explore those differences here. Rather I look for a similarity that can be seen as lying within this overarching difference.

A commonsense way of beginning is to take numbers as representative of the sorts of objects we find in mathematics. Many of us are comfortable with seeing numbers embedded in very practical matters like tallying with fingers or stones. We continue to talk of 'digits' alluding to a historical role for fingers, and perhaps for toes. We do not, however, expect that numbers should remain tied to those practical origins. Most people are quite comfortable with numbers being highly mobile, working so as to pattern and order, in almost any situation. Of course, there are many mathematicians and philosophers who would disagree with this way of coming up with a working definition of mathematical objects because it seems to downgrade the significance of numbers and other mathematical objects, a significance deriving from their proper status as 'abstract'.

My approach emphasises instead the ways numbers are embodied and embedded in ongoing collective life, irrespective of whether that is the rarified halls of university departments of mathematics, or the aisles of supermarkets and the anxiety ridden rooms of weight-loss clinics. Nevertheless taking this everyday collective and materialist understanding of number as a mathematical object seriously I suggest that it can provide a minimalist basis for comparing and contrasting Western mathematics with the mathematics in Aboriginal Australia.

Can we identify an arena of collective Aboriginal Australian life with the characteristics of rigor and systematicity, which is tied up with the working of entities involved in patterning and constituting order in multiple heterogeneous contexts? We could point to any Aboriginal Australian community and identify just such an 'Aboriginal mathematics', although it is likely that among the many different Aboriginal Australian communities such an arena would go under different names. Here I confine myself to considering some mathematical elements in the life of contemporary Yolngu Aboriginal Australians. We look at *gurruṯu* a mathematical-like discourse and set of practices embedded in Yolngu life. In Yolngu life, *gurruṯu* is expressed in the many and heterogenous material practices of doing kinship relations, including land ownership, although to render the term *gurruṯu* in English is just as difficult as expressing mathematics in the cluster of Yolngu languages. This mundane way of describing *gurruṯu* would not satisfy my Yolngu friends. However, recognising that caveat while putting it aside, just as I have put the concerns of mathematicians aside, I go on to explore some interesting similarities between Western and Yolngu Aboriginal mathematics. I begin by speculating about possible material origins of the contrasting mathetic objects in Western mathematics and *gurruṯu*.

A familiar story about origins of numbers in Western mathematics sees them as originating in the practices of material tallying. This is modeling an event or episode in the world with a material encoding process. We can see this as using a finger to encode the passing of a sheep through a gate, the placing of a pebble to encode the pointing at a soldier, or the engraving of a line on a bone or a piece of wood to record the filling of a vessel with grain. This imagines the involvement of fingers and toes in tally keeping in a non-linguistic way. One separated digit codes for one separated item. But if we then extend the coding operation and say a word which codes for the finger or toe, we have done something much more complex and ended up with a code which is much more useful than the material code of fingers and toes or display of objects like dropping stones into a bucket or adding another shell to the pile.

In saying a word as a finger is held up to code for an item involved in some event we understand that the word we say does not name either the item or the finger. It names a position in a progression. Numerals are words that code for a position in a series. A set of number names, a numeral system, is characterised by having a sequential base pattern and recursivity. Numerals constitute an infinite series by having a base about which repetition occurs, and a set of rules by which new elements are generated. The contemporary numeral system which has developed in association with Indo-European languages like English has ten as its base; in other words ten is the point in the series which marks the end of the basic set of numerals. As each ten is reached, the basic series is started again, each time recording in the numeral how many tens have been passed. The rule by which new elements are devised is addition of single units and base ten units.

A similar story can be told of origins of one set of mathetic objects in Yolngu Aboriginal life. Imagine Yolngu people plotting the spatial pattern of land sites owned by related groups of people. Stones and shells might be taken to represent positions in the mesh of family relations and the sites owned by the various groups. The shells/stones symbolise the links between people and land, and placed on sites through which land is owned they both express and demonstrate the pattern of the network of linkages between related groups of people and their lands. Naming can codify the relations, just as position in a sequence can be codified by names in numbering. But codifying relations with names is more complicated than codification of an event signalled with a finger. In fact two contrasting relations need to be encoded to begin. In *gurruṯu* the relation between brother and sister is contrasted as a formal opposite to that between husband and wife. By positing an ideal form of marriage a system of reciprocal names can be devised. So just as we find human bodies embedded in Western mathematics through numbering, so too we find human bodies embedded in *gurruṯu*. On biological grounds of life expectancy we could expect a way to express family links which recognises the presence of three generations; necessarily these will be differentiated along matrilineal and patrilineal lines.

The first mathetic objects are moieties. Brother and sister belong to the same moiety. Husband and wife belong to opposite moieties. In Yolngu life these formal opposites are named *Yirritja* and *Dhuwa*. This formal opposition of the organising categories of Yolngu life – patrilineal and matrilineal lines allows a matrix in which everything can be located with respect to all other things. Humans and non-humans, living and non-living, material and non-material, everything is locatable – people, places, concepts, images, languages, animals and plants.

The matrix is elaborated in naming a series of family relations. Reciprocal pairs of names code for relative positions in the kinship mesh. They do not name individual people or clans or places, but relations between them. *Gurruṯu* names are code for positions in a formal series, but not a series with a linear form as in numbers. This is a series with the form of a net or a matrix.

Gurruṯu is a form which is primarily a formal map. Just as the number series is used to 'reveal' value in the material world, the *gurruṯu* matrix is used to reveal relative location in the material world. For example it codifies the location of places in the landscape. Table 1 is a list the eight reciprocal pairs which constitute the base of the *gurruṯu* recursion. The easiest way to begin to understand these categories is to personalise them in terms of my kin relations.

Or I could do it the other way around: the person I call *gathu* (child) calls me *mukul bapa* (aunty – father's sister) and so on through to the person I call *dhuway* (husband) who calls me *galay* (wife). The dual names in some rows on the left-hand side of the pairs represent male and female holders of a position, necessarily brother and sister. Each of those pairs has the reciprocal relation of *yapa* (sister) and *wawa* (brother). The reciprocal pair *yapa* and *wawa* enable the pattern of names to work as a true recursion; they are not themselves members of the base set of reciprocal name pairs. Elaborating the list of names of *gurruṯu* relations is analogous to listing the set of numerals from one to ten. In that set zero holds a pivotal position, enabling iteration of the number pattern. Zero is not itself a member of the base set of names and can be understood as having a similar function to *yapa* and *wawa*. In just the same way as number, the name series of *gurruṯu* constitutes a recursion where elements, i.e. positions constituted in the series, provide the basis for further constitution of elements.

The matrix formed by naming these relations is understood as re-emerging across history. But the image of time embedded in history here is not linear; it is not the form of time Westerners are familiar with. For Aboriginal Australians time is cyclical. History accretes in place in going through the cycle mapped out by the matrix of *gurruṯu*. The cycle of the *gurruṯu* matrix can be mapped by the ideal cycle of marriage and child bearing in Yolngu life. This cycle is shown in diagrammatic form in Fig. 1.

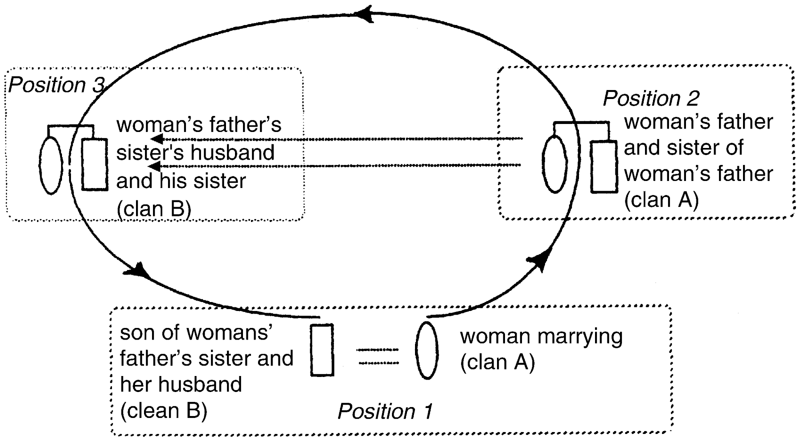
The father of the man marrying (and the father's sister) constitute one position (clan A – moiety 1), the mother of the man marrying (and her brother) a second position (clan B – moiety 2) and the wife (and her brother) of the brother of the mother of the man marrying constitute a third position (clan C – moiety 1). In the Yolngu case, the pattern of this geneological ideal implies either two *Yirritja* clans and a *Dhuwa* clan, or *Yirritja* clan and two *Dhuwa* clans.

One way to begin describing the structure of this matrix is to map it in the conventional form that anthropologists map genealogies. The basic unit in this map is the hypothetical ideal family tree shown in Table 2. This 'ideal unit' illustrates the fundamental contrast between the two different sorts of relations which constitute the *gurruṯu* system of relations: that between wife and husband and brother and sister.

Exhaustively specifying the primary positions generated in this genealogical ideal across the generations from grandchild to grandparent, constitutes eight reciprocal pairs, 16 positions: two groups and three reciprocal positions in each: two sets of two to the power of three. Naming this set of 16 positions constitutes a primary

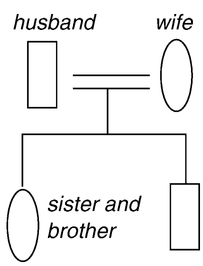
Mathematics of Yolngu Aboriginal Australians. Table 1 Kin relations

The person I call	Calls me
bäpa (man) – father	*gäthu* – child
mukul bäpa (woman) – father's sister	
ngäṉḏi (woman) – mother	*waku* – child
ngapipi (man) – mother's brother	
märi'mu – father's father and father's father's sister	*marratja* – grandchild
ngathi (man) – mother's father	*gaminyarr* – grandchild
momu (woman) – mother's father's sister and simultaneously father's mother	
märi – mother's mother and mother's mother's brother	*gutharra* – grandchild
mumalkur (woman) – mother's mother's brother's wife	*dhumungurr* – mother's brother's mother-in-law
ngathiwalkur (man) – mother's mother's brother's wife's brother	
mukul rumaru (woman) – mother's brother's wife	*gurrung* – mother-in-law
maralkur (man) – mother's brother's wife's brother	
galay – mothers' brothers' daughters and sons simultaneously brother's wife and her brothers	*dhuway* – sister-in-law



Mathematics of Yolngu Aboriginal Australians. Fig. 1 Pattern on a Yolngu genealogical idea.

Mathematics of Yolngu Aboriginal Australians. Table 2 A conventional genealogical map of the basic elements in Yolngu *gurruṯu*



template, just like naming the set of ten fingers constitutes a primary template. The eight pairs of reciprocals name across generations or across matrilineal or patrilineal lines. The brother/sister reciprocal pair completes the set of named relations and enables continuing iteration. Together the names and rules of generation form an infinite series. When we map the series of eight reciprocal kin relation pairs with this unit we get this diagram of the relations named (Table 3).

Laid out in this way it becomes obvious that in the *gurruṯu* system where every person and everything is exhaustively located with respect to every one else and everything else has a three generational interval known as the *mari–gutharra* (grandmother/father–granddaughter/son) relation.

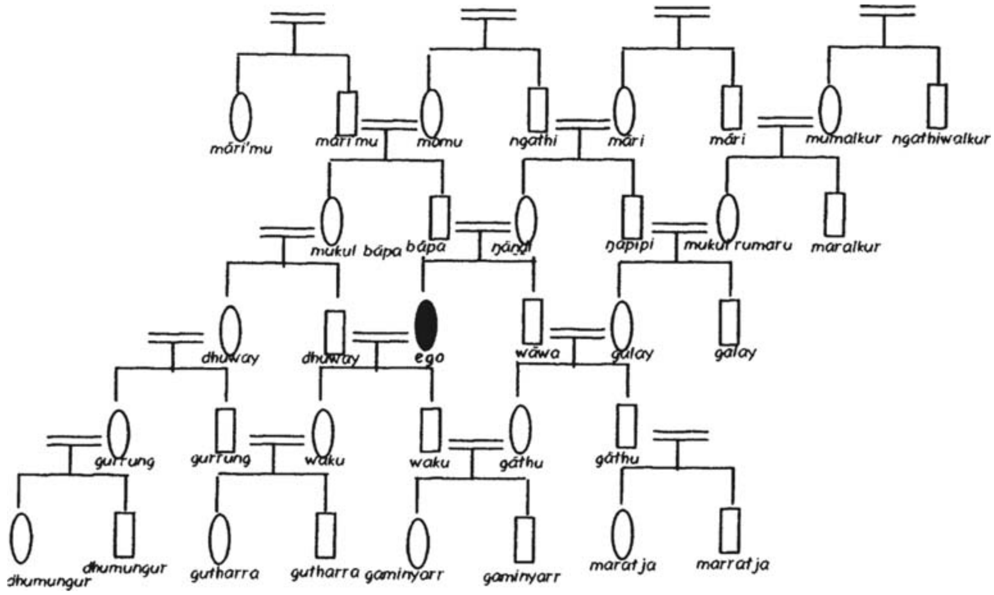
The triple generational/dual moiety recursion constitutes an encompassing pattern of Yolngu life and social order. Right from the beginning of their lives, Yolngu babies are instructed on the relation that this or that person has to them. The set of relations involve notions of hierarchy and equivalence, but not as a single-centralised hierarchy. Each position plays different roles in several different hierarchies; the many hierarchies are woven together to form a decentralised orderly mesh of hierarchies. *Gurruṯu* carries a powerful ideology; it achieves a general ordering of both the social and the natural world. It maintains an image of continuity and permanence across both time and space. And it is not only people who have *gurruṯu* positions; all entities in the Yolngu world have positions in the *gurruṯu* matrix.

I am presenting the number and *gurruṯu* recursions as analogous, but they are very different in their content. Should that worry us? These two great recursions – the tallying recursion codified in counting, and the genealogic recursion codified in ordering descent and ancestry – are of a kind, albeit different in form. They differ in structure: each number has one direct antecedent and one direct successor, and each *gurruṯu* position has two direct antecedent positions and one successor position. However the two systems are characterised by recursive definition. A recursive definition formalises the idea of 'and so on'. We can define *gurruṯu* positions as the members shared by all classes that contain a *gurruṯu* position, and the successors of all their own members. Similarly we can define the natural numbers as the members shared by all classes that contain one and the successors of all their own members.

Both these recursions are manifest to varying extents in all human societies. By noting the emphasis on the genealogic system in Yolngu society I am not saying that the tallying recursion is entirely absent from Yolngu life; it is not. Nor, in noting the predominance of tallying in European derived Australia, I am saying that the genealogic recursion (arranging matters on the basis of close and distant kinship) is entirely absent from Western life. What I am saying is that in Yolngu life the tallying recursion does not carry the ordering burden that the genealogic recursion carries. Conversely in Western society the genealogic recursion carries very little by way of ordering knowledge or productive processes.

Nor I am suggesting that the 'great recursions' operate quite independently of one another. In the Western world the tallying recursion predominates; it is

Mathematics of Yolngu Aboriginal Australians. Table 3 A genealogical mapping of the base set of *gurruṯu* elements



the recursion by which most social relations are effectively ordered. This is not to deny the influence that the genealogic recursion retains. Yet genealogic classifications are not exhaustive and applicable as objective classification throughout the community as we see them in Yolngu life. In Western life kinship classifications are discontinuous and discrete. They are variously regarded as important or not. Westerners can reject their genealogy and invent ancestors with impunity. They can lie about their genealogic relations. The genealogical recursion is taken as significant only in the biological sense. In the social sense people can choose to invoke or not to invoke the recursion.

In contrast to the dominant place of the tallying recursion as a foundation for reasoning in Western life, it is involved in Yolngu life in only a secondary way. Distributive arrangements for turtle eggs invoke an indigenous tallying recursion; here a recursive material arrangement – base 5 is engaged and linguistically encoded (each group of five is one *rulu*). In contemporary Yolngu society the use of base 10 tallying recursion predominates when the community or individuals are dealing with the white social order, but in exchanges involving only Yolngu the tallying recursion, as expressed in money for example, is subordinate to the working of the *gurruṯu* system. It does not carry the deterministic weight, the aura of inevitability it carries in non-Aboriginal Australia. People can choose or not to invoke quantification.

We should not go away with the idea that all genealogic recursions of Aboriginal Australia are worked in exactly the same way. Just as the tallying recursion can be worked differently for different purposes and by different groups, so Aboriginal Australian communities work with the genealogic recursion in different ways. In Yolngu life there are two distinct genealogical recursions which serve distinct functions. The distinction between them is something like the distinction between ordinal and cardinal numbers.

Juxtaposing number and *gurruṯu*, the primary principle embedded in these contrasting forms becomes evident. The primary principle for manipulating the categories constituted in the patterns derives ultimately from the practical, material system which formed the template of the recursion in its symbolic constitution. Going back to numbers we can see that the primary rule of that recursion is a version of the process of holding up another finger as another sheep leaps through the gateway. The important thing about this operation from the point of view of recursion is that each finger is exactly equivalent to each other finger. And any collected set of fingers has a precise and identifiable relation to any other collections of fingers; they relate to each other as a specific ratio. The primary principle of the number system is the principle of ratio: the ratio of any term to another is determined by the number of times one contains the other.

The primary principle of working the set of mathetic objects in *gurruṯu* is quite different. Going back to the ideal marriage arrangement which underlies *gurruṯu* we can see that an inherent reciprocity marks the form. Husband taker and wife taker are reciprocally related. Clan A and clan B together constitute a unity – the offspring of the marriage. This is an instantiation of the principle of reciprocity – two opposing elements constituting unity. A reciprocal is an expression so related to another that their product is unity. It is the inherent opposing duality constituting a unity, which is the fundamental principle of *gurruṯu*. Every position in the *gurruṯu* matrix is necessarily constituted by a two-way naming. The elements of the recursion must be specified from both ends before they come to life as an entity within the recursion.

Reciprocity can be pictured as two sides of a coin. On the old Australian penny (which had the head of the current king or queen of England on one side and a kangaroo on the other), 'head' and 'tail' constitute reciprocals, and together constitute a unity. The notion of reciprocal is often difficult for learners of Western mathematics centred around numbers to understand; they need to understand fractions before it is possible to understand reciprocals in a rigorous manner.

In *gurruṯu* reciprocity is primary. If you take any base family relation as a unit, for example *mari–gutharra* – the matrilineal relation across two generations (mother's mother or mother's mother's brother) – you can understand it as constituted by the mutual engagement by both sides. The descendant and the grandmother/great uncle are equally important in constituting the unity described by *mari–gutharra*. Each side is necessary to constitute the unity held between them. And just as reciprocity can be secondarily derived in the system of numbers pivoting around ratio, similarly the notion of ratio can be secondarily derived in *gurruṯu*. *Milmarra* is a name given to this way of rendering *gurruṯu*. A simple ratio involves juxtaposing a *yothu–yindi* (mother–child) relation with *a mari–gutharra* (child–mother's mother) relation: "If the two clans of the *yothu–yindi* are A and B, what is the Mari clan?" There is always only one correct answer which can be understood as expressing the ratio of the two reciprocals. Such puzzles are often set for learners of the *gurruṯu* system.

Number and *gurruṯu* are contrasting generalising logics. Perhaps the most challenging aspect of this is the notion that there are contrasting generalising logics in a contemporary way of life. Such a situation implies the need for continual translation between logics in that lifeway. Recognising that need opens the possibility for reflexive consideration of how different peoples might collectively go on, doing their differences, including their different generalising logics, together.

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Mean Motions in Indian Astronomy

George Abraham, J. Samuel Cornelius, N. Gnanamalar David

This article is a follow-up of a very important contribution to the understanding of Indian astronomy by Billard (Billard 1971, 1977; van der Waerden 1980, 1988) who has calculated the mean longitudes of the sun, moon, moon's apogee and node, and those of the five known planets, from the numerical data in the main astronomical texts. The errors of these longitudes are determined by comparing them with the results of the modern formulae.

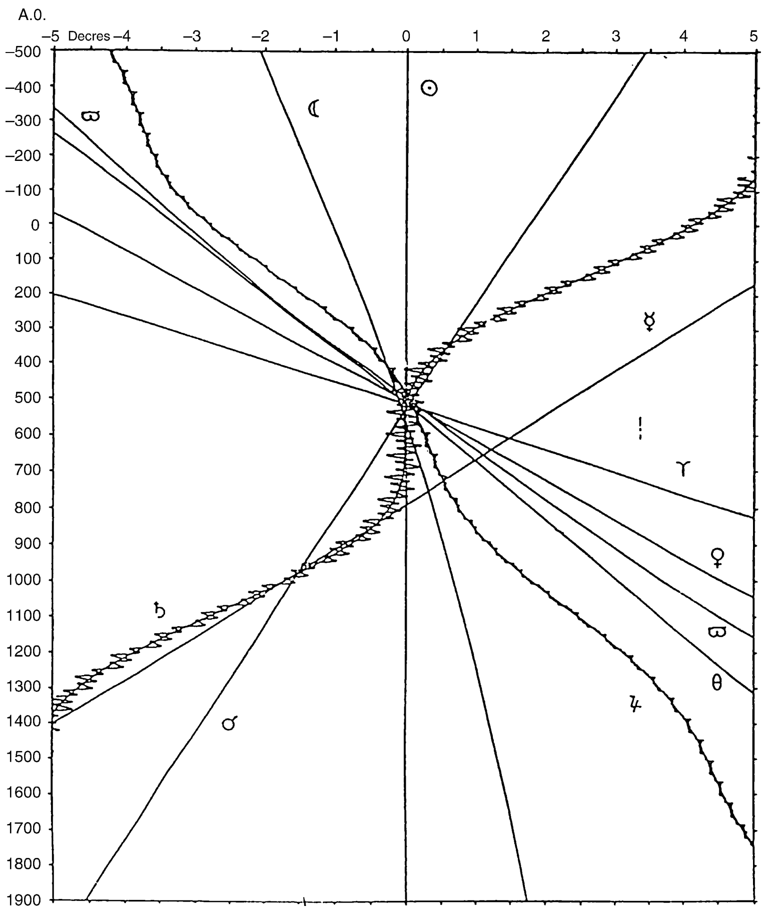
Billard uses the methods of mathematical statistics to find the most probable dates of the observations. His graphs, in which the errors of the longitudes are plotted against time from BCE 500 to AD 1900, illustrate his most important conclusions. For example, the Āryabhaṭa graph, Fig. 1, of this article, (Fig. 6 in Billard's book) shows that he made accurate observations at about AD 510. The error lines are for the Sun (☼), Moon (☾), Moon's apogee and node (ω, θ), Mercury (☿), Venus (♀), Mars (♂), Jupiter (♃), and Saturn (♄). There are large errors on earlier and later dates, showing that the rate of change of longitudes, the mean motions, are far from correct.

The synodic graphs of Lalla and Nīlakaṇṭha Somayāji (our Figs. 2 and 3 and Figs. 18 and 42 of Billard's book) stand out conspicuously, compared to the other graphs, because as many as six lines are close to the zero-line for most of the time span; therefore their mean motions are very accurate.

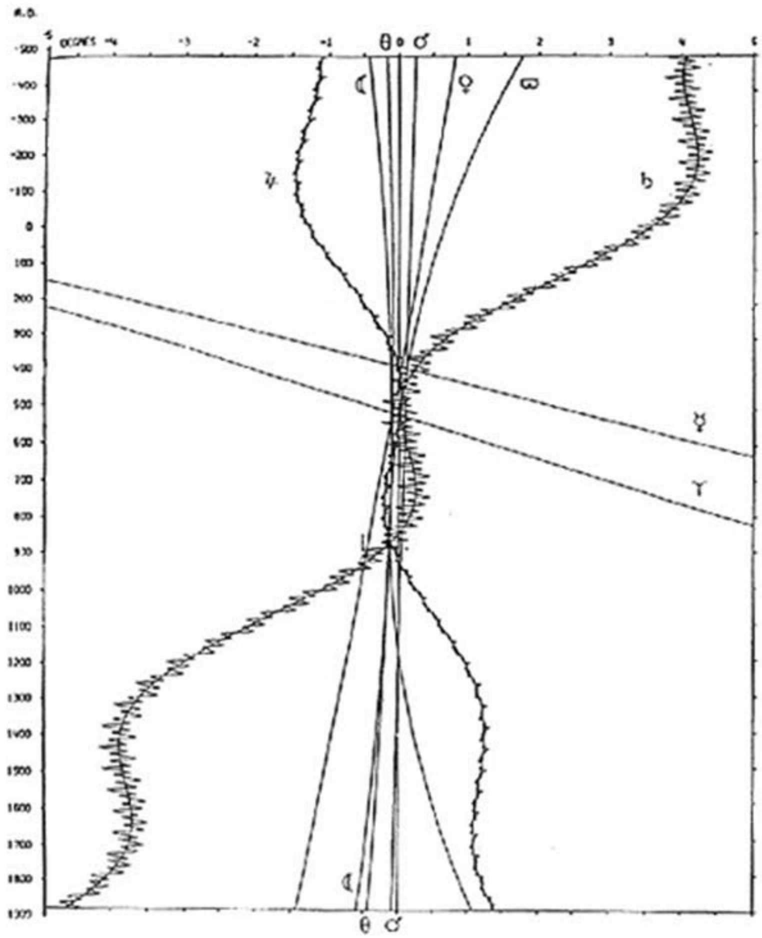
Another important finding of Billard, strongly supported by Raymond Mercier (1993) is that the date of the *Mahasiddhānta* is the early sixteenth century, against the AD 900 estimate of Dikshit (1985).

In this article, the focus is on mean motions, instead of longitudes. To begin with, we consider the following Babylonian period relations (Table 1) (Neugebauer 1975):

From these relations, we can calculate the ratios of the velocities of the Moon and planets to that of the Sun. The resulting numbers are in the first row of Table 2, denoted by O_1. The next row M_1 are the corresponding



Mean Motions in Indian Astronomy. Fig. 1 K. Āryabhaṭa.



Mean Motions in Indian Astronomy. Fig. 2 K. Lalla.

ratios calculated from modern theory of Simon et al. for the year BCE 300 (Simon et al. 1994). The third row numbers are the errors defined by

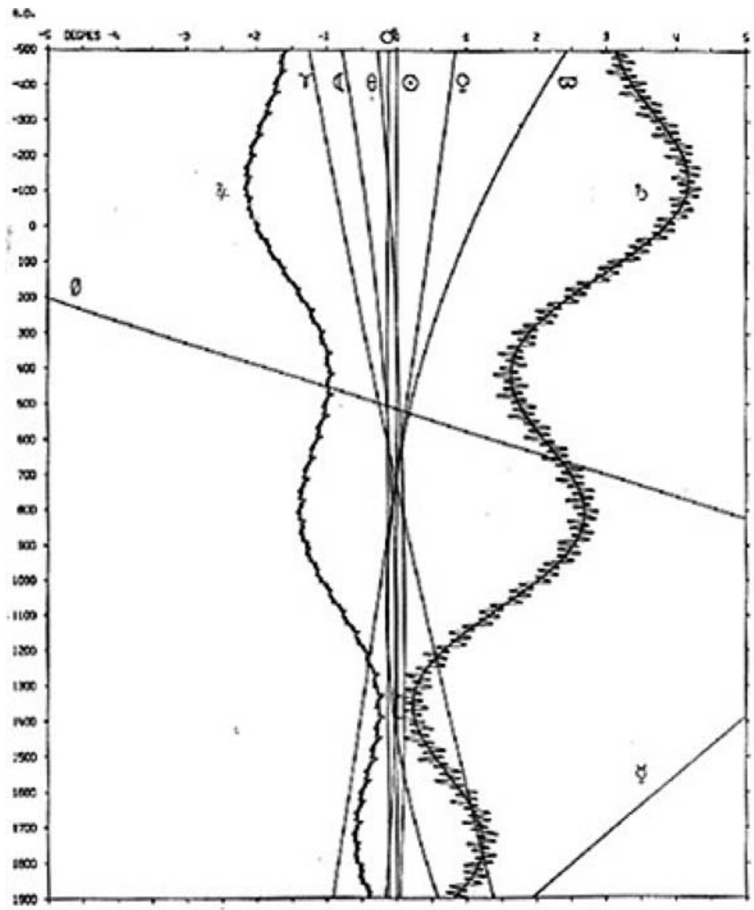
$$E_1 = \frac{|O_1 - M_1|}{M_1}$$

We now compare these Babylonian values to those of Ptolemy. His daily motions of the Sun, Moon, and planets are given in Billard's book (1971: 53). From these velocities, we calculate the same ratios as for the Babylonian observations and the resulting numbers, denoted by O_2 are in the fourth row of Table 2. The fifth row M_2 are from the modern theory (Simon et al. 1994) for AD 150 and the errors E_2, defined in the same way as in (1), are in the last row.

The mean values of the Babylonian and Ptolemy's errors are $\overline{E}_1 = 18.7$, $\overline{E}_2 = 5.8$. The reciprocals of these numbers are plotted in Fig. 4. Ptolemy is more accurate by a factor of about 3.

In an earlier paper, we calculated the errors of the mean lunar and planetary motions of Ptolemy and the most prominent Indian astronomers, Āryabhaṭa, Brahmagupta, Lalla, and Nīlakaṇṭha Somayāji. We now extend our investigation to include another seven Indian canons, which have been analysed by Billard. These are listed in Table 3. The first two columns give the names and the page reference in Billard's book (1971); the next column gives the approximate dates. The fourth column has the three lunar errors E_1^1, E_1^2, E_1^3 (synodic, anomalous, draconitic) and the errors E_2^2 to E_2^5 of the synodic daily motions of the five planets. The last column gives the mean lunar and planetary errors $\overline{E_1}$ and $\overline{E_2}$.In Fig. 5a,b we have plotted the values of $1/\overline{E_1}$ and $1/\overline{E_1}$, which are a measure of the accuracy of the Indian observers. The corresponding numbers for Ptolemy are also shown, based on the errors calculated in the earlier paper (Abraham 2003). In these figures P stands for Ptolemy and the 11 Indian canons are numbered 1–11 as in Table 3.

In Fig. 5a,b Ptolemy, Lalla and Nīlakaṇṭha Somayāji's *k.TantraS* are the most prominent. Their accuracy is the result of their own observations, also taking into account



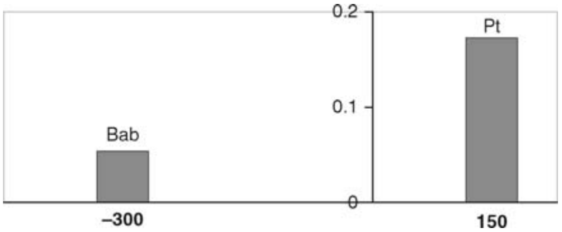
Mean Motions in Indian Astronomy. Fig. 3 K. Tantra.

Mean Motions in Indian Astronomy. Table 1 Babylonian period relations

	Moon	Mercury	Venus	Mars	Jupiter	Saturn
No. of revolutions	235	1,993	1,871	151	36	9
No. of years	19	480	1,151	284	427	265

Mean Motions in Indian Astronomy. Table 2 Ptolemaic values

	Moon/Sun	Mercury/Sun	Venus/Sun	Sun/Mars	Sun/Jupiter	Sun/Saturn
O_1	12.36842105	4.15208333	1.62554301	1.88079470	11.86111111	29.44444444
M_1	12.36827354	4.15197000	1.62549917	1.88075194	11.85681389	29.42471118
$E_1 \times 10^{-5}$	1.19	2.73	2.70	2.27	36.24	67.06
O_2	12.36841579	4.15197630	1.62549378	1.88076904	11.85763221	29.43201683
M_2	12.36827213	4.15196976	1.62509912	1.88075181	11.85680702	29.42460065
$E_2 \times 10^{-5}$	1.16	0.16	0.33	0.92	6.96	25.20



Mean Motions in Indian Astronomy. Fig. 4 Babylonian and Ptolemaic errors.

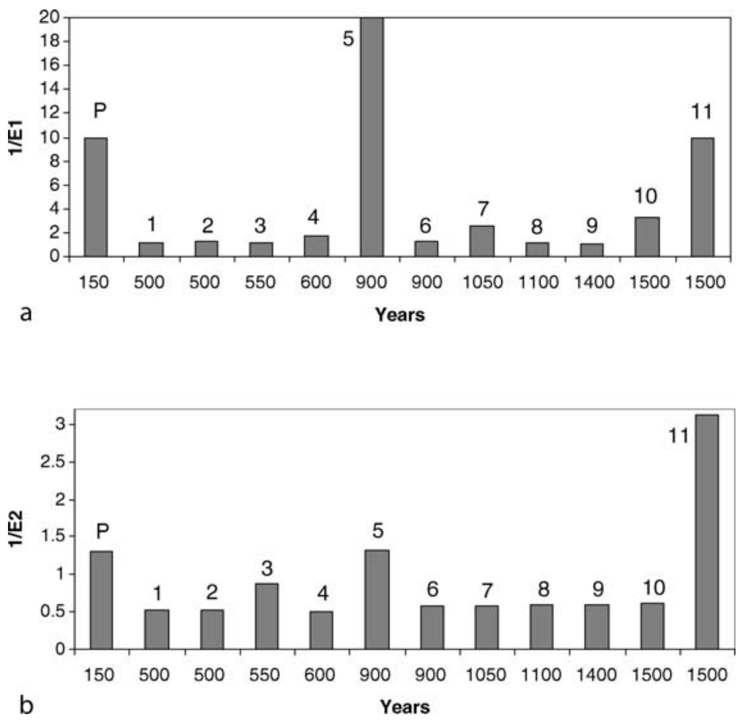
the observations of others, spread over a long period of time. Āryabaṭa's poor mean motions are due to his assumption of the conjunction of planets, at the beginning of the Kaliyuga (van der Waerden 1988).

The *Pancasiddhantika*'s corrections to the *Sūryasiddhānta*'s planetary motions make a significant improvement, indicating further accurate observations.

The improvements of the later *Sūryasiddhānta* over the earlier version, and of Siddhantasiromani's *k.BrSpS2* compared to that of Brahmasphutasiddhānta are insignificant.

Mean Motions in Indian Astronomy. Table 3 Seven Indian canons

No.	Treatise	Canon page no.	Approx. date	$E_1^1, E_1^2, E_1^3, E_2^1, E_2^2, E_2^3, E_2^4, E_2^5$	$\overline{E}_1; \overline{E}_2$
1	*Sūryasiddhānta*	*k. SūryS,* p.75	500	0.17,1.30,1.17; 0.88,4.10,1.94,1.25,2.56	0.88; 1.94
2	*Āryabhatīya*	*k. āryabh,* p.78	510	0.36,1.11,0.98; 0.71,4.12,1.96,1.33,1.58	0.82; 1.94
3	*Pañcasiddhāntikā*	*k. PañcS,* p.100	550	0.16,1.32,1.17; 2.06,1.45,0.86,0.41,0.96	0.88; 1.15
4	*Brāhmasphutasiddhānta*	*k.BrSpS,* p.115	600	0.34,0.83,0.53; 0.80,4.24,1.80,1.33,1.57	0.57; 1.96
5	*Sisyadhivrddhidatantra*	*k.Lalla,* p.143	900	0.03,0.26,0.08; 0.35,0.27,0.03,0.22,1.39	0.05; 0.76



Mean Motions in Indian Astronomy. Fig. 5 (a) Lunar accuracy, (b) Planetary accuracy.

The planetary motions of the later *Sūryasiddhānta* and those of Parameshwara's *Drgganita* are remarkably close as pointed out by David Pingree (1987: 613), leading to the same errors in our approximation. The lunar motions of the two canons are slightly different, perhaps due to Parameshwara's new observations.

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Meat Preservation in Ancient Egypt

SALIMA IKRAM

The ancient Egyptians consumed all types of meat: mammalian, piscian, and avian. It was an important source of protein, but one that was not always equally available to all levels of society. While piscian and avian meat sources were readily obtainable through fishing, hunting, and trapping, mammalian meat was sometimes harder to acquire due to restrictions on hunting wild game and the expense of killing livestock. Thus, mammalian meat tended to be more frequently consumed by the wealthy elite, although it would have been consumed by other social classes on feasts or at festive occasions.

Once slaughtered, the meat had to be consumed immediately to prevent spoilage, or it had to be processed and preserved for later use. There were several ways of preserving meats available to the ancient Egyptians – drying, salting (dry and wet), smoking, a combination of any of these methods, pemmicaning, or using fat, beer, or honey curing. Preserved meat provided a supply of protein for lean times, a commodity that could be traded, as well as a convenient food to take on all types of expeditions, whether exploratory, military, or commercial.

The evidence for the different types of meat preservation in ancient Egypt comes from two- and three-dimensional representations, mummified and preserved meat that comes from tombs, and artefacts, such as labeled pottery jars pertaining to meat. Additional information can be gathered from ethno- and experimental archaeology.

Drying

Drying is the easiest and most common way to preserve meat. Pieces of meat are cut from the carcass and hung in the sun to dry. The entire animal can be preserved in this way, although certain cultures seem to prefer specific cuts for drying. Drying time depends on the temperature and the thickness of the cut; generally it takes between 1 and 3 weeks. Dried meat can last up to 2 years, depending on storage conditions. Artistic and archaeological material shows evidence of such preservation practices.

Pounding meat before it is hung up to dry is a variation on this process. Some representations found in tombs support the idea that such a method was used to preserve meat in ancient Egypt. The pounding of the meat forces out the liquid in it that could cause spoilage, thereby making it possible for the meat to last longer. As a further protection, salt can be rubbed into the meat before it is dried. The term, *iwf ḏr*, suggests this method of preservation for meat.

Dried meat can also be prepared by boiling small pieces of meat, and then putting these in the sun to dry. This method tends to lower the nutritive value of the meat.

Fish can also be dried very effectively. Tomb representations show fish being cleaned, opened, and dried. Actual examples of these have been found at Deir el-Medina, and there are several references to dried fish found in Egyptian literature.

Birds were probably not generally dried. Only a handful of images suggest that poultry was dried, but these are inconclusive.

Salt

Salt curing is a simple and effective means of preserving meat, and salt was readily available in ancient Egypt. Both dry and wet (brine) salting would have been possible in ancient Egypt, but it is more probable that the former method would have been more commonly used. The basic idea was to immerse the meat in salt or brine, and then to seal it. The salt not only draws out the liquids in the meat that could cause spoilage, but also deters bacteria. This was the same precept governing mummification. Salt curing was faster and more efficient than simple drying, and the meat thus preserved would have lasted longer than dried meat.

Archaeological and artistic evidence suggest that dry salting was the most common method of meat preservation employed by the ancient Egyptians. Meat, fish, and poultry were all dried and salted. Scanning Electron Microscopy carried out on samples of preserved meat found in tombs supports this theory. Drying and salting fish is the most common way to preserve fish, actual examples of which were recovered from the tomb of Kha, and references to salted fish appear in texts, notably in the tale of Wenamun. Salt fish continues to be a staple of the modern Egyptian diet, especially for peasants. Mullet roe, the earliest caviar, also used to be preserved in salt and is still kept in this way today. Birds were also salted, and examples of these have been recovered from Kha's tomb.

Smoking

Although smoking meat in order to preserve it was hypothetically possible, it is unlikely that this method was used in ancient Egypt. The main reason for not using it was the relative paucity of wood, especially wood of any aromatic nature.

Fat

Animal fat is commonly used to conserve meat. Goose, mutton, or cow fat could have been used for this. Meat was cut up and then cooked with fat and salt and then placed in a container. Once cool it would have been sealed. This method, called *lahma mahfooz*, is still in use in Egypt today.

Honey

Honey might have been used to preserve food in ancient Egypt. Certainly, honey has preservative qualities. Indeed, Alexander the Great's body allegedly was preserved in honey. However, it is unlikely that this would have been used, as honey was a valuable commodity and the only sweetening agent available to the Egyptians.

Thus, although a significant variety of technologies were available to the ancient Egyptians, it is clear that drying and salting meat were the ones that were most commonly used.

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Mechanical Technology and Instruments of China

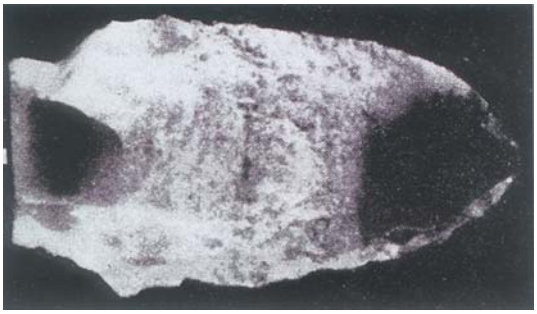
Tong Qingjun, Feng Lisheng

China was among the earliest countries to develop mechanical technologies, and its long history is full of achievements in technology for mechanical engineering.

Archeological work since the twentieth century has unearthed a large amount of prehistoric relics that provide a wealth of information about the evolution of technology for manufacturing tools and instruments in antiquity.

Paleolithic artifacts were mainly made of stone and wood, although sometimes bone was used. They were mostly chipped stone vessels that were formed by hammering and primary truing. Later, polished stone vessels were shaped to serve as tools that could chop, break, or scrape. Hammers, knife-edged tools, spheres, spears, and arrowheads made of stone can also be seen from this period. Arrowheads were found in a late Paleolithic site in Zhiyu, Shanxi province, that dates to about 28,000 years ago (Fig. 1) (Du 1984: 6) and the appearance of arrows themselves indicates that a relatively high level of mechanical technology had been attained. Also at the site are wooden sticks and polished needles made of other materials.

Neolithic artifacts were mainly made by a polishing technique that demanded selecting, cutting, polishing, and boring the stones. Copperware also appeared at this time. A sword and some fragments made of copper were unearthed in the early layers of Majiayao, Dongxiang, Gansu province, and date to 2575–2500 BCE according to carbon-14 analysis. Some scholars consider the sword to be the earliest bronze in China (Shen 1987: 919), but others have disagreed (An 1993). Plenty of tools for production – including adzes, axes, shovels, chisels, millstones, burnishers, pestles and mortars, spinning wheels, plows, swords, and hoes – have been found from this period, when the types of tools increased considerably and had special uses (Fig. 2). Also at this time, such complex machinery as original textile machines and pottery wheels appeared.



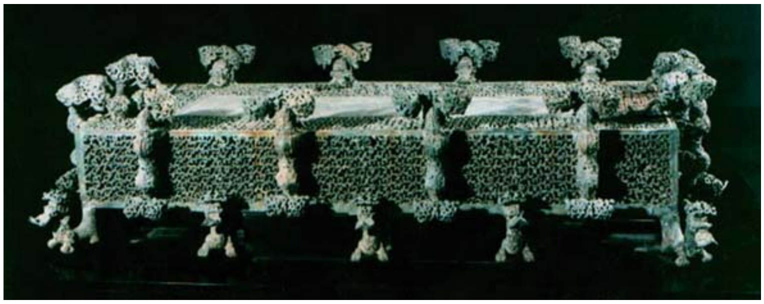
Mechanical Technology and Instruments of China.
Fig. 1 A stone arrowhead unearthed in Shuo County, Shanxi Province (from Hua 1997).

Mechanical Technology and Instruments of China.
Fig. 2 A tool to level soil, unearthed in Qiansanyang, Wuxing, Zhejiang Province (from Du 1984).

From the late Neolithic to the Western Zhou Dynasty (1046–771 BCE), animals and wind were used as the main sources of energy, as attested to by chariots and sails from these times. There is little evidence to demonstrate a relationship between the chariots of China and those of Western Asia, and although the earliest appearance of chariots has been recorded differently in the literature, we can conclude that two-wheel wooden carriages were used as early as the Shang Dynasty (ca. 1600 BCE, Fig. 3). Carriages of this time commonly had two wheels, a rectangular or square wagon box, a single thill (one of two shafts extending from the body of a cart or carriage on either side of the animal that pulls it), a crossbar, yokes at either side of the crossbar, and leather straps for pulling the cart. Cattle were used to cultivate the land, plows were widely used, but the agricultural machines and devices varied a lot. Booms, windlasses, and other such composite machines also existed in antiquity.

Bronze tools and instruments began to be widely used during the Shang Dynasty, and the techniques for smelting metals and casting utensils were at their highest even before the Western Zhou. Having begun with small-sized implements that had single-side and double-side patterns, the Shang eventually yielded large implements with composite patterns around a core, while advanced techniques such as separate casting were widely used in the middle of the dynasty and pottery patterns became more complex in its later stages. The largest known bronze vessel is the Simuwu Ding, which was unearthed in Wuguan village, Anyang, Henan province in March 1939. It weighs about 875 kg and embodies the high level of casting under the Shang. Fig. 4 shows the large-scale bronze wine table (*jin*) with a cloud design that was unearthed in Xichuan

Mechanical Technology and Instruments of China.
Fig. 3 A restored model of a chariot from the Shang Dynasty (from Hua 1997).



Mechanical Technology and Instruments of China. Fig. 4 Bronze wine table unearthed in Xichuan County (see uji ►www.chnmus.net).

考工記
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國有六職百工與居一焉或坐而論道或作而
行之或審曲面勢以飭五材以辨民器或通四
方之珍異以資之或飭力以長地財或治絲麻
以成之坐而論道謂之王公作而行之謂之士
大夫審曲面勢以飭五材以辨民器謂之百工
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江夏郭正域撰

Mechanical Technology and Instruments of China. Fig. 5 A page from the *Kaogong Ji* (from Hua 1997).

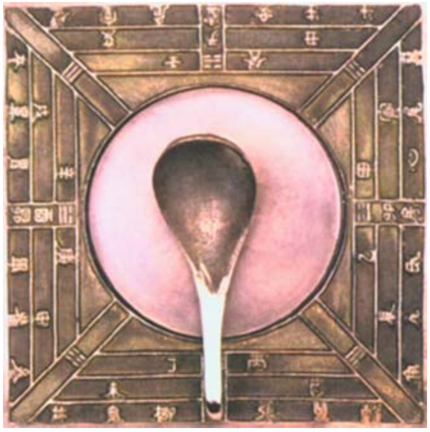
Mechanical Technology and Instruments of China. Fig. 6 A Western Han bronze clepsydra (from *Zhongguo Gudai Keji Wenwu Zhan*).

county, Henan province in 1978 and is the earliest known product cast according to the so-called "lost-wax process" (*shi la fa*) (Hua 1986: 231–232).

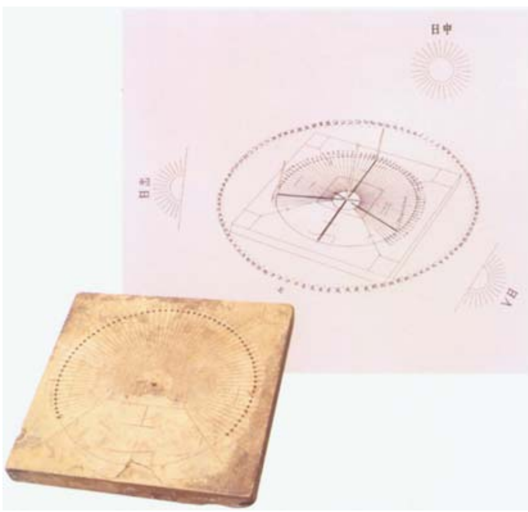
Ironware has been in use since the Spring and Autumn (Chunqiu) Period (771–476 BCE). The appearance and development of techniques for ironware casting made it possible to produce tools that were highly efficient. Techniques such as founding, forging, and softening that employed heat developed rapidly during this time, when many kinds of machines and devices, especially farm implements, were made from cast iron. In the Warring States (Zhanguo) Period (475–221 BCE), techniques for softening cast iron were developed.

The *Kaogong Ji* (Records of the Artificers, Fig. 5) is the earliest literary work on the techniques used in the handicraft industry in China. Most of it was compiled in the late Spring and Autumn and the early Warring States Periods, but some parts were added late in the Warring States. It includes information about how to manufacture carriages, weapons, sacrificial vessels, bells, and chime stones, as well as about architecture, hydraulics, dyeing, and techniques for other handicrafts (Dai 2003). Such problems as the elasticity of bows, rapidity of arrows, and stability of flight are also addressed thoroughly.

Many instruments for astronomy originated in early China. The gnomon, which utilizes directions and lengths of the shadow of the sun to determine south and north as well as the seasons, existed under the Shang and Zhou. Water clocks which measured time by means of the liquid were first developed in the Spring and Autumn or the Warring States Period (Fig. 6). An intact bronze clepsydra which was unearthed in Inner Mongolia in 1976 has a year engraved on it that dates it to the Western Han Dynasty (206 BCE–8 AD). Instruments utilizing lodestones that pointed to the geomagnetic poles were called *si nan* by the ancients



Mechanical Technology and Instruments of China. Fig. 7 A *si nan* (from *Zhongguo Gudai Keji Wenwu Zhan*).



Mechanical Technology and Instruments of China. Fig. 8 A solarium from the Han Dynasty (from *Zhongguo Gudai Keji Wenwu Zhan*).

(Jin 1999: 103). According to the reconstruction by Wang Zhenduo in Fig. 7, a natural lodestone shaped like a spoon was placed on a plate with the directions labeled, and the handle of the spoon when stabilized would point to the south. From the Qin or early Han Dynasty, the solarium with a graduated circle to indicate the time according to the position of the sun, and based on the gnomon, became widely used (Fig. 8). Furthermore, astronomical instruments such as armillary spheres and celestial spheres designed according to mechanical principles appeared in the Han Dynasty, and according to the *Tianwen Zhi* (Records of Astronomy) in the seventh-century *Jin Shu* (History of the Jin Dynasty), the armillary sphere and celestial

Mechanical Technology and Instruments of China. Fig. 9 Bronze chariots and horses, unearthed from Qin Shihuang's tomb (from *Qin Shihuang Ling Tongchema Fajue Baogao*).

sphere made by Zhang Heng during the Eastern Han Dynasty (25–220 AD) were of a fairly high level. The celestial sphere was in a closed box, was driven by water, and indicated the time that stars appeared and disappeared according to astronomical observations.

Mechanical technology during the Qin and Han Dynasties also progressed in other respects. The bronze chariots, warriors, and horses unearthed from the tomb of Qin Shihuang (r. 221–210 BCE) demonstrate a high level of mechanical fabrication, and their scales were one half of reality for the chariots and lifelike for the horses (Fig. 9). Even such details as the wheels that allow the chariots to move, the horse gear, and ropes were molded in realistic shapes. These artifacts are not only unrivalled throughout the world but also outstanding examples of mechanical engineering under the Qin. When hydraulic power came to be added to wind and animals as a form of energy in the Han Dynasty, water-driven machines and devices that included such mechanical breakthroughs as gears, cams, and toggle levers were created. Among the machines and devices were the waterpower reciprocator, hydraulic trip-hammer, south-pointing carriage, incense burner, and Zhang's armillary sphere and seismograph, all of which reflected quite a high level in mechanical engineering.

The earliest records related to bellows driven by water power are in the *Du Shi Zhuan* (Biography of Du Shi), in the fifth-century AD *Hou Han Shu* (History of the Eastern Han Dynasty), which notes that a water-power reciprocator (*shui pai*) had been invented, while the *San Guo Zhi* (History of the Three Kingdoms) records that Han Ji made *shui pai*. Besides an explanation of the structure of a *shui pai*, the *Nong Shu* (Book on Farming) by Wang Zhen includes illustrations to show the structure and how it operated. A *shui pai* (Fig. 10) included two horizontal wheels that were connected by a shaft, and when the lower wheel was driven by flowing water, the upper wheel rotated and, via a driving-belt, moved a pulley that was set with an eccentric lug or crank to move a connecting rod. This rod pushed two levers back and forth to make

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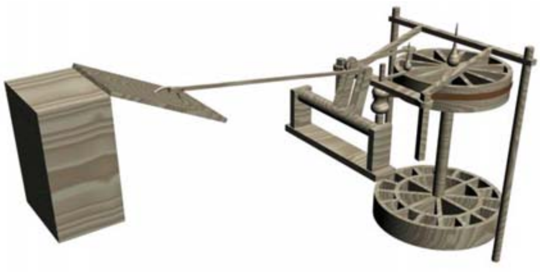
Fig. 10 Model of a south-pointing carriage (from *Zhongguo Gudai Keji Wenwu Zhan*).



Mechanical Technology and Instruments of China.
Animation 1. A *shui pai*.

a piston rod move. The effect was that the rotation of the lower horizontal wheel was linked to the reciprocating motion of the piston rod (Animation 1).

The south-pointing carriage (*zhi nan che* or *si nan che*) was said to have been invented by Huang Di – the Yellow Emperor – or Zhou Gong. In the *San Guo Zhi*, a person called Ma Jun from the state of Wei (220–265 AD) is noted as having manufactured a south-pointing carriage, while Zu Chongzhi, Yan Su, and Wu Deren are known to have made such a carriage later. Only for that by Yan, however, are there extant, detailed records about the shape and inner structure (Fig. 10).

The south-pointing carriage by Yan was driven by four horses and had two wheels and a rectangular wagon box. Inside was a gear linkage system that had nine gears in all, five serving as a transmission. In the box and connected with the other gears was a big horizontal gear, at the center of which stood a pole with a wooden person on top. Whenever the carriage moved, the hand of the person always pointed to the south, mechanically made possible by the automatic clutch system for the gears.

Mechanical Technology and Instruments of China.
Fig. 11 Model of a *li*-recording drum carriage (from *Zhongguo Gudai Keji Wenwu Zhan*).

Fig. 11 shows a drum carriage that recorded *li* (a distance of about half a kilometer) and was refitted from a drum carriage dating to the Han Dynasty. Mechanisms such as the decelerating drive gears and cam-and-lever devices were installed inside. As the carriage moved one *li*, the cam and a cord caused a wooden person to beat the drum with its right hand. The *Yu Fu Zhi* (Records of Carriages and Dresses) in the *Nan Qi Shu* (History of the Qi Dynasty) has a record of the *li*-recording drum carriage, the *Kui Tan Lu* (Records Ashamed of Tan) by Yue Ke of the Southern Song Dynasty (1127–1279 AD) records and explains how the gears worked, and the *Yu Fu Zhi* in the *Song Shi* (History of the Song Dynasty) has details about the devices and how motion was generated.

Zhang Heng is noted in the *Hou Han Shu* as having invented the machine known as "Chang's seismograph." According to the restoration by Wang Zhenduo, its inside structures include a pole, with a thick upper part and a thin lower part in the center, and eight curved levers around. The upper part of each lever is connected to the upper jaw of a dragon, whose lower jaw holds a brass ball. When the earth shakes, the pole falls down in the direction of the earthquake and presses the lower part of the corresponding curved lever, causing the upper jaw of the dragon to open and the ball in its mouth to drop down to a toad's mouth that is facing it. This makes it possible to recognize the direction from which the earthquake came (Animation 2).

Agricultural machines and implements developed rapidly during the Han Dynasty. The three-legged seed plow and the fan wheel (Fig. 12), which was a highly efficient processor of grain, were other noteworthy inventions. Other grain processing machines such as mills and trip-hammers not only appeared but also were improved. Mills with transmission gears and pestles driven by waterpower appeared during the Eastern Han Dynasty, and moldboards appeared under the Western Han, when the design of the plow was finalized. Hand reeling machines, looms, jacquards, and other important machines were also invented, while techniques for building ships during this period were highly developed. Such components of ships as sculls, helms, and sails became well established, and large ships with upper decks as well as warships were easily made at the time of the Han.

Mechanical Technology and Instruments of China. Animation 2. Chang's seismograph (from *Zhonghua Keji Wu Qian Nian*).

In this period, many kinds of machines and devices used natural rather than artificial power, and their operation changed from direct to indirect means. Transmissions of power and movement were completed by the machines and devices themselves, while the control of the machines by humans became indirect. Machines and devices such as the *shui pai*, pestles, and the *ma pai* (horse-powered reciprocator) were provided with three basic composite elements – prime motors, actuating mechanisms, and operating mechanisms – and their appearance demonstrates that the mechanical system had reached a high level of development. From the subsequent Three Kingdoms Period (220–280 AD) until the Yuan Dynasty (1206–1367 AD), the overall technical level of traditional machines and devices progressed considerably.

From the Three Kingdoms Period into the Sui (581–618 AD) and Tang Dynasties (618–907 AD), the techniques were substantially developed. Forged implements became dominant among the tools for farming, and as founding techniques developed, large-scale casts appeared. Progress was made in hydraulic machines, while the Jin Dynasty (265–420 AD) saw the appearance of automatic mill wheels (*mo che*), pestle-wheels (*chong che*), and water mills (*shui nian*). The water-lift chain-pumps (*fan che*) invented during the Eastern Han Dynasty were improved and popularized. Tools for irrigation such as a "noria for high lifts" (*gao zhuan tong che*; Fig. 13) were also invented, while the structure of the plow was improved under the Tang, and movable plow pan devices appeared. Shipbuilding techniques developed further, and paddleboats were invented.

Mechanical Technology and Instruments of China. Fig. 12 A fan wheel (from *Tiangong Kaiwu*).

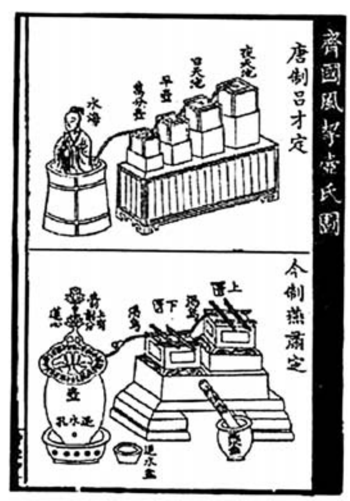


图1 《六经图》中的齐国风挈壶氏图

Mechanical Technology and Instruments of China. Fig. 13 A *gao zhuan tong che* (from *Nong Shu*).

Mechanical Technology and Instruments of China. Fig. 14 The "*Qi* Guo Feng *Qiehushi Tu*"(Illustration of the official who lifts the water clock according to the *Balladry* of Qi) in *Liu Jing Tu.*

Moreover, developments could also be seen in astronomical instruments. The *Tian Wen Zhi* in the eleventh-century *Xin Tang Shu* (New History of the Tang Dynasty) has detailed records about such an instrument designed by the monk Yi Xing and Liang Lingzan in the thirteenth year of Kaiyuan (725 AD). It had two wheel rings to represent the sun and the moon as well as a celestial sphere that was driven by waterpower. Two puppets inside marked the time by beating its drum and striking its bell. Earlier in the Tang Dynasty, Lü Cai (ca. 600–650 AD) had improved the water clock by adding several compensating clepsydras above the main clepsydra to make the time more accurate. Thereafter, Yan Su of the Northern Song Dynasty (960–1127 AD) created a lotus clepsydra (*lianhua lou*) which was widely used at that time. Fig. 14 shows the style of these water clocks as presented in an illustration in the *Liu Jing Tu* (Illustrations to the Six Classics) by Yang Jia and printed in 1153.

Incense burners made of silver or gold have been found in several tombs from the Tang Dynasty (Fig. 15). Among them are the elaborately constructed, elegantly encased ones unearthed at Shapo village, Xi'an in 1963 and from the Famen Temple in Shaanxi province in 1987. Incense burners were first recorded in the *Mei Ren Fu* (Ode to Beauty) of the Western Han Dynasty by Sima Xiangru (179–117 BCE) and the *Xi Jing Za Ji* (Miscellanies of the Western Capital) of the Jin Dynasty by Ge Hong (284–364 AD). There were two or three concentric rings between the outer shell and the hemispherical body for burning the incense in the center. This hemispherical body had minor axles at both ends of its diameter so that, supported by the two radial holes of the inner ring, it was capable of moving freely. The inner ring was supported by the outer ring, which itself was supported in the same way by the inner wall of the outer shell. The supporting axles for the body of the burner, the inner ring, and the outer ring were perpendicular to

Mechanical Technology and Instruments of China. Fig. 15 Incense burner (from Hua 1997).

M

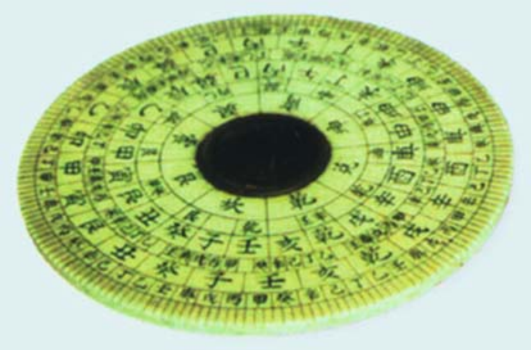
each other, and because of the force of gravity, the burner remained horizontal at all times regardless of how the shell rotated.

During the Song and Yuan Dynasties the development of traditional machines and devices in China peaked, and a great deal of progress was particularly made in those for agriculture. The plow colter (the cutting arm of a plow) appeared under the Song, and new farm implements like cramp irons (*tie da*) and hoof plows (*ta li*) were widely used while many kinds of hydraulic machines became more widely used. Among the monographs on agricultural machines that were published, the nonextant *Nong Qi Pu* (Book of Faming Implements) by Zeng Zhijin of the Song Dynasty discussed various kinds of farming implements. The *Nong Qi Tu Pu* (Illustrations of Faming Implements) in the *Nong Shu*, by Wang Zhen during the Yuan Dynasty, introduced and explained contemporary agricultural machines and many tools for production, making the work a base for later research and records. Weaving machines had also been developed, while the spinning wheels driven by waterpower, foot-powered wheels for spinning cotton, and other machines in the *Nong Shu* reflected the high level of such contemporary machinery.

Techniques for manufacturing weapons developed rapidly and included new weaponry such as tubular firearms and jet-fire arrows. While shipbuilding became more sophisticated, breakthroughs were made in instruments for astronomy to bring their traditional development in China to a peak. Among the different kinds that appeared were lotus clepsydras, Taiping armillary spheres (*tai ping hun yi*), "pseudo astronomical instruments"(*jia tian yi*), a water-driven astronomical clock tower, and "simplified instruments" (*jian yi*). Among the other important inventions at the time, typography, a two-way ram-acting air box, and cold-forging and cold-drawing techniques should be noted.

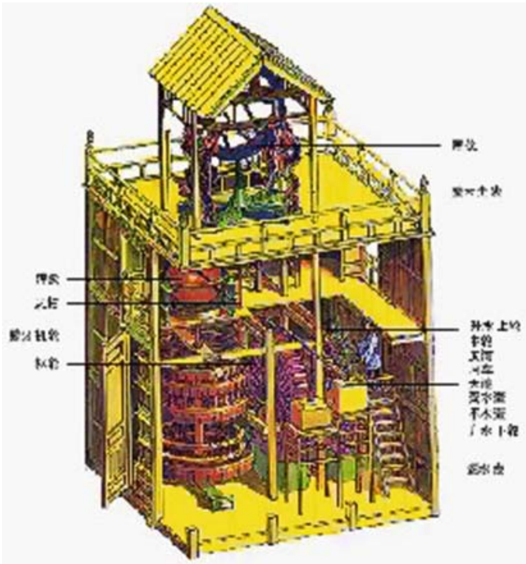
The magnetic needle was an instrument made by utilizing the property of lodestones to point to the geomagnetic poles. Early needles were simply made with natural lodestones and were improvements on the *si nan*. In the *Wu Jing Zong Yao* (General Military Principles), compiled by Zeng Gongliang in the early Northern Song Dynasty, is a record of how to construct a south-pointing fish that was precise whenever it was placed on a surface of water. The manual method of rubbing lodestones to magnetize steel needles was developed during the Northern Song Dynasty, when carved wooden south-pointing fish or tortoises with magnetized needles in their stomachs became rather popular. The dry land compass with a fixed point of support was invented in the Southern Song Dynasty, but water compasses which made use of buoyancy remained in general use (Figs. 16 and 17).

Mechanical Technology and Instruments of China. Fig. 16 A floating magnetic needle (from *Zhongguo Gudai Keji Wenwu Zhan*).

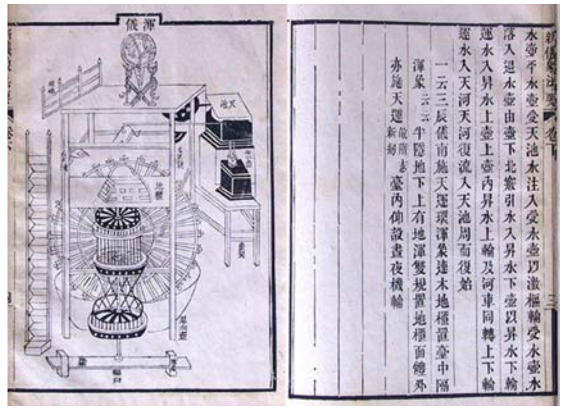


Mechanical Technology and Instruments of China. Fig. 17 An ivory water compass dating to the Qing Dynasty (from Jin 1999).

The water-driven astronomical clock tower in Animation 3 was the earliest astronomical clock in the world. Having included an armillary sphere, celestial sphere, and water clock, and being the work of Su Song in the seventh year of Yuanyou (1092), it was a square platform-like wood construction that measured about 12 m in height and 7 m in width. Its upper part was narrower than the lower part, and it had upper, middle, and lower layers. At the top was the coppery armillary sphere that illustrated observed celestial bodies, in the middle was the celestial sphere which marked about 1,400 stars and was used mainly as a planetarium, and at the bottom was the mechanism for indicating time. The machine was driven by a gear system which was assisted by chain drives (or a high ladder) and levers. "Celestial balances" (*tian heng*) and



Mechanical Technology and Instruments of China. Animation 3. Su Song's astronomical clock tower (from *Zhonghua Keji Wu Qian Nian*).



Mechanical Technology and Instruments of China. Fig. 18 A page from Su Song's *Xin Yixiang Fayao.*

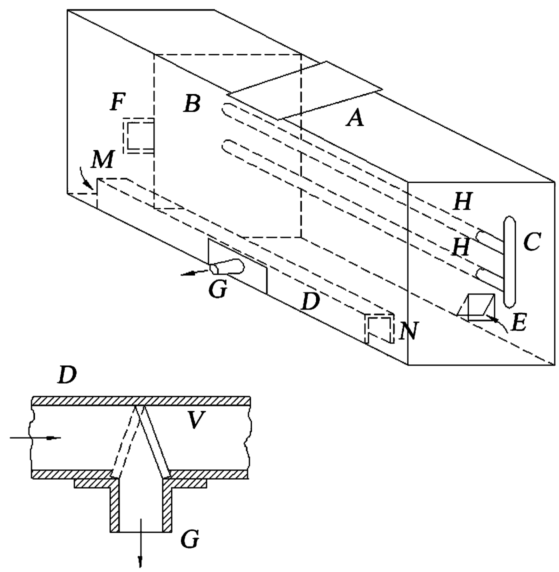
driving wheel (*shu lun*) comprised the coordinated escapement, which as a whole is regarded as a remarkable invention in mechanical history.

The driving wheel was the principal component of the clock tower, with 36 water boxes (*shou shui hu*) along the circumference. When the water in the box reached a certain weight, a series of control systems would be triggered, causing the driving wheel to rotate intermittently. The rotation was transmitted to the "celestial pole" (*tian zhu*) by the "terrestrial hub" (*di gu*), and then to the operating mechanisms by a drive system.

There was an escapement mechanism designed to keep the driving wheel rotating isochronally.

The astronomical clock tower was destroyed in the war between the Northern Song and the Jin in 1127. Fortunately, Su wrote the book *Xin Yixiang Fayao* (New Design for an Astronomical Clock, Fig. 18) after the instrument was completed in the early years of Shaosheng (ca. 1094–96 AD). Because it is the most detailed extant monograph on astronomical instruments and has illustrations of the clock tower as a whole as well as of its components, spare parts, and star images, it has been possible to recreate the astronomical clock.

The air-blast apparatus was first a leather bellows, then a *ma pai* and a *shui pai*, and finally an box-bellows with piston. As shown in Fig. 19, the piston-bellows was made of wood and had a blowing piston-board (B) in the middle and a square tube at the lower left. Two holes (M, N) were connected to the box, with a flow mouth (G) pointing outward in the middle. The free



Mechanical Technology and Instruments of China. Fig. 19 A box-bellows.

valve inside the tube could connect either part of the tube with the flow mouth freely, as illustrated below. The two free valves (E, F) at both ends of the box could only open inward, making the outer air flow into the box when the handle of the piston-board was pushed forward. Since the air behind the piston-board is of lower pressure, the air outside presses valve E inward and flows into the box. At the same time, the air in front of the board is of higher pressure, so valve F gets closed. The air before the board therefore flows into the tube and pushes the valve to move backward, causing the air to flow into the smelting furnace through G. As the handle moves forward and backward, the

Mechanical Technology and Instruments of China. Animation 4. How the box-bellows works.

higher-pressure air flows almost continuously and keeps the fire burning. Animation 4 shows how the box-bellows works.

The machines and devices of this period not only reached a high technical level, but they were also varied and many resulted from especially creative talent. Among their many makers were Ma Jun, Zu Chongzhi, Li Gao, Zhang Sixun, Yan Su, Su Song, Guo Shoujing, and Wang Zhen, and many Chinese machines and devices spread to other countries.

From the late Yuan Dynasty into the Qing (1616–1911 AD), there were a few developments in traditional machines and technology. Still, there were fewer great inventions in this period, although traditional mechanical technologies were still progressing. Cold-forging and cold-drawing techniques were improved during the Ming Dynasty (1368–1644 AD). The *Tiangong Kaiwu* (Exploitation of the Works of Nature) by Xu Guangqi records the cold-forging technique for making saws and the cold-drawing technique for making steel needles, while the many kinds of wrought products that existed demonstrate the development of forging techniques. In the Ming Dynasty there was one called “cold quenching,” which suggests that the understanding of quenching had advanced. Weapon-making techniques improved quickly as many kinds of weapons appeared and monographs on weapons such as the *Huolong Jing* (Book of Fire Dragon) and *Huolong Shenqi Zhenfa* (Array of Magic Instruments of Fire Dragon) were published, while shipbuilding continued to develop as China became a powerful maritime country. Furthermore, it was during this time that the hourglass, an important marker of time, was invented.

Toward the end of the Ming and into the Qing Dynasty, missionaries from the West brought Western science and technology to China. Machines and devices were also imported, and translations of works on machinery such as the *Yuanxi Qiqi Tushuo Luzui* (Illustrated Books of Western Magic Instruments) were published. From early in the eighteenth century to the 1840s, however, the Qing government opted for a policy of seclusion and broke communications with the Western world. The development of machinery in China then stagnated, and there were no notable inventions for more than a hundred years. Because it was at that time that the Industrial Revolution took place in the West, mechanical science and technology developed there rapidly and took the West far beyond the level of Chinese technology.

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Medical Ethics

Robert M. Veatch

The medical ethics of non-Western cultures are not as cleanly differentiated from the rest of their religious and cultural value systems as they are in the West. There the traditional medical ethic of organized professional medicine is summarized in the Hippocratic Oath and the tradition surrounding it. This ethic that guides health care professionals is often in conflict with religious and philosophical traditions that provide more general ethical frameworks. By contrast, in non-Western cultures, medical ethical questions are often addressed in the core ethics literature of the group, such as religious texts and philosophical writings.

The ancient cultures of Asia provide an example. Generally, they turn to classical texts for their medical ethical insights.

China

Although Chinese medicine has a history of at least 2,000 years, the first explicit medical ethical writing is usually attributed to Sun Simiao (also called Sun Simo, ca. AD 581–682). His "On the Absolute Sincerity of Great Physicians," which is part of the massive *Qianjin Yao Fang* (Important Prescriptions Worth a Thousand Pieces of Gold, or the Thousand Golden Remedies), is sometimes referred to as the Chinese Hippocratic Oath. Sun Simo, who is primarily associated with Daoist thought, but who also reflects Buddhist influences, is credited with differentiating medicine from more general social practices by demarcating a core group of "Great Physicians." This core group is held out as the normative ideal. The emergence of this concept of the great physician is thought to be the beginning of the professionalization of medicine.

Great Physicians practice the virtues of compassion and humaneness. They are committed to preserving life, a traditional Daoist moral orientation. In a manner typical of ancient Chinese medical ethical writings, but normally omitted from the Greek Hippocratic tradition, Sun Simo says that the Great Physician "should not pay attention to status, wealth, age, neither should he question whether the particular person is attractive or unattractive, whether he is an enemy or a friend, whether he is Chinese or a foreigner, or finally, whether his is uneducated or educated. He should meet everyone on equal ground" (Unschuld 1979). Paul Unschuld argues that this professionalization of the practice of medicine begins the effort to control the practice of medicine and its material and nonmaterial rewards.

About 150 years later, Lu Zhi (AD 754–805) provided a Confucian response in his *Luxuan Gonglun*. It also emphasizes the virtues of humaneness and compassion, but, according to Unschuld's interpretation, the classical Confucian perspective resisted the professionalization of medicine, holding that medical skills and knowledge should be distributed among all people, not just specialized professionals. The theme of the duty to treat all in medical need, regardless of status and concern over elitist professionalization, occurs throughout ancient Chinese medical ethics. In the seventeenth century Li Ting (fl. AD 1615) wrote his often cited *Ten Maxims for Physicians; Ten Maxims for Patients*, which repeats these themes, beginning with the necessity of mastering Confucian teachings. While the Daoist and Buddhist strands of Chinese thought have reflected strong prohibitions on killing, generally including condemning of abortion and insisting on prolongation of life, Confucian views have been more tolerant of such practices.

India

India, like China, incorporated its medical ethical teachings within its classical philosophical/religious literature. Among the Vedic texts, the *Āyurveda*, initially developed beginning in the first millennium BCE, contains the most important medical writings. Three such texts, the *Carakasaṃhitā*, the *Suśrutasaṃhitā*, and the *Vāgbhata*, include medical ethical writings. The first two also include oaths of initiation taken by students of medicine when they began their training.

The oldest, the *Carakasaṃhitā*, dates from the first century AD, but contains older material. Like the Hippocratic Oath, it requires the student to pledge loyalty to his teacher, to "dedicate thyself to me and regard me as thy chief." Reflecting Hindu reverence for animal species, it requires praying for the welfare of all creatures beginning with cows and Brahmanas, a large domestic fowl. In an unusual provision, though one understandable given the Hindu doctrine of karma, in which a person's conduct during the successive phases of his existence determines his destiny, the student pledges not to treat those "who are hated by the King or who are haters of the King," or those "who are extremely abnormal, wicked, and of miserable character and conduct." It also proscribes treating "those who are at the point of death." In spite of this reluctance to treat those who are dying, Hindu medical ethics stresses the importance of the proscription against killing.

The Hindu notion of *ahiṃsā*, the avoidance of suffering, is another central theme in Hindu medical ethics. It is sometimes interpreted as requiring caution in order to avoid injuring, a concern often reflected in Western medical ethics with its slogan *primum non nocere*, first of all do no harm.

Buddhist Culture

Some of these notions are also reflected in the Buddhist medical ethic of various Asian countries. The prohibition on killing, the concern about *ahiṃsā* and a commitment to veracity all contribute to the Buddhist tradition of medical ethics. These commitments are often in tension both with indigenous pre-Buddhist religious traditions (Confucianism and Daoism in China, Hinduism in India, and Shintoism in Japan) as well as with modern Western culture. Ratanakul (1988), commenting on the penetration of traditional Thai Buddhism by Western individualism, traces conflicts over four central themes of Buddhist medical ethics: veracity, noninjury to life, justice, and compassion. Hippocratic Western medical ethics has never manifested commitments to any of these until recent efforts have begun reflecting them at least in a modest way.

In Japan, Buddhist thought has provided the foundations for medical ethical thought. For example, in the sixteenth century a school of medicine, commonly known as the *Ri-shu* school, manifested classical Buddhist commitments. Students in this school were bound by *The 17 Rules of Enjuin*. Killing of any creature was proscribed. Even hunting and fishing were not acceptable. In contrast to the Hindu *Carakasaṃhitā*, the duty to rescue was extended even to those whom the physician disliked or hated. But virtuous acts were to be performed secretly so that they did not become known to people. Doing good deeds secretly was considered a part of virtue. In a fashion similar to the Hippocratic Oath, students were sworn to secrecy, being prohibited from disclosing any medical knowledge to outsiders. Unless a successor trained in this school was found, those of the Ri-shu school were even required to return all medical books to the school when a disciple ceased to practice.

In Japan, Buddhist medical ethics has survived in an uneasy tension with both modern Western thought and indigenous beliefs known as *kami no michi* (the way of Kami), or Shinto, according to the Chinese. For example, while killing is clearly condemned according to Buddhism, suicide and mercy killing receive more sympathetic assessment both by some proponents of the patients' rights movement imported from the West and by those reflecting traditional Shinto openness to *jyoshi* (love suicide) and *shinjyu* (group suicide). It is these latter influences that undoubtedly account for what could be called mercy killing in Japan.

The traditional influence is also seen in the resistance of Japan to the Western brain-oriented definitions of death. Japan is the only country that has not adopted such a legal definition. It is argued that the traditional Japanese notion of a life force penetrating the entire body clashes with Western notions of life related to brain or mental function.

The Near East

Near Eastern cultures have perspectives on medical ethics that date back at least to the second millennium BCE. Zoroastrianism of ancient Persia saw the physician as a force for good in the struggle between good and evil. It is suggested that this provides a foundation for a medical ethic that would oppose euthanasia. In both Assyria–Babylonia and in Egypt, suicide was proscribed. There are records of abortifacient remedies in ancient Egypt, but there is doubt concerning abortion's legality. It was, however, by the middle of the second century BCE prohibited by Assyrian law as it was in Persia.

The Babylonian Code of Hammurabi (1727 BCE?) provided stiff penalties for incompetent surgery. The surgeon's hand was to be severed if surgery was performed on a nobleman that resulted in death or loss of an eye. If death was caused by a medical procedure on a slave, the physician was obliged to replace the slave. This "sliding-scale" punishment was matched with a similar sliding-scale fee structure in both Assyro-Babylon and Persia. The higher the status of the patient, the higher the fee.

In Islam, medical ethics is grounded in the *Qurʾān*. A ninth century work, *Adab al-tabib* (Practical Ethics of the Physician, by al-Ruhawi) reflects the Islamic synthesis of Hippocratic, Greek, and Arabic medicine. In the thirteenth century an Arabic version of the Hippocratic Oath is found in *Lives of Physicians* written by Ibn Abī Uṣaybiʾah. Nevertheless, the core of Islamic medical ethics is explicitly grounded in the *Qurʾān* and its central teaching, "There is no god but Allah, and Muhammad is Allah's Apostle." This has sometimes given rise to a kind of fatalism in Islamic folk medical ethics. It is sometimes reported that Muslims oppose medical manipulations such as birth control for this reason. But a sophisticated ethical framework in Islamic medical ethics includes a rigorous commitment to the preservation of life, and opposition to all killing including killing for mercy and abortion.

> Whoever killeth a human being for other than manslaughter or corruption in the earth, it shall be as if he had killed all mankind, and whoso saveth the life of one, it shall be as if he had saved the life of all mankind (*Qurʾān* 5:22).

Islamic medicine, in contrast to Western Hippocratic medicine, is thoroughly theocentric.

This is reflected even in contemporary Islamic medical ethics. In January of 1981 Muslim scholars from throughout the world gathered in Kuwait at the First International Conference on Islamic Medicine. They produced the "Kuwait Document," a now-definitive Islamic Code of Medical Ethics. It contains 12 chapters outlining in detail Islamic positions supported by reference to the *Qurʾān*, culminating in "The Oath of the Doctor", a summary of the code. Among the prominent characteristics are a pledge to "protect human life in all stages and under all circumstances, doing my utmost to rescue it from death, malady, pain and anxiety." It also includes an exceptionless pledge of confidentiality that stands in contrast to the Hippocratic provision, which implies that some information ought to be disclosed to others. It also embodies a commitment to provide medical care for all, "near and far, virtuous and sinner and friend and enemy." Other chapters include an explicit recognition of the duty of the Islamic physician to society (a contrast to the exclusive focus on the individual in traditional Hippocratic medical ethics), further expounding on the sanctity of human life (including prohibitions on all abortion and mercy killing), and a full endorsement of the legitimacy of Islamic involvement in new biotechnological advances including organ transplantation. This last provision contrasts with the folk ethic that sometimes reflects a kind of fatalistic yielding to the power of Allah.

African Societies

Many African cultures have taken positions on matters related to medical ethics. Unfortunately, with the exception of ancient Egyptian views, relatively little is known about their specific medical ethical stances. In some sub-Saharan African tribal groups understandings of moral conduct related to life and death are closely tied to the religious culture (*Wiredu*). Since the cultures and languages are so diverse, it would be a mistake to assume that all African societies hold the same medical ethical views. Nevertheless some common patterns are reported. Although euthanasia is not widely discussed, it was and is reportedly practiced by family relatives for incurable and distressful mental illness and severe congenital malformations in many African societies. Likewise, abortion, though viewed with moral skepticism, appears to be practiced as it is elsewhere in the world.

Pre-Columbian Western Hemisphere

Among the most poorly understood medical ethical systems are those of the pre-Columbian Western hemisphere. There has never been any formal analysis of the medical ethics of the great Inca, Aztec, or Maya cultures or of the Native American tribal groups of North America. Most of what is known pertains to views about abortion, suicide, human sacrifice, and related practices.

The Incas viewed children as an asset, and, while abortion was known (by means of fetal massage, beatings, and special drugs), it was punished by execution of both the woman who aborted and those who aided her. Nevertheless among the Inca human sacrifice was practiced. Male children could be demanded for sacrifice, although the practice was apparently rare. Sacrifice of one's young children was reportedly a last resort to attempt to win the favor of the spirits. The yearly sacrifice of two infants was a part of the ritual of the most important temple. In contrast to Greek and modern infanticide, Inca sacrifices had to be of children without blemish.

Human sacrifice was also practiced by the Mayas, either by "heart-rending" or by throwing the one to be sacrificed into a cenote or large sink hole. The Mayas also offered sacrifices of their own blood by piercing their cheeks, tongues, or lower lips. The blood was considered to express "vital principles". Suicides were held by the Mayas to be sacred, deserving of their own special heaven. Human sacrifice was more common among the Aztec as it was in the society of the Caribs. By contrast in these pre-Columbian cultures, there are few reports of killings of either infants or adults for the purpose of euthanasia or the sparing of the afflicted. The close integration of religion, magic, and medicine in these cultures makes the differentiation of a uniquely medical ethic implausible.

Inca doctor–sorcerers, called the *camasca*, or *soncoyoc*, are said to have employed deception in their practice of medicine. They earned entrance into the profession by telling stories of vivid dreams or miraculous recoveries from fatal diseases. Once they had obtained the status of *camasca* or *soncoyoc*, they staged dramatic procedures. One example is surgery in which the doctor would claim that he had removed worms and stones – the supposed causes of disease – from the patient's body, when in actuality, he had recovered said items from no other place than his own pocket, using sleight of hand to make it seem as though they were being extracted from the body. In addition, the Inca physicians would create mixtures of herbs that they claimed to be deadly, in order to generate fear – and revenue – from their clientele. Despite all of this activity, to kill with magic charms was considered a serious crime. Like healers in many cultures, the practitioners were very exclusive about the practice of medicine, claiming that only they, the chosen ones, could practice it properly. Another source says that in some tribes, as in ancient China, herb healers were family based, and all professional information as to the nature of different herbs was kept as a family secret.

Medical ethical stances are derived from more general systems of ethics and belief. It is not surprising then to find that there are as many medical ethical systems as there are systems of ethical thought. To say that behavior in the medical sphere is ethical is, after all, simply saying that the behavior is ethical – at least according to some standard of ethics. Even those practicing medicine within Western culture will inevitably encounter patients who come from other cultures whose medical ethical values and beliefs may be quite different. Only by knowing the range of medical ethical systems will one's own positions be brought into focus.

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Medical Ethics in China

Angela Ki Che Leung

For most pre-modern civilizations with a certain degree of cultural sophistication, medical ethics were strikingly similar: hard work and concern for the poor and needy. A good doctor not only excelled in his medical skills, but also cared for the sick and poor. Material benefits should not be his major pursuit. In the West, such tenets naturally conformed to Christian morality; in China, Confucianism, Buddhism, and Daoism mostly contributed to the formulation of such ethics.

Despite the universality of these basic ethical requirements, there were specific features in the historical development of Chinese medical ethics which can be said to have gone through several stages of formation: the mythical period of Antiquity (ca. 771 BCE–AD 265); the period of Buddhist and Daoist influences of the early medieval era (265–960); the period of medical professional maturity of the late medieval era (960–1368); and lastly the late imperial period of Confucian influence (1368–1911).

In the period of Antiquity some of the basic tenets of medical ethics were put forward. From some of the earliest records of Chinese oracle bone writings and other texts, we know that medicine was then mixed with divination and magic. The shaman/doctor had a relatively high social position and a respectable one should, according to opinion of the time, have the quality of perseverance or stability (*heng*).

With the gradual emergence of professional doctors around the sixth century BCE, clearer notions of medical ethics appeared. In the *Huangdi Neijing* (Yellow Emperor's Inner Canon) attributed to the mythical Yellow Emperor, the basic medical classic compiled throughout a period of not less than 400 years beginning in the Warring States period (475 BCE–221 BCE), qualities such as erudition, rich experience, wisdom, humility, and hard work were evoked as necessary for a good doctor. Renowned doctors of this period were reputed to have most or all of such qualities.

Another major quality said of the early doctors was their concern for the poor and lowly. They did not only cure the wealthy and the powerful, and profit was never their major pursuit.

Prominent doctors of this period, such as Bian Que (fifth century BCE), Chunyu Yi (b. 205 BCE), Zhang Zhongjing (second to third centuries AD), and Hua Tuo (d. ca. 208), were later to be venerated as deities of the medical profession, and symbolized the very virtues of good doctors. The deification of these doctors, especially Hua Tuo, was based not only on their exceptional medical skills, but also on their outstanding and legendary morality.

In the Early Medieval period, Buddhism and Daoism had a marked influence of, not only on medicine itself, but also on medical ethics. For many modern historians of Chinese medicine, true medical ethics were not systematically composed in China until the seventh century, when one of China's greatest doctors Sun Simiao (also called Sun Simo, 581–682) wrote systematically on the duties of a physician in his book *Qianjin Bao Yao* (The Thousand Golden Remedies). In this work Sun not only reiterated the qualities already mentioned for model doctors of Antiquity, but also emphasized the importance of retribution as a safeguard for good virtues: "Lao Zi, the father of Daoism, said, 'Open acts of kindness will be rewarded by man while secret acts of evil will be punished by God.' Retribution is very definite. A physician should not utilize his profession as a means for lusting. What he does to relieve distress will be duly rewarded by

Providence." The notion of retribution, though here thought to be essentially Daoist, was in fact much influenced by Buddhism in this period.

The medical ethics put forward by Sun Simiao reflected other aspects of Buddhist–Daoist influences: to attend to all patients equally, disregarding their social and economic position, their age, and their physical appearances. Enemies and friends, foreigners and Chinese, the stupid and the wise should all be treated alike. All these categories should be considered as one single, general class by the doctor. This "equality" before medical care was something unfamiliar to Confucian morality but which has remained significant in medical ethics since the seventh century.

In the Late Medieval period, Chinese medicine reached maturity, both as an institution and a clinical art. The formal division of medicine into different branches or specialties (notably *fuke*, the branch of medicine specializing in women's diseases; *erke*, in children's diseases; and *waike*, in bone fractures and operations) implied a finer division of labor amongst physicians, and this was also reflected in a more elaborate and systematic training program for officially approved doctors in this period, and increased state intervention in the management of medical resources. Though some scholars think that in this period medicine was "a respectable field of study…but as a career and mode of life was highly controversial," one can still see the emergence of a certain medical professionalism, and with it, new elements in medical ethics.

One such element was the frequent caution against *yongyi* (common practitioners). The term was frequently evoked in Song medical texts. A *yongyi* is the antithesis of a *liangyi* (fine doctor), comparable to a *liangxiang* (fine minister). This comparison was first put forward by the famous Song minister Fan Zhongyan (989–1052), who had once considered becoming a doctor himself. The medical profession in the Song period took greater pains than before to draw lines between good and bad doctors, reflecting the emerging professional consciousness of doctors of the period.

However, the reputation of a fine doctor was not entirely based on his curing skills. A fine doctor now combined the religious selflessness and charity of the early Medieval period, as well as neo-Confucian ethics. One of the greatest *fuke* specialists of the Song, Chen Ziming (1109–1270), wrote that he came from a family of three generations of doctors, with an excellent private library of medical books. But his appetite for prescriptions and medical texts was so large that whenever he traveled in the southeast, he collected large quantities of texts which he studied in his free time. Obviously, a good doctor was now likened to a good Confucian scholar, for whom family tradition and textual learning were considered essential for professional success.

The increasing influence of Confucian morality on medical ethics was yet to be seen in the late imperial period. This was a period of relative political continuity and economic prosperity, accompanied by a significant growth in medical knowledge. However, this period was not one of institutional renovation and regulation in medicine. Consequently medical professionalism, in the sense of the maturation of a completely independent professional category, might have suffered. As Unschuld (1979) has said, "The Chinese physician as a definable entity did not exist." The respectability of a physician was, besides his curing technique, increasingly linked to Confucian morality.

One prominent sixteenth century physician, Xu Chunfu (1526–1596), wrote in his major work *Gujin Yitong Daquan* (Medical Tradition of the Past and of the Present) that "Confucianism and medicine cannot be separated." His contemporary, also a famous doctor, Gong Tingxian (1522–1619), put forward ten requirements for physicians, the first two being to cherish kindness and to understand Confucian principles. Another doctor, Li Ting (d. 1619), in his *Rules for Medical Studies* stated from the outset that, "Since medicine comes from Confucianism, unless one studies and understands the [basic] principles, one remains mediocre, vulgar and stupid…" At the same time, detailed instructions on treating female patients were increasingly provided in order to avoid transgressing the Confucian principle of the separation of the sexes.

However, it was also prominent "Confucian doctors" of this period that further defined medical ethics in more systematic ways. The above-mentioned Xu Chunfu was among the first to list the main "vices" of *yongyi*, including taking on the appearances of good doctors with a few tricks, extorting money out of patients, and freeing themselves of responsibility by any means in case of misdiagnosis leading to death. Another famous doctor of the seventeenth century wrote the first Medical Code in 1658. Yu Jiayan (ca. 1585–1664) wrote detailed technical diagnostic guidelines for professional doctors. He made the doctor responsible for all avoidable diagnostic errors, and in so doing, attempted to draw a clearer line constructed on technical considerations between a *liangyi* and a *yongyi*. In other words, development, though limited, was still perceptible in the professional consciousness of doctors despite the overwhelming influence of Confucianism in this period.

However, the incomplete growth of an autonomous medical profession inevitably left areas of ambiguities in medical ethics. One such is the transmission of "secret prescriptions." For some historians of medicine, "the dispensing of secret prescriptions was never considered to be unethical in China. Some even deemed it an honor for a physician to know a secret formula." However, there are indications that not all approved of this attitude. Among others Xu Youzhen (1407–1472), a scholar-official, accused contemporary doctors of preserving secret prescriptions for private profit. For him, effective prescriptions should be published in order to save more lives and to be passed onto posterity. An early nineteenth century physician, Bao Xiang'ao, wrote in the preface of his compilation of "effective prescriptions" that those who did not make effective prescriptions public were despicable.

This ethical ambiguity of the necessity of keeping prescriptions and healing techniques secret obviously was a consequence of the basic structure of the medical institution in late Imperial China: the lack of centralized control in the production of medical knowledge, either by the state or by a self-regulatory medical corps, and the accompanying uncontrolled distribution of medical resources in society. Each family or school of medicine thus had to preserve its share of the resources in order to be competitive in the field, though morally such an attitude was obviously questionable. Such a characteristic only encountered effective challenge when western medicine was introduced into China in the late nineteenth century, together with its ethics and institutions.

See also: ►Bian Que, ►Sun Simo, ►Zhang Zhongjing, ►*Huangdi Neijing*

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Medical Ethics in India

Prakash N. Desai

The origins of medicine in India stretch back to antiquity. The Harrapan city culture flourished in and around the Indus Valley ca. 2500 BCE; it is known for its elaborate bathhouses and drains and sewers built under the streets leading to soak pits. In the second millennium BCE, the northwestern parts of India were host to a series of Indo-European immigrants and invaders from Central Asia. With them began the classical culture of India. Vedas, the sacred lore of the Indo-Europeans, celebrate the *Bhesaj*, one knowledgeable in medicinal herbs. One of the four Vedas, the *Atharvaveda*, contains many chants, mantras, and herbal preparations to ward off evil, enemies, and diseases. The priest–physicians prescribed preparations of plants and herbs, and prayers and fasts for their patients. The Indian medical tradition, *Āyurveda*, meaning the science of vitality and long life, is considered a limb of the *Atharvaveda.*

A more formal system of medicine evolved from around the time of the Buddha (ca. 500 BCE). It became organized in textual form in the first century AD, and reposes in a vast body of literature redacted and updated from that time to the present. There are six principal texts of the Āyurveda. The older three are the two compendia, *Carakasaṃhitā* and *Suśrutasaṃhitā*, named after the two legendary physicians, Caraka and Suśruta, and the *Aṣṭāṅgahṛdaya*, the eightfold essence attributed to an eighth century physician named Vāgbhaṭa. The younger three are the *Mādhavanidāna* (ninth century), *Śārṅgadharasaṃhitā* (thirteenth or early fourteenth century), and *Bhāvaprakāś* Bhāvamiśra (sixteenth century). The word *caraka* also means one who moves about, and may have referred to the itinerant Buddhist and Jain monks who played a pioneering role in the evolution of the Indian medical tradition. In the realm of King Aśoka (273–232 BCE), who embraced Buddhist ideals, Buddhist monasteries served as institutions, like hospitals and hospices, for the care of the sick and the dying.

The earliest medical writings known as the Bower manuscripts, discovered in a Buddhist Stupa in Kashgar (modern China), and translated by Rudolph Hoernle, are considered to have been written by Buddhist authors around AD 450. These texts contain medical treatises which describe the virtues of garlic in curing diseases and extending the life span, elixirs for a long life, ways of preparing medical mixtures, eye lotions, oils, enemas, aphrodisiacs, and procedures for the care of children. Early Indian medicine was carried to Tibet along with Buddhism and was best preserved there, as well as in China. Travelers to and from China, Greece, Persia, and Arabia contributed to the spread of Indian medicine outside India.

The basic assumptions of Indian medicine are rooted in the religious and philosophical traditions of India. Early developments exhibited great diversity in opinion and formulation in keeping with the diversity in Indian thought, tied to Hindu, Buddhist, or Jaina philosophies in various measures. Similarly the system allowed for significant geographic variation as knowledge spread through the subcontinent over a long period of time.

The medical ethics which are closely linked to these religious and philosophical perspectives (*darśanas*) reveal variable, shifting, and accommodating attitudes.

Āyurvedic constructs of the body and the self, central to the medical enterprise, grew in tandem with the faith traditions. The primary vehicles of ayurvedic pathophysiology are the *doṣas* (humors): *vāyu* or *vāta* (wind), *pitta* (bile), and *kapha* (phlegm), and the *dhātus* (body substances). The three humors represent movement, heat, and moisture, respectively, in the body. The primary body substance, *rasa*, organic sap, is derived from food, moves throughout the body, is stored in various reservoirs, and is finally excreted as waste products. In processes of sequential transformation, the *dhātus*, flesh, fat, bone, marrow, and semen, are derived, semen being the purest and most vital product of this process.

The Indian system of medicine views health as a state of balance of body substances, *dhātusamya*, and illness as a state of disequilibrium. The body responds to many kinds of inputs: physical, as in food and drink, psychological, as in emotions of anger or jealousy, and social, as in affection, praise, or scorn. Each input is a potential source of a disease or a cure.

The theory of *guṇas* (lit. strands or qualities) introduces the notion of ethics as a material basis in the ayurvedic pathophysiology. Inherent and substantial, *sattva* (goodness), *rajas* (vitality or activity), and *tamas* (inertia) are qualities or traits found in all substances in various combinations. The balance determines the overall dispositions of persons, foods, activities, bodily substances, and so forth. *Sattva*, which is cool and light, produces calmness, purity, or virtue; *rajas*, which is hot and active, produces passion, happiness, or sorrow; and *tamas*, which is dark, heavy, and dull, produces sloth, stupidity, and evil. Contemplation, meditation, silence, devotion, and fasting promote goodness; love, battle, attachment, pleasure seeking, and emotionality enhance vitality. Sleep and idleness increase inertia. In a hierarchy of values, the *sattva* categories reign supreme and become less material, closer to the idea of *sat* (truth or essence), and often the same as the mind or self. The object of the therapeutic is to transform a person from lower to higher strands or qualities, which is accomplished through the prescription of foods and activities which build goodness. Thus the therapeutic and the ethical become coterminous.

In the Indian view life is not the opposite of death; birth is the opposite of death. Life begins when an embryo is formed out of the union of male and female germinal substances. Defining when human life begins was neither easy nor uniform and straightforward. Some texts maintained that life began with the aforesaid union, and others at the moment of quickening or the descent of the fetus into the pelvis; the latter was more frequently understood as a point of viability. Abnormal pregnancies, congenital deformities, multiple pregnancies, and infertility were explained in terms of defective germinal substances, unnatural coitus, failure in nourishment, or disturbances in humors in the mother or the fetus.

Among the religious obligations, having male progeny was imperative in order to secure a passage to the land of forefathers through the performance of funerary rites. In situations in which a woman failed to have a son, the man was to take another wife, or otherwise adopt a son. If the problem appeared to be male impotence or infertility, the husband's younger brother or another suitable man was to impregnate the wife (a custom called *niyoga*). Early medical texts elaborate on the ways of enhancing conception, and later texts discuss problems of contraception. Mythology also testifies to in vitro fertilization and embryo transfer.

The *Suśrutasaṃhitā* describes various forms of arrested fetal development or obstructed deliveries and describes ways of inducing labor and/or destroying the fetus, especially in the case of danger to the mother's life. A seventeenth century text also describes ways of inducing labor for purposes of abortion in cases of women in poor health, widows, and women of liberal morals.

In contemporary problems of medical ethics, no problem has caused as much furor as has amniocentesis. Preference for a male child, with an easily available technology to determine gender prenatally, has resulted in inordinate and indiscriminate use of abortions. Some states in India have enacted laws to restrict the scope of indications and use of amniocentesis.

There are three categories for the etiology of diseases in *Āyurveda.* External or invasive diseases are caused by foreign bodies, injuries, infestations, and possession by evil spirits. Internal diseases are disturbances of humors, in part caused by lapses in discretion, as in faulty or unseasonable diets, overexertion, sloth, sexual indulgence, or mental disturbances. In either case, the final pathway for the pathology of a disease is an imbalance of humors. The third category contains the diseases which are the fruits of *karma*, the operative principle of Hindu ethics. A very simple explanation might be "every action has a reaction" or "as you sow, so shall you reap," but the logic extends beyond one life. In *karma* theory, when a person dies his self moves to the other world, enveloped in the part material and part ethereal covering which carries the traces of all actions performed, and comes to determine its condition in the next life. Thus some diseases are the fruits of actions from past lives. The unseen hand of *karma* is invoked to explain the not so easily explicable. Events like epidemics and disasters are a result of bad actions of a whole community or the actions of a king.

Mental illnesses also arise from these etiologies: possession states, disturbances in humors, and lapses in discretion. Some disease states are also seen as the workings of time, as in aging.

Physicians in ancient India did consider *karma* in etiology, but they agreed that the passivity that results from assumptions of predetermination made the whole medical enterprise meaningless. Human effort was always a factor in the workings of *karma*, and caring and healing must be actively pursued by the physician. There was also a recognition of incurable diseases, in the face of which human effort was futile. The physician was prudent if he avoided heroic efforts to prevent the inevitable, which not only led to loss of income but also loss of prestige. If the case was hopeless, the physician was to do no more than attend to the nutrition of the dying patient, and even that might be withdrawn at the request of the family.

A category of "willed death" was also recognized in the various religious traditions and was understood to be different from suicide. Suicide was regarded as an act of desperation and willed death an act of determination. It involved permission of the religious order and was resorted to only when the quality of remaining life was likely to be poor.

The ayurvedic physician, called a *vaidya*, was esteemed for his powers but also shunned because of his contact with impurities such as body products, suppurative lesions, and corpses, and his mingling with common people. Taboos around touching ultimately resulted in palpation falling into disuse.

The physician was enjoined to strive constantly to acquire new knowledge, advance through practical experience, and enter into learned dialogues with practitioners from other places. His education began as an apprentice, with the teacher and pupil choosing each other. A good teacher was free of conceit, greed, and envy, and a student had to be calm, friendly, and without physical defects. Later on the *vaidya* became a subcaste or occupational division, and the profession passed from father to son.

The *Caraksaṃhitā* contains an extensive list of ethical directives in the form of an oath to be taken by one entering medical practice. Among these were injunctions never to abandon a patient even if that interfered with one's livelihood, to be modest in dress and conduct, gentle, worthy, and wholesome. A physician must not enter a patient's house without permission, and be mindful of the peculiar customs of a household. He was to avoid women who belonged to others and maintain confidentiality.

Quacks and charlatans were known by their pretense and arrogance, boastfulness and superficial knowledge. The fate of their patients was worse than death. The *Caraksaṃhitā* says that one can survive a thunderbolt but not the medicine prescribed by quacks.

Medical ethics was an integral part of ancient Indian medicine. The texts addressed ethical issues that arose at both ends of life, birth and death. Their approach was pragmatic and flexible, and the purpose of alleviating an illness was always considered in the context of geographic locale, time (the era and the stages of a patient's life), and the particularities of a person. The physician's conduct was also to be always above reproach both in his professional and personal conduct.

See also: ►Medicine in India, ►Caraka, ►Suśruta

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Medical Ethics in Islam

Azim A. Nanji

The ethical assumptions underlying the practice of medicine in Islam are inspired by two foundational texts: the *Qurān*, the divine message revealed to the Prophet Muḥammad; and the *Sunnah*, the paradigmatic life of the Prophet Muḥammad which complemented and exemplified the Quranic message. A secondary source of influence resulted from the Muslim conquest and expansion of the seventh to the eleventh centuries, when the cultural and scientific heritage of Antiquity was translated into Arabic and came selectively to be appropriated, refined and developed by Muslims. The integration of this heritage into Muslim civilization led to a new synthesis, not only of the science of medicine but also of the moral values supporting it. Although some of the medical traditions and values of Antiquity were sustained, they were set in Islamic contexts which allied their meaning and purpose to different goals.

The early centuries of Islam also represented a tremendous flowering of intellectual sciences. Muslims were encouraged by their faith and by the *Qurān* to engage actively in the pursuit of knowledge. This impetus translated itself into significant advances in the study of the natural sciences, cosmology, geography, mathematics, history, law, languages, and medicine to name some of the major disciplines. The emergence of Muslim medical ethics has to be situated within this matrix of scientific interest and intellectual commitment.

Muslim views regarding medicine evolved from that of a predominantly Arab cultural setting to that of a diverse and cosmopolitan civilization. The reconstruction in Muslim thought of a prophetic medicine, emphasizing the spiritual dimension and the role of faith in healing, represented an attempt to associate with the Prophet those practices of human life and healing promoted by the rise of a tradition of scientific medicine. The perception of Muslim adherence to prophetic medicine has often been misconstrued as promoting a kind of fatalism, but it would be misleading to extend this interpretation to the whole spectrum of medical ethics and values among Muslims. Prophetic medicine developed alongside professional medicine, which cultivated its own frame of reference for integrating ideas.

Adab is the Arabic term that best describes the pattern of medical ethics and conduct which evolved as a result of the synthesis of the Islamic message and Hellenistic thought. The term represents a set of cultural and moral assumptions articulating the linking of knowledge to appropriate behavior. Ishāq ibn ʻAlī al-Ruhāwi, a ninth-century Christian physician, translated one of the earliest texts dealing with medical ethics into Arabic. His work already reflects the vocabulary of Islam and a heritage of Prophetic religion integrated within a moral framework attributed to Galen and the ancient philosophers. According to al-Ruhāwi, medicine is a divine art granted to humanity by the Creator, whose healing role the physician imitates. Prayer, as the first and last act of the day, is recommended as part of the personal conduct and moral beliefs of physicians.

Within the larger harmony of moral and religious principles is the ethical concept of moderation. Muslim medicine did not accept the body/soul distinction of the Greek tradition but conceived of human beings as entities formed in symmetry and harmony. One of the most illustrious physicians of early Muslim history, Abū Zakariya al-Rāzī (Rhazes) argued for a healthy, moral life based on moderation between excessive indulgence and abstinence and an adherence to a life of knowledge pursued to balance physical, moral, and intellectual needs.

The *Qurān*'s message of social justice, developed into the notion of public welfare and charitable works toward the poor, influenced medical values in ways quite different from that of the Hippocratic tradition. The hospital, founded through royal acts of patronage or endowments, is an Islamic institution traceable to the eighth century. This larger social role, engendered by Islamic values of concern and care for the indigent, represents perhaps one major difference with the practice of Antiquity, where the emphasis lay mostly on the physician's concern and relationship with an individual patient.

The rise of the physicians and the medical ethics that guided the emergent profession in Muslim society cannot be separated from the general tenor of the civilization and the polity that had emerged after the founding and spread of Islam. The moral discussions and intellectual forces that emerged stimulated a concern for how moral and religious perspectives could be reconciled with intellectual modes of inquiry. But professional medicine was only one of several therapeutic systems available. As Sufism, the mystical and spiritual dimension of Islam, grew in influence and became institutionalized through a system of orders, the heads of these organizations came to be regarded as having the power to intercede in moments of crisis, including disease. In time this led to an extensive use of amulets, granting of prayers and recitations from the *Qurān* as aids to healing. Such traditions and practices came to occupy a relatively prominent place beside that of professional medicine during the premodern period, and continue to be influential in many Muslim societies.

Whereas the eighteenth and nineteenth centuries marked a new impulse in medical and ethical thinking in Europe, the events leading to the encounter of modern Western culture and political power with the world of Islam created a different context for the assimilation and practices of modern medicine. Muslims were faced with new tools and methods of healing which called into question all of the normative assumptions that previously had been integrated into their *adab* of medicine. The institutionalization of Western medical practices also resulted in moral and ethical consequences. Muslim responses reflected all of the ambiguities in the face of the challenge the new authority and its civilization brought. For some, Islam would serve as a moral sanctuary from which to combat secular ways of staving off disease. For others, it led to an acceptance of modernity and provided the impulse to shape it in conformity with the sources and perceptions of their past heritage. The process of change as it affected medical practice and value thus cannot be separated from the larger issues entailed by the colonial encounter and the patterns of medical education and practice, as well as attitudes to disease and healing that came in the wake of Western contact and influence. The measures instituted through European doctors and medicine eventually received acceptance by a new generation of professional physicians and led to the assimilation and emulation of the new practitioners and their values. The duality that resulted caused a failure to ground the new training and knowledge within Muslim theological moral and cultural contexts and separated the "new" physicians from traditional counterparts and their moral world. In many ways, this sense of duality and the effort to recover the center constitute the story of ethical issues facing twentieth and twenty-first century Islam. The most important challenge however remains the formulation of an *adab* that will guide the practice of medicine while remaining engaged with its past ethical underpinning and taking account of the dramatic changes brought about by population growth, poverty, and national policy.

In the field of medicine as in other scientific and technological areas, Muslims are faced with complex choices and newly emerging issues that raise moral dilemmas. There is a greater need to harness resources that advance skills in moral reasoning and enhance sensitivity, and to integrate these into perspectives of medical education, institutional development and the Islamic commitment to ameliorate poverty and disease.

See also: ►al-Rāzī

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Medical Paintings of Tibet (*Sman thang*)

Zhen Yan

Sman thang is the abridged form in the Tibetan language for Tibetan medical painting, in which *Sman* stands for medicine, while *thang* refers to *thangkha*, a hanging scroll commonly mounted on a piece of silk with vignettes of various backgrounds.

There is no definite conclusion as to exactly when the *Sman thang* appeared in history. However, in so far as the painting art of *thangkha* is concerned, there are some studies written by scholars outside China. The prestigious Italian Tibetologist, G. Tucci, provided very detailed descriptions on these works of art (1949).

Generally, it is claimed that the *thangkha* originated from religious demand, beginning with the painting of Buddhist icons. The paintings, in addition to the main Buddhist icons, provided contrasts with other items such as clouds in the sky, trees, birds, or beasts; later, landscape painting also appeared. Such primitive religious paintings were owned by lamaseries, and were hung in the Buddhist hall for worship by monks and devotees. Sometimes, the secular population also used them when storytellers were narrating their tales, so as to keep the attention of the audience and strengthen its attraction. Scholars claimed that the modern *thangkha* was systematized and flourished under the auspices of the Sa skya sect of Lamaism from the thirteenth century. This is based on Tucci and Pal's descriptions. The provenance of Tibetan medical *thangkha* might be so early, based on our investigation on the whole series of modern *Sman thang* and the in-depth study of the history of Tibetan medicine as a whole.

In the mid-seventeenth century, during the reign of the fifth Dalai Lama, because of the diversity of various patterns and styles of earlier *Sman thang* painting, there are differences regarding the recognition of Tibetan drugs, therapies, and moxibustion points. The Regent of Dalai Lama made up his mind to rearrange and systematize the existing *Sman thang*. After approval by the Dalai Lama, Sde srid sangs rgyas rgya mtsho used his *Baidurya sngon po*, the most prestigious commentary on the medical canon, *Rgyud bzhi*, as a basis, and painted a new whole series of *Sman thang*. Altogether 60 paintings were completed in the year 1688.

But the Regent was not satisfied, considering there was a need to further expand the series. With the members of the original team, based on some new materials, including the diagnosis and points for moxibustion included in *Sman dpyad zla ba'i rgyal po* of the Tubo Dynasty, drugs newly discovered and applied to different points and vessels for moxibustion and bloodletting in both Northern and Southern Schools, new *Sman thangs* were drawn. Ultimately, in 1703, the total number increased to 79. This might be the mother *Sman thang* series of modern colored *Sman thang* series.

When the fifth Dalai Lama died, 50 of the paintings were used as funeral objects and buried in the *chod rten* (mausoleum), since they had been viewed as treasures by the ruling class. New versions were duplicated during the reigns of the sixth and seventh Dalai Lamas.

The 13th Dalai Lama (reigned 1895–1933) also treasured the *Sman thang* series, which were reproduced, either individually or in a series, in 1918, 1923, and 1933 separately.

In 1923, the then director of the Sman rtsi khang (now Traditional Tibetan Hospital of Tibet Autonomous Region) painted a new *Sman thang*. Being the 80th in the whole series, this *thangkha* is very unique and different from the others. It is entitled "famous physicians of successive ages." Altogether 12 physicians are included. On the back of this *thangkha*, the date of printing was given, which was never seen in the previous ones.

The total number of the whole series of *Sman thang* is 80. It deals with the whole picture of Tibetan medicine based on the *Baidurya sngon po*. This includes the history of Tibetan medicine, the physiology, anatomy, pathology, diagnostics especially pulse taking and urinalysis, medical instruments, all clinical aspects, including the causes, manifestations, treatments of all diseases in internal medicine, sensory organs, gynecology, pediatrics, dermatology, Tibetan *materia medica*, recipes, drug forms, all sort of therapies, medical ethics, and macrobiotics.

All paintings in the current series were not painted at the same time, so the paintings in the whole set are not identical in their sizes. Some might be smaller, others bigger, measuring 75.0–86.0 × 58.0–68.0 cm in size. All the illustrations contain vivid Tibetan characters, architecture, clothes, natural scenes, and folk vignettes. A few special points need to be pointed out here.

First, the reader can learn the wisdom of the ancient Tibetan people and their customs and habits. The paintings contain such elements as national clothing, especially the special hairstyles and decorations with which comparative studies on clothing of ancient and modern periods can be made.

The expression of the Tibetan language throughout the *Sman thang* is unique. As shown in the second, third, and fourth *thangkhas*, there are special manifestations of a tree, the so-called "base wood," "allegorical," "unfolded," or "wish-fulfilling" tree. Of course, it is hard to say that the trees in these paintings are exactly the base wood; however, it is quite similar to the actual tree (referring to the original paintings, not to the reproductions drawn elsewhere). Through the roots, trunks, branches, leaves, flowers, and fruits of these trees and so on, the physiology, pathology, diagnosis, and treatment of Tibetan medicine are fully laid out. Through this imagery, it is easier to remember the three-factor theory, the seven materials and the three excreta, the etiology and causes of diseases, and the transmission routes, locations of lesions and the rules governing them, the sequelae, classification of diseases and causes of death, all kinds of diagnostic methods, food and drink, daily life, treatment, medication, and topical therapies. In short, by these three base woods, all the contents of Tibetan medicine are included, embodying the wisdom of the Tibetan people.

The application of a measuring system by ancient Tibetan people is, again, a unique one. The unit for anatomical measurement, for example, is *tong shen cun* (homophysical inch), namely, applying the length of certain part of the patient's own body as a unit for measurement, such as the finger or the fist, the thumb, or the two points between the ends of the radial creases of the second phalanges when the middle finger is flexed.

There are some very interesting paintings. In the painting of embryology, two points must be mentioned. First, the painting shows the development of an embryo beginning from the combining of the father's semen and mother's blood. The simple fertilized ovum develops gradually into a complex structure and increases in size and changes its structure gradually. Unlike some ancient embryologists who claimed that an embryo is nothing but a miniature baby that simply increased in size, without any other changes which is the so-called "preformation theory," popular at the time before being superseded by the scientific embryological theory of the modern age, Tibetan embryology is rather scientific as compared with the Western theory. Another point is that the painting shows that during the developmental processes of an embryo, there are three stages through which it should pass. These stages are called fish stage, tortoise stage, and pig stage. The ancient Tibetan embryologist might recognize this problem on the basis of the morphology of the embryo. Whatever the condition, this idea is exactly in line with the theory of modern embryology which claims that the human embryo is developed as a miniature of the evolutionary process of the animal kingdom, moving from simple water-borne organisms through the early stages of vertebral animals living in water and then passing on through the birds and mammals, until a human being was finally formed. The description in the painting, therefore, coincides with modern embryology, a very high achievement of Tibetan medicine.

Painting no. 51 is an anatomical illustration. In this painting, there are six illustrations. Among them, four show a sitting position, while the remaining two depict a standing position. The two sitting pictures at the center show an anterior and posterior view. The anterior view shows the internal viscera. The key points are the position and the contour of the heart. Here, the heart is in the shape of a lotus flower bud, with the round end situated in the middle lower part of the chest, while the sharp end is pointing upward, which is based on the description in the *Rgyud bzhi*, saying that “the heart is sitting on the throne like a king.” Hence it is sitting solemnly in the middle of the chest with its tip pointing upward.

This goes against the actual structure of the body in which the heart is situated in the left middle part of the chest, with the tip pointing leftward and downward instead of upward. During the reign of the fifth Dalai Lama, Lho brag sten zin nor bu, a physician and painter, through observation of cadavers, found the actual condition of the anatomical structure and produced a drawing to check the errors, declaring that this was “what I witnessed.” He also produced drawings of the gallbladder, lungs, stomach, intestine, bladder, kidneys, liver, and *bsam se’u*, all appended at the sides of this *thangkha*.

This painting is the most unique one in the whole series. It is evident that this *Sman thang* was prepared by at least two persons: an anonymous painter for the original painting and Sten zin nor bu for the revised one. This is the only case of its kind in the whole series and is of utmost scientific importance.

During the reign of the fifth Dalai Lama, Tibet was still a society ruled by a unified political-religious system, Lamaism, with Tibetan Buddhism being the highest ruling spiritual discipline, and the Dalai Lama being the secular and religious head. He was in the position as shown in the painting as the King of Tibet sitting in the middle.

To change this situation of supremacy according to the actual conditions, the painter risked being accused of blasphemy. The formal drawing of this *Sman thang* demonstrates, on the one hand, that the fifth Dalai Lama was open-minded enough to tolerate and respect natural science in order to publicize the real situation to the populace, and Sten zin nor bu was brave enough to insist on upholding this scientific spirit and the truth. This explains, at least, that, by then, anatomical science was respected and its dignity and purity was protected.

People now call *Sman thang* the gem of Tibetan medicine; and it is treasured by people all over the world. This whole series of paintings have been now published in atlases or albums in several languages with elaborate commentaries.

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Medical Texts in China

Richard Bertschinger

The texts of Chinese medicine are extremely voluminous. They have a continuous history of more than 2,000 years, of which little is known in the West. Standard works up to AD 1900 number around 190, and if popular writings are included this rises to at least 1,500. There has been great activity since the 1949 establishment of the New China, and a modern dictionary of traditional Chinese medicine written in Shanghai in 1988 refers to over 4,000 individuals and 8,000 works. And yet there are barely a dozen translations of these texts. The whole corpus also includes works on massage, diet therapy, and therapeutic exercise similar to the contemporary popular *Taiji Quan* (Supreme Ultimate Boxing) and *Qi Gong* (Breathing Therapy). These have been largely omitted from the following entry, which describes, in chronological order, the most important texts on medical theory, acupuncture and moxibustion, and herbal medicine.

The earliest extant systematic writings, which formed the cornerstone for all medicine in China, Japan, Korea, and the Far East, are collected in the large compilation made during the Han dynasty (202 BCE–AD 220), named the *Huangdi Neijing* (The Yellow Emperor’s Inner Canon). Extracting itself from the notion of ancestral curses and demonic attacks as the cause for illness, the reasoned tone of this compilation (and it is only one of many Han classics) laid a foundation for the next 2,000 years of medical writing, and its influence soon spread to Korea, Japan, and beyond.

The basic theory of Chinese medicine, as spoken in the *Huangdi Neijing*, involves the interplay and interfusion of *yin* (quiescent) and *yang* (active) forces, producing both health and disease. This alternation occurs both within the human body, and between the body and the natural world. Chinese medicine pays particular attention to natural rhythms and the *wuxing*, five fundamental elemental associations of vegetation, fire, soil, minerals, and fluids (wood, fire, earth, metal, and water), both within the natural world and as symbolic agents of change within the body. Illness is seen as a disorder of the *qi* (vital energy), perhaps enhanced by some external factor but primarily involving a deficiency within the individual.

The *Shennong Bencao* (Shennong's Herbal) appeared soon after the *Huangdi Neijing*. It is the earliest surviving materia medica, believed to have been compiled during the first century BCE. In this work 365 kinds of medicinal substances are listed and divided up into three classes: major remedies, medium remedies, and minor remedies.

An almost contemporaneous and equally important text is the *Shanghan Lun* (Discussion on Cold-Induced Disorders) which was written by Zhang Zhongjing (ca. AD 150–219) at the close of the Han, and which has proven to be one of the most influential texts in Chinese medicine. This was the first to advocate the analysis of medical conditions in accordance with the six channels (*taiyang*, *yangming*, *shaoyang*, *taiyin*, *shaoyin*, and *jueyin*) and eight syndromes (*yin*/*yang*, outer/inner, hot/cold, and excess/deficient). Along with the *Huangdi Neijing*, it formed a straightforward basis for the development of traditional Chinese medicine. Its companion text is the *Jingui Yaolue Fang Lun* (Concise Prescriptions from the Golden Casket, ca. 220), also by Zhang Zhongjing.

The importance of these two texts, the *Huangdi Neijing* and the *Shanghan Lun*, is that they illustrate the building up of a well worked out and heuristic, classificatory framework, involving the *yin* and *yang*, the five phases, the six channel types, and the eight principle syndromes of diagnosis, into which the results of any doctor's medical observations could be fitted.

The first textbook on acupuncture and moxibustion was the *Zhenjiu Jiayi Jing* (A–Z of Acupuncture and Moxibustion), written by Huangfu Mi some time around AD 280. Much of this text actually repeats verbatim the *Huangdi Neijing*, but it also gives the first systematic description of acupuncture points, each listed according to its position on the body, and also their function. In addition, the first book on pulse diagnosis, the *Mai Jing* (Pulse Classic, ca. 300), appeared during this period. The author, Wang Shuhe, perfected the art of pulse taking, describing in detail nearly 30 separate categories of pulse. This work, along with Li Shizhen's *Binhu Maixue* (Pulse Studies of Master Binhu), written later during the Ming, formed the core texts for this unique method, which is characteristically Chinese.

It is recorded in the Tang dynasty histories that the Imperial medical colleges based their teachings upon the *Huangdi Neijing* and Huangfu Mi's *Zhenjiu Jiayi Jing*. Among the books also at their disposal would have been the famous, and charmingly titled *Zhouhou Beiji Fang* (Emergency Remedies to Keep Up One's Sleeve, ca. 340), by the ardent Daoist Ge Hong. Ge Hong was also the compiler of the early alchemical and dietetic work *Bao Pu Zi* (The Work of Master Puzi).

Sun Simiao (also called Sun Simo), in 652, published the *Qianjin Yao Fang* (Remedies Worth their Weight in Gold) and its sequel the *Qianjin Yi Fang* (More Remedies Worth their Weight in Gold). These two volumes were extremely diverse, and together they summarized the medical achievements of the Tang, including practices as diverse as incantation, prayer, love philtres, exorcism, dietary restraints, as well as acupuncture and herbal remedies. They also contain the first known charts of the channels and points of the human body, with front, side, and back views. Sun Simiao's work also contains the early *Yinhai Jingwei* (A Detailed Study of the Silver Sea) which describes 81 eye conditions and their treatment, although this work has also been attributed to an author from the Yuan dynasty.

During this period, the earliest official pharmacopoeia ever to be published was sponsored by the Tang government, based upon the work of the earlier Shennong Herbal. The *Tang Xinxiu Bencao* (Tang Newly Compiled Materia Medica) was complied by Su Jing along with 22 other scholars, and it lists some 844 medical substances.

In AD 1027, at the establishment of the Song dynasty, two bronze statues were cast by edict of the Emperor, fashioned by a doctor, Wang Weiyi, who incorporated into them all the known acupuncture points. These statues were accompanied by his *Tongren Zhenjiu Shuxue Tu Jing* (Illustrated Canon of Acupuncture Points based upon the Bronze Figures, 1026). This text is still popular and used for point-location in acupuncture colleges throughout the world. Also around this time appeared the earliest work on bone setting, the *Lishang Suduan Mifang* (Secrets of Treating Wounds and Bone-Setting, ca. 946), put together by Lin Daoren. This outlined the use of traction, fixation, reduction, and reunion for fractures and dislocations.

The fixed attitude to traditional knowledge began to subside gradually during this period. With greater political stability and urbanization, medicine became more intensive and specialized. The number of medical publications during the Song exceeded those of all previous ages put together, and it is largely the Song view, and Song editions of texts, which are now extant. The work begun by Lin Yi, with his editing and reprinting between 1068 and 1077, produced the classical editions most in use today. This was also the century which initiated the massive Daoist patrology, the *Dao Zang* (Storehouse of the Dao).

The monumental *Shengji Zonglu* (Imperial Encyclopedia of Medicine), complied by a board of physicians under the emperor around AD 1111, was composed of 200 volumes. Other specialized works include the small pamphlet the *Yanglao Fengjin Shu* (Looking After the Aged, early eleventh century) by Chen Zhi, on the care and feeding of old people, and the famous monograph on beriberi, the *Jiaoqi Chifa Zongyao* (Every Essential on the Treatment of Beriberi, 1078) by Tong Zhi.

During this time, another influential book was the *Sanyin Jiyi Fang Lun* (Discourse on the Three Causes Ultimately for Any One Disease, 1174) by Zhen Yan. In this the cause of disease was seen as belonging to one of three categories: either internal (including emotional disturbances), external (climatic change), or neither (malnutrition, over-feeding, animal or insect bites and stings, wounds, hoarseness through shouting, drowning, etc.). There was also the gynecological *Furen Da Quan Liang Fang* (Collection of Excellent Prescriptions for Women, AD 1237) by Chen Ziming, consisting of 260 articles in eight divisions, and numerous books on children's illnesses and surgery. One of the earliest was the *Xiaoer Yaozheng Zhijue* (Treatise on Pediatric Pharmaceutics, 1119) by Qian Yi. This small book exerted a profound influence on pediatrics, giving valuable insights into measles, scarlet fever, chickenpox and smallpox, along with innovative methods of diagnosis and treatment. Also, in 1461, the Dr. Gou Bing produced the *Quan You Six Jiao* (Directions for Those Working in Pediatrics), in which indigestion or wrong feeding was held to be the probable cause of most ailments. The first treatise on forensic medicine also was published at this time, the *Xiyuan Jilu* (Instructions to Coroners, 1247), written by Song Zi. This too proved to be a foundation text.

Around this time medical colleges became well organized, and this setting of academic boundaries resulted in differing schools of thought. One considered disease to be caused by excessive heat in the body and advocated cooling medicines; another emphasized the use of purgatives and emetics; another extolled the use of tonics. The most influential book surviving from these debates was probably the *Piwei Lun* (Treatise on the Stomach and Spleen, ca. 1230) by Li Dongyuan, who put all disease down to disorders in life style and the digestive tract. Also notable is the *Rumen Shiqin* (A Literati's Dutiful Care of His Parents) by Zhang Zihe (1156–1228), which advocated the use of sweating, emesis, and purgation.

Arriving at the Ming dynasty (1368–1644) we find scholarship bearing remarkable results. The *Bencao Gangmu* (A Materia Medica Compendium, 1590) by Li Shizhen (1518–1593) is one of the most important works ever produced in China. It was a gigantic text in 52 volumes, listing nearly 2,000 medical substances, including plants, minerals, and animal products, with over 10,000 prescriptions. It detailed the appearance, properties, methods of collection, preparation and function of each substance. This was a truly encyclopedic work commenting on all branches of natural history, botany, zoology, mineralogy, and metallurgy. Mention should also be made of its forerunner, the *Puji Fang* (Prescriptions for Universal Relief, 1406), produced by Teng Hong, which contained an astonishing 61,000 prescriptions.

Great textbooks on acupuncture also appeared during the Ming. Again these were truly comprehensive, reproducing the best of the old along with reworkings and selections from the new. Most notable are the *Zhenjiu Daquan* (Acupuncture and Moxibustion in its Grand Entirety, 1439) by Xu Feng, the skillfully compiled *Zhenjiu Juying* (Gatherings from Outstanding Acupuncturists, 1537) by Gao Wu, and the last in this tradition, the monumental *Zhenjiu Dacheng* (Acupuncture and Moxibustion, the Grand Compendium), written by Yang Jizhou in 1601 – a book "still of the highest usefulness today" (Needham 1980).

Mention should also be made of the reordering of the *Huangdi Neijing*, the *Lei Jing* (Classified Classic) by Zhang Jiebin, which appeared in 1624; with this work, and its illustrated appendices, the summit of *Neijing* scholarship had been reached.

During the later centuries little work of influence appeared. An exception is the *Yizong Jinjian* (Golden Mirror of Medicine, 1749) by Wu Qian. It is mostly made up of extracts, revisions, and corrections of earlier writings. A government decree in 1822 actually eliminated acupuncture from the medical curriculum. And, although China's indigenous medicine survived, it met with disfavor from the established government until, as late as 1929, the Guomindang banned traditional Chinese medicine altogether. However, that same year, Mao Zedong wrote that both Chinese and Western medicines should be used to serve the population, and this has been the prevailing view ever since.

Since the founding of the People's Republic (1949) several medical colleges have been established, combining modern Western and traditional Chinese medicine, and an increasing number of texts have been reedited and published. Many new areas of research have been opened up: acupuncture anesthesia, ear-needling, the discovery of new points; and the translation of texts has begun. Finally, to appreciate the resilience and accuracy of Chinese medical texts we can compare two extracts.

One is from the first page of the first acupuncture book ever produced for the West (Beijing 1980):

> The theory of Yin and Yang holds that every object or phenomenon in the universe consists of two opposite aspects, namely, Yin and Yang, which are at once in conflict and in interdependence; further,

> that this relation between Yin and Yang is the universal law of the material world, the principle and source of the existence of myriads of things, and the root cause for the flourishing and perishing of things.

The second is from the *Huangdi Neijing* (ca. 100 BCE):

> Yin and Yang are the grand method of heaven and earth, the rule and pattern of the ten-thousand things, the father and mother of change and transformation, the fundamental origin of living and killing… (Ch. 5).

The continuously resilient nature of Chinese medical texts could not be more clearly shown.

See also: ►*Huangdi Neijing*, ►Sun Simo, ►Zhang Zhongjing, ►Li Shizhen

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Medicinal Food Plants

Nina L. Etkin

The connection between diet and health is recognized by all human societies, and for many, healthful eating is a pivotal construct of their medical ideologies. How central a role food plays in disease prevention and therapeutics ranges along a continuum, one pole of which represents such indefinite notions as "healthy foods." This is a feature of all cuisines, although which particular foods are so regarded varies with both place and time. Toward the other end of the continuum, more specific explanations of the healthful nature of foods are based both on physical characteristics or effects and on abstract qualities.

Among the abstractions that people apply in their assessment of medicinal foods are paradigms of binary opposition such as heating/cooling and wet/dry, representations of intangible qualities that are not related to actual thermal or hydrous states. These are expressions of health conceptualized as a balance between certain key qualities that can be mediated by diet. In China, for example, cooling foods such as carrot and seaweed restore equilibrium in the case of rash, constipation, and other hot disorders. This general kind of food therapy also characterizes the medical traditions of India, Southeast Asia, Latin America, the Near East, parts of Africa, and much of Europe, although the attributes ascribed to particular foods and diseases vary across, and even within, cultures. In China these binary oppositions intercalate with older traditions that symbolize the more cosmic *yin/yang* philosophy, take into account the theory of Five Phases (*wuxing*: earth, metal, fire, wood, water), and address the concept of *pu* (strengthening, patching up). These statements oversimplify, but they make the point that the healthful qualities of foods are manifold and are integrated in complex ways into different food cultures.

Regarding the physical characteristics of medicinal foods, the cultural dicta by which people interpret the appearance, taste/smell, or physical effects of foods are as varied as the religious beliefs, languages, marriage customs, etc. that distinguish societies from one another. A common link between food plants and diseases is the taste that defines their curing properties. Consider this complex example. The medical tradition of a Hausa population in northern Nigeria advises that the treatment of measles be aimed at several stages, beginning with efforts to expel disease substance from the body's interior. As soon as the measles spots appear, bitter and astringent foods and medicines are sought to chase out internal sores so that the rash matures. Foods and medicines that occur later in the therapeutic progression are cold and aromatic because the illness likes those qualities. In the event that nausea and fever accompany the rash, acid/sour tastes are indicated, to calm and cool. When there is evidence that all sores have been externalized (that is, when other internal signs such as fever and lymphatic inflammation have subsided), the rash is treated with astringent and emollient medicines, no longer with medicinal foods. In this example, taste features prominently in the selection of medicinal foods.

Among another physical attributes by which people identify foods for medicinal use, color, location, texture, and shape may be evoked as part of a "doctrine of signatures." This fundamental tenet in plant selection maintains that these attributes are signs of a plant's intended use. Some of these associations conform as well to theories of sympathetic magic, which is based on the idea that like affects like. Thus, for example, in US Colonial and Chinese medical traditions, the shape of walnut kernels suggested their effectiveness as a brain tonic, in Taiwan red foods such as tomato, red crab, and carrot are considered nutritious because red symbolizes prosperity and good fortune; in several Southeast Asian cultures, where red protects against spirits, red eggs are used to ensure fertility; and in Ecuador the red flowers of the amaranth plant are made into a beverage to restore menstrual regularity and purify the blood. That other medical traditions identify plants with red flowers or leaves to fortify blood finds a parallel in the US, some decades ago, when "good red meat" (beef) defined the core of an "all American," healthy cuisine. Similarly, yellow plant foods are designated for such liver disorders as jaundice in which the skin and white of the eye take on a yellowish tone, and plants whose leaves are shaped by several lobes are used in the treatment of lung disorders. These associations are not as simple as outlined here, because although appearance and other physical attributes are presented as the primary distinguishing feature of certain medicinal foods, they are understood to protect or interfere with disease processes in variable and complicated ways that bear on other characteristics that different medical cultures describe through such metaphors as "strength," "neutralization," and the like.

By the same token, foods also have negative health connotations, many of which have been systematically codified as food taboos, the symbolism of which is especially rich. Food prohibitions play a pivotal role in the traditional medicine of Thailand where there are five general taboo units: meats (cow, water buffalo, pig, and chicken; frogs and scaleless fish); seafood; pickled food; and certain vegetables (cucumber, gourd, and jackfruit). Further, specific foods and beverages are prohibited in particular conditions, and specific tastes such as sweet, fat, and sour are additionally proscribed in certain instances – for example, sour is discouraged because it is understood to result in the accumulation of pus, which should be avoided when one is treated for wounds. Similarly, for Hausa in Nigeria, food plants (e.g., okra, cat's whiskers) that are otherwise appreciated for the gelatinous quality they impart to soup, are avoided when one has congestion from flu, and in the case of certain backaches that are understood to be caused by an accumulation of phlegm within the body. For altogether different associations, Hausa understand that peanuts aggravate leprosy and offset the effect of medicines for anemia.

The cultural and social aspects of medicinal foods are especially apparent in circumstances in which their consumption extends beyond the sick person to include others. Among the Nekematigi of New Guinea, for instance, ceremonial therapeutic meals are shared by the entire community and consist of all purpose medicinal foods – ginger, for example – that are intrinsically healthful regardless of the cause of illness, and specific antidotes against the acts of enemy sorcery that account for most sickness in this society and that always originate from outside the village. If the illness persists, the meal is repeated, again involving the community and thus reaffirming solidarity in the face of malevolence introduced from outside the social body. Conversely, for Nigerian Hausa, whereas healthy foods such as fish and peanuts are shared among family members who eat from the same pot, specific medicinal foods are consumed only by the sick person. In other medical traditions the healer and patient consume the medicinal foods, usually at the same time, both to cement the therapeutic relationship and to empower the healer's empathy toward the patient.

Since people everywhere recognize the relationship between a mother's health and that of her nursing infant, one is not surprised to find, as among Hausa, that when a baby is ill, medicinal foods are also consumed by the mother, and exclusively so if the infant has not yet begun to eat solid foods. And on the Western Pacific island Espiritu Santo (Vanuatu, formerly New Hebrides), food taboos for children who have become ill as a result of malevolent magic are extended to the parents. The general point made here is that the consumption of medicinal foods occurs in a variety of social contexts that range cross-culturally along a continuum of inclusiveness with respect to patients, their families, and their communities.

The interpretation of these cultural expressions by social and health scientists has largely replicated a central idiom in Western thought – i.e., that food and medicine are separable categories. This is apparent, for example, in studies that inventory medicinal or food plants, overlooking the possibility that plants are not simply one or the other. In this way, whether or not a food is considered healthful depends on its intrinsic nutritional value. For the first half of the twentieth century nutrition scientists concentrated on identifying the nutrients that help the body's immune system fight infectious disease and whose deficiencies result in such discrete disorders as scurvy (vitamin C), rickets and osteomalacia (calcium, vitamin D), and beriberi (thiamin). (This can be related to the Chinese example above through observation that insufficiency of the vitamins found in carrots and other cooling vegetables typically eventuate in skin disorders.)

During the latter 1900s nutritional scientists focused on foods linked to chronic disorders, some revealing negative associations: foods high in salt, sugar, and fat have been implicated in hypertension, diabetes, and cardiovascular disorders, respectively. Conversely, other nutrients have healthful effects on chronic diseases: dietary fiber – such as provided by whole-grain cereals, fruit skins, vegetables, legumes, and nuts – has been linked to diminished risk of colorectal and stomach cancers, high blood pressure, diabetes, high cholesterol, atherosclerosis, and coronary heart disease. Vitamin A – present in yellow and orange fruits and vegetables (carrots, bell pepper) and dark green leafy vegetables (spinach, kale) – has been reported to protect against lung and prostate cancers and to decrease the severity of measles. Vitamin E (found mostly in green leafy vegetables) and C (high in fruit, especially citrus) both have been linked to lower cancer risks as well.

In sum, to date the frame of reference has been the nutritional composition of medicinal foods, and apart from the conventional nutrients – vitamins, minerals, protein – foods have been regarded as chemically inert, thus of no salience to specific disease processes. But foods are not chemically mundane. Most people are aware of toxins in potentially nutritious foods, so why not drugs? The line between toxin and medicine is in any case an uncertain one – toxic in what dose, and for whom? Many of the toxic "secondary" metabolites produced by plants are a primary defense against fungi and bacteria, microorganisms not unlike the pathogens with which human societies contend. Accordingly, people have taken advantage of these characteristics of plants, in some cases modifying that chemistry through selective breeding and special planting of food plants to exaggerate certain features and to reduce or eliminate others.

In view of this, a more recent development in medicinal food study is to focus on the drug-like qualities of plants. Attention has been paid especially to spices, perhaps because their role in the early history of Western medicine has made this category of plants the more likely subject of pharmacologic inquiry. In a biomedicine so strongly informed by the germ theory of disease, the antimicrobial action of many spices merits attention; and because spices – like pharmaceuticals – are small (in quantity) and powerful (in smell, taste), they fit an allopathic model of healing. Evidence for pharmacologic activity in spices includes: capsaicin in chili pepper diminishes risk of cluster headaches and stomach cancer; sulfides in garlic and onion inhibit blood clotting and promote cardiovascular integrity; West African black pepper has anticonvulsant activity; ginger is effective in the treatment of motion sickness and nausea; cricetine in saffron has antiatherosclerotic activity; vanillin and catechin in vanilla have, respectively, liver protective and anticariogenic actions; and caffeine, theophylline, and theobromine in chocolate elevate mood.

More recently attention has been directed as well to more ordinary foods: sulforaphane in broccoli protects against certain cancers; gamma-amino butyric acid in tomatoes is hypotensive; rhubarb has antibacterial activity; epicatechin gallate from tea leaves lowers serum cholesterol; and pigeon pea is helpful in diminishing the symptoms of sickle cell anemia.

These catalogs offer only an incomplete story of the medicinal potential of food, since much of what is reported is based only on laboratory studies of purified substances and/or on animal studies using healthy subjects. Thus, although some medicine-like action may be confirmed, one cannot be certain that this will indeed be the outcome when the plants are ingested by sick humans. One gains more insight by considering food use in its broadest physiological and cultural contexts, in order to take into account preparation and incidence and quantity of consumption.

In many traditional societies the same plants are used as both food and medicine, their function and preparation depending on how they are identified for a specified context of use. Over the last two decades, anthropologists have been especially adroit in detailing how foods and medicines overlap. This is significant on at least two levels. First we recognize that the use of plants in more than one context extends the range across which people are exposed to active constituents. Second, we begin to appreciate how very complex human–environment interactions are. For the latter it signifies that foods tend to be prepared in ways that diminish the risk of toxicity, especially cooking, thereby allowing the consumption of otherwise potentially dangerous foods in relatively large volume and at regular intervals. The same plants intended for drug use may be prepared differently – neutralizing pharmacologically active constituents only partially or not at all – and are consumed in small quantities, allowing the action of toxin against pathogen or symptom without overwhelming the human host.

Hausa people of northern Nigeria are a case in point that food plants overlap conspicuously with medicines. Ninety-six per cent of the 119 plants that one Hausa village identify as foods number as well among the 374 plants that make up the local pharmacopoeia. Hausa clearly distinguish foods from medicines by parts used, preparation, and, especially, intended outcome (nutritive or preventive/therapeutic). Further, Hausa have much more to say regarding the healthful qualities of a medicine compared to a food. While medicines address specific symptoms, dislodge phlegm, expel spirits, and so on, foods simply strengthen, fortify blood, or promote growth. Extending overlapping use beyond foods and medicines reveals that all of the 20 plants used cosmetically have medicinal uses, five are foods as well; of the 16 plants used in personal hygiene, all are used as medicines, six are foods, and three are cosmetics. The point, again, is that attention to the different contexts of plant use accounts most fully for the range of people's exposure to the drug-like actions of botanicals.

An interesting question is raised in the rank ordering of use: medicine first or food first? These are not, of course, mutually exclusive positions; pharmacopoeias and cuisines are created in increments, not all at once, so that one pattern or another may apply for a given plant. A sizeable number of plants used today as food were first appreciated for their medicinal qualities. Throughout the Andes and Mesoamerica the ritual and medicinal uses of red amaranth pigments were once more common than the use of these plants as a source of food grain. In the Mediterranean and Near East licorice was domesticated for medicinal use (it has estrogenic and antimicrobial activities), as were a variety of other plants that are used today as flavorings. Soybeans and *Mo-er* (black tree fungus) of Chinese cuisines were first cultivated as medicines. The latter demonstrates the kind of antiplatelet activity that might provide protection against atherosclerosis. In light of the especially uncertain distinction between medicine and food in Asian cultures, other plants also are likely to have been cultivated first as medicine. Drawing attention again to Hausa in Nigeria, a significant number of their wild plant foods have been "identified" first as medicines. This is revealed by the inventory of Hausa medicinal plants, which is considerably more inclusive of local flora than lists of Hausa foods and other useful plants; the list of medicines includes all plants from those other categories, whereas the reverse is not the case. Hausa oral tradition further reinforces the primacy of medicinal use over food use for some plants. This perspective cannot be applied wholesale to all societies, since the cultural and environmental circumstances under which pharmacopoeias and cuisines are created involve different patterns of need and knowledge about particular plants. But this does challenge a conventional, unidirectional view that people learn about medicines only secondary to their search for food.

A comprehensive perspective on plant use better characterizes the interconnected histories of human food and medicine, and accommodates both nonfood first and food first models to explain the development of botanical knowledge. Thus, whereas it is customary to talk about the "traditional" medicines and foods of a people, region, or religion, in fact therapeutics and diet are dynamic. Transformations in the content and intent of medicines and diet are shaped in part by shifting concerns with health.

Today, in the West, an analogue to medicinal foods exists in the growing popularity of food supplements. This term is apprehended by the consuming public as a range of products that include conventional supplements (e.g., vitamins) and extend as well to a great diversity of plant and animal products. The popularity of these products bears on several interrelated issues – dissatisfaction with biomedicine and the search for holistic and natural medicines; patients' seeking agency in their own health care; and the commodification of health and healing.

Finally, a timely issue relates the topic of medicinal foods to concern with environmental protection. Contemporary debates on the preservation of global biodiversity have focused on plants that development planners and national polities identify to be at risk. This cross cuts other international efforts directed at alleviating or preventing the effects of famines and lesser food shortages. Collectively these programs highlight staple foods in their efforts to assure that "important" and varied foods are available to the world's peoples, or that other "interesting" plants are preserved for their potential contribution to the pharmaceutical industry of the West. Thus, Western scientific paradigms and various economic and political agendas have been instrumental in shaping the direction of environmental protection and restoration efforts. These programs should be credited with the results achieved to date, as well as with their more recent inclusion of local populations in the planning of sustained efforts. In light of the present discussion of medicinal foods, one might wish to add certain refinements that assure that local cognitive categories and the specific contexts of plant use are given attention, including an examination of what the existing or restored diversity affords in human cultural terms. More specifically, to the extent that the same plants serve dietary and medicinal objectives, their significance to local populations is greater than what development planners might have considered; additional contexts of use elevate the local value of those plants even further.

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Medicine and Colonialism in India

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Ancient India

The Indian subcontinent was well inhabited by the first millennium BCE. The inhabited territory extended west into areas that today are in Pakistan and Afghanistan. These ancient Indians had a well-developed system of medicine termed Āyurveda (The Science of Life). Ayurvedic physicians practiced medicine and to a lesser extent, surgery. The system and its practitioners were held in high regard and Indian physicians are known to have been in the courts of the Muslim rulers. Some of the Ayurvedic texts were translated into Arabic early in the history of Islam.

The basic thrust of Colonialism is to exploit the colonized for the benefit of the colonizers. Usually after a long period of colonization the two groups come to a situation of better parity. Both these phenomena are well illustrated in the colonization of India.

Muslim Invasion

From the early eighth century, India was invaded by the Muslim kings ruling in the west across the Himalayas. Initially these Muslim pockets were small and often short-lived. By the twelfth century, a Muslim kingdom had been established in Delhi, though the ruler(s) recognized their western center outside India as the capital. By the thirteenth century Muslim occupation in India had become permanent, and ultimately the Muslim rulers assimilated into the Indian culture. The Turk, Babur, established his capital in Delhi in 1526, though it was not until his grandson, Akbar (1556–1605) ruled, that the Mughals considered themselves Indians. The Muslims had brought with them the Islamic system of medicine, Unani or Tibbi, based largely on translations of Greek Medicine. However, Āyurveda was also in use, not only in the Hindu population, but also among the Muslims.

With the arrival of the Europeans, European physicians also practiced in India though in small numbers. From the time of Shahjehan, Akbar's grandson, some European physicians are known to have practiced in royal courts. Thus, Niccolo Manucci (1639–1717) was an artilleryman to Shah Jahan's eldest son Dara Shukoh. He later took up the profession of medicine (even though untrained) and practiced both professions (!) in various royal courts. Manucci's memoirs name some other European physicians practicing in India. François Bernier, a Frenchman with a medical degree from Montpellier, served Dara Shukoh and later his brother, the Mughal emperor Aurangzeb (Majumdar et al. 1994).

European Colonization

Portuguese

From the middle of the sixteenth century, European nations turned their eyes eastward for territorial expansion and trade. The Muslims had established themselves in the Middle East from today's Syria southwards to Egypt and across North Africa to the southern half of Spain. Trade with India and further East had become dangerous and expensive. There was also the need to spread Christianity.

The first to arrive in India was the Portuguese Vasco da Gama who landed at Calicut (now Kozhikhode) in southwest India on 20 May 1498. By 1510 the Portuguese had an established presence in Goa on the west coast. Goa remained a Portuguese possession until 1949 when it joined the Republic of India. In the 450 years of its association with Portugal, Goa became a medical center of sorts. It had the oldest European-style hospital and medical school in the East.

The Royal Hospital was started in 1510 and by about 1546 western medicine was being taught. The Hospital was fully supported by the Portuguese rulers and was a showpiece in its time. The continuing rivalry between the Dutch and the Portuguese, however, caused a decline in Goa's prosperity and the Hospital started to decline by the mid-seventeenth century. In order to have a cadre of assistant physicians, non-Portuguese natives were taught the rudiments of medicine.

Some Portuguese physicians and apothecaries traveled to Goa and some even stayed behind. The most prominent among them was Garcia d'Orta. A converted Jew, Garcia d'Orta was born to Jewish parents who had been expelled from Spain in 1492. They were converted to Catholicism but were always looked down upon. D'Orta studied medicine in Spanish universities and returned to Portugal in 1523. He then joined the faculty at the medical school in Lisbon. In 1534 he left for Goa with his friend, who was to become the Governor-General of Goa and the Portuguese territories in India.

D'Orta became a very successful practitioner, not only for the rich Portuguese in Goa, but also for the rulers of neighboring Hindu and Muslim kingdoms. (Other Portuguese physicians also became court physicians and many rich Indians came to Goa for treatment.) D'Orta is remembered today for his book *Coloquios dos Simples e Drogas da India* – an Indian materia medica, which was published in 1563, in the first printing press in India. The book gained great renown and was very popular in Europe. D'Orta died in 1568, probably quite poor as the Catholic hierarchy had turned against him. His bones were burnt at an auto-da-fe in the cathedral in Goa some years after his death. D'Orta remains the first author of a western-style medical book from India.

A woman medical doctor, Dona Juliana, came to Goa and later on moved to the court of the Great Mughal

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Akbar. Nicolau Manucci, mentioned above, came and practiced in Goa for a short while but was then thrown out by the authorities.

Around 1842 a formal medical school, Escola Medico-Cirurgica de Nova Goa was established in Goa. The number of graduates (strictly limited to Christians) from this school was never very high, though many of them went on to achieve professional distinction in Goa, in India and in the Portuguese territories elsewhere (Pandya 1982). The school was discontinued at the time of Goa's admission to the Republic of India.

Following the Portuguese, the French, the Dutch, and the Danes established trading centers in India. The latter two countries had undistinguished and short stays in India. The French remained in Chandernagore, Pondicherry, Mahe, Yaman, and Karikal, all isolated enclaves until Indian independence in 1947. During this period they had no significant medical establishments either as medical schools or hospitals.

Medicine and Colonialism in India. Fig. 1 The tombstone and epitah (in English and Arabic) of William Hamilton in St. John's church, Kolkata, India (Photograph by author).

British

Starting with small trading posts in the seventeenth century, the British ultimately occupied all of the Indian subcontinent and the history of colonial medicine in India is almost exclusively that of the development of medicine during British rule (1857–1947).

Medical practices under the British will be described in two phases. The first was under the East India Company, the next under the British crown as a part of the Empire.

Phase 1: The East India Company

The East India Company was a profit-making body administered by local administrators in India. In theory the Board of Governors in England were responsible for the supervision with some generally minimal oversight by the British Parliament. Under the Company, fortune making and profiteering were rampant and generally tolerated. Only a very few people were ever brought to justice in the courts or impeached in the Parliament. The entire western-style medical setup was for the British, largely the armed forces; the native population depended upon the indigenous medical systems.

Each ship coming to India had a (naval) surgeon on board.[1] They sometimes deserted (often without punishment when captured), settled as surgeons to the trading settlements on land and not infrequently fought as soldiers in the many and frequent battles between the British, the French (the Carnatic and Mysore Wars),[2] and the native Indians.

While a number of the naval surgeons were of great service to the British, two are of special interest, signifying different aspects of the duties of the navy surgeon. William Hamilton of Dalziel in Scotland is hardly remembered today Fig. 1. However his epitaph (still to be seen in the graveyard of St John's Church in Kolkata, India) states "…his Memory ought to be dear to this Nation for the Credit he gained ye English in curing FERRUKSEER the present king of Indostan… by which he made his own name famous at the court of that great monarch; and without doubt will perpetuate his Memory in Great Britain as well as in all other Nations of Europe." Hamilton was apparently trained as a surgeon and did not have a university degree in medicine. He was attached to the small Company trading post in Calcutta. The Company had been trying to get a *firman* or permit to carry on trading with the local populace under advantageous terms and lowered customs duties. The Company sent a delegation to the Surman Embassy to the court of Farrukhshiyar, the reigning Mughal monarch in Delhi. On arrival at Delhi, the delegation found that Farrukhshiyar was seriously ill with infected lymph nodes in the groin. He had been

[1] The training and career of a naval surgeon of the times are well detailed in *The Adventures of Roderick Random* (1748) by Tobias Smollett (1721–1778) who was himself a physician trained at the University of Aberdeen.

[2] The Carnatic and Mysore Wars were fought in the latter half of the eighteenth century by the British against the Marathas, rulers of Mysore, and the French to establish British power in southern India.

treated by the court (native) physicians unsuccessfully. Hamilton treated the emperor (apparently lancing the boils) which resulted in rapid recovery. The emperor also had an anal fistula that Hamilton successfully treated.

The grateful monarch issued a firman in favor of the British, munificently rewarded the young surgeon, and wanted him permanently in his employ. Hamilton died soon thereafter and was buried in the Company cemetery in Fort William, Calcutta (Wilson 1911).

John Zephania Holwell (1711–1798) was quite a different type of physician. Born to well-established parents (his father was a timber merchant in London) Holwell studied in England and Holland and trained as a surgeon in Guy's Hospital, London. He came to India in 1732 and to Calcutta, which had the most important British factory in India, in 1736.

In 1756 the British settlement in Calcutta was attacked by Siraj-ud-Dowlah, the ruler of Bengal. The Governor left the Fort with all the ladies and most of the men for a safe refuge on the river Ganges. Holwell remained as the governor of the fort, put up a stiff fight, was defeated and captured. He with the 156 other captives was put in a small chamber termed the "Black Hole." Only 23 survived the night (Holwell's description of this event has been seriously criticized. Probably the numbers reported were exaggerated though the confinement did happen. A monument erected by Holwell to recall the event was later removed but can still be seen at the back of St John's Church.)

Holwell became the temporary Governor of Bengal after Robert Clive's return to England and finally returned to England in 1761. He wrote a number of books on his experience, knew a number of languages including Arabic, and was one of the first to study Hindu antiquities.

Phase 2: The British Raj

In 1857, there was a revolt by some of the Indian regiments and Indian rulers against the East India Company. Known variously as the Sepoy Mutiny (by the British) and the First War of Independence (by the Indians) the immediate result of this conflict (which the British won) was the takeover of the Indian territories by the British Government. The Government sent representatives of the Crown (Governor Generals) to rule over the Indian territories.

Even though the Government was mainly geared to British interests, there was some beginning interchange between the Indians (mainly the Hindus) and the British rulers. Calcutta remained the capital and the seat of government (until 1911) so most of the action occurred there (Bala 1991; Arnold 2000).

With the establishment of the Raj, the early British officials were very interested in native customs and learning. In 1776, (Sir) William Jones, a superb linguist, and a Judge of the Calcutta High Court, established the Royal Asiatic Society of Bengal with the support of the Government specifically for oriental studies and research. Both he, Warren Hastings, and other high-ranking officials encouraged the study of the Indian systems, and this helped establish the Calcutta Madrassah for the study of Arabic and Persian and the Sanskrit Colleges of Calcutta and Benares for the study of Arabic (Majumdar et al. 1979).

Because of the lack of practitioners trained in Western medicine, the local British physicians would train their assistants for 1 or 2 years and then certify them as being capable of practicing western medicine independently. In order to increase the number of better-trained medical practitioners and the number of assistants to the European physicians, the Government started a Native Medical Institution in 1824 in Calcutta (and later in Bombay) mainly to produce assistants, dressers, etc. Auxiliary Medical sections were also established at the Sanskrit College in Calcutta where Āyurveda was taught together with some western medicine. (A hospital with 30 beds was started for these students in 1830.) At the Calcutta Madrassah, rudiments of western medicine were taught together with Unani or Tibbi – the Arabic medical system. The western system had a therapeutic armamentarium that was possibly inferior to the native systems. Its nosology (classification of diseases) was different but not much better; the main difference was in the study of human anatomy by dissection and surgery (without anesthesia).

A Bengal Medical Service had been started in 1763 – similar provincial services started in Madras and Bombay. Membership was limited to the British for many years and when Indians started to be admitted to the Indian Medical Service they were usually assistant or subassistant surgeons. Created to serve the needs of the Empire, the IMS had a prime responsibility to the armed forces and military matters; service to civilians was secondary.

Arrangements for the institutionalized treatment of the employees of the East India Company and the soldiers and sailors had existed from the beginning at the three main British centers – Calcutta, Madras, and Bombay. Madras had a hospital since 1664. A hospital for Europeans was started near St John's Church in Calcutta in 1707. In 1768 a General Hospital for other Europeans (including indigents) and visiting European sailors was started in Calcutta. This Presidency General Hospital still exists.

Lord William Bentinck was the Governor-General from 1828 to 1835. He was convinced that education was to be Europeanized. In 1835 the Native Medical Institution and the medical sections of the Sanskrit College and Calcutta Madrassah were abolished. The Bengal Medical College was opened in Calcutta with three British and one Indian faculty (Anon 1935). The

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Indian, Madhusudan Gupta had been a student (and later a teacher) of the Vaidyaka Sreni or medical section of the Sanskrit College. A remarkable person in all respects, Gupta initiated cadaver dissection in 1836 (Chakravorty 1997) Fig. 2. In 1857, with the establishment of the University of Calcutta, the College changed its name to the Calcutta Medical College. The Madras Medical College also started in 1835. Amongst other achievements, this institution was the first to formally train women in medicine. The Grant Medical College of Bombay was started in 1845.

Women

The first special attention paid to native women by the British physicians followed a law enacted in Britain. From 1805 to 1833 and again from 1868 to 1880, venereally infected prostitutes and soldiers were kept in "lock hospitals." Christian women missionaries from the west played a large role in looking upon native women's health, although the main object was probably conversion to Christianity (Balfour 1929). The first was Clara Swain, who in 1869 established the American Methodist Episcopalian Mission in Bareilly. Here she also trained Indian women in nursing and midwifery. Many women missionaries came from Great Britain, Canada, and the United States to render service to native women and men.

Ida Scudder, an alumna of Cornell University Medical School, opened a medical college and hospital for women in Vellore, Madras Province. In 1945 the college was opened to men also. Today it is the biggest Christian hospital in the world and one of the best-teaching institutions in the country. India was a haven for women medical graduates from the British Isles. They had problems in being accepted in Great Britain but had much better opportunities in India.

Medicine and Colonialism in India. Fig. 2 Painting by Madhusudan Gupta by Mrs. Belnos in the Anatomy Department, Medical College, Kolkata, India (Photograph by author).

A specialized case was that of Lady Dufferin's Fund (Lal 1994). Initiated by the wife of the Viceroy, Lord Dufferin, this organization collected donations to start hospitals for women and train nurses and midwives. Though always short of funds, the Fund played a significant role in women's health care. It also helped establish the Lady Hardinge Medical College for Women in Delhi in 1916.

As in all other countries, women had difficulty in receiving formal education in medicine. Among the first woman physicians of India was the English woman (Dame), Mary Scharlieb who was the wife of a prominent lawyer of Madras. Her husband's family was well known to the Governor and the Superintendent of the General Hospital in Madras. She first took courses in midwifery but later with three other Anglo-Indian ladies was allowed to attend classes and sit for the final Licentiate examination in 1878. Of her colleagues, Dora White became a physician to the Nizam's Government in Hyderabad and D'Abreu (who had come to Madras as she had not obtained admission in Calcutta) became a medical missionary. She later returned to England and became very well known as a physician.

The first Indian woman to graduate was Kadambini (Basu) Ganguli (1861–1923). She was the first woman to get the Bachelor's degree at Calcutta University (together with Bidhumukhi Bose). She obtained her licentiate from Calcutta University in 1886. Later she went to Great Britain and obtained degrees from Glasgow and Edinburgh. She was a very successful practitioner of medicine, obstetrics and gynecology, and surgery.

Anand(a)ibai Joshi of Pune graduated from the Women's Medical College of Pennsylvania in 1886. She returned to practice in India in charge of the Female Ward of the Civil Hospital in Kolhapur, Maharastra, but died of tuberculosis soon thereafter.

Diseases, Public Health, and Research

India has its own spectrum of diseases, many of which were unknown to westerners. I will discuss only three of the most devastating.

Malaria had been a devastating disease in India and the countries around the Mediterranean for centuries. Because of the lethality of malarial fever, the British Indian authorities had established a Fever Commission (of which Madhusudan Gupta – see above) was a member. Later "Burdwan fever" – a malignant febrile illness, generated a great deal of discussion, without any effective resolution of its nature and treatment. The use of Jesuit's Bark, Cinchona (quinine), was known and in fact had been used by Ayurvedic physicians since 1860. However it was not until Ronald Ross (1857–1932) working in the Presidency General Hospital in Calcutta established the life cycle of the malarial parasite in the mosquito that the disease was finally understood. Born in India and educated in England, Ross joined the Indian Medical Service in 1881. He was awarded the Nobel Prize in 1902. He left India for England in 1901 and died there in 1932.

In 1859, the prevalence of infectious diseases and a high mortality amongst Europeans in India had resulted in the formation of a Royal Sanitary Commission with Dr John Snow (who had written the book *On the Mode of Communication of Cholera* in 1855) as its chairman. In 1863 a Commission was setup to inquire into the Cholera Epidemic of 1861 in Northern India. With Robert Koch's identification of the causative organism in the water of a reservoir in Calcutta in 1884, the possibility of controlling cholera through sanitary measures became practicable. (Koch became a Nobel Laureate in 1905.)

Smallpox had been a devastating disease all across the world for centuries. Variolation – the introduction of live smallpox from a patient to a healthy person by scarification had been used for immunization for centuries. The Indian Medical Service accepted and used this method till the discovery of vaccination (the introduction of cow pox by scarification) by Edward Jenner (1749–1823) in 1796. Both variolation and vaccination were used in India for immunization for a while until the Smallpox Commission in 1850 stated that the latter was superior and safer than the former.

Research

Though Ronald Ross was the physician to get the highest accolades, the members of the Indian Medical Service carried on investigations into common local diseases. In later years some Indians (outside the IMS) also became well known for their research findings. Thus Sir U. N. Brahmachari discovered the cure for Kala-Azar (Leishmaniasis), and Sir K. N. Das was a pioneer obstetrician who wrote a classic text on the discovery, development, and use of the obstetric forceps.

In the 190 years of British occupation of India, the relationship between the colonizer and the colonized had equalized considerably. In 1887, Dr R. G. Kar and colleagues started the Carmichael Medical College as the first non-Government Medical College in the country. Today the R. G. Kar Medical College is one of the prime teaching and research institutions in the country. In the earlier half of the twentieth century, the medical programs in the country were more and more in the hands of the Indians, though postgraduate education abroad, especially in the British Isles was almost mandated for a teaching position and even for successful private practice. Indian physicians today occupy many prestigious chairs outside India, especially in English-speaking countries. This is one of the legacies of colonial medicine in India.

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Medicine and Colonialism in Sri Lanka

Soma Hewa

It is generally accepted that Western medicine introduced by European colonizers and missionaries saved millions of lives in Africa, Asia, and the Americas (Comaroff and Comaroff, 1992). In this context, Western medicine represented a higher civilization and social order that lifted people to modern ways of life. David Livingstone, known for his religious zealotry, chose a medical career to heal the suffering of Africans: "In the glow of love which Christianity inspires, I soon resolved to devote my life to the alleviation of human misery… and therefore set myself to obtain a medical education, in order to be qualified for that enterprise" (Livingstone 1858; Moffat

[3] A number of publications in Bengali have significant information on this subject. They have not been mentioned here.

1969). Medical missionaries believed that the eradication of fatal diseases among the indigenous people would encourage the "heathens" to embrace Christianity. Commenting on the effort to establish a public health department in India by the British colonial government in the mid-nineteenth century, Florence Nightingale observed that "it was not only a noble task but also a part of a mission to bring a higher civilization into India" (Cook 1914). Even though Western medicine was regarded as an integral part of culture, medical services were rarely extended to the masses without reservations.

Several studies have argued that medicine and medical services in the colonies evolved in response to political and economic needs of Western imperialism. They suggest that medicine played a critical role in the expansion of imperialism in the late nineteenth and early twentieth centuries (Headrick 1981; Arnold 1988). Medicine, as it was introduced to non-Western societies by imperial forces, was an instrument of political, economic, and cultural domination. With the expansion of European colonialism in Asia, Africa, and Latin America, the threat of "tropical disease" became a major obstacle to colonial rule. New medical sciences were developed to deal with diseases such as cholera, malaria, dysentery, and yellow fever for the protection of the European troops and administrators from diseases originating in the indigenous communities (Kavadi 1999). Radhika Ramasubban, who has done an extensive analysis of the origin and the development of Western medicine in British India, suggests that the main concern of British colonial policy was to protect the health of the British army and the European civilian population living in India. As a result, colonial medical policy in India created medical "enclaves," leading to the exclusion of local populations. Such policies were justified by the colonial administrators who contended that the Indians were "superstitious and backward," and would not accept modern medicine even if it were offered (Ramasubban 1988).

In the larger context of colonial rule, medicine and medical services were important political and psychological tools that bolstered the colonial grip over local populations.

1. It became clear that the health of the European personnel, particularly members of the military, could not be protected by measures directed at them alone when there were epidemic diseases among the native populations (Worboys 1988; Turshen 1984).
2. The increased trade and political interactions with the colonies led to a heavy traffic of people and materials across the continents. As a result, the increased vulnerability of Europe itself to epidemic diseases stemming from the tropics became a matter of concern (May 1958).
3. The supply of raw materials for the industries in Europe and North America were dependent upon the productivity of the colonial labor force. Therefore, to sustain the capitalist economic development in the West it was necessary to improve the productivity of the people in the colonies (Emmanuel 1982).
4. The expansion of the market and future investments by the industrialized countries in these colonies were dependent upon the receptiveness of the masses to Western cultural and social values. Hence, the ability of Western medicine to eradicate diseases in these societies would "reduce the cultural autonomy of the agrarian people and make them amenable" to Western values and life-styles (Brown 1976).

Against the background of these recent interpretations of the role of medicine in colonial rule, we examine the impact of British colonial economic policies on the health of the colonial labor force in the plantation sector of Sri Lanka (formerly known as Ceylon) as a case study. The laissez-faire policy of the colonial government enabled the British planters to ignore even the most basic sanitary requirements such as latrines on the plantations in order to maximize profit. As a result, the plantations became breeding grounds for many parasitic and infectious diseases found on the island during the late nineteenth and early twentieth centuries. When the International Health Board (hereafter IHB) of the Rockefeller Foundation arrived in Sri Lanka in 1916 to set up a hookworm control campaign, there was an epidemic of hookworm infection on the plantations and the neighboring villages.

Historical Background

The British captured the Kandyan Kingdom of Sri Lanka in 1815, slaughtering thousands of natives and destroying scores of villages (Marshall 1846). Dr. Henry Marshall, a senior medical officer of the 89th Regiment that led the war against the Kandyan Kingdom, wrote that "the incursions of our troops into the Kandyan territory... were calculated to fill the population with the most unfavorable opinions of our justice and humanity, and to confirm the worst prejudices against the European race." As Marshall predicted, the bitterness of the war persisted among the Kandyan Sinhalese for a long time. When the British established plantation industries in central Sri Lanka during the mid-nineteenth century, the Kandyans refused to work on the estates. To fill this deficit, laborers were brought from the southern Indian state of Tamil Nadu for the year-round work in the plantation industry. Unlike in other British colonies, such as Mauritius and the West Indies, where the Indian labor had been employed since the early nineteenth century, the colonial government never directly participated in the recruitment of Indian estate labor for Sri Lanka. The authorities maintained that Sri Lanka was close enough to India to leave such recruitment to private economic enterprises (Kodikara 1965). The estates' agents, or *Kanganies*, recruited the laborers in India. The number of laborers recruited gradually increased with the expansion of the plantation industries: coffee in the years 1841–1880, tea in the years 1890–1910, and rubber in the first two decades of the twentieth century. By the turn of the century, about 100,000 workers and their families arrived annually in Sri Lanka (Heiser 1936; Philips 1955).

According to the contract, the planters provided living and hospital care for the workers (Chattopadhyaya 1979). The workers lived in barrack-like "lines" that were constructed of temporary materials. Each family was given two small rooms and as many as twelve people lived in a 8 × 10 ft room. One of the unhealthiest aspects of the living conditions on the estates was that the lines were not provided with latrines (Rockefeller Archive Center 1914, hereafter RAC). The workers had no choice but to relieve themselves wherever they felt the inclination. As a result, the sanitary conditions on the estates were deplorable (RAC 1914). The lack of government regulations over the affairs of the plantation industry made it easier for the planters to maximize their profit at the expense of the basic needs of their workers. In the extremely poor sanitary conditions on the plantations, immigrant workers and their families faced the threat of a wide range of diseases such as hookworm infection, malaria, smallpox, and cholera, which often became epidemics in many parts of the country. S. V. Balasingham, a Sri Lankan historian, describes the desperate conditions of the immigrant workers as follows: "The spread of epidemics, like cholera and smallpox in certain years in Ceylon has been traced to these immigrants and epidemics of either disease are reported to have carried away large numbers of the immigrants themselves.... There were reports in the Ceylon Times of starvation among these laborers and sale of children owing to the impossibility of maintaining them on the low wages of 6d a day" (Balasingham 1968).

The Prevalence of Hookworm Disease

Hookworms are tiny, slender parasites from one-half to three-quarters of an inch in length. Although parasitic in the bowel, the worm does not gain entrance through the mouth but through the pores of the skin when it comes in contact with polluted soil. The hookworm infection causes under-nutrition, anemia, and lassitude. The victims of hookworm infection sometimes die because the worms literally suck away the blood necessary for life. Usually, however, death occurs because—drained of blood—the sufferers are too weak to resist new infections (Cort 1921).

The hookworm infection (anchylostomiasis) first appeared in the administration report of the Principal Civil Medical Officer (hereafter PCMO) of Sri Lanka in 1888, when 31 cases were diagnosed at General Hospitals in Colombo, Badulla, and Kurunegala (Sri Lanka National Archive 1888, hereafter SLNA). This number increased rapidly, and by 1899 about 239 deaths from anchylostomiasis had been reported in the island. According to Allan Perry, PCMO, over 80% of the reported cases were immigrant workers, and the rest were people living in the neighboring villages of the plantation areas. "The greatest number of cases occurring in the planting districts... Yet other provinces show some cases, notably the Northern, which returned 57 cases for the year" (SLNA 1899). Although, the authorities were fully aware of the cause of the spread of the disease, they were reluctant to interfere with the private economic decisions of the planters (SLNA 1916). Consequently, by 1916 the hookworm infection had reached epidemic proportions; more than 90% of the population in the plantation districts was infected with the disease. Although the main cause of the spread of disease was the poor sanitary conditions in the plantation areas, the economic interest of the planters took precedence over the health of their workers (RAC 1914). Even though a large number of the immigrant laborers arriving in Sri Lanka each year seldom lived more than "a couple of monsoons," the planters were not concerned with the high death toll. According to K. M. de Silva, in the years 1841– 848, about 70,000 (10,000 per year) or 25% of the immigrant workers died of various causes. These figures, according to de Silva, had been published by *The Colombo Observer*, a leading newspaper of the day, which argued that the death toll in Sri Lanka was much higher than that of Mauritius, where Indian laborers received relatively better treatment (de Silva 1965). Particularly, with the proximity of Sri Lanka to South India and the large reserve of cheap labor there, the planters never felt any economic urgency to take the hookworm epidemic seriously. Moreover, the Kanganies who recruited laborers for the estates were always willing to bring as many laborers as the planters required. According some observers, "Kanganies" who recruited laborers in India acted as leaders of each gang of up to one hundred workers. In addition to their salaries for working as supervisors, the Kanganies received 2 cents per day from each laborer's wage under their supervision. Further, they received a bonus when their workers turned up, and therefore they made every attempt to bring as many workers as possible to the plantations (Chattopadhyaya 1979).

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Philanthropic Medicine

The Rockefeller Foundation initiated the hookworm control campaign in the early 1900s, when the disease was a major health problem in the southern United States (Fosdick 1952). The public health program was started in the South for the purpose of integrating its

Medicine and Colonialism in Sri Lanka. Table 1 Death from Hookworm Infection, Sri Lanka 1900–1922

Year	Estimated Population[a]		Death Rate Per Million	Year	Estimated Population[a]		Death Rate Per Million
1900	Island	3,565,954	72.3	1913	Island	”	534.7
	Plantation	441,601	217.3		Plantation	”	3449.1
1904	Island	”	88.3	1914	Island	”	641.6
	Plantation	”	346.4		Plantation	”	4348.8
1905	Island	”	157.6	1915	Island	”	504.0
	Plantation	”	656.7		Plantation	”	3269.9
1906	Island	”	256.5	1916	Island	”	610.0
	Plantation	”	1173.0		Plantation	”	4021.6
1907	Island	”	266.6	1917	Island	”	624.6
	Plantation	”	1259.0		Plantation	”	4035.3
1908	Island	”	352.2	1918	Island	”	566.9
	Plantation	”	1893.1		Plantation	”	3458.8
1909	Island	”	416.7	1919	Island	”	635.1
	Plantation	”	2497.7		Plantation	”	3412.0
1910	Island	”	446.4	1920	Island	”	794.1
	Plantation	”	2586.0		Plantation	”	4307.9
1911	Island	4,106,350	489.7	1921	Island	4,498,605	651.3
	Plantation	513,467	2894.0		Plantation	568,850	3678.9
1912	Island	”	448.8	1922	Island	”	415.4
	Plantation	”	3075.1		Plantation	”	2132.5

[a]Population figures for the Island and the Plantations are based on the 1900, 1911, and 1921 census. Department of Census and Statistics. *Census Data, Ceylon Year Book*, Colombo 1970; Rockefeller Archive Center, *Ceylon Population*, 4, 1914, Record Group 5, Series 2, Box 47; Sri Lanka National Archive, *Ceylon Administration Reports, Vital Statistics: Report of the Registrar General of Ceylon* (1900–1922).

agricultural territory into the more stable, industrial economy controlled by the capitalists in the North. John D. Rockefeller Sr. and his close advisors believed that the disease, illiteracy, and unemployment in the South were not only causing political and civil unrest, but also contributing to the sluggish economy. By improving the health and education of the whole population, beyond racial boundaries, the Rockefeller Foundation expected to expand its industrial and commercial base in the South (Brown 1979).

The political and economic interests of the Rockefeller philanthropists were certainly not limited to the United States. They clearly recognized the interrelationship between their own personal economic interests and those of the capitalist class and the global economy in general. Consequently, with the experience of controlling hookworm infection in the South, the International Health Board of the Rockefeller Foundation (hereafter the IHB) willingly extended its capital to other countries, particularly to the British Empire. Frederick T. Gates, who was one of the architects of the Rockefeller philanthropies, wrote to John D. Rockefeller Sr. in 1905 stating that the hookworm control campaign was one of the “special programs that has direct physical and economic benefits, and a means of creating and promoting influences” (Brown 1976). The “concept” of health, for the Rockefeller philanthropists, was clearly an economic term embedded in the capitalistic pursuit of global economic and political domination. They had the foresight to understand that disease has no geographical or cultural boundaries. In relation to the hookworm control program in Sri Lanka, Dr. Victor Heiser, the director of the public health program of the IHB in the East, maintained that “disease never stays at home in its natural breeding place of filth, but is ever and again breaking into the precincts of its more cleanly neighbors.... It should also have been evident to employers of colonial labor that human life had a direct monetary value... even though it might vary greatly with age and race” (Heiser 1936). The Rockefeller philanthropists believed that if health could be achieved in the British colonies, which included the largest share of the global market, Western industrial capitalists could not only expand their trade to those countries, but also influence the national political affairs of those nations. In this context, they expected that medicine would help unify and integrate the emerging industrial economies and their social and cultural values with those of less developed agrarian societies and legitimize capitalist activities by diverting attention from structural and other environmental causes of disease (Brown 1976).

When the IHB began the hookworm control campaign in Sri Lanka in 1916, the United States was already an emerging superpower with an established military presence in the East. Following the Spanish-American war in 1898, the United States was in control of the Philippine Islands (Wolff 1961). While the U.S. Army Board of Health was responsible for the overall public health activities of the islands, the Rockefeller Sanitary Commission was engaged in some philanthropic work in the field of tropical sanitation. Sri Lanka was a special interest case for the IHB in the East for specific reasons pertaining to the long-term objectives of the Rockefeller Foundation. Wickliffe Rose, the director of the IHB, pointed out that Sri Lanka was a key location in Asia where a successful public health program could attract a great deal of interest in the whole region (RAC 1915). Among some of the specific reasons that he indicated for the choice of Sri Lanka were:

1. The government offered a favorable administrative framework,
2. The agricultural industry provided an effective economic medium,
3. The island delimited a large, but discrete, area,
4. The geographic location of Sri Lanka in the East might tend to help spread the new knowledge and its benefits (Philips 1955).

By implementing a hookworm control program for a selected group of people in the country, the IHB expected to achieve high visibility and recognition in the international community. Furthermore, by eradicating hookworm infection among the workers in the plantation industry the Health Board believed that it could help increase productivity (Brown 1976). In his speech to the Planters' Association in Kandy on May 12 1916, Dr. Howard, a project advisor of the hookworm control campaign in Sri Lanka, specifically mentioned the economic benefits of the hookworm campaign: "it is of immense importance to the planters and estate owners since their profit must be dependent upon the efficiency of the labor with which they operate. Further, not only would the efficiency rate of the treated laborers increase by 20–40%, but also they were less likely to return to India necessitating the importation of others to replace them" (RAC 1916).

The cultural and political aspects of the location of Sri Lanka were equally important for the Rockefeller Foundation. Sri Lanka, as the center of Theravada Buddhism in the East, was identified as an important cultural "laboratory" for a public health campaign of Western medicine, the success of which could be used by the Rockefeller Foundation as an example to highlight the benefits of Western culture (Jayawardena 1988).

Organization of the Project

The project was begun in 1916 under the direction of an American doctor, John E. Snodgrass, who reported both to the IHB of the Rockefeller Foundation and to the PCMO of Sri Lanka. All the other subordinate staff working in the project was selected locally. The immediate objectives of the project were outlined as follows:

1. To reduce the cost of annual recruitment of new workers by reducing morbidity and mortality
2. To cut down hospital expenses by reducing the rate of hospital occupancy
3. To increase the rate of fertility among female workers and to produce a native-born permanent labor force by treating anemia and
4. To increase daily productivity by reducing the number of sick workers (RAC 1916).

By the end of 1922 over 600,000 people had been treated. The rate of infection dropped dramatically, and hookworm related deaths in the island declined to their lowest level of 415 per million persons in 12 years. The reduced hospitalization among workers showed the planters the economic benefits of the campaign. Annual reports emphasized the increased productivity and the reduced absenteeism. "There have been indications that the health of many has improved since the treatment. There has been an increased capacity for work" (RAC 1918). Reports were carefully worded to avoid any misunderstanding that could jeopardize the confidence in Western medicine or the work of the Rockefeller Foundation. For example, in the case of death following treatment, the locally recruited dispensers were accused. "Careless administration of treatment... may have caused one or two deaths in the hookworm campaign. There were mistakes and instances of irresponsibility on the part of some of the local staff, but all known emergencies were met by the doctors with an almost perfect record of medical success" (RAC 1917). American doctors working in the field often interviewed plantation management to get their reaction to the increased productivity as a result of the treatment. One planter reported that "the whole labor force is healthier... there has been very little sickness lately and... one outcome of the treatment is the pending heavy increase in the birth rate. My coolies on the whole have great faith in the treatment" (RAC 1918).

The increased productivity immediately after the treatment created a great deal of enthusiasm among planters as well as the Rockefeller field doctors. Almost every communiqué from the field doctors to the IHB officials clearly emphasized the fact that the laborers were healthier and working hard. But this enthusiasm was not translated into fundamental sanitary reforms on the plantations. Although the field doctors insisted upon the establishment of latrines in workers' lines, it was beyond their power to impose such orders on planters. With the experience of reinfection under poor sanitary conditions in other countries, the field doctors made a number of appeals to the Planters' Association

Medicine and Colonialism in Sri Lanka. Table 2 Persons Examined and Treated for Hookworm Disease by the International Health Board, Sri Lanka, 1916–1922

Year	Persons Examined[a]	Percentage Found Infected[a]	Persons Treated[b]	Percentage Cured[b]
1916	7,645	96.3	6,752	82.5
1917	42,828	97.2	35,675	82.5
1918	26,424	97.0	50,374	88.9
1919	15,542	77.5	88,602	77.9
1920	16,961	75.5	126,529	76.2
1921	497	84.9	117,209	n/a
1922	7,137	83.7	262,545	n/a

[a]Rockefeller Archive Center Summary figures, Ceylon anchylostomiasis campaigns, 1–2, 1925, Record Group 5, Series 3, Box 196;
[b]Sri Lanka National Archive Ceylon Administration Reports, Principal Civil Medical Officer and Inspector General of Hospitals (1916–1922).

and colonial government for constructing latrines in the workers' lines. They recommended the following steps for permanent control of hookworm infection on the plantation:

1. The construction and improvement of latrines and line compounds in order to meet basic sanitary requirements,
2. The mass treatment of all employed laborers annually until the re-infection declined to a negligible level,
3. The establishment of quarantine camps in South India, where the plantation workers originated, to treat them before leaving for Sri Lanka (RAC 1925).

The Rockefeller Foundation's hookworm control campaign on the plantation began with the understanding that the planters would take the appropriate measures to improve the sanitary conditions on the estates. However, these preventive measures required some spending which the planters did not want to undertake. As a result, the rate of reinfection continued to increase in the plantation areas. In one district alone (Matale), a year after the workers had been cured, the rate of re-infection was 88% among a total of 3,000 persons examined (RAC 1920a). The field doctors reluctantly admitted that the planters were unwilling to improve sanitary conditions, though they were happy to see that the laborers were being treated. In their annual reports, they recommended sanitary reforms as a fundamental requirement for the prevention of the disease. However, these cogent recommendations of the field doctors were not matched by sufficient will on the part of the IHB officials, whose mandate it was to negotiate with the government and planters. For political reasons financial contributions were approved so long as good will continued to prevail between these parties. For instance, in recommending $5,000 for a plantation company to provide treatment for their laborers, Dr. Jacocks, a senior representative of the IHB in Sri Lanka, wrote to the New York office, "I asked Dr. Rutherford [PCMO] for his opinion as to whether the granting of such a contribution by the Board at Government's request would help to "heal the break" [original emphasis] between Government and the planters. He said that he thought it would, as it should be evident to planters that the aid could not have been granted without Government consent. He thought further that a more kindly reciprocal feeling between planters and Government would follow" (RAC 1920b). Perhaps even in a more crucial ideological sense, presented with the choice of pressing for fundamental sanitary development or continuing medical treatments, the IHB officials consistently authorized the latter, which it favored due to its bias towards curative medicine. Instructing on how to spend the $5,000 grant, Dr. Jacocks stated, "this sum to be used for post treatment as well as first treatment" (RAC 1920b). Despite the apparent failure of the hookworm control campaign on the plantations, the IHB felt it had achieved its goal by demonstrating the relationship between the treatment for hookworm disease and increased productivity. Therefore, in 1922, the IHB decided to close its program on the plantations (Hewa 1995).

While medicine and medical services were developed to overcome the threat of tropical diseases, these medical services were not extended to the people of the colonies until it was realized that the repeated outbreak of epidemics in the colonies would not spare the European troops and administrators. Moreover, the diseases in the colonies eventually found their way to Europe through trade. For example, the spread of cholera from India to Europe between the period of 1816 and 1880s was a major concern that directly influenced the scientific research of John Snow, Louis Pasteur and Robert Koch (May 1958). While the health of the Europeans was always the first priority of colonial policy, the health of the indigenous people, as long as it did not threaten the economic and political interests of the empire, was ignored. Indian labor was exploited extensively for the expansion of the empire in

Asia, Africa and the Pacific in the same manner as African slavery was used to build the colonial economy in America and the Caribbean.

As shown, the hookworm epidemic in Sri Lanka was the result of a colonial labor policy which compromised the basic sanitary requirements of the workers for the purpose of maximizing profit. Although there was nothing inherently evil in the medical services provided by the IHB in Sri Lanka, or anywhere else for that matter, the predominant interests of the IHB–as epitomized by its partiality for curative medicine - effectively precluded the success of their campaign to cure disease at their source. This curative bias of the IHB official changed overtime as they continued to work in Sri Lanka. This was evident in the subsequent Health Unit Program (Hewa 2005) begun in the late 1920s that became the foundation of the primary care system developed in the last 75 years in Sri Lanka.

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Medicine of Tibet

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How can we understand the practical applications of healthcare systems from different cultures? This chapter about the theory and practice of traditional Tibetan medicine (TTM) attempts to point to possible answers to that question.

Traditional Tibetan medicine approaches health from the perspectives of balance, synergy and integration of multi-dimensional aggregates that span body and mind, simultaneously and without distinction. The emphasis of TTM involves dealing directly with the nature of imbalances among the aggregates that result in the appearance of signs and symptoms of disease and illness. The approach includes dealing with issues of mind – including conflicting emotions and mental afflictions – as well as dealing with the external influences that adversely affect a person's specific constitution and condition. TTM avoids the schism of mind and body that is so prevalent in western medical care.

His Holiness Dalai Lama XIV offered a statement about the utility of TTM at the First International Congress of Tibetan Medicine in 1998 (Dalai Lama 1999):

> As an integrated system of health care, Tibetan medicine can offer allopathic medicine a different perspective on health. However, like other scientific systems, it must be understood in its own terms, as well as in the context of objective investigation. In practice it can also offer Western people another approach to achieving happiness through health and balance.

Dalai Lama states a position of cultural relativism – that opportunities are present to study culturally different traditions of healthcare that may benefit people in western cultures. This is possible if the native culture is understood and examined from its own premises, rather than maintaining an ethnocentric position. His Holiness also points to a priority of TTM – a primary goal of healthcare is to attain happiness. This goal is often not considered in western biomedical traditions of healthcare, where there is more emphasis on materialistic aspects of technologic interventions to overcome disease.

The notion of disease can be viewed as a culturally bound concept – one that depends upon assumptions, motivations, and selective attention of the people in that tradition. Disease is a reified concept, based upon meaning and interpretations assigned to patterns of the subjective symptoms and experiences of illness and concurrent objective symptoms (Kleinman 1981). One intention of this chapter is to examine the premises underlying the theory and practice of TTM, so that the engrained approaches of western biomedicine may become more accessible, understandable, and meaningful by comparison and contrast (Leslie and Young 1992).

Anatomy and Physiology in Tibetan Medicine: Aggregates and Elements

Maintaining balance among the three aspects of bodily constituents (Tibetan: *Nyipa sum*) is the goal of Tibetan medicine (Dhonden 1977, 1986, 2000). The three aggregates are complexes of mind-body that include physical, personality, and spiritual aspects. The three aggregates are *rlüng*, *mKhris-pa*, and *Bad-kan*, often collectively translated as "humors" and translated as "wind," "bile," and "phlegm". However, these terms do not accurately portray the unified and multi-dimensional nature of these aspects. Alternatively, the terms "rlüng, mKhris-pa, and Bad-kan" can be translated as "subtle energy, transforming energy, and supportive energy." These alternative terms convey the qualities of functional interactions that are prominent within Tibetan medicine. The term "aggregates" will be used in the remainder of this chapter, in place of the more common translation as "humor."

The aggregates of TTM are composed of elements. The elements that comprise the ordinary physical body in TTM are translated as space, air, fire, water, and earth (*nam mkha*, *rlüng*, *me*, *chu*, and *sa*). The five sensory consciousnesses (hearing, touch, sight, taste, and smell) each correspond to the same respective elements. Thus, each element is a metaphor, or "sphere of influence" (Porkert 1974), representing the many dimensions of life experiences. For example, space represents formless potentiality (e.g., consciousness) and air is associated with subtle movements (e.g., conduction of impulses in the nervous system, circulation, respiration, or intuition). Fire represents active transformation (e.g., digestion of food into nutrients or intellectual discourse), while water represents cohesion and communication (e.g., empathy, lubrication, or feelings), and earth is manifest form (e.g., anatomic structure or physical sensations). Each element is

Medicine of Tibet. Table 1 Five elements and their cellular, tissue, and physiological functions

Elements	Physiological functions
Earth	Muscle tissues, bones, nose, and sense of smell
Water	Blood, body fluids, tongue, and sense of taste
Fire	Body temperature, complexion, eyes, and sense of sight
Air	Respiration, skin, and sense of touch
Space	Body cavities, ears, and sense of hearing

Medicine of Tibet. Table 2 Relationship between the five elements, aggregates, and three poisons

Element	Three aggregates	Three poisons (mental and spiritual)
Earth and water	Phlegm (Tibetan: Bad-kan)	Delusion, ignorance
Fire	Bile (Tibetan: mKhris-pa)	Aversion, hatred
Air and space	Wind (Tibetan: rlüng)	Attachment, passion

Medicine of Tibet. Table 3 Characteristics and functions of three aggregates

Aggregates	Characteristics	Functions
Wind (Tibetan: rlüng)	Rough, light, cold, subtle, hard, and mobile	Physical and mental activities, respiration, urination, defecation, development and delivery of the fetus, menstruation, spitting, burping, speech, clarity of the sense organs, sustain life by acting as a medium between mind and body
Bile (Tibetan: mKhris-pa)	Oily, sharp, hot, light, fetid, purgative, and fluid	Hunger, thirst, digestion and assimilation, promote bodily heat, gives luster to body complexion, provides courage and determination
Phlegm (Tibetan: Bad-kan)	Oily, cool, heavy, blunt, smooth, firm, and sticky	Firmness of the body, stability of mind, induces sleep, connects bodily joints, generates tolerance, and lubricates the body

associated with a sense organ and sensory perception, emotions, sacred images, and more (Tables 1–3).

The elements combine to form the aggregates that represent a person's constitution (Tibetan: *Rang bZhin*). Space and air together comprise rlüng (Sanskrit: *vata*). Rlüng is traditionally considered the most important aggregate in Tibetan medicine, since movement is so basic to all vital functions. Consequently, rlüng conditions are highly prevalent. Fire is the primary element in mKhris-pa (Sanskrit: *pitta*) constitution, while water and earth combine to form Bad-kan (Sanskrit: *kapha*) (Lad 1984).

Usually one aggregate predominates as a person's constitution. The aggregates can also combine so that primary and secondary aspects are present. For example, primary rlüng and secondary mKhris-pa constitutions (and vice versa) allow for refined behavioral and medicinal prescriptions. When all aggregates are afflicted simultaneously, a condition known as *mug-po* is present. The Tibetan elements differ from the five-phase theory in the traditional Chinese medical model (Porkert 1974).

An example of the explanatory model for aggregates in Tibetan physiology may be useful. When we eat, the nutrients go to the stomach where Bad-kan helps to mix them (lubrication function). Then the mKhris-pa will help to digest them (transformation activity), and the rlüng will help to separate the essential nutrients from the waste products (movement metaphor). The essences of the nutrients eventually form blood, and in a cascade of events, the essence of blood forms muscle tissue, the essence of muscle tissue forms fat, the essence of fat forms bones, the essence of bones forms marrow, and the essence of bone marrow forms the regenerative fluids. The qualities of the regenerative fluids are responsible for the radiant glow of good health (Sanskrit: *ojas*). When the three aggregates are balanced, then the seven bodily sustainers mentioned above are also balanced.

Functional relations are emphasized more than physical anatomy in Tibetan medicine (Rechung 1976). From the spiritual perspectives of Tibetan Buddhism and in the context of TTM, the organs, their functions, and elements are each related to a particular wisdom portrayed in sacred iconography (Lauf 1976: 117–137). Each bodily structure is also associated with meditational deities and sacred sounds (*mantra*). Each element and aggregate is related to aspects of mind, sensory perceptions and emotions and modes of cognition. Body and mind, mundane, and spiritual are fused within Tibetan medicine. Thus, health and disease are multi-dimensional, including spiritual dimensions.

Clinical Diagnosis in Tibetan Medicine

A Tibetan physician employs his own senses to examine the patient's general balance of health. There are three main methods of diagnostic examinations in Tibetan medicine: questioning, observation, and palpation. Interactive and subjective clinical assessments are the essence of the diagnostic method. Objective technologies for clinical diagnosis are practically non-existent in TTM. There are modern clinical survey instruments to assess Ayurvedic constitution (Sachs and Rapgay 1995; Chopra 1991), but no psychometric studies are readily available to validate their clinical utility.

Diagnosis by Questioning

Questioning is based on a series of 29 items that help to identify the nature of the imbalance in constitution and condition (Clark 1995). Questioning is analogous to taking a clinical history in western medicine, whereby signs, symptoms, patient perceptions, and meanings are elicited. For example, the cause of disease may lie in consumption of unwholesome foods or improper behaviors. Asking about specific signs and symptoms assists the physician in understanding the imbalances among the three aggregates. (Finckh 1988) When assessing constitution and condition, the qualities that the patient exhibits in responding to the questions are as important as the content of the answers.

Diagnosis by Observation: Urine and Tongue Diagnosis

The urine is examined to assess constitution, condition, and response to treatments. For constitutional assessments, the patient is instructed to refrain from eating spicy foods, drinking alcohol, performing unusual strenuous activity, and having sexual intercourse on the day before the examination. The physician examines the first early morning urine sample by stirring it in a small bowl with a clean stick and then examining the color, vapor, odor, bubbles, sediments, and scum.

The color of urine is determined by the intake of food and drink, seasons, diseases, and imbalances. In general, a reddish color with a small volume of urine indicates a hot disorder, while whitish clear urine with a large volume indicates a cold disorder. For the patient with rlüng, the urine is clear like water and it has many big bubbles that may last only a short time. The urine from a person with mKhris-pa constitution is a reddish-yellow color, with a very strong odor, and moderate-scant volume. The Bad-kan patient has urine that is clear in color, with little odor, large volume, and small bubbles that often last a long time. Repeat urine analyses are used to gauge the accuracy of diagnosis, the efficacy of the treatment and as a guide to refining the treatment.

The Tibetan doctor may view the patient's tongue to provide additional clinical information. For example, the rlüng patient will probably have a red, dry, and rough tongue. The patient with mKhris-pa constitution will likely have a tongue with a thick yellow coating. The tongue of a Bad-kan patient is white, smooth, and wet. Tongue and pulse diagnosis may also prompt additional questioning to support or reject clinical assessments.

Diagnosis by Palpation: Pulse Diagnosis

Examination by touching includes palpation of the body parts to assess temperature, areas of tenderness, tightness, weakness, or abnormal growths. Pulse diagnosis is a key method for assessment (Dhonden 1986; Dhonden and Topgay 1980; Finckh 1978; Steiner 1987–1989). The physician interprets the waveforms of the patients' radial arteries to assess ongoing physiologic processes and relationships between body parts and aggregates. Patients are instructed not to engage in sexual intercourse on the day prior to the pulse reading, not to consume alcohol, eat excessively, or engage in strenuous activities. These recommendations are intended to normalize the three aggregates by minimizing extraordinary external influences. The assessments of constitutional pulses are typically performed during the early morning, while the patient's stomach is empty.

The physician palpates the radial pulses on both wrists, while the patient is in a comfortable and quiet environment (Fig. 1). The left hand is slightly flexed, so that the wrist creases are clearly visible. A special pillow may be used to rest the wrists during this part of the examination. The doctor places the fingers of his right hand on the left radial pulse of the patient, so that the right index finger is proximal to the wrist crease, at a distance about as wide as the patient's distal thumb. The second and third fingers then fall naturally along the artery. The three palpating fingers generally do not touch one another unless the patient is small in stature. The patient's right radial artery pulses are palpated in a similar manner. The physician may examine the pulses on one wrist at a time, or he may examine both wrists simultaneously. The radial pulse is palpated with increasing pressures at each site proximal to the wrist crease.

Medicine of Tibet. Fig. 1 Positions of the physician's fingers for reading the pulses.

Each of the physician's palpating fingers can assess the functional characteristics of specific physiologic systems form the observed and interpreted qualities of the pulses. It is again important to note that although the names for organ systems are used here, these terms are metaphors for the mind-body functions associated with the elements and aggregates. According to the text, the heart and small intestine are assessed at the first position on the male patient's left hand, the spleen/pancreas and stomach with the second palpating finger, and so on. Similarly, the pulses at the first position on the male patient's right radial artery correspond to the lungs and large intestine. Liver and gall bladder pulses are located at the second position, and right kidney and urinary bladder are at the third position.

The pulses of women are reversed at the first position only, so that the heart and small intestine are assessed at the first position on the woman's right hand and the pulse for lungs and large intestine is read on a woman's left radial pulse. The reason for the switch is due to slight differences between genders for the apex of entry for consciousness that enters the heart, although no physical differences in the anatomy of the hearts is present. This is consistent with teachings of Tibetan embryology.

There is a complex system for interpreting the qualities of the pulses at each of the 12 sites on the radial arteries. For example, floating, irregular or intermittent beat qualities may be present in the pulse in the presence of disorders of rlüng. This finding often indicates the presence of pain symptoms that may radiate or have a breaking quality in specific sites indicated by the pulse. Rlüng symptoms have a tendency to change or be fleeting. Protruding and rolling pulses in the proximal sites are often present in early pregnancy, a finding attributed to the excess blood from the fetus (Bad-kan condition). Fast or jumping qualities indicates excess heat (mKhris-pa). Underlying patterns within the pulses can be discerned; this allows the physician to select various medicines in accord with their taste, potency, and site of action (Fig. 2).

Medicine of Tibet. Fig. 2 A Tibetan physician reading the radial pulses.

Constitution Analysis and Treatment Methods

The first priority in Tibetan medicine is to restore harmony to each person in the context of his or her life experiences. Symptoms are a result of an imbalance caused by disturbances in circumstances such as diet, lifestyle, and seasonal and mental conditions. Treatment depends on the total situation rather than the individual symptom; therapy varies with constitution and condition. Two people with the same symptom may be given very different advice and treatment, if constitution and condition differ.

Tibetan medicine provides a systematic approach to treatment and prevention. There are four methods of intervention: diet, behavior modification, medicine, and physical therapies. The three constitutions (rlüng, mKhris-pa, and Bad-kan) each have patterns of symptoms, preferences, and tendencies that can be remedied with categoric therapies. If the illness is not serious, diet and behavioral advice may be sufficient; otherwise, prescriptive medicines may be needed.

However, the best use of medical treatment cannot provide good health through physical means alone; a healthy mind is needed as well (Tai Situ Rimpoche and Terhune 1992: 21). Tibetan medicine gives priority to psychological and spiritual factors in its definition of health. It teaches that we can make peace with the disease once we know and understand it. The literature is rich with specific meditation techniques used to restore balance (Rimpoche 1996; Sachs and Rapgay 1995; Tulku 1979; Thondup 1998; and many others). Each constitution and typical treatments are discussed below.

Constitution and Conditions in Tibetan medicine: rlüng

The physical characteristics of rlüng constitution typically include an asthenic body (lacking strength or vigor), sensitivity to cold, and a talkative and lively personality. Rlüng people are easily aroused from sleep, tend to eat small amounts of food frequently, and work hard but sweat little. They are prone to worry and sorrow. Symptoms of excess rlüng tend to be worse during cold and windy climates, during summer, or during early morning and/or late afternoon. Aging tends to produce imbalances in rlüng, so that these conditions are more common among the elderly.

From the spiritual perspective, egocentric mind is the usual source for imbalances of rlüng. Relational issues about attachment, sometimes translated as passion, essentially characterize people with rlüng constitutions (Sachs and Rapgay 1995). Ego, in this context, is the identifying with the false concept that each person is separate and independent from the world in which we live. In Tibetan medicine and culture, ego is viewed as

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a limitation to be overcome, rather than a psychological resource to be enhanced. Ego is synonymous with self-clinging habitual patterns of mind, and so it is viewed as an obscuration to the clarity of the self-liberated mind. Ethical motivations and meditative practices with an experienced teacher can be an aid to realizing and dissolving such barriers.

Diagnosis by observation of a person with excess rlüng shows a tongue that is rough and dry (Fig. 3). Pulse diagnosis shows qualities that are irregular, empty, or floating. Urine is clear and has many large or variable size bubbles that last only a short time (Fig. 4). Diagnosis by questioning may reveal symptoms that are worse with ingestion of foods with light or rough potency and symptoms that change quickly over time. Typically, symptoms worsen when the patient is hungry and they may be relieved with foods that are oily, hot, or heavy. Symptoms tend to have a breaking quality, particularly in the bones and joints and in the lower body. Nervous symptoms including anxiety are common in this group.

Medicine of Tibet. Fig. 3 Wind tongue is dry, with a red tip.

Medicine of Tibet. Fig. 4 Wind urine is clear with lots of large bubbles that do not last long.

Patients with excess rlüng are typically instructed to rest – both physically and mentally. Minimizing anxiety and worry is important, since this psychic discord is a basic manifestation of rlüng. They can be advised to stay in comfortable, quiet, dimly lit, warm places. Company with a few close friends is beneficial, as are small amounts of alcoholic drinks. Patients should avoid excessive indulging of strong coffee and black tea, cold or refrigerated food and drinks, smoking, unripe fruits and vegetables, bitter gourd, junk foods, pork, foods and drinks with bitter and astringent tastes. Patients are encouraged to eat sweets, protein and nutritional foods and drinks, oily and warm foods and drinks, warm milk, butter, wine, garlic, caraway, leek, onion, sesame, cauliflower, radish, nuts, pomegranate, strawberry, apple, nutmeg, flax seed, clove, star anise, cabbage, mushroom, mustard, sunflower seed, cinnamon, and soya bean.

Patients with rlüng disorders are asked to pay special attention to regulating their lifestyles (e.g., eating, sleeping, and excretory function), to find time for calm activities and socializing, and to exercise in ways that promote good overall circulation, using techniques such as hatha yoga exercises and pranayama (yogic breathing). External cautery, similar in principal to traditional Chinese or Mongolian moxibustion (the application of burning moxa or other combustible materials at the acupuncture points) may be used to heat the body. Figures 5 and 6 show some typical herbal ingredients used to diminish excessive rlüng.

Constitution and Conditions in Tibetan Medicine: mKhris-pa

People with mKhris-pa constitution may be very ambitious; they tend to be active and may try to control situations physically or through positions of power. They tend to be keen thinkers and may have extraordinary motor skills. Yet control and aggression are sources of suffering for them. Spiritually, people with mKhris-pa constitutions can be characterized by aggressive behaviors sometimes translated either as “hatred” or “aversion.” The attitudes and behavioral characteristics of mKhris-pa also rest upon a false sense of ego-clinging identity, just as was present among those with rlüng. However, the varieties in constitution and condition allow for different manifestations of this basic ignorance.

Patients with mKhris-pa constitutions are typically medium size, muscular, with a yellowish tinge to the skin. They are frequently hungry and/or thirsty, sweat easily, and they like activities and challenges. They are prone to annoyances and anger. Symptoms of excess mKhris-pa tend to be worse during hot and dry climates, during autumn, or during midnight and midday hours. Imbalances in mKhris-pa tend to occur among middle age groups.

Medicine of Tibet. Fig. 5 Clove or Eugenia caryophyllata, an ingredient of Sem-De, a traditional herb medicine to reduce excessive rlüng.

Medicine of Tibet. Fig. 6 Nutmeg or Myristica fragrans, an ingredient of Agar 8, a traditional herb medicine to reduce excessive rlüng.

Diagnosis by observation of a person with excess mKhris-pa shows a tongue that is coated with a thick, yellowish substance (Fig. 7). Pulse diagnosis shows qualities that are fast, strong, and jumping. Urine is yellowish-red, with a strong odor and small bubbles (Fig. 8). Diagnosis by questioning may reveal symptoms that are worse after eating, especially after foods with sharp or hot qualities. Symptoms may include a bitter taste in the mouth, a sense of heat or fever within the body and aches in the middle and upper parts of the body. Ingestion of cool foods may relieve the symptoms.

Therapy for mKhris-pa is directed to foods and medicines that are sweet, bitter and astringent in taste and cool, smooth and blunt in potency. Patients with an imbalance in mKhris-pa should eat beef, vegetables, butter, low fat cheese, cow's yogurt and buttermilk, and drink weak tea or spring water. A simple vegetarian diet is suitable, including legumes, potatoes, artichokes, bitter vegetables (e.g., dandelion), and turnips that may

Medicine of Tibet. Fig. 7 Bile tongue with yellow coating.

be seasoned with cumin, coriander, or fenugreek. Foods that are heating in nature should be avoided, including peanut butter, mustard and hot spices, garlic, ginger, onion, alcohol, grilled meats (esp. lamb), oily and greasy foods, and soups made with bones.

Syrups and powders are traditional types of prescribed Tibetan medicines for mKhris-pa. Purgatives and strong laxatives are used to reduce the excessive amount of heat in the body. Behavior changes include the use of cold baths and showers, sitting in shaded

Medicine of Tibet. Fig. 8 Yellow, foul smelling urine for case with excess mKhris-pa (bile).

Medicine of Tibet. Fig. 9 Herbal remedy for excessive mKhris-pa (bile) is *Saussurea lappa*, an ingredient of Tik-Ta 8.

places, walking by the sea and cooling scents such as sandalwood. Individuals suffering from a mKhris-pa disorder should avoid situations causing conflict and direct, excessive exposure to the sun. Physical activities that are relaxing are encouraged; an environment that is conducive to calmness is beneficial. External treatments may target the production of sweat and may also include bloodletting. Typical herbal ingredients for excess mKhris-pa are shown in Figs. 9 and 10.

Constitution and Conditions in Tibetan Medicine: Bad-kan

The physical characteristics of Bad-kan constitution are typically a large or tall body, someone who can endure hunger and thirst well, who shows a pleasant, easy going and friendly personality. People in this group tend to sleep soundly, eat too much and too quickly, and wear clothing that is insufficient to keep them warm. Excessive sleeping can worsen conditions. Bad-kan people tend to be slow, persistent, and methodical in daily routines. Cultivation of good habits can be beneficial and enduring. Established routines are easily maintained, but changing habits can be difficult. Changing unhealthy habits may call for exertion that may initially make the person uncomfortable. This information is part of the prescription for health for this constitution. Babies and young children tend to have imbalances in Bad-kan.

The spiritual dilemma of people with Bad-kan constitutions can be characterized by ignorance, also known as delusion or confusion. Ignorance is one of the three poisons. It means not relating to self and others with a proper view. Ignorance has no relationship to intelligence, as we use the term in western societies. As such, it cannot be remedied with more studies or acquisition of mundane knowledge. Spiritual insight is the key to resolving the dilemma of ignorance.

Medicine of Tibet. Fig. 10 Herbal remedy for excessive mKhris-pa (bile) is *Rosa sericea* Lindl., an ingredient of Tri-Nam.

Diagnosis by observation of a person with excess Bad-kan shows a tongue that is moist, smooth, glistening with a thick gray lusterless coating (Fig. 10). Pulse diagnosis shows qualities that are slow, weak, sinking, or deep. Urine is usually clear, with little odor and few bubbles that last a long time (Fig. 11). Diagnosis by questioning shows that symptoms are worse after eating, especially after heavy foods, and relieved after warm or hot foods. Symptoms include a sense of discomfort, heaviness or coldness in the upper body or a sense of heaviness in the mind (Fig. 12).

Therapy is directed to foods and medicines that are pungent, sour and astringent in taste, with potencies of sharp, rough, and light. Patients should adopt a heating diet with respect to both the nature and the temperature of the food. For example, they are encouraged to consume a traditional diet to counter excess cold and retention of fluids, including: hot water,

Medicine of Tibet. Fig. 11 Excessive Bad-kan (phlegm) tongue is wet and coated white.

Medicine of Tibet. Fig. 12 Excessive Bad-kan (phlegm) urine is clear with small bubbles that last a long time.

cooked foods, mutton, fish, barley, pomegranates, sheep cheese, yogurt, ginger, radish, honey, garlic, and wine. They should avoid cold drinks and raw foods such as salads, potatoes, tomatoes, eggplant, bell peppers, and sugar.

Patients with Bad-kan disorders may be instructed to keep warm and perform vigorous exercise such as running or dancing. Swimming in cold water is not appropriate for Bad-kan conditions. Periodic emetics (e.g., induced vomiting) are recommended as part of a traditional health maintenance routine, since this reduces the excessive amount of cold and damp that tends to accumulate in the body. An environment that is conducive to heat producing activities is beneficial, including lots of exposure to warm sun and fires burning in the home. External treatments may target the

Medicine of Tibet. Fig. 13 Pomegranate, an ingredient of Se-Dru 5, a traditional herb medicine to reduce excessive Bad-kan.

Medicine of Tibet. Fig. 14 Rhododendron, an ingredient of Dhe-Nyom, a traditional herb medicine to reduce excessive Bad-kan.

cautery and other forms of heat. Traditional herbal remedies to reduce excessive Bad-kan are shown in Figs. 13–16.

Pharmacology in Tibetan Medicine

Natural herbal preparations are a large part of therapy in Tibetan medicine. The goal of herbal remedies is to restore balance among the constituents of the body-mind complex. The medicinal effects associated with Tibetan preparations are not due to the presence of a specific ingredient, as in western pharmaceuticals. Rather, the herbal combinations act on the body-mind aspects of the afflicted aggregates and elements to restore balance. Remedies act on the specific imbalance, while other ingredients support the aggregates that are not maligned during the period of the intervention, although they may be challenged during the dynamics of therapy and healing (Fig. 17).

Medicine of Tibet. Fig. 15 Saffron, an ingredient of Dhe-Nyom.

Medicine of Tibet. Fig. 16 A medical student gathering herbs.

Medicine of Tibet. Fig. 17 Medical students cleaning gathered herbs in Northern India.

Most of the ingredients in the Tibetan *materia medica* are herbs and plants. There are eight categories of natural substances used in preparing prescribed therapeutic remedies: precious metals and gems, stones, earth medicines, trees, resins, plants, herbs, and animal products (Clark 1995; Clifford 1990; Dash 1976). The remedies can take ten forms: decoction, pills, powder, gruels, medicinal butters and calxes, concentrated extractions, medicinal wine, herbal medicine, and gems as medicine. Enemas, especially if oily, mild, and soothing, are useful for rlüng imbalances. Purgatives reduce the heat in mKhris-pa conditions. Emetics reduce water and mucous associated with excessive Bad-kan.

Tibetan herbal pills are often complex, with 3–150 herbs per formula. Each herbal formula is prescribed to fit the manifestation of the disease and the evolving condition of the individual patient. The herbs are often sought from natural settings, often harvested from a great distance or requiring expertise in climbing or other skills to access the plants. The plants are gathered under specified circumstances, including time of day, phase of the moon, etc. Special mantras are often recited during collection of the herbs, during preparation and after the pills are formed, to imbue the remedies with healing qualities.

The physician often starts with less potent preparations and advances to stronger forms if necessary. Typically, two to four formulas are prescribed for each day at specific times. Morning remedies commonly include those for Bad-kan disorders or digestive disorders. Afternoon remedies are typically used to treat mKhris-pa disorders. Remedies given in the late afternoon or evening are usually given to treat rlüng disorders. Herbal remedies are often modified at each visit (Figs. 18 and 19).

The substance in which a medicine is dispensed is called the medicine horse (*Men-Ta*) (Burang 1974). Typical carrier agents include water, alcohol, sugar, treacle, or honey. According to tradition, sugar is the men-ta for dispelling mKhris-pa, treacle is the carrier for reducing rlüng, and honey is selected for

Medicine of Tibet. Fig. 18 Modern methods for making TTM pills.

Medicine of Tibet. Fig. 19 Packaging the pills.

Medicine of Tibet. Fig. 20 Various forms of modern Tibetan medicines.

overcoming Bad-kan. The compounded remedies are sometimes coated with resins, so that they pass through the stomach and into the intestine where they are integrated into the body in accord with traditional concepts of physiology (Fig. 20).

The art and science of preparing TTMs is based on tastes and potencies. The tastes are associated with medicinal properties. Each taste is present as the result of interaction between two or more elements. Specific tastes can increase or decrease the activity of specific aggregates. The text says that sweet, sour, and salty tastes overcome (reduce) rlüng. Likewise, bitter, sweet, and astringent abate excessive mKhris-pa, and pungent, sour and salty tastes counter Bad-kan (Table 4). These same tastes also describe the medicinal properties of common foods and spices.

The properties of herbal remedies and traditional medicines can be determined by the refined sense perceptions of Tibetan doctors. The tastes and actions of therapeutic agents on specific parts of the tongue correspond with medicinal properties at specific parts of the body. For example, medicines with astringent tastes that influence the sides of the tongue may be useful for treating imbalances that adversely influence the gallbladder organ and associated dimensions, including some migraine headaches. Knowledge about tastes and medicinal actions of therapeutic agents is embodied in a cultural tradition of health care, known as microsystems of anatomic correspondence (Porkert 1974).

Typically the Tibetan pharmacist is also a physician. Preparation of botanical medicines involves collection of specimens, drying, cleaning, storage and preparation, detoxification and neutralization, and compounding. Various parts of plants are gathered at different seasons – fruits in the autumn, leaves during the summer, branches and barks during the spring, and roots during the winter. Mantras to invoke the Medicine Buddha and other deities are often recited during the time of collecting and during other stages in processing to imbue the remedies with additional potency (Fig. 21).

One fundamental difference between modern biomedical sciences and TTM is the notion about the interdependent nature of reality. Interdependent realities include the participatory awareness of an observer in interactions with the relative world of appearances, including measurable phenomena. The perceiver, the object of perception, and the sensory faculties for perceptions are all interdependent. From this perspective, to exclude the observer from an investigation and analysis of phenomena is akin to making an artificial reality. Experiential qualities of relationships are valued as much in TTM as are objective measures of form.

Indeed, one of the strengths of TTM is that mind and body, and mundane issues and spiritual aspirations, are each intimately linked with one another. The perspective of TTM and Tibetan Buddhism pose that the world we experience exists only in the context of our human presence and interactions. In short, the world is an aspect of Mind. Questions posed by western health scientists tend to assume that the nature of reality is independent of the observer. This positivist view typically

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Medicine of Tibet. Table 4 Influence of tastes and qualities on the aggregates (adapted and modified from Clifford 1990: 120; Lad 1984; and others)

Elements	Taste	Qualities	Food and spices	Aggregate increased	Aggregate decreased
Earth–water	Sweet	Cooling	Wheat, rice, peppermint	Bad-kan	Rlüng; mKhris-pa
Earth–fire	Sour	Heating	Yogurt, cheese, lemon, rose hips	mKhris-pa; Bad-kan	Bad-kan
Water–fire	Salty	Heating	Salt, kelp	mKhris-pa; Bad-kan	Rlüng
Water–wind	Bitter	Cooling	Dandelion, turmeric	Rlüng	mKhris-pa; Bad-kan
Fire–wind	Pungent	Heating	Onion, radish, ginger, garlic	mKhris-pa; rlüng	Bad-kan
Wind–earth	Astringent	Cooling	Unripe banana, persimmon, goldenseal	Rlüng	mKhris-pa; Bad-kan

Medicine of Tibet. Fig. 21 Monastic community rituals for blessing TTM medicines.

asks questions about form and status of external phenomena – the “what” of measurable components of nature. Thus, western sciences seem to be bound and limited by concept, form and reliance on objective measurements. TTM defers involvement of the inherent mind-body split of western science and medicine by defining mind as part – if not the source – of reality.

Thus, the very notion of disease and clinical reality as we know it in western biomedicine are challenged in TTM. TTM addresses the process-oriented issues about “how” more than “what.” For example, “How might we live within this precious human birth in a manner that brings happiness to ourselves and all sentient beings?” is a basic motivation among practitioners of TTM. The focus is more on the dynamics of process and relationship, rather than on the parts to be measured. Yet form is not ignored in TTM – it is recognized as simply one mode of perception and relationship among many other possibilities. The dynamics of subtle anatomy and the interactions among the elements and aggregates are the core methods for identifying imbalances to be addressed through traditional methods of TTM.

Thus, a tension is acknowledged between biomedicine and TTM, where TTM focuses on processes for realizing subjective well being for all involved in life experiences, while modern biomedical care seems intent upon attaining disease-free states of objective health status for specific individuals. Yet, perhaps each health care system makes sense when viewed from its unique perspective. Each system is logically consistent within itself.

Does TTM offer any opportunities for new understandings of health and well being among people in western societies? That may depend upon the willingness of western scientists to overcome some engrained notions about the nature of reality and the nature of mind (e.g., of the observer–participants) in scientific investigations. Valid research methods to investigate culturally different health care systems may make use of hypothesis generation from the traditional perceptive, with psychometrically examined key measures that support the traditional view, complemented by known biomedical measures (Anderson 1992; Steiner 2003). Such methods for cross-cultural research, including hypothesis generation from the traditional perspective, may yield new insights about best practices in medical care.

Traditional Tibetan medicine offers an alternative view to health and healthcare, as well as a choice to western scientists. That choice is to consider complementing the focus of western sciences on measurable phenomena with an inward investigation about the nature of mind of the perceiver. In some Tibetan schools of mindfulness training, the inwardly directed investigations are initially analytic and conceptual in nature, but proceed to realizations about the nature of mind itself that are embodied within our human experience – but are not limited by ordinary dualistic conceptual thinking (Thondup 1998; Wallace 1996). That choice is available for any person who is willing to focus on the mindfulness of life experiences, as offered through the guidance of lineages and teachings of wisdom traditions from Tibet, including TTM. The study of TTM offers an opportunity to examine a participatory universe. In short, entering the path of health, healing and well being in accord with principles of TTM, is a choice.

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Medicine in Africa

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Health and healing practices in sub-Saharan Africa have evolved over three millennia in constant interchange with those of other world regions. The medicine of Ancient Egypt shaped ideas of the civilizations around it, including the medicine of classical Greek and Roman Antiquity. This complex in turn spread to African regions, through the influence of Islamic Medicine. Another dimension of Islam, "prophetic medicine," brought notions of health and healing to Africa from Persia and Arabia.[1] Christian faith healing, which spread first with early Christianity across North Africa and Ethiopia, later was part of European colonial expansion to sub-Saharan Africa. Post-Enlightenment scientific medicine, building upon ancient medicine, brought its ideas of public health and curative medicine. All these perspectives coexist in the early twenty-first century with African perspectives on health, sickness, and healing.

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[1] The term "Islamic medicine" encompasses the traditions of medical theory, practice and literature that have been developed in Islamic cultural contexts and expressed most commonly in the languages of Islam, principally Arabic, Persian, Turkish, and Urdu. There are two medical traditions that developed in Islamic contexts. One ultimately derives its authority, and many of its theoretical and practical components, from ancient Greek and Hellenist sources, called in this essay Islamic medicine; the other encompasses traditions associated with the Prophet Muhammad, or prophetic medicine.

What then is African healing and medicine? Africa is of course a vast continent with a multitude of societies of great diversity, and we admit a certain hubris with the very idea of generalizing about it. We will focus our attention on the ethnolinguistic group known as Niger-Congo, within which we have ourselves had most of our experience.[2] This group of societies is geographically widespread and numerically large, covering sub-Saharan Africa from the Wolof of Senegal to the Swahili of coastal East Africa, and down to Southern Africa. The Niger-Congo grouping relates the Bantu-speaking peoples of the Congo basin and southeastern Africa historically and culturally to the dense population of West Africa. All of these societies share, in addition to historically related languages, "attitudes about God, religion, kinship, the nature of the world, and life" (Murphy 1972: 179), and within them, health-related practices and beliefs.

Tools and Perspectives for the Historical Study of Changing Healing Traditions

Ecologically distinctive zones of the rainforest, savanna, and desert have shaped both health and adaptive responses by human communities. The modes of living – hunting and gathering, cultivation, herding, and then urban societies – also shaped the underlying determinants of health.

Hunters and gatherers, for example, such as the remaining Khoisan speakers of Southern Africa in the early twentieth century, practiced infanticide for population control and birth spacing of up to 4 years between children. They also picked up camp whenever diseases broke out, in order to reduce deaths in the settlement. Given their small population concentrations, contagious diseases did not have a chance to take hold and become endemic. The health of the band was promoted through spirit healing ceremonies led by leading healer-singers (Katz 1982; Katz et al. 1997).

Both the West African and the Bantu-speaking civilizations, defined primarily by sedentary agriculture, have also been cattle herders and pastoral nomads throughout their histories. Where the tsetse fly has been absent – as across the Sahel, the eastern Sudan, in the lake region of East-Central Africa, and into moderate Southern Africa – pastoralism has brought with it a distinctive set of ideas about health, sickness, and medicine.

As livestock herding spread southward about six millennia ago, it skirted the rainforest area. This created at the center of the African continent a vast population without domestic large animals. As a result, this population is unable to digest animal milk – a condition known as lactose intolerance. The boundary between pastoralist and nonpastoralist societies has historically been that between rainforest and wet savanna on the one hand and the dry savanna and the desert on the other. On the one hand, the pastoralists have had to manage their herds, concentrating on good breeding, learning the politics of being good neighbors (or superior raiders) on their annual transhumance treks to find seasonal pasture, and understanding the danger zones of the tsetse fly's habitat. On the other hand, the cultivators without large livestock have had to emphasize crop fertility, soil fallowing, irrigation and water management, and the importance of rainfall.

In West Africa, the domestication of plants and animals in sedentary settlements was well underway by 4000 BCE. Urban centers and stratified societies emerged in the West African and the Sudanic savanna by the early centuries of the first millennium AD, and trade routes linked West Africa with the Mediterranean and Europe. By the early second millennium AD the influences of Islam and Arabia were felt in the savanna, but pre-Islamic healing rituals or therapeutic practices were not fully supplanted.

The spread of food cultivation and sedentary social modes southward through and around the equatorial rainforest has come to be associated with the spread of the Bantu, Cushitic, and Nilotic cultures and languages. Perhaps as early as 1000 BCE the Bantu languages had begun to spread from the region that is now Cameroon and Nigeria. These languages ultimately came to be spoken throughout the whole of Central, Eastern, and Southern Africa, facilitating exchange of ideas and practices, including those related to healing. Food production and iron working spread rapidly through this area during the first millennium AD. The sedentarization of community life in sub-Saharan Africa and the domestication of food plants and livestock provided a moving threshold that also affected health and healing. With the transition to cultivation and larger, sedentary communities, new diseases appeared. There was sleeping sickness (endemic in the rainforests, a major threat to pastoralists), malaria (endemic in rainy forested areas), and smallpox (endemic once population concentrations emerged). Together with widespread environmental risks such as poisonous vipers, these diseases offer examples of health threats that encouraged the creation of "medicines" directed at them. They also show the vocabulary of health-related terms and concepts in a common linguistic and cultural background.

Language history – along with archeology and the study of the distribution of cultural practices including uses of plants, animals, and other natural substances – offers one of the most promising avenues for the study

[2] For Janzen, Central Africa (specifically, the Western southern savanna and Kongo coastal regions, the Great Lakes region, coastal Tanzania), and Southern Africa (Swaziland and Capetown); for Green, Swaziland, Mozambique, Southern Africa, East and West Africa.

of the history of African medicine and health related practices (Ehret 1998; Janzen 1992; Schoenbrun 1998; Vansina 1990). Analysis of the words and their meanings and uses by language family permits the determination of which concepts, practices, terms, and phrases are part of the institutional infrastructure of these varied adaptations. Language analysis assists in determining which are inventions along the way, and which are borrowed from elsewhere. Language history also allows the reasonable dating of the origin and spread of specialized institutions, practitioners, techniques, concepts and ideas, and materia medica.[3]

The common vocabulary of the Bantu expansion from about 1500 BCE includes terms for suffering (*-*duaad*-), healer (*-*ganga*-), medicinal plant (*-*ti*-), the power of words and will to affect health in social relationships (*-*dog*-), and song–dance ceremonies of trance and healing (*-*goma*-) are found throughout Equatorial, Central, East and Southern Africa (Janzen 1992; Vansina 1990).[4] Such a constellation also characterizes medicine on the Guinea coast and West Africa. As this cultural complex moved eastward to the Great Lakes region, the basic term for healer became bifurcated and the root term for "big man" or chief (*-*kumu*-) came to be applied to diviner (*-*mufuumu*-), suggesting the importance of the diviner in social control (Schoenbrun 1998).

Profound transformations were brought to African medicine by the mercantile trade of the sixteenth to the nineteenth centuries, and then by nineteenth and twentieth century European colonialism. Foreign trade, technology, ideologies, and social forms were often imposed by force. New ideas about health were part of this colonialism, ideas that discredited African medical systems. Missionaries and colonial regimes came to evangelize Africa. Just as Islamic crusaders had attacked "pagan" African forms of healing and religion, so Western Christian missions discredited the basis of knowledge as the overall approach to ritual healing. At a time when early positivist science was analyzing the causes of contagious diseases and public health campaigns were being waged to make Africa safe for "progress," assumptions that social dynamics could cause sickness were dismissed as witchcraft. Since they had cures for diseases such as yaws, leprosy, and later malaria and dysentery, Christian missions and their hospitals contributed to the conversions of many Africans. Although Christianity gained widespread following in sub-Saharan Africa, many of the marks of the African worldview of misfortune have been reincorporated or persisted quietly in private. In the postcolonial era – generally from 1960 on – the process continues of sorting out what indeed were precolonial health codes and realities and evaluating what in them is of importance and might be endorsed, revived, and further developed.

The latest economic and health crises lent an immediacy to these debates. African traditional medicine continues to be widespread, as biomedicine is expensive and often locally unavailable. The epidemic crisis of HIV/AIDS has revived the question of whether the African pharmacopoeia has something to offer. Such pressing issues have again raised questions about the fundamental character of African medicine and its ideas of health.

Interpreting Practical Applications of Materia Medica

Examples of pragmatic and empirical solutions to health threats include diagnoses and interventions for

> bone-setting, midwifery, and a host of specific interventions for such ailments as fever, rheumatism, intestinal disorders, parasites, lactation deficiency, earache, toothache, headache, epilepsy, menstrual disorders, and more. Most of the African pharmacopoeia under discussion here is derived from plants, but medicines from animal parts, sea shells, coral, soils and other substances of natural origin may also be used. Medicine may be drunk as herbal decoctions, or they may be ingested through inhalation, vaccination (dermal incisions), enemas, vaginal infusions, massage, bathing, or fumigation, in forms that include powders, porridges, soups, ointments, smoke, fumes, or eye drops (Bibeau 1980).

These medications variously reflect the desert, savanna and rainforest ecologies and pastoral and

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[3] One of the best methods for reaching back through contemporary and recent African experience to find the faint images of ancient thought and practice is to follow the widespread vocabulary having to do with health, the nature of disease, and the ideas and techniques of healing. Sub-Saharan healing is not codified in written texts, but it is transmitted through rich oral instructions from generation to generation. These texts and their vocabulary are as persistent and more durable – in the tropics – than papyrus or parchment. Historical linguistics is based on the premise that core vocabulary in language remains relatively constant and can be traced by comparing languages with a historical affinity. Core vocabulary shows both lexical and phonetic change at a rate of about 20% per millennium. Thus, if two languages are shown to have a 60% common core vocabulary and related phonetic structure, they are about 2,000 year apart in their history. Newer techniques, ideas and related terms will show a different distribution, whose origins can sometimes be traced by examining the distribution and the phonetic transformations they have undergone. Phonetic changes occur in certain directions within the basic human sound-making potential. This "historical linguistic" methodology permits scholars to study concepts at a depth of up to 5,000 year.

[4] A term headed by an asterisk (e.g., *-*ganga*-) indicates that it is a widespread cognate in either the proto-Bantu or proto-regional reconstructed core of verbal concepts.

farming ways of life. Following are two examples of pastoral knowledge of sleeping sickness and its vector the tsetse fly. The early nineteenth century Nguni king Mzila, as he was expanding his territory in Southeastern Africa, concentrated his people in large settlements and had them garden close-in territories; then he sent his hunters out to kill all large wildlife in the savanna forests at a greater distance before allowing his herdsmen to take the cattle into those areas (Swynnerton, in Ford 1979). The Turkana pastoral nomads of northern Kenya are well aware of the dangers posed by the sleeping sickness bearing tsetse fly to their cattle and themselves during the rainy season, especially in the lush grasses near streams. Therefore they send out young herders with the least valuable animals to graze in those sites to establish their safety from the tsetse before bringing in fertile cows. (Gray 1997, based on fieldwork with the Turkana in Kenya).

Malaria is an endemic disease over much of Africa. It is usually that variety of malaria for which the Anopheles mosquito serves as vector. It became a problem for West and Equatorial African cultivators at the time they settled into sedentary communities and began to clear forests for crops. A genetic adaptation to the high death rates occurred soon after, in the form of the blood cell sickling that in its heterozygous form created immunity to malaria (although proving lethal in its homozygous form). Clearly no one was aware of the genetic structure of this adaptation to malaria. However, settlers preferred to build villages and towns on breezy hillsides rather than in the quiet thickets. Thus, before quinine and the late nineteenth century association of mosquitoes with malaria, breezy hilltops were the preferred settlement site, provided they were near sources of good water.

Smallpox too has been a scourge in sub-Saharan Africa since the advent of cultivation and large concentrations of people (Dawson 1992: 90). The central placement of Ipoona, the god of smallpox, in the pantheon of Yoruba (and other West African) societies, suggests that it has a history of millennia rather than centuries. In addition to the sacrifices made to the angry god Ipoona, who could kill, a pattern of actions during smallpox epidemics suggests pragmatic public health consciousness as well. Examples include the separate burial of victims, the abstinence from mourning in close proximity to the victims, and quarantining infected households or settlements. Most intriguingly, they refer to attempts to immunize those not yet infected by taking pus from the poxes of infected individuals and introducing it into scratches in their skin.[5]

Immunization as seen in the case of smallpox may be part of a broader principle of confronting the evil of disease or threat. Several kinds of poisonous vipers have posed a serious problem in the lands of the Nyamwezi and Sukuma peoples of Western Tanzania. Organizations of snake handling experts actively promote the encounter with these poisonous vipers and other snakes through public dance performances in which they demonstrate that they can come to terms with the threat. The demonstration includes allowing the otherwise venomous snakes to bite them. However, the snake handlers have been inoculated with small doses of venom that they have milked from the vipers. This understanding of immunization is mainly available to those who have been appropriately initiated to the Snake Handling Order. These examples of immunization to smallpox and snake venom are part of the much wider notion of the need to incorporate or confront the threat in order to overcome it.

Curative plants are central to African medicine. Two examples illustrate the ways in which specific problems were, and are, approached with the curative powers of plants and techniques. Mirau, a herbalist of the Meru people studied by Finnish ethnographer Harjula (1980) who records many of the healer's herbal treatments as one-disease, one-plant related, practices a widespread treatment for intestinal microorganisms. Although this conveys a somewhat simplistic picture of African herbalism, it does permit a clear examination of Mirau's work from the outside. One of Mirau's 200 single-plant treatments is for children's diarrhea, a serious problem in many regions of the continent where infant mortality often reaches more than 100 per 1,000 births. Using the plant known locally as *mamiso* (*Bidens pilosa L.*), Mirau takes 15–20 flowers and boils them to obtain one dose, which is given twice daily as oral medicine. According to Watt and Breyer-Brandwijk's (1962) massive compilation of East and Southern African medicinal and poisonous plants, this plant carries antibacterial substances against microorganisms, including five enteric pathogens. The same plant is reported in use against dysentery and colic in other regions of East and Southern Africa.

In another well-documented study from the national Zairian Research Institute (Bibeau 1980), the work of six healers in Kinshasa was examined for effectiveness in 22 diabetes cases. Independent examination of blood sugar levels revealed an average glycine rate of 500 mg/108 ml of blood. After treatment, which lasted a week or longer, 17 of the cases experienced a decline of glycine levels to an average of 100 mg/108 ml of blood. Although a surprisingly large diversity of plants was used in preparation of the oral medications, several plants stand out for their repetition from healer to healer, including *Crossopteryx febrifuga* (Rubiaceae), *Nauclea latifolia* (Rubiaceae), *Anchonames difformis* (Arceae), and *Bridelia feruginea* (Euphorbiaceae), the latter of which is used in Ghana for diabetes therapy.

[5] See Green 1999: 69–70 for such evidence in southern Africa.

Some of the Kinshasa treatments were accompanied by dietary proscriptions for salt, ripe mangoes, pepper, beer, manioc, and mushrooms.

Thus far these treatments have appeared to be of the empirical type that scientifically oriented Westerners would recognize. However, in classical African medical thought the added dimensions that Westerners might call "symbolic" or "social" are added without a conceptual break. In the next two examples of treatment with materia medica the fusion of the natural and the human dimension is evident; they deal with two types of bodily swelling.

Mama Mankomba of Mbemba village in the Luozi region of Lower Zaire was well known for her treatment for bodily swelling. She distinguished between two types of swelling, the first thought to be due to heart congestion, the second to poisoning, the result of anger growing out of animosity. Simple swelling was dealt with by an initial emetic from the drops of sap of the finger cactus (*diza kia nlembo*, *Euphorbia tirucalli L.*) with a soapy base to keep the poison from harming the body. This was followed by a potion made from the roots of six savanna plants taken three times daily (*Nlolo, Annona arenaria Thonn, Annonaceae; Mumpala-mbaki, Crossopteryx febrifuga* (*Afz. ex G. Don*) *Benth*. = Rubiaceae; *Nkizu, Syzygium guineense* (*Willd.*) DC. = Myrtaceae; *Votila, Psorospermum febrifugum Spachh*. = Guteriferaceae; *Luvete, Hymenocardia acida Tul*. = Euphorbiaceae; *Kinsangula, Maprounea africana Muell. Arg*. = Euphorbiaceae). Dietary restrictions against sugar, salt, and pepper were also imposed. Poisoning cases received the same initial purge, but were followed by a second purge of the bark scrapings of only the kinsangula plant with salt and palm oil to provoke diarrhea and vomiting. Although Mama Mankomba treated the physical manifestations of anger illness, she refused to become involved with the deeper causes of anger which required conflict resolution and judicial action (Janzen 1978).

The use of multiple plants and techniques not only introduces a degree of complexity from the botanical and chemotherapeutic compound involved, but also adds to these symbolic classifications, names, songs, and other ritual connotations and devices, and above all, the human dimension in health and disease. Studies of plant uses in circumstances where both chemotherapeutic and consciously exercised symbolic principles and human issues are at work need to be examined further (Figs. 1 and 2).

Divination: Differentiating What "Just Happens" from "Agency-Caused" Misfortune

As important as practical medicines is the pervasive concern that Kongo therapy managers spoke of as "something else going on" (Janzen 1978). There is a shift from pragmatic to ritualized therapy that occurs because the misfortune or affliction is perceived to be fraught with anxiety and fear of pollution by both human and superhuman conflict (Janzen and Prins 1981). This shift amounts to a purposeful amplification in practical care with affective symbols referring to the human dimension, to spirits, and to efforts to manipulate them. Usually only consecrated persons are considered capable of handling such powerful therapies as the purification of polluted persons and settings, making sacrifices to ancestors or neutralizing menacing spirits.

Medicine in Africa. Fig. 1 Kongo healer-herbalist Kitembo of Balari commune in North Manianga stands in a forest clearing with a handful of leaves collected from wild plants, as is most of his pharmacopoeia. However, other Kongo healer-herbalists tend botanical gardens for their most frequently used herbaria. (Photo by Janzen.)

The pervasiveness of divination in treating African sickness and misfortune attests to the importance of causation, especially the suspected shift in cause from a mundane to a highly charged cause in the human or spirit realm. Usually consultation with a diviner is not undertaken until there is sufficient reason in the kin group of the sufferer to suspect causes other than natural ones. Such a precipitating factor may be the worsening turn of a sick person, a sudden and mysterious death, the coincidence of a sickness with

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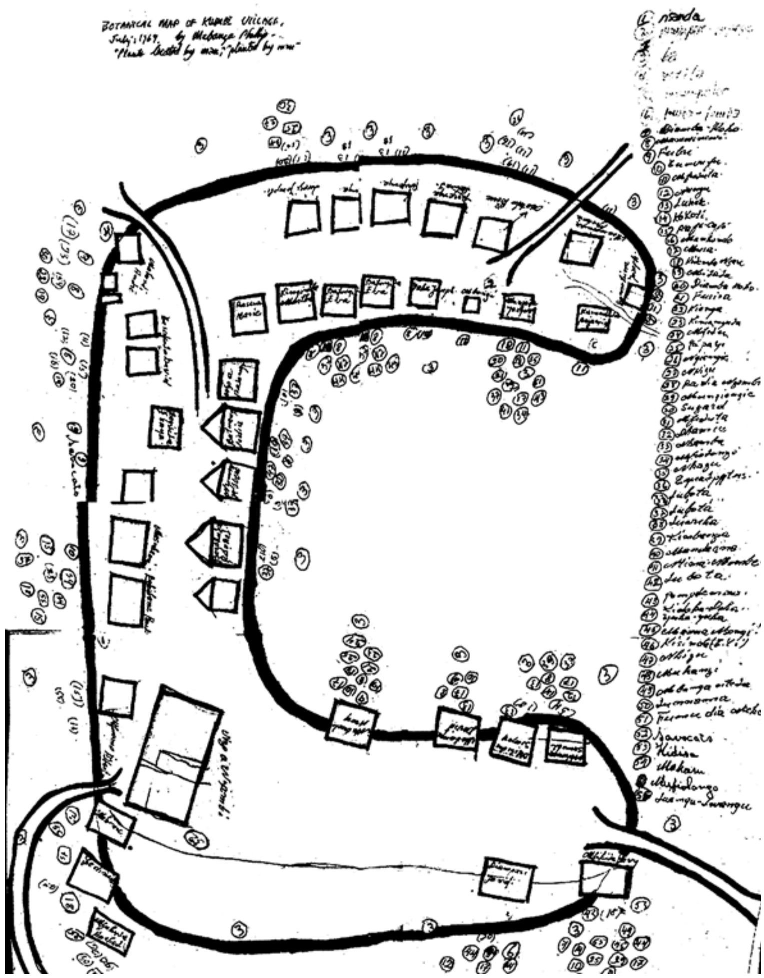


Medicine in Africa. Fig. 2 A 1969 botanical survey map by Mabanza Philip of "plants planted by man" in Kumba village in North Manianga, Lower Congo, Democratic Republic of Congo. The map shows 56 varieties of shrubs and trees for food, medicinal, ritual, and other purposes. The *ba*, oil palm (3) part of the ancient West African domestic plant set, is used for cooking oil, palm wine, and raffia fiber. Others, such as *payi-payi* (25) and avocado (52) are much cherished edible plants. *Kienga* (22) and *lubota* (42) are potent medicinal plants; *lemba-lemba* (6) is a sedative and a symbolic plant of the entrances; *mpese-mpese*, a poplar, used to outline chief's courtyards, here marks the men's lodge. *Kidiza* (53) is a cactus whose poisonous sap is used to catch fish and for emetics. The *nsanda* fig tree (*Ficus bubu*, sp. = Moraceae) (1), a harbinger of water, thus of a good village site, is said to be the first planted to determine the quality of the site. A botanical map such as this reveals the 2000-year history of plant domestication and agriculture, just as the illustration of healer Kitembo with wild plants in his hand suggests the continuing history of foraging. Both modes of making a living are joined in Kongo culture and medicine.

a conflict in the close social environment of the sufferer, or the paradoxical occurrence of a disease on only one side of a family. In such cases the clients are looking for answers to questions not only of "Why did it happen?" but "Why did it happen to us?" and possibly "Who caused it?" and "What should we do about it?"

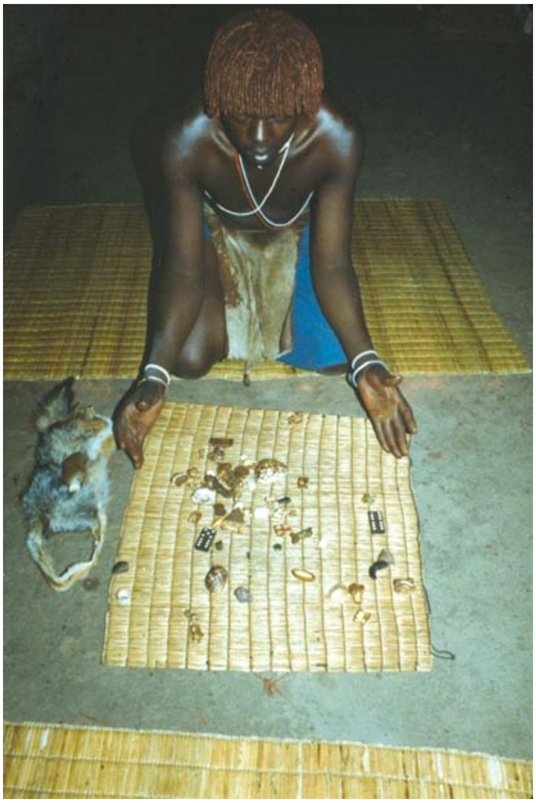
Scientific explanations of health may not necessarily lay to rest these questions, which are of a different order from the ideas in natural causation. A community may know very well that the spirochete transmitted by the bite of an anopheles mosquito causes malaria in the blood of a human. But the diviner may shed light on the question of why some people are infected and not others, or why some died when all were infected. Divination may also clarify the human causes behind accidents or provide a pattern with which to explain them. Western medicine is often good at answering "why?" but not "why me?"

In the broad West Africa belt from Central Nigeria to Ghana, the prevailing mode of divination is known as Ifa. A cup bearing a set of usually 16 cowries or pods is thrown out into a tray. The combination of "ups" and "downs" is coded to indicate a set of verses, numbering in the thousands, which illuminate the life situation involved in the affair before the diviner. The tray or the cup usually bears the image of Eshu Elegba, the trickster, who is believed somehow to hold in his hands individuals' and families' fortunes. At least he attempts ceaselessly to surprise humans with contradictory and unintended turns of events, often for the worse. Thus he and his character of trickery, deceit, and surprise embody the essence of what divination seeks to illuminate (Pemberton, in Pelton 1980: 136).

On the Southern Savanna, from the Atlantic coast southeastward to the Copper Belt, the Ngombo basket mode of divination is common. Its thorough integration into the societies suggests that the genre may be a thousand years old. Carved figurines and natural objects, representing human situations and predicaments, lie together in the basket. As the basket is shaken, one of the objects emerges at the basket's rim between two lumps of clay, one red, and the other white. This "gateway" of white and red suggests the liminality of the threshold between the visible and the invisible spirit world. The diviner reads the case before him in the light of the emergent object or the constellation of objects in the basket (Turner 1975: 315–316).

In Southern Africa a common mode of divination is a bag of animal bones and perhaps seashells (brought or traded from coastal areas) which are shaken out and thrown onto a mat before the diviner and the client (Fig. 3). The bones, whose constellation represents issues in human life, relationships, and the world of spirits, may be combined with trances to indicate a complex hierarchy of causation behind the surface realities of a misfortune.

These and many other types of divination in sub-Saharan Africa are predicated on the assumption that sickness or other misfortunes may be caused by an untoward turn of events in the human or related spirit world. The immediate cause or agent such as the sign or symptom of disease is thought to require interpretation in the light of ultimate natural, human or spirit agents. Thus, despite widespread acceptance of modern science, divination continues to be a common method for discerning the dividing line between that which "just happens" and the human or mystical factor that is seen as important in the pattern of misfortune.



Medicine in Africa. Fig. 3 Divination by means of throwing "bones" in Swaziland. (Photo by Green.)

Science or Magic? A History of Scholarly Debates About Etiology in African Medicine

Anthropologists and other scholars have debated the nature of African medicine and thought ever since David Livingstone published his debate with an Mbundu rain maker (Janzen 1978: 38–40), designed to show that the latter, although rational, was arguing with false premises. All participants in the anthropological debates accept empirically effective medicines, as mentioned earlier. The debate focuses on the nature of the other logic – the human and spirit logic – and the relationship between these and the empirical or "natural" realm of causes and cures. The arguments range along a spectrum from prioritizing the empirical treatments to charging that witchcraft overrules other causalities in African medical thought. A range of terms has been put forward to identify the several logics that work together in African healing thought, as for example naturalistic, personalistic, God-caused, or human-caused.

Many scholars of African medicine today would not be likely to use Foster's global distinction between "personalistic" and "naturalistic" treatments (1976: 775), because it just does not fit well. Illnesses that "just happen" – we would say naturally – are attributed to God, a personalistic force. Nor would this dichotomy very readily do justice to impersonal ideas of pollution brought about by exposure to the dead, to certain diseases, and brushing one's feet against polluting substances. Similarly, few would accept Murdock's global survey of theories of illness, in which African societies, based on the survey's reading of available ethnographies, demonstrated a prevalence of supernatural (including fate, ominous sensations, contagion, mystical retribution, soul loss, spirit aggression, sorcery, and witchcraft)

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over natural (including infection, stress, deterioration, and accident) etiologies (1980: 48). Nevertheless, British anthropologist Pool, who has studied Cameroonian societies (1994), has joined Murdock and scholars of other disciplines, missionaries, travelers, government administrators (pre- and postcolonial, foreign and African), doctors and health officials, and economic development professionals, who have simply taken these simplistic dichotomies and characterized African health beliefs as operating primarily, or solely, in the domain of "personalistic" or "supernatural" shaped witchcraft, sorcery and/or spirits.

Evans-Pritchard's classic on Azande ideas of misfortune (1937: 67) would seem to endorse their views. Yet Evans-Pritchard has been much misrepresented by his excerpt on the Azande granary's collapse being attributed to witchcraft rather than natural causes. A careful reading of Evans-Pritchard reveals that he describes a "hierarchy of resorts ranging from simple to serious, with recourse first to empirical treatments, then to magical interventions" (Janzen 1981: 188–189). Yet many scholars of African healing and religion, who have experienced attributions to witchcraft for events Westerners would say were caused by gravity, germs, or sheer coincidence, prioritize this explanation over one in which events merely occur because they occur (e.g., see Turner on the Ndembu 1967: 300–301).

A third group of anthropologists began to find evidence of empiricism and rational, logical thought in African ethnomedicine (Horton 1967; Fortes 1976; Yoder 1982; Morris 1998). Horton in particular sought parallels between African and Western thought, including in the domain of health and illness. Anthropological opinion has changed considerably since the 1970s, in part because of the involvement of anthropologists in applied research of infectious diseases such as child diarrhea and sexually transmitted diseases (Inhorn and Brown 1990; Green 1999).

For example, recent research suggests that while magico-religious or supernatural ideas may often be associated with mental illness and certain other conditions, naturalistic etiologic notions rooted in empiricism are often found to underlie the infectious and contagious diseases that have always accounted for the greatest morbidity and mortality (Green 1999). Diseases such as malaria, tuberculosis, schistosomiasis, cholera, amoebic dysentery, AIDS and other sexually transmitted diseases, typhoid, acute respiratory infections including pneumonia, yellow fever, leprosy, and dengue tend to be understood within a framework that may be called indigenous contagion theory. In this analytic framework, one becomes ill because of impersonal exposure. One comes into contact with something that anyone could come into contact with, not because an avenging spirit or an ill-intended person singles one out for misfortune in the form of sickness (Green 1999).

A fourth and final group of scholars have sought to formulate the relationship between disparate types of logic and misfortune causation in African thought. Morris notes that Chewa medicine includes an "empirical herbalist tradition, based on a belief in the intrinsic efficacy of certain plant and animal substances." Yet it also includes "a cosmological tradition, which sees the human subject as a microcosm of the world and in which health was seen as restoring a balance or mix between certain vital 'humors' or principles, and a tradition that focused on 'communal rites of affliction,' and involved spirit healing" (Morris 1998: 86). How do these multiple realms of African healing relate to each other?

The late Rwandan scholar and physician Pierre-Claver Rwangabo offers an insight into contemporary African thinking on the question. Even though not all aspects of the Rwandan medicine system are amenable to modern science, Rwangabo believes that it is a part of modern reality rather than a fossil. He divides the causal domains of Rwandan medicine into "physical" and "mystical" causes. Diseases range across a variety of types which may be attributed to either causal category or to both. Rwangabo's medical training is evident in his listing of disease classes that include: parasitic diseases, microbial diseases, systemic diseases and bodily accidents, gynecological and obstetrical diseases, and psycho-mental and behavioral diseases. But under the latter group he identifies current psychopathologies that entail abnormal behavior as understood in traditional thought and diseases believed to be caused by broken prohibitions and beliefs about ancestors (*abazimu*) and other spirits (*ibitega, amahembe, nyabingi, amashitani, amajini*) which often are identified in relation to mental illnesses. "Poisoning," the result of human aggression, is a major aspect of the human source of misfortune. Misfortunes brought on by the breach of social rules also have a mystical though not necessarily mysterious causal character. Rwangabo's insight into the character of traditional medicine lies in the observation that most pathologies may have both a physical and a mystical dimension. This affects the way therapy will be arranged. The decision to seek physical or other therapy has to do with the context in which it occurs, its severity, the suspected human etiology, and response to treatment.

This emphasis on the context of the causal attribution makes all the difference in how sufferers, their therapy managers, diviners, healers and medical practitioners will treat illness. If the misfortune is considered to be ordinary and predictable, it will be seen along the lines of the material world. If catastrophic forces or circumstances have precipitated it, or if it seems to be the result of the chaos of underlying affairs in the human and mystical realm, it must be handled differently. Thus the same condition may need to be treated with different medicines. The first realm we might term "natural," the second "unnatural." But this dichotomy requires closer examination so as not simply to read into it influences of Western thinking.

In widespread sub-Saharan African parlance in the twentieth century, the natural realm is associated with God, or caused by God – the God of the created universe (Turner 1969: 52; Orley 1970: 137; Swantz 1970; Ngubane 1977: 22–24; Gilles 1976: 358–369; Janzen 1978: 44–49; Davis 2000: 94–5), not the God of a mechanistic Enlightenment world nor the God of puritanical retribution for human sin, as in the African Islamic or Christian view. Rather, God-caused misfortune is widely seen to be the created order of things such as the seasons and rhythms of birth and death in society and in the surrounding world. The death of an elderly person would be "in the created order," whereas the death of a child-bearing mother, for example, would be seen as "unnatural," or caused by some other human or spirit force. The unnatural source of misfortune – which may be manifested in an otherwise scientifically understood disease – may be attributed to human error or malicious motive, arising from the many inconsistencies inherent in human society, or the deceptive, antisocial nature of some individuals. This view of humanity often includes the ancestors or demigods who have a vested interest in the outcome of human affairs, especially in their clans and localities.

Paradigms in African Medical Thinking

Sub-Saharan African understandings of health, sickness and healing are often couched ideas about the nature of the world and life within it, ideas or images which offer powerful metaphors with which to make sense of suffering and uncertainty. These ideas are discernible in verbal concepts that have a deep history and broad geographical and cultural distribution and a continuing use in diagnosis, the formulation of the sickness experience, and in therapies.[6]

The first organizing idea defines an ordered structure of the body. Any disruption, negation, or distortion of this ideal suggests sickness, as expressed in a verbal cognate that extends from West to Equatorial Africa – *eela* or *ele* in Yoruba of Nigeria (Buckley 1985); *beela* in Kongo of Western Zaire (Janzen 1978, 1992). This notion often relates to a nonverbal code of three or more colors and related substances used in medicine and ritual to situate the body within a wider cosmology. Chalk or kaolin from stream banks is used to represent purity and wholeness; camwood or other red is used to represent transition and danger. Charcoal or a substitute represents human chaos. White is associated with goodness and the legitimacy of the created order. Chalk is the most widespread of these colors used in healing and ritual. For example, chalk is smeared onto the face and body to represent the presence of ancestors, white beads are strung around the body or head to represent spirit possession, flour or another white powder is used to trace the outlines of sacred space, and white sap may allude to milk or semen as sources of life. Whiteness represents the realm of the water, the spirits, and the beyond. It usually stands for the clarity and goodness of the spiritual world where human life is rooted. Usually, the colors are used in combination. Redness, smeared on the face and body, dyed into cloth, or covering a ritual object, appears alongside whiteness to suggest the juxtaposition of "the white" with transition and danger. The combination suggests power that can build up the created order but can also destroy it. Hierarchies of spirits may appear represented in these two colors. Charcoal, the remains of fire, represents the chaos and destructiveness of human life left to itself. In association with white, this chaos and energy is balanced by the clarity, legitimacy, and order of spiritual truth. Turner wrote the classic study of this color code in sub-Saharan African ritual about the Ndembu of northern Zambia (1967: 59–92).

In a second idea, balance or harmony is necessary to a state of health in the relationship between an individual and the people surrounding him or her, as well as between the human community and the natural and spiritual environment. The verbal concept *lunga* refers to a principle of health in the Zulu society of South Africa (Ngubane 1977) and the Kongo society of Western Congo (Janzen 1978) and to a type of healer in the Luba-influenced Tabwa culture of the western shores of Lake Tanganyika (Davis 2000). In regions influenced by Galenic humoral theory via Islamic medicine, balance may have the connotation of an equilibrium between the humors and between heat and cold. Balance between opposing humors or fluids leads to health, imbalance to disease.

The idea of balance or harmony often extends to relations with kinsmen, neighbors and others with whom people come into regular social contact. Social disharmony leads to resentment, anger, envy, evil-wishing, cursing, and gossip, and often finds expression in sorcery and witchcraft. Cases of illness or misfortune that seem particularly dramatic or ambiguous are commonly a cause for divination.

A third concept is that of "coolness" as grace and health, in contrast to the "heat" of conflict and ill-health (widely distributed in sub-Saharan Africa under the term *-*pod*- in connection with cooling down, being cured). Conflict and anger are often associated with heat and fire that like energy out of control can cause

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[6] This is the most recent of a series of formulations of such broad ideas in sub-Saharan African medicine. The present essay is particularly informed by "sub-Saharan African Healing" (Janzen 1997).

great destruction, disease, and death (among the Ndembu of northern Zambia, Turner 1969: 27–31; among the Tabwa of eastern Congo, Davis 2000: 58–60). Medicines that extinguish the fire or cool the situation or sufferer are administered as an antidote to the dangerous condition. A balance between the extremes of fire and the cold of death are regarded as important for health and life (in the widespread *ngoma* ritual of healing, Janzen 1992; among the Hemba of eastern Congo, Blakeley and Blakeley 1994). The sub-Saharan African concept of the "cool" extends an aesthetic notion widely seen in the arts and in human relations into a definition of health.

Fourth, the widespread concept of "flow and blockage" is the closest to a classical African anatomy that inspires clear ideas about health and infuses numerous therapeutic practices. The prevalence of purgatives and emetics, fertility medicines, and herbal drinks in the African tool kit reflects this conceptual scheme (Janzen 1978: 170). However, the physiological coordinates are usually linked to the wider world of a person's relationships in society, if not to society itself as a body. In fact, an outside observer sees a clear homology between the physical realm of the body and exchanges in society. Both are seen as needing to flow openly to thrive. Just as food and fluids need to be ingested for the physical body to be healthy, so the body social needs to be fed with reciprocal gifts and gestures of good will. Grudges, envy, and ill will in the social body are seen to cause blockage in the physical body (Taylor 1992).

A fifth idea expresses purity, a ritual state in which the dimensions of the human world are in order; its opposite is a state in which these affairs are out of order, causing ritual pollution or sickness. Several Africanists have noted the importance of the antonymous concepts of pollution and purity and have noted practices related to these ideas in widely distributed Bantu-speaking societies (e.g., among the Kongo of Western Equatorial Africa, Janzen 1982; the Lele of southern Congo, Douglas 1966; among Nguni-societies of southern Africa, Hammond-Tooke 1981; Ngubane 1977; and in Mozambique and elsewhere, Green 1999). Pollution commonly results from mystical contamination, which in turn is caused by death (including abortion) and women's reproductive processes (birth, menstrual blood, breast milk). The distinguishing feature in all of these examples seems to be an absence of an absence of spirits, witches or other malevolent humans as the cause of distress. Pollution is an impersonal condition that can be righted by purification rituals or curative interventions. In the course of years of applied ethnomedical research in Africa, Edward Green came to believe that purity and pollution concepts represent a traditional set of natural contrasts that may have served in the past as a foundation for ideas of health and disease prevention.

Finally, sixth, there are the related notions of contagion and protection, or immunization. That microorganisms can spread diseases is in fact a relatively old idea that goes back well before the theory of microbial vectors of disease. It is a widely held notion in African thinking about health, although that which is believed to spread and infect may include ill will, poison, malefic medicines, and a variety of forces which may cause harm. A well-known example of this idea is the case of precolonial Kenya, where smallpox-infected communities were quarantined as a health measure and the healthy were immunized with a bit of fluid from the pustule of an infected individual (Dawson 1992: 96).

In most societies where this theory is found, the agents of infection are described as worms or tiny insects, e.g., *kadoyo* among the Bemba (Zambia), *iciwane* among the Zulu (South Africa), *liciwane* among the Swazi (Swaziland), *atchi-koko* among the Macua (northern Mozambique), *khoma* among the Shona (central Mozambique), and *kokoro* among the Yoruba of Nigeria (Green 1999; Foster et al. 1996). Sexually transmitted diseases are often thought to involve such infection agents.

Some scholars speak of African contagion as mystical, comparing it to pollution (cf. Murdock 1980). Yet it is not so mystical when closely examined. People become ill as a result of contact with, or contamination by, a substance or essence considered dangerous because it is unclean or impure. Africans considered in an unclean or polluted state are often kept apart from other people, since they are considered contagious until ritually purified. In central Mozambique, people believe that several kinds of child diarrhea and/or dehydration are caused by contact with polluting essences (or by eating bad or spoiled food). One source of pollution that may appear mystical is unfaithful behavior on the part of a parent: if a mother or father commits adultery, he or she acquires a contaminating essence that makes the child sick. The immediate cause is physical contact with the child, or drinking "hot," "spoiled" or "contaminated" breast milk. This belief reinforces the importance of fidelity in marriage (Green 1999: 13).

A third component of contagion theory, environmental danger, is based on the belief that elements in the physical environment can cause or spread illness. One expression of this is the notion that contagious illness can be carried in the air or wind. For example, the Bemba of Zambia believe that tuberculosis is an "illness in the air," spread by inhalation of unclean dust carried by the wind. The Bambara of Mali classify smallpox, measles, and other contagious illness as "wind illness," because only wind has sufficiently widespread contact with the body to cause outbreaks (Imperato 1974: 15). *Tifo temoya* (illness in the air) is a general Swazi term denoting illnesses that are contracted through inhalation. Colds, influenza, tuberculosis, severe headaches (probably malarial) and some types of contagious child diarrhea are examples (Green 1999: 189–90).

Recognition of this sort of contagious disease, along with sound preventive practices, can also be found in indigenous African veterinary practices. McCorkle and Mathias-Mundy (1992: 67) have noted:

> African herding strategies often reflect a highly sophisticated understanding of contagion and immune responses. For example, Fulani may move upwind of herds infected with hoof and mouth disease in order to avoid contagion; or they may move downwind so as to expose their animals to the disease, knowing that a mild case confers immunity.

Health in the Social Fabric: Shrine Communities and Cults of Affliction

The texture of society is extremely rich in sub-Saharan Africa. Social codes and the power of words are considered important to shaping health. A widespread verbal concept whose root is reconstructed as **-gidu-* refers to the role of social prohibitions, taboos, and the consequences of their violation. This is mentioned with reference to the restriction on eating or killing one's clan or individual totems and familiars. Other observers note that these prohibitions help individuals adhere to social codes in general, including health promoting restrictions on such things as overconsumption of alcohol, overeating, or health destroying excesses of any kind (Rwangabo 1993).

Another aspect of the social dimension of health is bound up in the role of human agency in sickness or misfortune, in the action of anger or ill will in a relationship, and the action or gesture to harm the other, be it an injurious word, a blow to the head, or a bit of poison in the drink or food. The single root that most frequently refers to this "human cause" of misfortune is **-dog-* or **-dok-* (part of the Proto-Bantu lexica of at least 3,000 years ago), modern derivations of which are found from Cameroon and the Kongo coast in the west (KiKongo: *kuloka*), Central Africa (Kinyarwanda: *kuroga*); to the Nguni-speakers in South Africa (Zulu: *kuthaka*).

In contemporary diagnoses of misfortune, victims will often identify a string of misfortunes and try to recall the exact words spoken by others prior to or in association with the events, drawing the logical inference that these utterances had caused, or could have led to, the bad luck. Words of warning or injurious words spoken in anger are especially suspect. Therefore, in divination, these moments are recalled so that the individuals or the relationships may be repaired. Without treating the root cause, the surface signs and symptoms cannot be permanently overcome.

There have been collective healing rites based on common afflictions or groups of devotees identified with gods or spirits considered to be the cause or medium of these afflictions. Such communities or orders have arisen and declined over time as particular constellations of afflictions have occurred. Often they have been a kind of barometer of the major dislocations and diseases in a region.

In West Africa, shrine communities and cult memberships were often associated with major shrines and cults to the earth, to the water, to nature, and to the sky, as well as to the rulers of local cities and states. Some shrines were addressed to specific conditions, such as twinship (as in the Ibeji of Yorubaland), or particular diseases, such as the very widespread shrine complex to the god of smallpox (variously Ipoona, Shapanna, Shapata). On the Guinea coast forms of gender-divided societies developed around the female Sande association and the male Poro association. These addressed many aspects of health and the public good such as instruction of youth, midwifery, social control, and hygiene. These shrine societies and cults of West Africa may well have been part of very early agrarian society, having become an integral feature of the cycles of celebrations and sacrifices.

Across Equatorial Africa this type of therapeutic ritual assembly often centers around particular issues as well, such as fertility, twinship, women's reproductive issues, the health and well-being of infants and children (Turner 1968, 1975; Devisch 1993; Spring 1978), debilitating chronic conditions, fortune and misfortune for men in hunting, mental illnesses, the survival of kin groups (Janzen 1992; Nisula 1999), and a range of social and environmental issues (Janzen 1992; Van Dijk 2000). Membership was usually made up of the afflicted and formerly afflicted, who underwent a therapeutic initiation with stages from sufferer-novice to healer-priest. These "drums of affliction," as Turner (1968) dubbed them, are often associated with the voice of the ancestors and spirits which inhabit the celebrants and are expressed in the song-dances at the core of the ritual performances. Sometimes the mark of growth or healing in the sufferer-novice is the creation of a personal song based on the ordeal of suffering, a dream/vision, or other moving experience. Such a song constitutes a unique set of powerful words, recalling the cognate *dok*, that offset and overcame the destructive forces of disintegration, misfortune, sickness and chaos of the previous period of the individual's life. Where such a "drum of affliction" addresses community issues, the healing ritual may be directed to the community, and society becomes the body that is cured (Fig. 4).

These cults and shrines have related to Christianity and Islam for centuries. Sometimes the African institution has absorbed the outside idea or symbol, in other cases Christian and Islamic institutions have recreated the African forms and substance. Especially widespread in sub-Saharan Africa are the Independent African Churches, many of which encourage healing, exorcisms, and various kinds of incorporating rites of purification, protection, and sanctification (Sundkler 1976; Jonker 2000). Prophet-founders play the role of ancestor-mediators, while prominent or talented members assume the diagnostic role of diviners.

Although orthodox Muslims frown on blending Islam with African indigenous religion, the interpenetration of Islam and African ritual healing is extremely common (among Hausas of Northern Nigeria, see Abdullah 1992; Wall 1988). *Jin* and *amasheitani* spirits widely cohabit the spirit worldviews of ngoma associations in Eastern and Central Africa. Muslims healers of the Swahili coast have long practiced ngoma as part of their medicine kit, along with reading the Koran; the purification symbolism of African healing merges with that of the ritual ablutions of Islam in connection with prayer. In northern Swahili towns such as Lamu, early twentieth century ngoma Maulidi was introduced for performance in the mosque; its songs celebrated the prophet Mohammed, much to the chagrin of fundamentalist Muslims.

New Health Crises and the Relegitimization of African Medicine

The financial crises of African societies, and the search for an infrastructure of health, have led planners to take a second look at African institutions such as cults of affliction and the education of healers. By 1998, findings from a survey by the World Health Organization's Regional Office for Africa showed that a national management or coordination body for traditional medicine activities existed in 17 of 30 countries surveyed. Twenty-two indicated that associations of traditional healers had been established, and ten said that a national directory existed. Four countries reported that a training program for healers existed (the actual number would surely be higher) and 17 countries had such programs for traditional birth attendants. Twenty countries indicated that institutions in their country were carrying out research related to traditional medicine. Fifteen reported that there was local production of indigenous medicines, and 17 countries reported having botanical gardens or arboreta for cultivating medicinal plants (WHO 2000).

Research related to the medicinal value of plants in the African materia medica is important for several reasons related to public health (1) achieving community or national self-reliance in health by promoting locally available and already-accepted herbal medicines; (2) developing an indigenous pharmacological industry, based on local plants, that reduces national dependence on expensive, imported drugs; (3) promoting natural health care and reducing the iatrogenic effects of modern medicine; (4) finding out what traditional healers are using and, if medicines are found to be dangerous and highly toxic, trying to persuade healers to substitute safer plants or at least reduce dosages; or (5) finding an effective-seeming indigenous medicine for the symptoms of a high-priority illness such as child diarrhea, then finding ways to promote more widespread use of the medicine (Green et al. 1994: 44).

Medicine in Africa. Fig. 4 (Continued)

Medicine in Africa. Fig. 4 "Doing ngoma" in Guguleto Township, Capetown, South Africa, 1982. This composite shows the essential elements of a very widespread Central and Southern African therapeutic ritual. Lower left, two novices provide the drum rhythm; upper left, other novices sing-dance and "confess their dreams" to novices and a few senior healers; right, a trained graduate of ngoma leads this particular event with her bold sure step and her colorful clothing and beadwork, which represents her well-developed sense of self in contrast to the novice-sufferers, who are entirely "white." (Photo by Janzen.)

Preliminary pharmacological research is showing that phytomedicines (medicines derived from plants) used by African healers may indeed be effective for diseases in three of the most severe current public health crises: schistosomiasis and childhood diarrhea.

Ndamba et al. (1994) analyzed the most commonly used plants used to treat schistosomiasis by 286 traditional healers in Zimbabwe, administering the crude extracts orally to hamsters infected with *S. haematobium cercariae*. It was found that plant extracts from *Abrus precatorius* (Leguminosae), *Pterocarpus angolensis* (Leguminosae) and *Ozoroa insignis* (Anacardiaceae) were lethal to adult schistosomes. In a study of HIV-positive Ugandans with Herpes zoster, herbal mixtures used by healers were found to be at least as effective as biomedical treatments, including the antiviral drug acyclovir, in treating symptoms (Homsy et al. 1999).

Recent phytochemical research has shown that the roots of *Mirabilis jalapa*, used in South Africa as a purgative to treat some child diarrheas, in fact exhibit antibacterial activity against an impressive range of diarrhea-causing pathogens: *Staphylococcus aureus, Streptococcus pyogenes, Escherichia coli, Enterobacter sp., Vibrio cholerae, Shigella flexneri* and *Salmonella typhi* (Chifundera et al. 1991).

At the World Health Organization Forum on Traditional Medicine in Health Systems held in Harare in 2000, the African Regional WHO office expressed keen interest in the mass production of phytomedicines for the treatment of malaria, AIDS, and other diseases identified as priority diseases by member states. It is a strategic objective of the WHO to develop a framework for the integration of traditional medicine into national health systems. The idea is to encourage local industry to invest in the local production of indigenous medicines and make them commercially viable. Governments were urged to create policies related to conservation, safety and toxicity, and regulation in order to assist a local production industry (Green 2000) (Fig. 5).

Mass production, promotion, and distribution of African phytomedicines have begun. For example, Nigeria has developed medicines for ulcers, anemia, contraception, malaria and HIV, and it now holds patents for some of these in several countries. In late 2000, Nigeria became the first African nation to officially promote a plant medicine for the treatment of HIV/AIDS.

The ratio of traditional healers to the general population of various African countries seems to be in the range between 1:200 and 1:800, based on surveys and censuses (cf. Green 1994: 19 for a review of studies). In Mozambique, a doctor theoretically serves about 10,000 people. In practice, coverage is even less. Most doctors live in larger cities, while most rural Africans are lucky if they live within 5–10 km of a clinic staffed by a minimally trained nurse, where medicines may or may not be available (Fig. 6).

It is widely accepted that at least 80% of Africans rely on traditional healers for much or all of their health care. This had led some that work in public health to think that healers ought to play a role in curbing the spread of infectious disease. From a public health viewpoint, this would seem to make sense. Healers are found everywhere; they are culturally acceptable; they explain illness and misfortune in terms that are familiar.

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Medicine in Africa. Fig. 5 An example of African medicine given a modern scientific basis and commercialized. Dr. Byamungu Lufungula, left, French trained pharmacist, stands before instruments in his laboratory in Bukavu, Kivu, Eastern Congo. In 1994 his enterprise, SODIPHAR, employed 25 workers. Pharmacies in Goma, Bukavu, and Uvira sold about 20 products, all based on laboratory tested traditional medicines obtained in collaboration with herbalist healers. Byamungu is the author of *Les Plantes Médicinales, Les Rites Therapeutiques, et Autres Connaissances en Médicine des Guérisseurs au Kivu*, 1982.

Medicine in Africa. Fig. 6 Indigenous South African healers collaborating in public in AIDS prevention program, 1993. (Photo by Green.)

Medicine in Africa. Fig. 7 South African diviner-mediums (traditional healers) teaching each other biomedical ideas about HIV/AIDS, in a USAID-sponsored workshop in Tsitsikama, South Africa, 1993. (Photo by Green.)

In the 1970s there were several collaborative programs involving traditional healers in areas such as child diarrheal disease and family planning (e.g., Green 1987, 1996; Good 1987; Warren 1989) (Fig. 7).

With the explosion of HIV/AIDS in east and southern Africa, an even greater number of collaborative programs developed. In southern Africa, once they had participated in workshops on AIDS and sexually transmitted diseases (STDs), healers proved willing to promote condoms and safe sex. Once it was accepted that standard STDs facilitate the transmission of HIV, it occurred to some that healers ought to be involved in STD treatment programs – at least through referrals to clinics – since patients with STDs so often consult healers. Moreover, avoiding AIDS by sticking to one partner usually made sense to healers because they already interpret locally recognized sexually transmitted illness as resulting (at one level at least) from violations of the codes that govern proper sexual behavior and exposure to essences believed to be polluting (reproductive fluids, death). They feel encouraged to learn that their own governments as well as the international community *also* wish to warn people against having sex with "just anyone," with too many people, with strangers, with prostitutes, or with someone other than one's wife or husband. Finally, with drugs and hospitals in short supply, healers are already caring for a large proportion of those already infected with HIV. UNAIDS, the United Nations agency for coordinating HIV/AIDS programs, recently published an official "Best Practices" paper summarizing the role of healers in HIV/AIDS prevention and support programs, which concluded that they have made a substantial contribution (King 2000), although the situation regarding HIV in Africa remains grim.

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Medicine in Ancient Egypt

Hedvig Győry

In pharaonic time people saw their everyday life as a mixture of rational facts and supernatural phenomena, and the healing texts and the relating archaeological artefacts reflect a similar double-sided medical attitude as well. According to their beliefs, each illness had two causes. One was of direct origin, caused by an invisible pathogenic material personified, such as a disease-demon, an evil spirit or an animal, or an object of the material world. The other was of indirect origin, caused by a god or goddess who was malevolent or who punished the patient, or by a curse invoked by individuals. This meant that the curing process had to be directed both to the physical and the divine world. One had to appease (*sḥtp*) the appropriate god or exorcise the evil spirit or demon by religious or magical means and to fight the physical symptoms by the application of a remedy or physical treatment.

As the Egyptian themselves summarised, "Magic is effective together with medicine. Medicine is effective with magic" (Eb.2).

Sources

The study of ancient Egyptian medicine is based on various sources. The most complex are the ancient Egyptian texts from the pharaonic period, which instruct us not only about the scientific knowledge of the time but also about the way of thinking and the results physicians expected of their intervention. The medical anthropological study of human remains demonstrates the level of efficacy of ancient medications together with the general state of health of the population. There is also a good deal of analysis of the chemical–physical properties of pharmaceutical preparations that were used or applied in given cures.

In addition, scholars are able to look at religious, magical, historical, sepulchral, epistolary, and other types of texts written either by Egyptian or foreign people, archaeological and art historical finds or buildings, and (paleo)ethnographical parallels. All these sources are, however, not enough to provide a detailed medical overview of the complex of medicine in any period of ancient Egyptian history. The best-known period is the New Kingdom as most of the Egyptian medical literature known today relates to it. By contrast, the scientific analyses of the mummies are performed on mostly Late Period or Graeco-Roman mummies.

Healing Papyri and Ostraca

The healing texts, known from papyri (see Note 1) and ostraca (a potsherd used as a writing surface), can be divided into medical and medicomagical (=iatromagical) ones. Iatromagical spells are constructed the same way and contain exactly the same expressions such as in any other type of traditional magical spell, but the purpose stressed is medical – the annihilation or elimination of a disease-demon, the invisible enemy of the health of the patient. There are also prayers to various deities. The term medical papyri means those texts which deal with the physical reality of a disease. The mixture of medical and iatromagical texts is also common.

Medical spells can have several genres. Most of the extant medical papyri consist of prescriptions (*pẖrt*), which just name the disease to be treated or say, "another one", followed by a list of materials and key words for the preparation process. These were sometimes finished by an evaluation such as "proved a million times". Texts relating to paediatrics and obstetrics often contain prognoses. Surgical case studies are documented in instruction form (*sšꜣw*), which contains both diagnosis and therapy, if needed.

The papyri are usually compilations of different "books", often comprising groups of prescriptions. The original books seem to be arranged by the parts of the body the therapy had to be directed to, but the extant papyri often contain several books (or parts of them) mixed in with each other. Thus they were copied from various scrolls for practical guides to medication or for teaching or reference purposes. Only a few might be a copy of one original book, centred around one medical topic, such as curing methods (trauma in the Smith papyrus) or treatment of the same part of the body (such as the Kahun papyrus).

Many tracts must have been destroyed down through the centuries, but, according to ancient Egyptian traditions, the earliest medical book – an anatomy – already existed during the reign of Djer or Dewen, kings of the first Dynasty. If this is so, it must have been a list of anatomical expressions. Recipes are also attributed to Old Kingdom persons, such as the mother of Teti, sixth Dynasty (Eb.468), and spells against snakebite are listed among the Pyramid texts. In the tomb of Uash-Ptah we can read on the wall that he collapsed in front of Noferirkare, king of Upper and Lower Egypt. The pharaoh then sent for a physician who returned with a book to look up a possible way to save him, unfortunately without success. The known medical papyri originate beginning with the Middle Kingdom, and the last we hear about are mentioned by Clement of Alexandria (second half of the second century AD). He knew about six Egyptian handbooks devoted to specific aspects of medicine such as anatomy, illnesses, surgical instruments, drugs, eye diseases and gynaecology.

Human Remains: Mummies and Skeletons

Paleopathology is a relatively new branch of science. For a long time it relied entirely on bones. Thus, it meant not examining the mummy, but during the autopsy everything was taken from the bones: wrapping, funeral goods, skin, soft tissues and muscles. The pioneer of its systematic application was Sir Marc Armand Ruffer, from the Cairo Medical School (1896–1917), who also changed to a scientific means of examination. He introduced regular X-ray examinations, which were first made for an Egyptian excavation in 1898, for Flinders Petrie. This is a non-invasive method to learn about possible diseases or fractures of the body, or to discover the cause of death. Even so, the destruction to artefacts and skeletons did not stop. Today's methods are much more subtle and much less harmful. This is especially the case with computer tomography, which also helps in reconstructing a "living picture" of the examined person. The aim is now to get maximum data with no or minimum destruction. With very few samples (taken for instance by fibre-optic endoscopy) it is possible to determine the blood group, the DNS/DNA or the antigens of various infections. Scientific examinations resulted in finding severe infections from worms such as taenia (tapeworm), ascaris (roundworm), draconculiasis (guinea worm), strongyloides, trichinella or schistosoma. Bacterial and viral infections, such as tuberculosis, variola (smallpox) and mastoiditis (middle-ear inflammation) are also attested.

The arteries reveal the existence of arteriosclerosis; mummified lung tissues reveal sand pneumoconiosis, pulmonary tuberculosis or (probably lobar) pneumonia. The alterations and deformations of the bones demonstrate arthritis, periostitis, ostitis, osteomyelitis, osteroporosis, osteochondrom, multiple basal-cell naevus syndrome, pelvic contraction or vesico-vaginal fistule, and several types of tumours. Growth disturbances (indicated by Harris lines) together with various types of distortions of the backbones reveal spondylitis, scoliosis or Pott disease. Different types of innate distortions of the skull point to acrocephaly and hydrocephaly; other bones indicate achondroplasy, Klippel-Feil-Syndrom, talipes equinovarus or other disorders. The teeth are usually worn out and abrased, or else they have tartar or abscesses, if they are not missing. Caries are present mostly from the Ptolemaic period. By the mummification of the inner organs it is also possible to examine the parts of the body, which show signs of anthracosis, silicosis, pneumonia, lung-emphysema; kidney hyperplasia, abscess, calculus, bladder stones; gallstones, cholecyctitis; liver fibrosis; megacolon, prolapsus recti and several other diseases.

To what extent did the ancient Egyptian prosthetic medicine work for living persons? Some mummies are outfitted with prosthetic devices. In cases of the nose or stick legs, they were probably made for the afterlife, but some others might have been used. This is the case with a woman, probably in her 50s, in the Theban T95 tomb from the twenty-first Dynasty, who had an artificial wooden big toe.

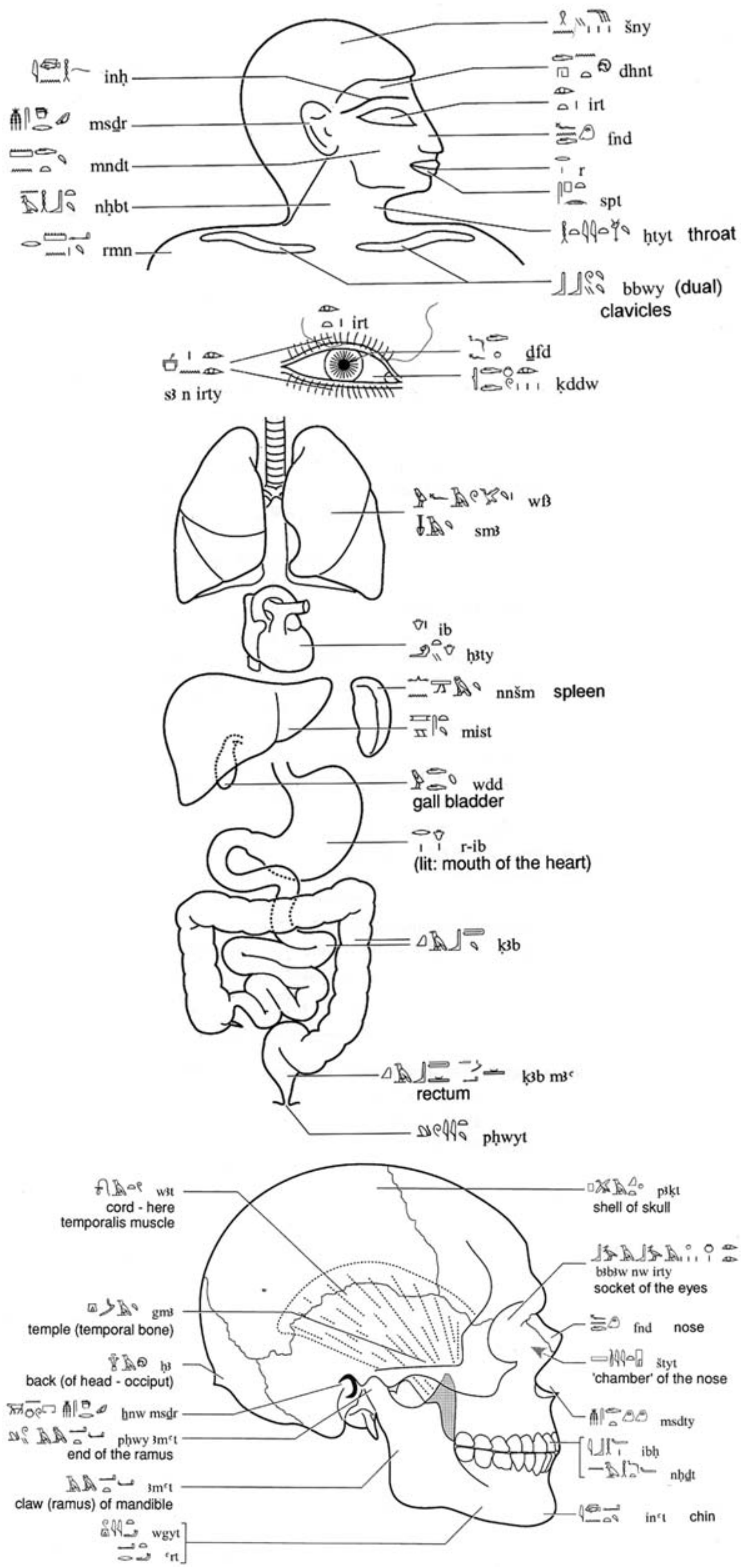
Theoretical Background

Anatomy and Physiology

Ancient Egyptians had advanced anatomical and physiological knowledge. It must have been due to extended observation but also to the custom of mummification. This was a completely different science in the pharaonic period, and according to the data known today, persons executing it were never healers and had no connections to physicians. Characteristic to Egyptian culture, both fields of science had many specialised books, which were kept in libraries – available for every professional, which might mean a reciprocity of giving and receiving knowledge by embalmers and healers. Another opportunity for gaining similar experience might be from accidents or battles. For instance, the process of emptying the skull through the nostrils (a route applied often in modern brain surgery) by means of a long hook attests to a good knowledge of the anatomy of the head and brain. The exact description of the latter is given very vividly in the Smith papyrus (Sm.6). They obtained reliable information about the meninges, the cerebrospinal fluid, and twitches and pulsations, and they noticed a connection between the state of the brain and body control, although they did not develop it into a theory. A similar feature can be observed at the spinal cord, the dislocation of which was connected to paralysis of the four limbs and incontinence (Sm.31), although the nervous system is not mentioned.

Their main concern was directed to the heart. Its position was described precisely, and some of its disorders, such as missed beats, were discussed. It was recognised as the centre of a circulatory system, where the various *mtw* – "canal" systems – met. They seem to have had two different schools for anatomical explanations (Eb.854, 856, Brl.163) concerning the numbers and roads of *mtw*. The *mtw* supplied the body with every substance it needed. They thought the blood vessels contained air in a healthy and blood in an ill state. Their vessels were thought to be hollow and have a mouth. The heart "spoke" through them, as they determined the pulse, and told the physicians at any part of the body about the general state of health of the patient. By this they recognised the peripheral pulses, but they were not aware of the circulatory system in a modern sense. All the fluids in the body, including air and blood, but also any type of body secretion, excretion and discharge flowed in a series of these interconnecting canals in the human body. The system was described based on everyday life: fluids and pathogens or even disease-demons were sailing there like Egyptian people were said to sail on the water of the Nile or its tributaries, with the Sun in the sky or on the river of the Afterworld. Thus *mtw* meant any blood vessel (veins and arteries), ducts or passages in the body, but they were also used as the technical term for muscles, tendons and nerves.

Ancient Egyptians sometimes used in the medical literature different words for a part of the body than were used in everyday life (for instance *wfꜣ* for *smꜣ* as lung). For the names of body members see Fig. 1a–c. The vocabulary was rich for external parts, but relatively few names remained for the inner parts of the body. For instance, the kidney is not mentioned at all, though some hieroglyphs show such organs (lung and heart as *nfr*, heart as *ib*, intestins as *pẖr*), but with



Medicine in Ancient Egypt. Fig. 1 Body members with their ancient Egyptian names. Source: Nunn J.F., Ancient Egyptian Medicine. British Museum, London, 1996, Figs. 3.3a,b and 3.4.

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animal origins. They knew very little about their function. Regarding the respiratory system, they knew that the *tȝwnʿnḫ* (breath of life) entered through the nose, and then the heart and the lung gave it to the entire body (Eb.855a). There was another type of breath – the "breath of death" – which entered the body through the left ear (Eb.854f). The concept of the digestive system was also simple; food and drink went to the stomach, and part of it left through the anus. The details are unmentioned and, based on the treatments of the disturbances, they seem to not have been understood at all.

Pathology

Physicians often treated internal cases, where they could not see the alterations of the organs. They developed their concepts based on symptoms given by the patient and on exterior alterations of the body or of the given organ, experienced by palpation. Patients thought they had become ill because of an outside disease matter; namely the name of diseases was written in several cases by the figure of a god at the end. Among these "disease demons", as they are called today, an enigmatic one is the *wḫdw*. The verb *wḫw* means "to suffer". This pathogen afflicted many organs, causing suffering for the patient, and is a designation for all sorts of symptoms which changed their location. This meant that the *wḫdw* was wandering in the body (Eb.856). All the disease matters and demons entered the body from the outside world by natural or occasional openings. Thus, an important part of the cure and the prevention of morbidity was the physical and magical protection of the openings. A next step could be the cleaning of the *mtw*, the route of travelling of these elements. This theory is also the explanation of the frequent use of enema in treatments.

As the same treatment in a seemingly same case could end, however, with different results, they thought to seek for help in the divine world. This was important at each step of the treatment: from choosing the materia medica and the devices, preparing and administering the drug or performing the operation. This way they aided recovery not only by their medical knowledge but also by favouring the patients with psychological conditioning.

Medical Practice

Egypt was famous in the ancient word for its hygiene. Egyptians often cleaned themselves and their belongings. For this they used natron, ashes, or soda which are all good detergents and dissolve fatty matter. Probably it was also an important factor in the care of the sick. Another aspect is drug administration which was often carried out at home, without professional help. This is what Homeros hints at, saying that everybody living in Egypt is a physician, for the whole population there originates from Paieon (*Odysseia* IV, 231–232).

Medical practice included the use of herbal remedies, but also surgery, various types of physical treatments, religious invocations and as an essential part, magical incantations. For the cure, healers had to handle problems concerning medical history, examination, diagnosis, prognosis, and various means of treatment if they were general practitioners or specialised in various fields of medicine.

Way of Examination

Medical practice was performed in a systematic way. According to the available clinical descriptions, before any treatment could be administered, a detailed history taking and questionnaire took place. The first course of action for the physician was to make a diagnosis, employing his powers of observation and experience to detect as many symptoms and to elicit as many signs as he could for determining the nature of the disease. He referred then to the medical papyri to determine the most appropriate course of treatment. Normally, this would take the form of a potion, unguent, ointment, balm, pill, poultice, enema, suppository or an eye lotion comprised from a concoction of natural ingredients.

The case study comprised several steps:

1. Interrogation of the patient
2. Detailed inspection of the face and skin, smell of the body, urine and faecal matter, palpation
3. Percussion of the body and diseased organs, functional testing
4. Diagnosis and verdict ("An ailment which I will treat", "An ailment which I contend" or "An ailment not to be treated")
5. Treatment

Treatment

Contrary to the statement of Herodotos (II.77), physicians seem not to have been concerned so much with prevention of an illness, but rather with treatment of an ailment, using all the means at their disposal. And they had many. Unfortunately, we do not know details of them, as the texts are very limited. It is, however clear, that the physician gave patients medicaments, or he prescribed rest if needed (Kah 10). The duration of the treatment is often omitted, but it is sometimes specified by exact days (most frequently 4), or paraphrased (typical in the Smith papyrus: "until he recovers", "until the period of his injury passes by" or "until you know that he has reached the decisive point").

If medicine was prepared and administered according to the physician's teachings, he was exempt from all blame if the treatment did not work. However, if he deviated from the traditional remedies and tried to increase his knowledge through experimentation, he risked losing his life if it failed (Diodoros I.82). These principles may have hindered changes in the medicine of Ancient Egypt.

Drug Therapy

Drug administration was the most popular method; drugs were either prepared by the physician himself or followed according to his instruction by an apprentice. Most of the medical texts describe a sole treatment. Medicaments contained a multiplicity of drugs simultaneously. The choice of selection seems to have been influenced by magical considerations. As a vehicle they usually used wine, beer, mothers' milk, oil or grease (*mrḥt*) or honey; they used also active drugs in their own right; in addition to the most common, water. *mrḥt* came in many many varieties, according to the plant or animal it was extracted from or made of. The measures were usually given in units or fractions expressed by the drawing of the components of the *wedjat* eye. The means of their utilisation is usually very short. It was a secret science. The chemical knowledge of the Egyptian physicians was so vast that some would attribute the origin of the word "chemistry" to "Kemet", the ancient name of Egypt.

The preparation process not only had its own rules, but also the administration – method, timing or dosage – was sometimes also specified. Some of these were very complicated. Regulations adhered to the same guidelines physicians apply today. In some prescriptions even the dosage of the different drugs was adjusted to the patient's age: "If it is a big child, he should swallow it like a draught, if he is still in swaddles, it should be rubbed by his nurse in milk and thereafter sucked on 4 days" (Eb.273).

Surgery

Surgery was considered in trauma and in a few cases of tumour and swelling. Based mostly on the Smith Papyrus, the simplest repertoire of surgical procedure is known, but these reveal a remarkably scientific manner and clean environment. There is, however, no mention of any sort of anaesthesia. Bandaging, stitching, bounding with oil and honey belonged to the usual wound managing. Infection of the wound was regarded to be a normal step of recovery. Evidence of operation is very sporadically attested on mummies. Fracture reduction was found a bit more frequently, and it was often successful, as were dislocations – also healed according to Kocher's method.

Complementary Therapies

The ancient Egyptians practiced several other therapies. In the tomb of Anh-mahor (sixth Dynasty, Saqara) a sort of physiotherapy or reflexology might be inferred: the manipulating of fingers and toes were depicted. Chambers equipped with basins were found near Dendera temple, suggesting hydrotherapy in the sanatorium by the use of healing statues. Again they used the ultraviolet of the sunrays (heliotherapy) by exposing an anointed ill body in the sunshine. The treatment by mud and clay was also known (Eb.482).

Magical practices

One of the most powerful tools in the healer's armoury was magic. It was regularly used in conjunction with rational medical practices. Some materia medica seem to be chosen mainly on the magical character assigned to them, such as virgin's urine, crocodile excrement, black pieces of bull hair, or tortoise bile. The administration of the medicament, as with surgical intervention, was also accompanied by prayers and offerings or magical spells addressed to malign or angry deities. In addition, some objects sacred to certain gods or provided with supernatural properties or deemed as a reminder of a myth might give additional help in various other forms. They might be amulets, drawings, statuettes or tiny steles, or using an object as a model (e.g. crocodile statuette in Chester Beatty V. 4, 5–9) (Fig. 2).

If the medical treatments were deemed not to be working, the healer could call solely upon the divine world for destroying "the enemy". Predominantly benign deities, in particular Isis, Horus and Ra, were usually invoked. As expectations and environmental effects have measurable curative value, this was widely employed by ancient healers. Their emphasis on magic was an even more powerful psychological opportunity, the application of which improved therapeutic efficiency. In many cases, especially after attacks of animals such as snakes or scorpions, the spell casting activity of the healer–priest seemed to be decisive. It was thought to be the only treatment for a long while. After the publication of the Brooklyn Herpetological Papyrus, however, prescriptions became known which provided a very deep knowledge of snakes and the effects of their poisons.

Materia Medica

Pharmacology was a secret part of the physicians' studies and knowledge. There are a great variety of materials which cannot be identified, regarding the amount and quantity of usage, or time and way of gathering the raw material; these were guided by experience and theological concept. Physicians prepared the remedies themselves. They were made from natural ingredients, in raw or prefabricated conditions, such as:

- Small amounts of (toxic) *minerals*, like copper oxide, sulphate, antimony, zinc, lead, arsenic, malachite, natron, common salt, haematite, chalcedony
- Various parts of more than 200 *plants*, with about only a fifth identifiable with certainty. Among the

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Medicine in Ancient Egypt. Fig. 2 Small Horus stele amulet in the Museum of Fine Arts, Budapest.

common plants were fenugreek, sycamore, castor oil, acacia gum, carob, wormwood, juniper, Cyprus grass, cinnamon, date, lotus or sycamore fig. Vegetal components were collected not only in Egypt itself, but were also imported (such as the mineral lapis lazuli)

- *Animal* parts (meat, milk, fat, blood, skin, hair, bile, liver, brain matter, urine, or excrement)
- *Human* body products, such as milk, sweat or blood

Ancient Egyptian prescriptions do not say which elements were expected to exert pharmacological effect and which were used as a vehicle, or added for taste or general conditioning capability. Some constituents were used very extensively in most cases, but the texts often do not give the reasoning. The choice of the material changed during the history of ancient Egypt, which is well reflected by a comparison between New Kingdom and Roman time medical papyri, but it is impossible to follow the process because of our lack in knowledge of the time in between.

Instruments

As medical treatments consisted of rational and magical components, they required both medical devices and magical instruments.

Medical Devices

Healers required some objects for storing substances (such as special milk jugs, kohl pots, jars) or for preparing drugs, such as perforated plates for straining (*ʿtḫ*), bowls for getting a homogenous mixture (*m ḥt wʿt*), pots for grinding (*nḏ*) and cooking (*ps*), small measures for volumes (the most convenient are *hnw*, approximately 450 ml and *ro*, approximately 14 ml) or sticks and spoons for the mixing procedures. For enema there were some sort of clysters; for fumigation there were burners. All the devices needed had to be packed in the house or sometimes in a bag to take to patients.

For the treatment of injuries we find “fire drill” which consisted of a stick and board used for starting fires by friction, as a cauterising tool, and various types of bandages. From the New Kingdom onwards, they used small metal knives as well as tools such as hooks, forceps, “disposable” lancets and blades fashioned from reed stems, spatulas and spoons.

In Kom Ombo, the Antonine (Roman) period inner decoration of the surrounding wall of the Sobek and Haroeris temple bears a table of surgical instruments, divided into four horizontal rows. The relief shows knife blades, a saw, spoons, spatulas, forceps, pincers, small bags, a small scale, specula and *wedjat* eye amulets. In the bottom register there are two round forms (possibly vases), a papyrus scroll, two packages for needles or small instruments, an oval object, needles and cleaning tools.

Magical Instruments

As magic and religion played a major role in treatment, magical instruments were also important. Amulets, models and other magical objects such as knots, magic wands, statuettes of gods and “concubine statuettes”, bowls, representations of symbols and scenes or various inscriptions were generally used. Some of them had a specific aim; others had a wider range of applicability. As these practices changed continually, we can specify the time of their use. For instance magic wands was used almost exclusively during the 12–13th Dynasties while the Horus-cippi, which repelled reptiles and cured people who had been bitten, started to appear during the eighteenth Dynasty and stopped after the end of the Ptolemaic era.

Diseases

Degenerative diseases tend to afflict people the same way; other diseases are dependent on environmental factors. These were different in antiquity not only because of the thousands of years during which the virulence and geographical boundaries of many pathogens (and hosts) could have changed significantly but also because of alternating ethnical mixtures of people and changes of life patterns such as diet, way of life, quality of air or geographical factors. There are some which are already extinct. Thus the pathogens were less or more different, and they could cause slightly different symptoms. Examinations of the human remains reveal, however, that diseases usually resulted in the same conditions as they do today.

About 300 diseases are mentioned in ancient Egyptian texts. They are very hard to identify, because the prescriptions usually do not give any or enough description. Moreover, several diseases mentioned are only signs or symptoms (heat, cough, vomiting, obstruction, voiding of blood), which can occur in many diseases. Disease descriptions are also inaccurate for today's diagnoses. For instance the so-called "Asian disease", described very vividly in H.170, has been interpreted differently: bubonic plague (Goedicke), leprosy (Bardinet) or smallpox (Győry). Ancient Egyptian medicine paid detailed attention to the anus. Nevertheless, it is difficult to find a technical term for constipation or diarrhoea, though many remedies cleared the bowels and stopped evacuation (*wsš*). There is no doubt in the meaning of *gs-tp* – "half head", modern migraine (Eb.250, ChB V.4), and the probability is high in the identification of the passage Brl.67 as facial nerve paralysis (Bell's palsy). Due to the widespread nature of dental disease, halitosis (bad breath) must have been a common complaint. A prescription has been discovered to combat this condition.

Another difficulty in understanding ancient Egyptian medical texts is that a lot of words have specific medical meanings, which are only rarely explained in a gloss. Some of them were not well understood even during pharaonic times. That is the reason we have glosses in the Ebers and Smith papyri. Thanks to them, we know much more about surgery and healing wounds than about any other medical cases. In the Smith papyrus, case 7 gives for instance a very plausible description of tetanus.

Prescriptions often speak about worms, as several disease terms are determined with the sign of a snake, the hieroglyphic sign also for worms. There seem to be only two, *ḥfꜣt* and *pnd*, with a sense of a specific worm. And there is no clue for the identification of these two. Several types of vermifuges were used against them, such as pomegranate or wormwood in medical texts or garlic, radish and onion in everyday life, but they are not specific. We have a nice description for the treatment of dracunculiasis (Eb.875), but the worm taken out over a painstaking month is not given a specific name. There is a possibility that the snakes for the emblem of Greco-Roman and modern medicine (caduceus) may be related to this procedure.

Ancient Egyptian representations could be a big help, because they were often accompanied by explications. The medical papyri are, however, not illustrated, and the reliefs on tombs give ambiguous information for medical interpretation. Servants are often represented as humpbacked. We do not know whether this represents poor posture or the result of a disease, such as Pott's disease, ankylosing spondylitis, porter's hump or a sort of fracture. The representations with gynaecomastia or elephantiasis are no better; they can be caused by several diseases, most often by schistosomiasis or filariasis. Similarly, the picture of the equine deformity of the foot of Rama can be the representation of either poliomyelitis contracted in childhood or a variety of clubfoot. The dilemma is the same with the mummy of pharaoh Siptah. The stela of Bak shows him with a high probability of having Simmer's fibrosis caused by schistosomiasis. The case of Seneb, who is sitting beside his wife on a statue from his tomb in Gisa, is a classic example for achondroplasiac dwarfism. But dwarfism was not considered a disease.

The Healers

Health was very important for ancient Egyptians. For many maladies, however, they needed special health care performed by specialised physicians who were remunerated for their services in barter and money-barter by the state or with gifts by private persons. They worked usually on their own, as pharmacists, nurses or midwives.

Herodotus (II, 84) attests in the fifth century BC that

> The practice of medicine is so divided amongst them that each physician treats one disease and no more. There are plenty of physicians everywhere. Some are eye doctors, some deal with the head, others with the teeth or the belly, and some with hidden maladies…

A similar picture is reflected by the medical titles of the Old Kingdom and Late Period among the *swnw*, the ancient word for physician (from the root word "*swn*" meaning "to suffer pain".) The hieroglyph contained the sign of an arrow, which might lead to a possible origin of the occupation such as removing arrows from the injured, or it might allude to Thoth, who not only gave written instructions but also cared for the wounded in battle.

Another type of physician were the priests of Sekhmet, the lion-headed goddess who dispensed disease especially at the end of the year, or cured it. They were called "the wab-priests of Sekhmet, who can dispel evil spirits". They are thought to have been surgeons and might also be veterinarians. A third type of healer was the magician, called *sꜣw* (the protector). These three main categories of healers might function simultaneously for a given patient. All of them could perform the classical medical examination, including palpation. The main difference among them was their way of approaching the disease and consequently the treatment. All three functions could be united in one person as is the case with Hery-shef-nakht (Hatnub, twelfth Dynasty).

The magician healer used mostly magic, which did not exclude operations or medicaments prepared according to the medical prescriptions. His fields were probably centred around fertility and severe illnesses hardly or not curable by physical treatments. They might also be specialised in some diseases; for instance, some healers of the first decades of twentieth century's Egypt (AD) only took out maggots from the eye. Very specialised, the *ḫrp Srḳt* (a sort of priest to the scorpion goddess Selket) dealt only with scorpion stings and snakebites by the recitation of spells and incantations. Surgeons used a "knife-treatment" operation for a wide range of cases, although the act was preceded and followed by religious acts such as offerings, prayers or incantations. The *swnw* were concerned with pragmatic medicine, but again with some divine help.

They adopted a rather elaborate hierarchy system for the health service, with titles such as:

- *swnw* – physician
- *ḥry-swnw* – one with authority over physicians
- *imy-r-swnw* – overseer of physicians
- *wr-swnw* – chief physician (possibly *smsw-swnw* – eldest physician in some cases)
- *sḥḏ-swnw* – inspector of physicians

During the Old Kingdom and Late Period there were many specialists in the different fields of medicine, such as the *swnw jrtj* (ophthalmologist), *swnw ẖt* (physician of the abdomen; i.e. gastroenterologist), *nrw pḥwy* (shepherd of the anus; i.e. proctologist), who probably administered enemas; or *jryw-jbw* (dentist) and *jr-jryw-jbw* (great of those who are concerned with teeth), first given to Hesy-Re in the royal palace of the third Dynasty. Besides the palace, the army also had its own physicians, as well as some social groups such as the royal tomb builders, or miners. Some physicians held several specialised titles, such as Ir-en-akhty (First Intermediate Period), who was both court physician and their inspector, as well as proctologist, ophthalmologist, gastroenterologist and *ꜣʿʿ mw m-ẖnw ntntt* (interpreter of the liquids in the intestines(?)).

The ancient Egyptian physician was generally educated and trained by his father and relatives or within the temple schools and libraries, the so-called *pr-ʿnḫ* (house of life). The most famous New Kingdom medical institutions were in the temples of Heliopolis and Sais. Pupils underwent a formal apprenticeship under an acknowledged master. Training was so successful that Egyptian physicians became renowned throughout the ancient world for their skill. For instance, at the request of Hattushili, Ramses II despatched a physician to the Hettite court and later, at the request of Cyrus Amasis II, sent an Egyptian ophthalmologist to the Persian court. Many Greek people wandered to Egypt to learn from the Egyptians. Even Hippocrates highly esteemed their knowledge; he used the same method of reaching a diagnosis and deciding on a plan of action.

The title of *swnw* was held in high esteem in Egypt itself. More than 150 names of *swnw* have survived. Being an overseer of these was an important rank: Mereruka (son-in-law of pharaoh Teti, sixth Dynasty) was proud of being *jmy-r gswy dpt swnw prʿꜣ* (overseer of the two sides of the boat of the physicians of the pharaoh). There is one story of a female physician: the mother of Akhet-hotep (fifth/sixth Dynasty) was their overseer – *jmj-r swnwt*. Moreover, two persons without known contemporary evidence of bearing this title – Imhotep, the royal chamberlain to Djoser (third Dynasty) and Amenhotep-son-of-Hapu, the royal scribe to Amenhotep III (eighteenth Dynasty) – were deified from the Late Period, the former one also identified with Asclepius by the Greeks (Fig. 3).

If one had to be ill in antiquity, ancient Egypt would be the preferred place. Although the basis of their medication was mainly empirical and aimed at the relief of symptoms, they thought to eliminate the cause of the disease by winning the gods' benevolence. The medical knowledge of their physicians was without equal at that time; their formal, structured and logical approach to the patient is unchanged in modern medicine; and their techniques and treatments are often comparable to today's medical profession.

Extra 1: The Most Important Medical Papyri

The earliest texts originate from the Middle Kingdom (Amenemhat III). The *Kahun papyrus* was found in the town of Illahun by Flinders Petrie in 1889, and is badly damaged (Griffith 1898; Stevens 1975).

Medicine in Ancient Egypt. Fig. 3 Bronze statuette of Imhotep. Dyn. 26. Source: 1. Nagay, Guide to the Egyptian Collection. Museum of Fine Arts, Budapest, 1999. p. 67.

All the paragraphs are gynecological, but the first half is written in instruction form, while the second 17 paragraphs are prescriptions or pregnancy prognoses. The 17 *Ramesseum papyri* were found in a magician-healer's tomb in the great temple of the Ramesseum, Thebes. They are also fragmentary and originate presumably from the 13th Dynasty. *Numbers 3 and 4* contain several prescriptions and also magical spells treating various parts of the body, though many deal with birth and babies or the eye. Scroll *number 5* is in the best state of preservation among them, and the writing suggests it to be the earliest copy. It collects cases concerning the *mtw* – that is the "canals" of the body – in this case usually muscles and tendons. The other Ramesseum scrolls are mostly magical.

The 4.5 m long *Edwin Smith papyrus* was purchased in Thebes in 1862 by its eponym, and published in 1932 by James Henry Breasted in two superb volumes. The recto gives an excellent insight into the surgical practice of ancient Egypt with the 48 trauma cases in instruction form. There are several corrections written in the paragraphs and explanations (glosses) appended behind them, which indicate that the original text was not understandable any more. Its language suggests a Middle Kingdom origin. It outlines procedures and techniques that are considered antecedents of modern surgical practice. The 48th case ended abruptly in the middle of a sentence. The verso was finished by another hand and consists of various medical paragraphs together with iatromagical incantations. The style of the writing dates the scroll approximately to 1550 BCE.

The longest medical papyrus is *the Ebers papyrus*, which was also bought by Edwin Smith in 1862. It was said to be taken from between the legs of a mummy in Assasif, Thebes. It measures some 20.23 m in length and 30 cm in height. A passage on the verso dates it to the ninth year of Amenhotep I. Georg Moritz Ebers published it in 1873. The recto contains 877 medical paragraphs of various topics arranged unsystematically in many books with some loose prescriptions and randomly placed glosses. The pages were numbered by the ancient compiler, who collected material from the ancient Egyptian medical literature – ophthalmology, obstetrics, contraception, dentistry, urinary and digestive system, psychiatry, etc. The "book of the stomach" (188–207) and the injury section (857–875) are in instruction form. It also contains two anatomical treatises (854–56) and a detail of a herbarium (251).

In 1901, a scroll of papyrus was presented at the Californian Phoebe Hearst expedition in Deir el-Ballas. The scroll, later named *Hearst Papyrus*, was written during the reign of Tuthmosis III and is a less systematically written compilation of several topics, probably a practicing physician's formulary. It is concerned with diseases of the urinary system, blood, hair, bites, etc. More than a quarter of the paragraphs are similar or very close parallels to the Ebers papyrus. The recto *of Chester Beatty VI* of the nineteenth Dynasty from Deir el-Medina consists of prescriptions for rectal ailments. The *Berlin Papyrus*, acquired by Giuseppe Passalacqua in Saqqara and sold to Friedrich Wilhelm IV of Prussia in 1827 for the Berlin Museum, bears a great similarity to the Ebers papyrus, and also contains an anatomical treatise (163). Beside the prescriptions for various illnesses there are also some birth prognoses. The paleography indicates that it is of the nineteenth Dynasty. Unknown is the origin of the badly damaged *Carlsberg Papyrus VIII* written by two different hands and dated to the nineteenth/twentieth Dynasties. Its language suggests a Middle Kingdom origin. The recto gives prescriptions for eye diseases and the verso prognoses for pregnancy.

The *Brooklyn Herpatological Papyrus* concentrates exclusively on snakebites and dates to the thirtieth Dynasty or Early Ptolemaic Period. It starts with a systematic description of the properties of 38 snakes and their bites (the first 13 were on the missing part of the papyrus), while the second section describes prescriptions to "drive out the poison" of snakes, scorpions and tarantulas and to "seal their mouths". The *Fayum Medical Papyrus*, originating from the library of the Sobek temple of Crocodilopolis in the second half of the second century AD, is a compilation of prescriptions for various diseases. Although it is written in demotic and the structure is traditional, it is completely imbued with the Mediterranean medical praxis and drugs.

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Extra 2: The Most Important Mixed and Pure Iatromagical Texts

The provenance of the *London Medical Papyrus* is unknown. It was given to the British Museum by the Royal Institute of London in 1860. It is a palimpsest in very poor condition dealing with various topics such as gynaecology, ophthalmology or proctology. The earlier work dates to the reign of Tutankhamun. Of its 61 paragraphs, 25 are prescriptions; the others are magical spells. Among the 19 *Chester Beatty Papyri* given by Sir Alfred Chester Beatty to the British Museum, spells are often cast for unidentifiable diseases (*VI verso, VIII, XV*). Then again there are some systematic books – incantations against headache (*V.*) and scorpion stings (*VII recto*). The collection was found in a tomb at Deir el-Medina in 1928 and belonged to the archive of the family of the scribe Qen-her-khepeshef for over a century during the nineteenth Dynasty. The *Mother and Son Papyrus* in the Berlin Museum was auctioned from the Athanasi collection in 1843 as burial good from Memphis or Thebes. Written in two hands at the beginning of the eighteenth Dynasty, the papyrus contains three prescriptions for the newborn and 18 magical spells against children's illnesses or for delivery, mother's milk and the general safety of the child.

The *London-Leiden magical Papyrus*, which consists of a few prescriptions and many incantations for various ailments, was written in the third century AD. The two halves, sold first by Anastasi, the Swedish consul of Alexandria and aquired much later by the British Museum and the Dutch government, were discovered by the first publishers, Francis Ll. Griffith and Herbert Thompson. Although it is basically demotic, it also contains many Greek glosses, some coptic words and a few hieratic signs.

Typical pure magical texts were written against snakebites, and not only on papyri or ostraca but also carved on stone from the New Kingdom – mainly on *Horus-cippi*. Probably the most complete collections are the *Metternich stela* and the inscription of the *healing statue* of Hor-udja. These incantations often quote mythical events in connection with the child-god Horus or the goddess Isis. Other types of spells were cast over pain and aches in different parts of the body. The *Turin magical papyri* contains a large collection of these and snakebite spells.

See ▶Maps and Mapmaking in Egypt: Turin Map.

See also: ▶Mummies

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Medicine in Ancient Mesopotamia

Semaàn I. Salem

The art of medicine is as old as humanity itself. Diseases must have existed as soon as life was formed and early human beings tried to rid themselves of the pain and discomfort they caused. This art is not restricted to human beings alone; many animals even some plants have ways to combat sickness.

Early people probably practiced two completely different methods of medication: a practical method originating from the obvious, and another resulting from combating the unknown and the mysterious. When a thorn or a similar object penetrates the flesh, removing it relieves some pain and discomfort and is therefore a cure. Pressing one's finger or hand on a wound stops the bleeding and thus is a form of medication. On the other hand a cure for a mysterious or a supernatural illness, such as a high fever or epilepsy, is not as obvious and therefore requires a supernatural treatment. Not knowing the nature of such mysterious illnesses or how they entered the body of their victims, early humans accused demons and evil spirits, and called on magicians and exorcists to chase away the offending demons. Thus to combat diseases, the help of a benevolent god was invoked either directly by prayers and sacrifices, or through a medium, an expert in communicating with such a super power. This type of treatment survives today, practically unchanged into the twenty-first century, in many places.

Most of the almost one thousand medical tablets uncovered in Mesopotamia treat most diseases in this fashion: a disease is the invasion of the body by an evil spirit or a harmful demon, and the cure is always described as a method to force the demon to leave the patient. This is accomplished either by a healing god, or by scaring, or disgusting the intruding demon. The evil spirit may become disgusted and forced to leave by feeding the patient repulsive materials, such as dirt or excrement. In Mesopotamia, the healing god was usually associated with a snake, the symbol of healing.

On one of the oldest Mesopotamian medical tablets, the Sumerians attribute numerous diseases to harmful demons and evil spirits and call upon their goddess for medical help. In their incantations, she is addressed by various names, such as Bau, Ninisinna, and Gula. An example of this kind of treatment is found on several tablets describing the disease that overwhelmed Tabi-utul-Enlil, the ruler of Nippur. He calls on various gods and goddesses, begging them to rid him of the evil demons that entered his body. There was no other cure mentioned.

An evil demon has come out of its (lair);
It struck my neck and crushed my back,
It bent my high stature like a poplar;
Food became bitter and putrid,
The malady dragged its course.
My flesh was wasted, my hands were wan.
All day the pursuer pursued me;
At night he granted me no respite whatever.

Then Tabi-utul-Enlil mentions how the diviner failed him and his gods deserted him.

The disease of my joints baffled the exorcist,
And my omens were obscure to the diviner,
The exorcists could not interpret the character of my disease,
And the limit of my malady, the diviner could not fix.

He was baffled by his punishment, as he was a pious ruler, who performed his duties to gods and men.

As though I had not set aside the portion for the god,
And had not invoked the goddess on the meal,
Had not bowed my face and bought my tribute;
And had not taught my people fear and reverence.
I thought that such things were pleasing to the gods.

Here, Tabi-utul-Enlil states that since he is such a pious man, he should not have gone through so much suffering. The good god should have prevented the evil spirits from entering his body. But he never lost faith in his benevolent god. Finally, the good spirit appears, and cures all his ailments; a mighty storm drives all the demons out of his body.

He sent a mighty storm to the foundation of heaven,
To the depth of the Earth he drove it.
He drove the evil demon into the abyss.
He tore out the root of my disease like a plant.

Cured, Tabi-utul-Enlil praises his god, offers sacrifices, and calls upon his subjects to have faith, and never to despair.

This piece of Mesopotamian literature provides a clear insight into Mesopotamian view of diseases and cures. There is no difference between demon and disease; the two words were synonyms. And so were the words god and cure. Many historians see similarities between Tabip-utul-Enlil's story and that of the biblical Job.

Although magical cures were prevalent in ancient Mesopotamian society, there are indications that even in the early stages of Mesopotamian development, plants, and other substances were consumed for medical purposes and some specialized medicine existed. A clay tablet, written toward the end of the third millennium BCE was uncovered in Nippur and brought to the Museum of the University of Pennsylvania, where it was translated by Samuel Kramer and Martin Levey. Considered the oldest medical document of record, this tablet describes over a dozen remedies extracted from plants such as myrtle and thyme, and from trees such as willow, pear, fir, fig, and date. It also mentions extraction from milk, snakeskin, and turtle shell as well as table salt and potassium nitrate. This tablet has two drawbacks: it fails to mention the diseases for which these remedies were intended or the quantities to be used in the treatment. Another clay tablet that dates to the middle of eighteenth century BCE mentions aloe as a cure for "anything that ails you." An Egyptian papyrus written around 1500 BCE confirms the Mesopotamian claim; it states that aloe relieves skin afflictions, infections, and constipation.

Modern scientific studies have confirmed what Mesopotamians and Egyptians knew some 3,500 years ago, that aloe has therapeutic powers; it heals burns, skin lesions, and frostbite; it reduces inflammation and enhances the immune response. If taken internally, certain components of aloe reduce stomach acids, relieve the pain of arthritis, and reduce blood sugar in diabetic patients.

The therapeutic effect of plants is also mentioned in one of the Sumerian creation stories. Uttu, the goddess of plantations, after being impregnated by her grandfather Enki (Lord-Earth), fulfilled her duty and created a variety of plants. Enki visited Uttu's plantations and, in an effort to determine their medical power, he ate some of them. The goddess Ninhursag (Queen-Mountain), enraged by what had happened, cursed Enki, who as a result, fell grievously ill. The Anunnki (Great Gods), troubled by Enki's illness, brought Ninhursag to Enlil (Air-God), their leader, who persuaded her to heal Enki. To perform that function, she placed the sick god close to her vulva and began to create a god (a specialist) for each of the diseases that inflicted him.

Ninhursag placed Enki at her vulva.
'My brother what hurts you?' – 'My tooth hurts me.'
'I have caused Ninsutu to be born for you.'
'My brother what hurts you?' – 'My mouth hurts me.'
'I have caused Ninkasi to be born for you.'
'My brother what hurts you?' – 'My rib hurts me.'
'I have caused Ninti to be born for you.'

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The similarity between the creation of Ninti (Lady of the Life or Lady of the Rib) from the rib of Enki and the creation of the biblical Eve from the rib of Adam has been recognized since these verses were translated.

The therapeutic effect of plants was mentioned only rarely. The general public believed that demons and evil spirits caused all diseases, and magical cures were predominant. This led to devising and adopting various protective methods, such as hiding from the sight of evil demons, which in turn led to the use of masks and symbolic chains that protected loved ones from harmful contacts. Another way of hiding from evil spirits was by painting the patient in a variety of colors, and this is might be the origin of tattoos. Changing the patient's name was another way of fooling the evil spirits, preventing them from finding him.

Other forms of protection against harmful demons included the administration of seven drops of a liquid, the assistance of a special person – a child, a virgin, a firstborn – and a variety of amulets such as odd-shaped stones, and threads spun from a virgin kid. Such charms were attached to the head, neck, or limbs of the patient, or tied about his bed or at the entrance of his dwelling.

These ancient protective devices may be viewed as the precursors of ornaments or signs used today, such as the statues of Buddha, crosses, and small boxes containing Quranic verses, usually worn around the neck, and also the signs of the cross painted above the doors of certain homes and statements such as "God bless our home," hung on the wall.

In a society governed by demons, magic, and fetishes, individuals who possessed the power to pacify angry spirits and triumph over powerful evil forces became respected and admired. They were the priest–magicians–physicians, who rose to prominence, not only in Mesopotamia, but also in other societies. They called for the help of benevolent gods to frighten away evil spirits. In many instances they also foretold the future by observing the stars and other celestial phenomena, or by studying the liver of an animal or a fellow human being. They taught the people how to avoid forthcoming calamities. In modern religions, this function has been taken over by prophets, saints, and the clergy, who could intercede with God on behalf of people in need.

Mesopotamian society was host to such practices for some 2,000 years, from the early Sumerian period until Hammurabi's rule. During that long period, magician–priests were the dominant factor in medical practices. But astrology also played an important role. The conjunction of the stars at the birth of a child was thought to determine his lot all through life as well as the time and manner of his death. This belief is still held by many people, and many prominent newspapers still publish a daily astrological column. This is but one of many ancient myths still flourishing in our time.

Another magical concept came about from the belief that blood is responsible for all vital functions and for the continuation of life and must be provided with the proper nourishment. The liver was assumed to be the organ that receives the blood and was considered the seat of all life processes. Accordingly, when an animal was sacrificed, its liver was thoroughly examined for signs of destiny. Divinations were derived from its position, its form, and any irregularities it possessed. This concept passed unaltered from Sumerian medicine into Assyrio-Babylonian and then west into Canaanite, Hittite, and Etruscan medicine. In turn, the Etruscans passed it to the Romans. The Latin word for liver, *haruspex*, has its origin in the old Babylonian word for liver, *har*. Haruspicy, or divination using livers of animals of slain enemies, survived in Greece for several centuries after the advent of Christianity.

Various forms of magic were used to rid the patient of the invading demon. A magician–physician would wear a terrifying mask, cover himself with animal skin, and make wild noises, dance and jump, and rave until the patient laughed, a sign that the invading demon was frightened away. Did the ancient Mesopotamians discover the healing power of laughter? Another method to get rid of the demon was to set its image on fire. Often the image was shown bound, hand, and foot, its eyes pierced, and its tongues pulled out. Then the mutilated image was thrown into the fire.

Yet another method of extracting the demon from the body of the patient was to find a substitute: a lamp, a pig, or a bird. The chosen substitute was placed near the sick person, and then killed by tearing out its insides, enticing the demon to leave the patient and enter the body of the substitute. The animal was then offered to the gods as a sacrifice. Humans did not consume its meat. This notion of passing an unclean spirit from a person to an animal survived and spread west with Christianity as Jesus ordered the unclean spirit, Legion, to leave a mad man and enter a herd of swine (*New Jerusalem Bible*, Mark 5: 8–13). Based on the belief that the evil spirit could enter a person and drive him insane, many people so inflicted were chained and put in dark caves, dungeons, or locked in a cellar, barn, or an attic to force the evil spirit to leave them. This method continued to be practiced in Europe and the Middle East well into the nineteenth century.

All medical treatments were based on the notion of forcing the evil spirits to leave the body of the patient, and all cures, regardless of their nature, were effective because they performed that function. In time the approach did change; scaring or disgusting the invading spirits gave way to pleasing and appeasing them. This was accomplished by treating the patient and therefore the evil spirits with delicious drugs, such as honey, milk, and sweet smelling herbs.

Based on their experience with irrigation and the effect of sweet water on the growth of vegetation, the

Mesopotamians reasoned that water held healing powers. As this phenomenon was common and readily observable, many ancient civilizations reached similar conclusions, and sweet water became the medicine of choice, and the gods of healing in many civilizations were associated with sweet water. The Sumerian god Enki, whose abode was Apsu, the underground sweet water, was the god of healing, and so was the Babylonian god Ea, the god of the underground sweet water, and the wisest of all the gods. The Phoenician god of healing, Ashmun, was associated with the river and the pond that bears his name (the name has since been changed to al-Awwaly), and most of the Greek and Roman gods of the medical art were associated with sweet water. To wash away an ailment, the patient drank the water, sprinkled it over his head, or bathed in it. As a result many rivers, lakes, and pools became sacred and revered for their healing powers. Many still are.

When water was administered to relieve a patient from the clutches of demons, an incantation was usually chanted. One such incantation associated with the god Ea ritual reads:

With pure, clear water,
With bright, shining water,
Seven times and again seven times,
Sprinkle purify, cleanse!
May the evil Rabisyu depart!
May he step to one side!

The water was sprinkled seven times and again seven times because the number seven was considered sacred. The ancient use of sweet water as a healing commodity may have served as a prelude to Christian baptisms. Other rituals were later introduced. Among them was rubbing the patient with butter, milk, or oil while chanting the proper incantation.

During the golden age of Babylon, King Hammurabi put forth his code of law in which he detailed reward for various successful medical operations and describes penalties for failures. One such law reads, "If a physician performs a major operation on a nobleman with a bronze lancet and saves his life, or opens up the eye of a nobleman with a bonze lancet and saves the nobleman's eye, he shall receive ten shekels of silver." In Babylonian society there were three classes: nobility, commoners, and slaves. The eye of a commoner was worth half that of a nobleman's, and if a practitioner saved the eye of a slave, his reward was only two shekels.

To discourage imposters, Hammurabi put stiff penalties on failures. "If a surgeon shall make a severe wound with an operating knife and kill the patient, or shall open an abscess with an operating knife and destroy the eye, his hand shall be cut off." This was probably intended to prevent imposters from practicing medicine. Of course, penalties were less severe if the patient was a commoner or a slave. "If a physician shall make a severe wound with a bronze operating knife on the slave of a free man and kill him, he shall replace the slave with another slave. If he shall open an abscess with a bronze operating knife and destroy the eye, he shall pay half the value of the slave."

The fact that such legislation was needed in eighteenth century BCE proves that such operations were fairly common, and that the people of Babylon were enjoying the services of a class of able physicians. It also proves that empirical medicine was beginning to displace magic and exorcist medicine, but not to eliminate it. The two survived side by side for centuries, as they still do.

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Medicine of the Australian Aboriginal People

Dayalan Devanesen, Patrick Maher

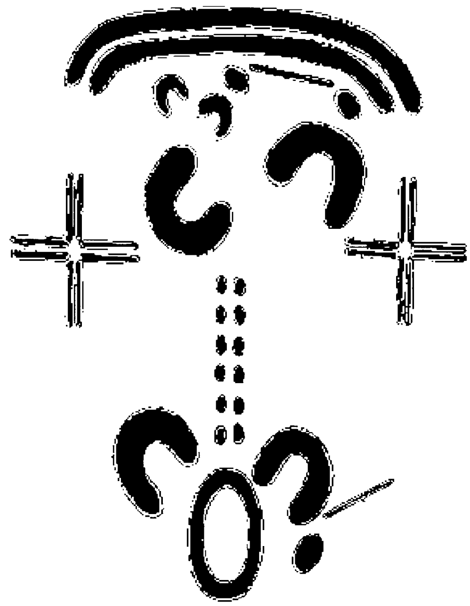
Australia is the only continent to have been occupied exclusively by nomadic hunters and gatherers until recent times. Carbon dating of skeletal remains proves that Australian Aboriginal history started some 40,000 years ago, long before Captain Cook landed on the eastern coast in 1770. This history is not completely lost. It is retained in the minds and memories of successive generations of Aboriginal people, passed on through a rich oral tradition of song, story, poetry and legend. According to Aboriginal belief all life forms, human, animal, plant and mineral are part of one vast unchanging network of relationships which can be traced to the great spirit ancestors of the Dreamtime.

The Dreamtime continues as the "Dreaming" or *Jukurrpa* in the spiritual lives of Aboriginal people today. The events of the Dreamtime are enacted in ceremonies and dances and chanted incessantly to the accompaniment of didgeridoo or clapsticks (Isaacs 1980). The Dreaming is the source of the rich artistry, creativity and ingenuity of the Aboriginal people.

In Australia, Western health services have been superimposed on traditional Aboriginal systems of health care. However, these traditional systems have survived despite the dramatic influence of cultural contact, and Aboriginal medicine is still widely practised in the Northern Territory today (Tynan 1979; Nathan and Japanangka 1983; Reid 1983; Soong 1983; Devanesen 1985; Maher 1999). The Northern Territory occupies one-sixth of the Australian land mass. It has a population of just under 200,000 of which 28% are Aboriginal. The vast majority of the Aborigines live in small remote communities scattered across the Territory.

Traditional Aboriginal medicine is a complex system closely linked to the culture and beliefs of the people, knowledge of their land and its flora and fauna. Its survival is explained by its "embeddedness" in the social fabric of Aboriginal culture. Reid (1983) has shown that, though Aborigines living at Yirrkala in the Northern Territory choose Western biomedicine to treat the majority of their sicknesses, they continue to explain the causes of these sicknesses through their traditional beliefs. This may be because the health beliefs continue to play a role in providing meaning to events and thereby helping people to cope with serious illness and death (Reid 1983).

The Aboriginal approach to health care is a holistic one. It recognises the social, physical and spiritual dimensions of health and life. Their concept of health in many ways is close to the World Health Organisation definition of health: "a state of complete physical, mental and social well being and not merely the absence of disease or infirmity". The Warlpiri Aboriginal tribe have described health as "life" or *Wankaru*. Their definition takes in a whole of life cycle. The front of their health centre at the Aboriginal settlement of Yuendumu is adorned with the painting in Fig. 1. It shows family life, food, shelter, warmth, water and exercise, all of which are essential for health (Devanesen 1983).



Medicine of the Australian Aboriginal People. Fig. 1 Health symbol for Yuendumu: Napangardi women's *Jukurrpa* or Dreamtime.

Traditional Indigenous Health Systems

The traditional health beliefs of Aboriginal people are interconnected with many aspects of Aboriginal life such as the land, kinship obligations and religion (Tynan 1979). The sociomedical system of health beliefs held by Aboriginal people places emphasises on social and spiritual dysfunction causing illness. This approach emphasises that "individual well-being is always contingent upon the effective discharge of obligations to society and the land itself" (Morgan et al. 1997: 598). A person's social responsibilities and obligations may take precedence over their own health because of the priority given to social relationships in this model.

Sorcery and supernatural intervention are part of the perceived reality of Aboriginal life (Waldock 1984), and in Aboriginal society explanations in terms of sorcery are often used. The deaths of infants or the very old or chronically ill are considered to be in the normal course of events, while deaths outside these groups may have a supernatural influence, especially if they are regarded as premature, unexpected and sudden (Reid and Mununggurr 1977).

There are many beliefs associated with supernatural interventions and sorcery:

- Sorcery exists in many forms. Its effect is to manipulate and alter behaviour and cause morbidity and mortality.
- Sorcerers can be specialists or non-specialists.
- Distant groups have the most virulent sorcery and are the most feared.
- Many diseases come from dangerous, secret sacred sites. They are manifestations of the forces or power emanating from those sites.
- Unskilled or uninitiated people may release forces from a dangerous site by disturbing the site.
- Sorcery is carried out in secrecy.
- Retribution sorcery is directed serially at members of a family or lineage. Therefore, the serious illness or

death of one member is followed by the illness and death of others.

- A traditional healer can apply counter measures to identify the cause and source of illness and death, but the healer should not interfere if it is the result of legitimate punishment (Biernoff 1982).

The ill effects of sorcery will not necessarily be felt only by the "offender", but may also be felt by his/her family and descendants. While the thought of sorcery is prominent in Aboriginal life, people do not live in constant fear of sorcery. Sorcery is usually an explanation that is applied retrospectively to explain deaths, serious illness or injury (Reid and Williams 1984).

The concept of supernatural intervention and sorcery plays an important function as "it explains why one person and not another died or became ill at a certain time and not at another" (Reid and Mununggurr 1977: 39). It provides the explanations of "why me" and "why now" which cannot be answered in terms of Western medical theory. It provides the answer to the ultimate cause of the event.

Many have acknowledged the cultural diversity, particularly in regard to health beliefs, between Aboriginal groups and communities (Reid 1983; Elkin 1994). We have therefore chosen to describe the features of the traditional indigenous medical system by particular reference to one tribe, the Warlpiri.

Traditional Health System of the Warlpiri Aborigines

The Warlpiri Aborigines comprise one of the largest tribes in the Northern Territory. They are scattered over many Aboriginal communities in the northwest of Central Australia. The main components of the Warlpiri health system are the *ngangkayikirili* or traditional healers, commonly referred to as *ngangkari* or *ngangkayi* (healing power), *Yawulyu* ceremonies; healing songs and herbal medicine. In addition there are laws governing behaviour that are aimed at preventing sickness.

Ngangkari

Traditional healers have a variety of roles, including providing strong spiritual and social support (Reid 1983; Soong 1983); determining the ultimate cause of a serious illness or injury (Nathan and Japanangka 1983; Reid 1983; Peile 1997; Tynan 1979); determining cause of deaths at an "inquest" (Nathan and Japanangka 1983; Reid 1983; Peile 1997; Tynan 1979); and employing counter sorcery to remove the evil influences causing illness (Reid 1983; Tynan 1979). They are believed to have many powers to undertake these roles and utilise numerous different healing techniques (see Table 1).

Professor Elkin (1994) referred to the traditional healers as Aboriginal men of high degree. The healers

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Medicine of the Australian Aboriginal People. Table 1 The powers and healing techniques of Aboriginal traditional healers

Powers/capabilities	Healing techniques
• have assistance from the spirit world to assist healing • telepathy • divination • X-ray vision • clairvoyance • telesthesia • control the weather • mind reading • walk on fire • inserting healing objects into patient's body • magically heal wounds including internal wounds • travel at fast pace • protect people against attack from spirits via counter sorcery • commune with spiritual beings including the dead • manipulate a patient's spirit • spirit travel • able to project their spirit into the body of patient • able to replace patient's blood with their own • able to communicate with the spirit world	• provide positive emotional support • physical contact and touching • massage • extraction of objects causing illness from a patient's body via sucking, rubbing or massage • smoking used ritually (after initiation or death) or therapeutically for mothers and babies after childbirth • use of healing songs and chanting • counselling • using objects with healing powers • dreaming • cleansing the patients' internal organ(s) while they asleep

Sources: Nathan and Japanangka (1983), Reid (1983), Elkin (1994), Peile (1997), Cawte (1974), Taylor (1977), Tonkinson (1982), Toussaint (1989), Berndt (1964), Soong (1983), Brady (1995), Hunter (1993) and Eastwell (1973). From Maher (1999). Used with the permission of Blackwell Science Asia.

are kindred to Amerindian “men of power” and shamans. These healers are specially chosen and trained to remove the influence of sorcery and evil spirits and to restore the well being of the soul or spirit. Their role is extremely important because most serious illness is thought to be brought about by loss of a vital substance from the body (soul loss), introduction of a foreign and harmful substance into the body (spirit intrusion or possession) and violation of taboos or sorcery (singing). The traditional healers usually gain the power to heal through inheritance or through special spiritual experiences. They possess a spirit called *mapanpa* which is associated with healing power. This is different from the spirit that every Warlpiri person has “like a shadow” (Tynan 1979).

The traditional healer carries out a healing ritual which often includes sucking the sick person. After sucking, the healer usually spits out a wooden object called *yarda* which is covered in blood. The *yarda* represents the evil influence. Sometimes, the traditional healer massages the patient, manipulates the body or sings during the ritual. The traditional healer may diagnose the state of the spirit, e.g. *kurrunpa yulangu* (the spirit is sad). The traditional healers do not use herbal medicine in their practice.

Yawulyu Ceremonies and Healing Songs

Warlpiri women frequently perform *Yawulyu* ceremonies. These ceremonies improve the health of sick people but cannot remove the influence of sorcery. The ceremony consists of singing songs and painting designs on the sick person. These designs are derived from the power of the Dreamtime (see Fig. 2). Each ritual is carried out by the *kirda* (owners) or *kurdungurlu* (managers) of a particular “Dreaming”. Sometimes the songs and designs appear to the people in their dreams and are thought to be revealed by spirit creatures called *yinawuru* (Munn 1973). During the ceremony the sick person may be massaged with fat and red ochre. These materials derive special potency from the songs. In some cases senior men and women sing songs without the ceremony to strengthen sick people. Songs are sometimes sung to ensure safe childbirth. The *Yawulyu* ceremonies and songs assist in providing strong family support for the sick person.

Medicine of the Australian Aboriginal People. Fig. 2 *Yawulyu* designs on women – yam dreaming.

Herbal Medicine

Herbal medicine and knowledge of plants is not the domain of any particular group in the Warlpiri system. The whole family shares its knowledge and use. The Warlpiri have extensive knowledge of plants and have published their own book which lists several plants and their medicinal uses (Henshall et al. 1980).

Medicinal plants are mainly used symptomatically for coughs and colds, pains and aches. Some are used as dressings for wounds and sores. The main conditions that herbal remedies were used for reflect the types of sickness that Aborigines had before contact with Western society. They were joint and muscle pain, toothache and sore mouth, gastro-intestinal disorders, symptoms of colds and flu, e.g. fever, headache and ill-defined pain, congestion, cough, general malaise, sore throat, sores, boils, cuts, scabies, bites, stings, burns and major wounds, warts, allergy rash and itchy skin disorders, ringworm, other tinea form skin infections, eye disorders and fever.

Aboriginal expertise regarding plants has been acknowledged for many years. Webb (1969) has shown that many Aboriginal bush medicines contain biologically active compounds. Bitter Bark (*Alstonia constricta*), used to prepare a tonic, contains reserpine, a tranquilliser and antihypertensive. Plants used on sores and wounds contain proteolytic enzymes that help healing. Spilanthes, a native daisy used to treat toothache, has been shown to contain spilanthol – a local anaesthetic. Over half the world’s supply of the drugs hyoscine and scopolamine come from an Australian native tree Duboisia, which was used by Aborigines as an emu and fish poison (Pearn 1981).

Herbal medicine was the first component of the Warlpiri health system to be eroded by the introduction of Western medicine. However, the movement of the Warlpiri people back to their traditional land has led to a renewal of interest in the use of herbal medicine.

A program by the Northern Territory Department of Health that commenced in 1973 to collect information regarding the Aboriginal use of plants has helped non-Aboriginal staff to appreciate the great knowledge and complexity of the Aboriginal health system (Devanesen and Henshall 1982).

In 1995 staff at a remote health centre in the Northern Territory carried out a study to compare the effectiveness of wound healing by the use of a traditional remedy, Bauhinia root (*Lysiphyllum cunninghamii*) and a Western preparation in the treatment of boils, sores and scabies. The study concluded that the herbal medicine was as effective as the Western preparation. In addition the Aboriginal people felt more comfortable using the traditional remedies and felt a sense of pride in their own traditional knowledge and culture (McLean et al. 1996).

The Warlpiri Health System

The Warlpiri health system can be represented as in Fig. 3.

When someone falls sick, one of the three main components of the health system is tried. If it does not work, another component is used or the same component tried again until there is a definite outcome.

Preventing Sickness

Reid (1982) gives a good description of prevention at the level of personal relationship and religious injunctions:

> Preventive measures can include avoiding foods prohibited during ceremonies or life crises, obeying ritual proscriptions, taking care not to abuse ones' land or trespass on territories of others, avoiding prohibited sacred sites or approaching them with ritual protection, observing debts and obligations to others, containing anger, violence or jealousy, exercising caution in interactions with strangers and taking steps to avoid sorcery or often conflict with others.

The methods of preventing illness link in directly with what are regarded as the ultimate causes of illness under the Aboriginal model of causation of illness. In summary, good health is associated with strict adherence to approved patterns of behaviour and avoidance of dangerous places, people and objects (Biernoff 1982).

The Place of Western Medicine

Western medicine has been incorporated into this system at the same level as herbal medicine. By doing this, the Warlpiri are able to retain their belief in spirit causation of illness while using Western medicine for the relief of symptoms.

Changes are taking place in the illness-related beliefs of Aborigines in the Northern Territory. Reid's study at Yirrkala shows that this change is characterised by the "gradual addition of causes and elaboration of the existing causes within the aetiological domain". Reid lists three categories of causes (1) social and spiritual causes, e.g. sorcery or breaking the law; (2) causes other than social or spiritual, e.g. emotional state, old age, assault; and (3) emergent causes, e.g. alcohol, sin, smoking (Reid 1983).

Aboriginal people use the strategy of domain separation to divide illness into Aboriginal and Western causes. This involves thinking in terms of separated cultural or social domains and deciding when to apply the rules of each domain (Harris 1988). This strategy occurs not only in the area of health beliefs, but also in other areas to respond to cultural uncertainty, to reduce social complexity and stress and to deal with social dilemma (Harris 1988).

There are a variety of behavioural patterns of seeking medical assistance that traditional people use during illness:

- Sequential (use one practitioner then another kind, e.g. Western then traditional or vice versa)
- Compartmental (using traditional medicine for conditions which have established traditional explanations)
- Concurrent (concurrent use of traditional and Western forms of health care; Armstrong and Fitzgerald 1996)

Aboriginal people use all these patterns (Reid 1983; Peile 1997; Tynan 1979; Elliot 1984; Tonkinson 1982; Gray 1979; Berndt 1964). This model is best expressed in Fig. 4.

Generally combinations of traditional and Western medicines are used (Reid 1983; Tynan 1979). Western medicine may relieve symptoms and provide explanations to the mechanism of how something occurred while traditional explanations provide the reason why it occurred and are able to address the ultimate cause. In cases of supernatural intervention Western medicine is used to treat the symptoms and to hasten the cure, provided it does not conflict with traditional beliefs, but it is not able to remove the cause of the illness (Tynan

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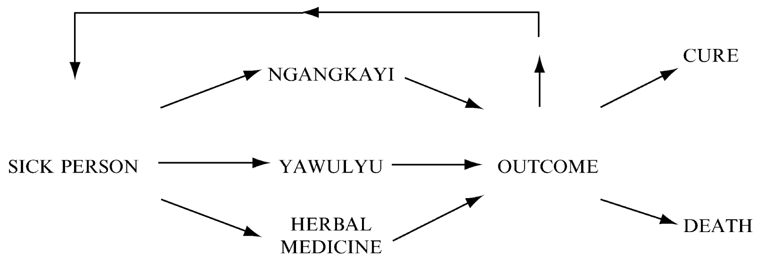
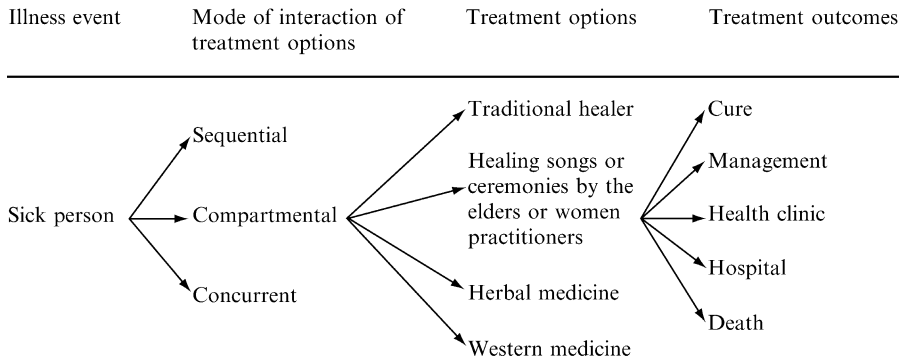


Medicine of the Australian Aboriginal People. Fig. 3 The Warlpiri health system (adapted from Tynan 1979).



Medicine of the Australian Aboriginal People. Fig. 4 Model of Aboriginal behavioural patterns of seeking medical assistance (from Maher 1999). Used with the permission of Blackwell Science Asia.

1979; Waldock 1984). In contrast only Western medicine can affect emergent Western illnesses (Waldock 1984; Scrimgeour et al. 1997).

In spite of this attempt to incorporate Western medicine into the traditional system, there are areas of conflict. Western medicine is based upon particular Western explanatory models. Variation in the underlying beliefs, assumptions and general medical information has been implicated as the basis for the conscious rejection of Western health care by some Aborigines (Hamilton 1974). It is well known that differences in underlying knowledge systems impede even willing compliance between culturally divergent groups. The lack of a common conceptual framework within which patient and practitioner can interact may result in decreased compliance and satisfaction (Maher 1999).

Development of Traditional Practice in Health Services to Aboriginal People

There has been government support with recognition for traditional Aboriginal medicine since the 1970s. A report on Aboriginal health by the Australian Parliament recommended that:

> Aboriginal cultural beliefs and practices which affect their health and their use of health services such as their fear of hospitalisation, their attitudes to pain and surgery, the role of traditional healers and the differing needs and roles of Aboriginal men and women, be fully taken into account in the design and implementation of health care programs (Commonwealth of Australia 1979).

Bicultural Medicine

Two-way medicine is the term that has been coined by Aboriginal health workers (AHWs) to describe a bicultural approach to health care. It is based on the principle that "if you can use what is best in modern medicine together with what is best in traditional healing, the combination may be better than either one alone" (Werner 1977). The Northern Territory Department of Health's first policy on Aboriginal health stated that "traditional medicine is a complementary and vital part of Aboriginal health care, and its value is recognised and supported" (Northern Territory Department of Health 1982). The Northern Territory Department of Health over the years has established several programs that recognise the traditional health system, Aboriginal values and beliefs.

Support for Traditional Healers/Ngangkari

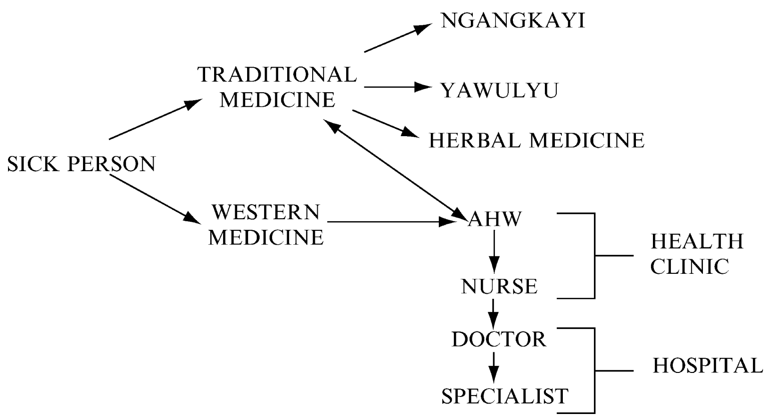
Traditional healers were employed by the Northern Territory Department of Health at various rural health centres in Central Australia in the early 1970s. While this practice has ceased, rural health centres continue to recognise and cooperate with traditional healers in the management of sick people, and some remote health centres run by Aboriginal Community Controlled Organisations have recommenced the employment of traditional healers. The healers often act also as consultants for determining culturally appropriate service delivery.

A meeting of Ngangkaris was held near Uluru, Central Australia, in April 2000. Over 40 Ngangkaris gathered together to discuss the production of an information manual about the work, history and traditions of Ngangkari (Mullins 2000).

A recent proposal to establish an Aboriginal Healing Centre close to the Alice Springs Hospital is being examined. The centre would develop a place to promote spiritual health supported by a network of traditional Aboriginal healers.

Aboriginal Health Workers

There are over 300 AHWs in the Northern Territory today. The AHW training program is recognised as one of the main strategies for improving Aboriginal health. AHWs are selected by their own communities and



Medicine of the Australian Aboriginal People. Fig. 5 Aboriginal medicine and Western medicine.

trained in various Western medical skills. They have proved highly successful in treating common health problems in Aboriginal communities, such as diarrhoea, chest infections, trachoma, and ear and skin infections. They also act as mediators between Western and traditional medical systems.

Aboriginal health workers bridge the "cultural chasm" separating the traditional and Western worldviews. They relate Western beliefs to an Aboriginal conceptual framework, making it possible for Aboriginal patients to understand what is being said and to assess the validity of the statements. They make it possible for the health centre teams to communicate with Aborigines in language and concepts that they understand. In most Aboriginal communities, the people's point of entry into the Western health system is through the AHW who may refer them to a nurse or doctor or back to the traditional system as shown in Fig. 5.

The Bush Food Program

Aboriginal people often view food as their medicine. Many foods are known to strengthen the body against sickness or promote healing. Some prized foods such as the witchety grub (*Xyleutes*) are crushed and used for treatment of burns and wounds. The grubs are nutritious as well, with protein (15.1%), fat (19.2%), 100 mg thiamine and 5 mg vitamin C per 100 g (see Fig. 6).

In 1981, the Northern Territory Department of Health launched the Bush Food Program which sought to establish a durable record of traditional Aboriginal food practices and beliefs and develop a more relevant and acceptable style of nutrition education.

A publication on the nutritional composition of 42 Bush Foods collected through this Program has some interesting results (Brand et al. 1983). The green plum (*Terminiala ferdinandiana*) contains 3,150 mg/100 g of Vitamin C, making it the richest source of Vitamin C in the world. The bush banana (*Leichardtia australis* and *L. leptophylla*; see Fig. 7) and the water lily root (*Nymphae macrosperm*) contain very high proportions of protein, and the list goes on.

The Bush Foods Program has led to the stimulation of reciprocal learning processes between two cultures and the self-examination of attitudes and values.

Medicine of the Australian Aboriginal People. Fig. 6 Witchety grub (*Xyleutes*).

Medicine of the Australian Aboriginal People. Fig. 7 Bush banana (*Leichardtia australis*).

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The current health status of Aboriginal people is characterised by unacceptable levels of morbidity and mortality. Aboriginal life expectancy is 20 years less than other Australians; Western medicine has not solved many of the Aboriginal health problems.

Traditional medicine is part of Aboriginal culture. Its recognition can bolster the self-confidence of Aboriginal people and improve the delivery of health services to Aboriginal communities. Two-way medicine needs to be supported and developed with ongoing research to evaluate the therapeutic value of traditional medicine. The increasing worldwide popularity and use of complementary and alternative medicine may assist in the development and sustainability of Aboriginal traditional medicine and healing in Australia.

Acknowledgements

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Medicine in China

CAI JINGFENG

The term Chinese medicine has a dual implication. It refers both to all medical systems prevalent in contemporary China and to traditional or indigenous medicine in its narrow sense (TCM for short). The former includes three medical systems: traditional, biomedical, or Western medicine as the Chinese call it, and integrated Chinese and western medicine.

Traditional Chinese medicine includes the experiences of fighting against disease, keeping fit, and seeking longevity. It was created by all nationalities of the Chinese people and is the synthesis of the medical systems of all ethnic groups. For historical reasons, TCM has been applied exclusively to the indigenous medical system created by the Han nationality. Logically, TCM should also include Tibetan, Mongolian, Korean, and Uyghur medicine and that of all other ethnic groups as well. Unfortunately, this interpretation would go against the common understanding of TCM. Hence, in this article we also use TCM in its narrow sense, referring to the Han-Chinese medical system only.

TCM has a history of at least three to four millennia. Archaeological findings reveal that the application of fire in the Paleolithic age not only brought warmth and cooked food, which was beneficial to health, but also resulted in the invention of moxibustion therapy. The Neolithic age also saw ancient Chinese people applying the stone knife and “needles” for treating some external diseases. These passed through a long process of evolution from stone to needles made of bamboo, wood, porcelain, bronze, and ultimately metal. Shining gold and silver needles over 2,000-years old have been unearthed. The last kind of needle, in fact, is the basis for the invention of the unique channel system, though other factors may also have contributed (Cai 2000). In terms of materia medica, legend has it that Shen Nong tasted and tried all kinds of plant herbs and other remedies from natural sources, beginning at the period of agriculture, about 7000 to 5000 BCE. People of other nationalities also discovered some effective remedies, such as wine from highland barley for stopping hemorrhages, which was used by Tibetan people, and Cistanche Salsa, Koumiss for nourishing the body, which the Mongolian people use (Cai 2000).

Early in the Xia and Shang Dynasty (twenty-first to eleventh centuries BCE) some 3,000 years ago, some characters related to medicine were inscribed on bone and tortoise shells as oracles, including *yi* (medicine), *bing* (disease), and up to several hundred archaic characters relevant to the healing art. As early as the Zhou Dynasty (eleventh century BCE–475 BCE), medicine in the imperial court was divided into four departments: internal medicine, ulcerative (external) medicine, dietetic therapy, and veterinary medicine. TCM had already applied the four diagnostic methods – inspection, auscultation and olfaction, interrogation, and palpation (looking, listening and smelling, asking, and feeling) – by this period. Of these, palpation is the most worthy of mention. Chinese ancient physicians may have been the earliest to apply the art of pulse taking for medical purposes. In the *Shi Ji* (Historical Record), compiled by Sima Qian (b. 145 BCE), the Herodotus of China, in the Western Han Dynasty (206 BCE–AD 24), it is recorded that the physician Bian Que of the Warring States Period (475 BCE–221 BCE) was the first one to apply pulse taking in clinical practice (Chen 1957).

The most famous medical classics were compiled in the Pre-Qin period (before 221 BCE) and completed around the Han Dynasty (206 BCE–AD 220). Among them, the most important and extant ones are *Huangdi Neijing* (*Yellow Emperor's Inner Canon*), *Shennong ben cao jing* (*Divine Husbandry's Classic of Herbology*), *Nan Jing* (*Classic of Questioning*), *Shang han lun*

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(*On Diseases Caused by Cold Evil*), and *Jin gui yao lüe* (*Synopsis of Golden Chamber*). These lay the foundation for clinical science with definite treatment principles and diagnostics. Chunyu Yi of the Western Han (206 BCE–AD 24) Dynasty first formulated case records for the patients with a fixed pattern.

Chinese pharmacy reveals some outstanding achievements at this period. *Shennong's Classic of Herbology* presents many specific effective remedies. It sets up the theoretical basis of drug use, as well as describing collection, preservation, compounding, simple processing, and method of administration. Therapeutic effects of specific drugs, such as *rhei* for catharsis, coptis root for asthma, seaweed for goiter, mercury for scabies, and many others are mentioned (Anonymous, 1956). Their effectiveness has since been proved by modern techniques. The famous surgeon of the Later Han Dynasty (AD 25–220), Hua Tuo, first applied *mafei* powder as an anesthetic for some major operations, including abdominal surgery. As early as the third century AD, the *Mai jing* (*Classic of Sphygmology*), written by Wang Shuhe, recorded 24 kinds of pulse, touching the issues concerning heart rate, rhythmicity, condition of blood flow, texture of the artery, and the nature of blood itself such as viscosity and hemorrheology. Later, this Classic spread via Tibet and India to the Arabic countries, and it is not surprising to note that in the *Canon of Medicine* by Ibn Sīnā (980–1037), Arabic sphygmology has a lot of content in common with Wang Shuhe's. The *Classic of Sphygmology* has been translated into several foreign languages.

From the second century AD, medical disciplines were professionalized. The following are worth mentioning: *Zhen jiu jia yi jing* (*A–B Classic of Acupuncture and Moxibustion*) by Huangfu Mi, *Lei gong pao zhi lun* (*Master Lei on Drug Processing*) by Lei Xiao, and *Liujuanzi gui yi fang* (*Liu Juanzi's Recipes Bequeathed from a Ghost*) by Gong Qingxuan, a textbook of surgery in the fifth century. Clinical medicine developed tremendously during the period of the third to tenth centuries. Ge Hong (265–341) was an expert in clinical medicine and a famous alchemist. His work, *Zou hou bei ji fang* (*Handbook of Prescription for Emergency*), contained discoveries on tsutsugamushi (mite-borne typhus) and smallpox, inventions for the treatment of hydrophobia by applying the brain tissue of the mad dog, and treatment of malaria by the juice squeezed from the artemisia herb, resulting in the extraction of a new effective anti-malaria remedy which is called artemisinin in modern biomedicine. Moreover, new medical techniques such as abdominal paracentesis, catheterization, first aid therapy for foreign bodies in the esophagus, and chiropractic were also introduced (Cai 1984).

The Sui-Tang Dynasties (618–907) also saw several major medical issues. The Tai Yi Shu (Imperial Academy of Medicine) and the *Xin xiu ben cao* (*Newly Revised Materia Medica*) (659) are, respectively, recognized as the earliest medical university and pharmacopoeia. Several important medical works were compiled in this period, representing the improvement of medical science. Cao Yuanfang's *Zhu bing yuan hou lun* (*On Pathegenesis and Manifestations of All Diseases*) is the first elaboration on etiology, pathology, pathogenesis, and semiology in China. Sun Simiao's *Bei ji qian jin yao fang* (*Essential Recipes Worth a Thousand Gold*) contains a great thesaurus of valuable recipes for many diseases, some still in use today. Wang Tao's *Wai tai mi yao* (*Clandestine Essentials from an Imperial Library Curator*) records many effective recipes. During the Song Dynasty in the tenth to thirteenth centuries, a Jiaozheng Yishu Ju (Bureau for Reviewing Medical Publications) and Huimin Heji Ju (Bureau of Compounding Remedies for Benevolence) were set up by the Imperial Court. What should be mentioned here is the casting of two life-sized bronze human models for acupuncture and moxibustion in the year 1026, on which the acupoints and channels were cast on their surfaces. This is not only a valuable and sophisticated work for appreciation, but also a skilled model for intuition education which greatly enhanced the development of the art of acupuncture and moxibustion.

During the Jin-Yuan Dynasties (1115–1360), four main academic medical schools appeared, namely the Schools of Cold-favoring, Spleen-Stomach Benefiting, Drastic Attack, and *Yin*-nourishing. Each had its own emphasis and advocacy, both theoretical and practical. This greatly advanced the academic development of Chinese medicine.

The academic standard of Chinese medicine was further elevated in the Ming-Qing Dynasty (1368–1910). A new school, the Wenbing Xuepai (Warm Disease School) evolved from the traditional Shanghan Xuepai (School of Disease of Exogenous Cold Evil). This new school was devoted to acute infections. It successfully tackled many infectious diseases such as B-encephalitis, acute viral hepatitis, influenza, and other viral diseases. Another outstanding contribution of Chinese medicine in this period was the invention of a human pox inoculation (variolation) from which Edward Jenner's smallpox vaccination drew its inspiration. Variolation should share the merit with vaccination in the global campaign to eradicate smallpox. The naturalist Li Shizhen (1518–1593) contributed his pharmacological knowledge to opening a new era in the history of Chinese materia medica. His rich knowledge on natural science aroused the interests of the evolutionist Charles Darwin, who indirectly cited many biological examples as evidence supporting his theory of evolution.

Beginning with the middle of the nineteenth century, Western medicine, so-called by the Chinese people since it was introduced by Western medical missionaries, came to China, resulting in the formation of three different academic factions in the medical province: biomedical, traditional or indigenous, and integrative.

Through the ages, Chinese medicine applied and created a series of unique theoretical systems and practical techniques. The following is a brief introduction (Needham, 2000).

The philosophical concept of *yin–yang* is based on the observation of contradiction in nature. This was coordinated into a *yin–yang* theory for explaining the law of changes. In the medical circle, people made use of this idea to interpret the complex relationship between upper and lower, inner and outer, the body and nature and society. The equilibrium and harmony between these two aspects within the body is essential to and the base of the body's normal activities and functions. Conversely, once the harmony is broken, disorders of the body will develop, thus affecting normal physiological activities. Physiologically, *yin* refers to those tangible structures and *yang* to invisible functions. Thus blood itself belongs to *yin* while its circulation function falls under the category of *yang*. These, in TCM terms, fall under the categories of the so-called blood and *qi*. *Yin* and *yang* are mutually dependent. Without *qi*, blood will be stagnant and become a pathological entity, while *qi* attaches itself to the blood as its place to stay in. Without blood, *qi* will be "homeless." These ideas have direct bearing on the theory of treatment. Hence, *yin* and *yang* are mutually rooted, interdependent, and inversive.

Ancient philosophy states that the whole universe is constructed with five basic kinds of materials: wood, fire, earth, metal, and water. Each element has its own characteristics. As a microcosm, the human body, which is comparable to the universe, is also made up of these five elements. Like the universe, all the organs, tissues, functions, and systems can be compared with and assigned to one of the five categories. For instance, under the wood category, we have liver (*yin* viscera), gallbladder (*yang* viscera), eyes (sensory organ), sinews or tendons (tissue), sour (taste), wind (climatic factor), spring (season), anger (emotional state), and green (color). In the meantime, we have heart, small intestine, tongue, vessel, bitter, hot, summer, joy, and red under the fire category; spleen, stomach, mouth, flesh, sweet, damp, long-summer (the last month of summer), anxiety, and yellow under the earth category; lung, large intestine, nose, hair, pungent, dry, autumn, sorrow, and white under the metal category; and kidney, urinary bladder, ear, bone, salty, cold, winter, apprehension, and black under the water category. The five categories have a dynamic rather than a static relationship, the order being wood, fire, earth, metal, water, and wood. Each category can also be conquered or restricted by another category, the order being wood (restricted by) metal, fire, water, earth, and wood. Hence we have the title Five Phases or *wuxing* with its theoretical system.

Both the *yin–yang* principle and the Five Phases theory are applied clinically for directing and interpreting physiology, pathology, diagnostics, treatment, or even prognosis, and they were proposed and completed some 2,000 years ago. The *yunqi* (activity of *qi*) or the *wu yun liu qi* (five activities and six climatic factors) theory or hypothesis investigates the influence of astronomical, atmospheric, and climatic factors on the human body and the occurrence of diseases. By five activities, it refers to the cyclic activities or movements of the five phases – wood, fire, earth, metal, and water – within the four seasons, while the six climatic factors refer to wind, cold, damp, dry, hot, and fire. This theory estimates the law of disease occurrence and yearly changes of weather with astronomy and the calendar as its parameters. In general, the yearly weather changes are wind in spring, hot in summer, damp in long-summer, autumn dry, and winter cold. Thus liver diseases are apt to occur in spring, heart diseases in summer, spleen diseases in late-summer, lung diseases in autumn, and kidney diseases in winter. The theory stressed the relations between weather and disease which, though a bit mechanical and controversial, has something to do with chronomedicine. This theory reached its zenith a thousand years ago (Editorial Committee, 1992).

The theory of visceral manifestations deals with the physiology and pathophysiology of the five *yin* viscera: the heart, kidney, spleen, lung, and liver; the *six yang* viscera: the small intestine, large intestine, stomach, bladder, gall bladder, and triple *jiao* (pancreas?); as well as the extraordinary viscera: the brain, marrow, bone, vessels, and uterus. The *yin* viscera function for the storage of essence and spirit of the body, while the *yang* viscera are responsible for the digestion, transformation, and transportation of residual materials. It is claimed that there exist mutually dependent inhibition relations among the *yin–yin*, *yin–yang*, and *yang–yang* viscera. Visceral manifestations also involve other body substances, including blood, saliva, mucus, sputum, body fluid, as well as body functions such as *qi*, spiritual forces, and genetic functions. The totality of the above-mentioned contents forms the visceral manifestations (Guangdong College, 1972).

Visceral manifestations are closely tied to the theory of channels. Channels, the passages and tracts for the circulation of blood and *qi*, connect the outer with the inner part of the body and branch repeatedly to form a network spread over the whole body. Thus, through its connection, the whole body forms an organic whole. There are altogether twelve main or orthodox channels, each with its own underlying viscera, and eight extraordinary channels and collaterals and capillary networks. When channels are affected, their functions change accordingly, manifesting signs and symptoms by which a correct diagnosis can be made. Regulation of their functions through various stimulations, such as acupuncture, moxibustion, massage, electricity, and percussing, yields therapeutic results (Guangdong College, 1972).

TCM stresses the importance of recognition of etiological factors, which have a direct bearing on the treatment and prognosis of disease. Harmonious relationships among the *yin–yang* viscera themselves, and between the body and its environment, are crucial to the health of the body. All diseases occur on the basis of the disturbance or breaking down of this harmony. Diseases used to occur when the orthodox *qi* (body resistance) was defeated by the heteropathy (pathogenic evil). Orthodox *qi* is responsible for the body's resistance, preventing it from contracting a disease. Pathogenic evils include exogenous (climatic), endogenous (emotional), and others (trauma, accidental insect or snake bites, injuries, dietetic, behavior, etc.). The relative force between body resistance and pathogenic factors determines the result of their struggle, either keeping healthy or falling ill. The aim of treatment is to support the body's resistance and remove pathogenic evils so as to keep one in good health.

There are four diagnostic methods. Inspection includes the spirit, complexion, form, and status of the patient. A tongue picture is also essential, including the texture of the tongue and its coating, the sense organs, and the condition of excreta. These provide much information about the condition of the internal viscera. Auscultation refers to hearing the patient's voice, including speaking, respiration, and smelling the odor from the patient's body and excreta. Interrogation refers to questioning the patient and other respondents about his present illness, past history, and family history. Palpation includes feeling the pulse and other parts of the body. It is sometimes said that TCM puts its main stress on pulse taking, or even relies solely on pulse taking. This is not true. TCM emphasizes that an overall diagnosis should have all four diagnostic methods interpreted comprehensively with equal importance, instead of relying on any single method (Guangdong College, 1972).

The determination of syndrome manifestation (*bian zheng*) is the kernel of TCM clinical science. It is the process of analyzing the information and materials obtained from the four diagnostic methods, differentiating the causes, nature, location, stage of disease, and the reciprocal condition between the body and the pathogens. The result of this process is the identification of the type of syndrome manifestation, which is crucial to therapy. Long experience enables Chinese physicians to form an ensemble of methods, or determination of syndrome manifestations. There are many methods. The important ones are the *ba gang* (Eight Rubrics), applied for all kinds of diseases; the Triple *jiao* Method for warm infectious diseases, and the Six Channel method for diseases due to cold evil.

Among them, the Eight Rubrics method is the most important and universally applied one. Eight Rubrics denotes outer and inner (location of illness), cold and hot (nature of illness), depletion and repletion (reciprocal condition between the body resistance and pathogens), and *yin* and *yang*. Within the Eight Rubrics, the *yin–yang* is the key couple Rubric that dominates the other three. Furthermore, a timely, correct determination of syndrome manifestations, especially the Eight Rubrics, is the key to a reasonable and satisfactory therapy. The conception of Eight Rubrics has taken shape since the Han Dynasty (Cai 2000).

The basic principle for treatment is the exploration of the root of disease, on which various therapeutic methods are based. The uniqueness of this is its flexibility, which varies with the analysis of the condition. Different treating measures may be given to the same disease because of different conditions manifested. Conversely, the same therapeutic measures may be administered for different diseases because of their common manifestations. The major principles include the regulation of *yin–yang*, supporting the body's resistance, and removing pathogenic factors. During the treatment, differentiation of the true nature and superficial manifestation, emergency and steadiness, severeness and mildness are of paramount importance (Guangdong College, 1972).

Moreover, therapy and medication in TCM should be adjusted to the season, the place, and the different individual. First, changes of climate in different seasons exert definite effects on the body. During summer, the pores in the skin and neighboring tissues are open; in winter, they are contracted and closed. Hence, while treating cold disease due to wind and cold evils, therapy in the summer should not apply too many drugs of a pungent and warm nature, in order to avoid profuse sweating, or outer depletion would result. In winter, for the same cold disorders, pungent and warm drugs can be applied in substantial amounts, in order to expel the pathogens through perspiration without the risk of outer depletion. Since cold is very common in the north, for cases of external, pathogenic disorders, one can use a heavy dose of pungent and warm drugs for dispersion of pathogens through perspiration. Applying the same principle to the southern part where weather is generally hot, only a light dose of pungent and warm drugs can be used, to avoid profuse perspiration. Thirdly, all patients vary in sex, age, and body constitution. Moreover, women have the added complications of childbearing, menstruation, and vaginal discharge, while children have tender and delicate visceral systems. These conditions should be taken into account and carefully considered when prescribing. For instance, with a patient who is sensitive to cold with a constitution of cold tendency, cool or cold drugs should be used with caution, and vice versa for those of hot tendency.

As to concrete treating measures, basically there are eight therapeutic methods: diaphoresis, emesis, catharsis, mediation, warming, clearing, removing, and benefiting. All these methods are applied not only for drug therapy, but also for non-drug therapies such as acupuncture, moxibustion, massage, and others (Guangdong College, 1972).

In terms of Chinese materia medica, all the drugs applied are natural products, including those from the plant and animal kingdoms as well as minerals. Most of the pharmacological knowledge is derived from practice. Pharmacological theory is summarized, again on the basis of experience. The theory is also unique. It claims that the potential of the drug comes from its "nature," composed of four *qi* and five flavors. The four *qi* are cool, cold, warm, and hot, while the five flavors refer to sour, salty, sweet, bitter, and pungent. The theory also includes channel tropisms, the functions of ascending, descending, floating, and sinking, as well as the toxicity of drugs. The nature of drugs is relevant to the condition of the disease as determined by diagnosis through differentiation of syndrome manifestations within the Eight Rubrics. Antagonistic therapy such as cool or cold drugs for heat disease, and warm or heat drugs for cold disease, is commonly used. Drugs with ascending nature are applied for heat disease of "collapsed" nature, such as gastroptosis and the like, whereas drugs with descending nature are applied for disease of uprushing or adverse ascending flow of normal *qi*, such as hiccough, belching, vertigo, dizziness, and rushing up of liver fire. The channel tropism of drugs is directly related to the channel attribution of disease. For instance, the primordial stage of influenza falls under the category of Taiyang Channel disorders; hence, drugs of Taiyang Channel tropism are to be applied. Compatibility of drug compounding and toxicity of drugs are all highly stressed in Chinese pharmacy. Precautions when administering drugs are also unique. The breaking of necessary precautions would lead to failure of even a correct treatment. All the drugs are prepared in various forms, including decoction, powder, paste, pills, bolus, ointment, patent drug, and also modern drug forms like injection and aerosol. TCM also pays attention to the time of taking drugs, claiming that this has a direct bearing on the chronophysiology of the body and on its therapeutic efficacy.

The ingredients for compounds of Chinese medical recipes are differentiated into the "king," "ministers," "assistants," and "servants." The aim of this compounding is to focus on the mutual synergic and detoxifying action among the ingredients. As a result, the effect is much more satisfactory than single drug administration, and the toxicity is much ameliorated or even eliminated.

Acupuncture and moxibustion are special treating techniques as well as health care measures in TCM. Acupuncture refers to the needling of specific loci, the acupoints for stimulation, to regulate the disharmonious state and arouse the resistance potential of the body. Moxibustion refers to the application of heat stimulation with a moxa roll or cone on the point or affected site instead of using a needle. As soon as the body is stimulated by these means, the afflicted *qi* and blood inside the channels and viscera are improved, activated, and regulated. Pathogens are expelled or eliminated, and normal physiological function is restored. The basic idea of acupuncture–moxibustion is also established on the same principles as TCM, i.e., treatment based on the differentiation of syndrome manifestations, although it also has its own special demand such as manipulation techniques.

Massage and *qigong* exercise are also integral parts of TCM. The former is performed by specific manipulation techniques on acupoints or specific locations, while the latter is a self-care method in which the patient consciously controls his/her own mind, body, and the circulation of *qi* through controlling one's breathing movement. It is said that a proficient exerciser may even direct the flowing of *qi* in his/her own body at will.

TCM pays attention to disease prevention, or so-called "treating pre-illness" in the Chinese term. Various measures are proposed for this purpose, among them self-care massage, Daoyin, Taiji boxing, hygienic measures, and breathing exercises.

Since the basic conception of traditional Chinese medicine took its shape several thousand years ago, it applied concepts which are rather abstract and vague, not tangible or perceptible, let alone quantitatively estimated. To meet the needs of modern investigation and understanding, over the decades TCM workers have been encouraged to integrate and interpret their knowledge by modern scientific concepts, means, and techniques. A new school, the School of Integrated Traditional and Western Medicine, has thus emerged. This has become one of the modem trends in the development of China's medical science (Cai 2000).

See also: ►Moxibustion, ►Bian Que, ►*Huangdi Neijing*, ►Medical Texts in China, ►*Yin–yang*, ►Acupuncture, ►Ge Hong, ►*Shanghan lun*, ►Ibn Sīnā, ►Li Shizhen, ►Five Phases (*Wuxing*)

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Medicine in China: Forensic Medicine

Cai Jingfeng

Forensic medicine refers to that part of medical science pertaining to legal and political affairs. In order to provide materials and evidence for trying and investigating cases, the discipline of forensic medicine deals with the issues of reconnoitering the scene, surveying the cadaver, and studying the material evidence, poisonous substances, and other relevant items.

Chinese medico-jurisprudence makes its appearance in the Warring States period (475–221 BCE). *Li Ji* (Record of Rituals) and *Lüshi Chun Qiu* (Master Lü's Spring and Autumn Annals) both mention "investigating the wounds and trauma, inspecting and analyzing cases, reconnoitering and judging, and making decisions on lawsuits with justice." In 1975, some bamboo slips, later entitled "Qin Slips from Yunmeng," were unearthed from Yunmeng, Hubei Province in China. Within the slips, legal articles of the Qin Dynasty (221–207 BCE) and criminal cases were recorded. About 7 of the 22 cases involved forensic medical jurisprudence, in which killing, hanging to death, chopped-off heads, abortion due to trauma, and leprosy are included with records from the scene. Foot, hand, and knee prints, as well as blood and stools are mentioned. Circumstantial descriptions are given on the differentiation between homicide and suicide by hanging. All these demonstrate that achievements in legal medicine appeared as early as two to three thousand years ago (Jia, 1980).

The earliest extant Chinese feudal code, *Tang Lü* (Law of the Tang Dynasty) was promulgated in 653 AD. This stipulates that when investigating fake illness, feigned death and injuries, false or incorrect reports will result in punishment in a grade next to that given to the swindler. For victims of illness, death, or injuries, a fake report would be given punishment equal to that of the sufferers themselves. Issues pertaining to autopsies of legal medical cases, including the severity of injury, fake illness, self-mutilation, administering abortion, disability, age, and critical diseases are also mentioned (Jia, 1984).

Medical jurisprudence developed a step forward in the Song Dynasty (960–1279). First, the officials responsible for the investigation of cases are stipulated in writing, saying "for examining cadavers *Canjun* (Adjuvant) at the provincial level and *Xian Wei* (district defendant) at the county level are responsible. In case *Xianwei* is absent, officials of *Bu* (*appointee*), *Cheng* (aide), and *Jian* (directorate) will be responsible in that order. The county governor himself should be responsible when all these staff members are absent." Regulations for responsibility and dereliction of duty, such as when those officials in charge are inaccessible, when there is a delayed presence at the scene, or when the wrong decision for the cause of death is made are also stipulated. *Gemu* (Pattern Catalog), a compulsory regulation for the examiner, is mandated to avoid malpractice; this is claimed to be an important achievement in this field. This rigorous system for examination offers a firm basis for the advent of the prominent monograph on legal medicine, *Xi yuan ji lu* (*Collected Records of Washing Away the Wrong Cases*) and other similar works. Prior to these monographs, other works on legal medicine made their appearance, including *Nei shu lu* (*Record of Forgiveness*) and *Jian yan fa* (*Method for Examination*), which were unfortunately all lost. *Xi yuan ji lu* is an epitome of the achievement in the discipline of Chinese medical jurisprudence. Its merits include records on (Song, 1936 Rpi).

- The occurrence and distribution of cadaver speckle
- Conditions influencing the advent of putrefaction
- The relationship between the cadaver manifestations and the duration after its death
- Types of rope used for hanging
- The features of strangulation and how to differentiate those from self-hanging for suicide
- The difference between drowning and suffocation by compressing someone's nose and mouth
- The difference between fractures before and after death
- The determination of fatal wounds and
- Various methods for determining different causes of death

During the Yuan Dynasty (1271–1368), a formal pattern for examination of Confucian officials was announced. This is entitled *Jie an shi* (*Pattern for Winding Up a Case*). It deals with issues relating to medical jurisprudence, including examination of the cadaver, biopsies for wounds and illnesses, and material evidence. This monograph is the first to combine the three integral portions of medical jurisprudence into a whole.

The Chinese made a significant contribution to legal medicine. Important Chinese monographs on legal medicine including *Xi yuan ji lu ping yuan lu* (*Reassuring the Wrong Cases*) and *Wu yuan lu* (*Free of Wrong Cases*) were translated into many foreign languages, including Korean, Japanese, French, German, Dutch, and English (Jia, 1984).

After 1911, performing autopsies became legal. When procurators and police officers are unable to ascertain the causes of death with a cadaver, an autopsy is performed by a medical practitioner rather than by the old-style *Wu Zuo* (cadaver examiner). This procedure is rigorously regulated.

The first Department of Forensic Medicine was established in the Medical College of Peiping University in 1930, while the First Institute of Forensic Medicine was established in Shanghai in 1932, and a *Medical Jurisprudence Monthly* was first published in China in 1934. A wealth of forensic medicine professionals has been cultivated, in order to increase public security and justice (Jia, 1984).

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Medicine in India: *Āyurveda*

Guy Mazars

Āyurveda or 'the knowledge (*veda*) for longevity (*āyus*)' is an ancient medical system whose main theories were already fixed more than 2,000 years ago. It has roots in the *Veda*, especially the *Atharvaveda* (Mazars 1991; Zysk 1996), and the conceptions of the ancient ayurvedic physicians have played a great role in the general culture of India and have spread everywhere in Asian countries. With Buddhism, Āyurveda travelled to Sri Lanka, Nepal, Tibet, Central Asia and as far as Japan, and it reached Indonesia with the Hindu culture and civilization (Filliozat 1934).

The legends related by the ancient Sanskrit medical texts make of this system a revealed 'science', annexed to the *Veda* sometimes as an 'annexed member' (*upāṅga*) of the *Atharvaveda*, sometimes as a 'subveda' (*upaveda*) of the *Ṛgveda*. Created by Brahman and transmitted to men by the successive interventions of Prajāpati, the Aśvins and Indra, this science is theoretically divided into eight branches:

1. General surgery (*śalya*)
2. Surgery of the head and the neck (*śālākya*)
3. Internal medicine (*kāyacikitsā*)
4. Toxicology (*agadatantra*)
5. Demonology (*bhūtavidyā*)
6. Obstetrics and paediatrics (*kaumārabhṛtya*)
7. Tonic medicine (*rasāyana*)
8. Aphrodisiacs (*vājīkaraṇa*)

In fact, very few ancient texts follow this division which has been particularly in vogue among more recent authors. As regards their content, it represents in reality the fruit of the activity of medical observation and speculation in the course of the seven or eight centuries which preceded the Christian era. Unfortunately the documents going back to this period that are properly medical have disappeared, and they have been supplanted by more recent texts.

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Source Texts

The classical doctrine of Āyurveda is already expounded in two famous treatises dating from the beginning of the Christian era, the *Carakasaṃhitā* or 'Caraka's Compendium' (Sharma 1981–1994) and the *Suśrutasaṃhitā* or 'Suśruta's Compendium' (Bhisagratna 1963), which are the oldest Sanskrit medical texts that have come down to us (Wujastyk 1998). Although these two works agree remarkably in their general teachings, they are too different for us to suppose that one may be an imitation of the other. But they manifestly rely on the same older doctrinal heritage. These two texts were the object, from a period even earlier than the tenth century, of very elaborate commentaries whose purpose was to clarify and add precision to their contents (Filliozat 1964).

Later texts of great importance include the *Aṣṭāṅgahṛdayasaṃhitā* of Vāgbhaṭa (ca. AD 600), the *Mādhavanidāna* of Mādhavakara (ca. AD 700), the *Śārṅgadharasaṃhitā* of Śārṅgadhara (thirteenth or fourteenth century) (Murthy 1984) and the *Bhāvaprakāśa* of Bhāvamiśra (sixteenth century). Vāgbhaṭa is the most celebrated author after Caraka and Suśruta (Hilgenberg and Kirfel 1941). His identity has been the subject of unending discussion, and Indian critics hold that there was an 'elder Vāgbhaṭa' in addition to 'Vāgbhaṭa', grandson of the former and son of Siṃhagupta. In the *Mādhavanidāna* or 'Aetiology According to Mādhava', the author treats causes and symptoms of different diseases, by taking up in a systematic manner the data of Caraka, Suśruta and Vāgbhaṭa (Meulenbeld 1974; Murthy 1993). The *Mādhavanidāna* was the object of numerous commentaries, which proves that the treatise achieved considerable fame. Of considerable interest is the *Śārṅgadharasaṃhitā*. Śārṅgadhara is the first author to discuss several new elements, including diagnosis by pulse (Murthy 1984). He also gives for the first time detailed information on many previously undocumented medical procedures, especially regarding the preparation of remedies. In fact, the main subject of the work is pharmaceutics (Sharma 1979). A whole section deals with pharmaceutical forms, giving exemplary formulations under each category, and adding new drugs and new techniques. Many recipes from Śārṅgadhara's *Compendium* are still in use. There are also divergences between the nosological system of the *Mādhavanidāna* and the nosology described in the *Śārṅgadharasaṃhitā*. New names of diseases are mentioned in the texts. Syphilis is described for the first time, under the name of *phiraṅgaroga*, in the *Bhāvaprakāśa* of Bhāvamiśra (sixteenth century). Alongside the great classical treatises and their commentaries there exists an abundant medical literature that comprises other general texts, specialised manuals and repertories of *materia medica* (Mazars 1995b).

Philosophical Foundations of Āyurveda

The conceptual edifice of Āyurveda rests on ideas which are those of the *Sāṃkhya* philosophy, a system of thought having as its basis the analysis and classification of the constituents (*tattva*) of the world. It is not known in fact which of the two systems influenced the other. Some authors consider that ayurvedic doctrines are older than *Sāṃkhya* whose basic text is the *Sāṃkhyakārikā* or 'Stanzas of *Sāṃkhya*' (fourth century?). However that may be, according to ayurvedic treatises as well as according to *Sāṃkhya*, the human body is composed of the same basic elements (*bhūta*) that constitute the universe: earth (*pṛthivī*), water (*ap*), fire (*tejas*), air (*vāyu*) and void (*ākāśa*), represented, respectively, by the solid parts, the liquids, the body heat, the breath and the emptiness of the hollow organs (Filliozat 1964). The combinations of the five basic elements form the differentiated substances of the body, the *dhātu*, seven in number: chyle or nutrient fluid (*rasa*), blood (*rakta*), flesh (*māṃsa*), fat (*medas*), bone (*asthi*), marrow (*majja*) and semen (*śukra*).

As it is described in the great treatises of Caraka and Suśruta, ayurvedic medicine distinguishes itself explicitly from empiricism, magic and religion. For, the conditions for the validity of the observations and reasoning which are at the root of diagnosis, prognosis and treatment interested the ayurvedic circles very early. Thus, the *Carakasaṃhitā* contains a teaching of logic intended to guide the future physician in his reasoning. Long passages and allusions appearing in various parts of the treatise constitute the exposition of this logic. The most systematic passages are found in Chaps. IV and VIII of the section of the *Carakasaṃhitā* entitled *Vimānasthāna*. This logic, allied to the classical Indian logic, the *Nyāya*, acknowledges three methods of judgement (*pramāṇa*): the teaching of those who are accepted to be an authority (*āptopadeśa*), observation (*pratyakṣa*) and inference (*anumāna*) (Mazars 1995b). There has been much discussion concerning the relationship between Āyurveda and the philosophical system of *Vaiśeṣika*, which has as its object the study of the special characteristics of things, their *viśeṣa*. The *Vaiśeṣikasūtra*, which constitutes the reference text of this school, dates from the early centuries of the Christian era, but its contents seem to show older interpolations.

Ayurvedic View of the Body

The anatomical nomenclature of Āyurveda is rich, but the notions covered by them are fairly rudimentary, especially as regards visceral anatomy. However, the value of opening corpses was known and the *Suśrutasaṃhitā* (Śārīrasthāna, V, 49–56) even describes a procedure of dissection closely resembling the procedure of *hydrotomy* suggested by Lacauchie in the nineteenth century (Lacauchie 1853). As the conceptions of the brahmanical moral code were opposed to true methodical dissections of well-preserved cadavers (Zysk 1983), anatomical knowledge remained scanty. Hence, errors and lacunae are numerous in the lists of organs furnished by the ancient medical texts. Osteology is fairly important in Indian anatomy (Hoernle 1907), but it holds out little interest as regards the constitution of the medical doctrines.

The hollow organs or 'receptacles' were better known. The stomach is called the 'receptacle of the uncooked' while the intestines are the 'receptacle of the cooked'. The gall bladder is the 'receptacle of the bile', the bladder that of the urine and the uterus that of the embryo. In fact, among the organs, the best described are those on which surgical operations were performed: the rectum, the uterus and the bladder. Today limited to minor operations, such as bone setting and to reductions of dislocations and fractures, ayurvedic surgery was once probably the most remarkable in Euro-Asiatic antiquity. The *Suśrutasaṃhitā* mention various operating techniques (incision, excision, scarification, puncturing, catheterisation, extraction, draining and stitching of wounds) as well as instruments and accessories. The *Suśrutasaṃhitā* also describes surgical operations which reveal the great daring of the surgeons of that period: the lowering of cataracts with a needle, grafts for repairing the nose and the earlobe, perineal lithotomy for extracting vesical calculi, resection of scrotal elephantiasis, Caesarean section, surgical removal of a dead foetus from the womb.

The *Carakasaṃhitā* and the *Suśrutasaṃhitā* even teach a very daring procedure for intestinal sutures which avoids the use of non-absorbable threads whose intolerance by the tissues had been recognised. This procedure consists in bringing the edges of the wound together and having them bitten by black ants. The bodies of the ants are then cut off from the head, whose mandibles serve as staples. It only remains thereafter to close up the abdomen by ordinary suture. This was the procedure in case of laparotomy for penetrating wounds of the abdomen and for intestinal occlusion. But instances of success must surely have been rare. One of the commentators on the passage quoted above observes moreover that the outcome of the operation was very uncertain. That was no doubt why the method is no longer taught in the later treatises.

The Indian surgeon had above all to know the 'vulnerable regions' (*marman*), injury to which is either fatal or particularly serious. The notion of *marman* goes back to a Vedic conception. The word is derived from the root *MṚ*, which means 'to die', and denotes above all a lethal point. The classical treatises, which carefully catalogue these bodily zones, describe them as seats of vital energy. They list 107 of them divided into five categories according to their location (flesh, pipes, ligaments, bones and joints) and into five categories according to the seriousness of the harm resulting from injuries to them. The details given by the texts enable us to locate them fairly easily. They are anatomical reference points corresponding most often to big vessel-nerve bundles, tendons or important nerve ganglia, injuries to which are serious because of haemorrhage, paralyses or disabilities that they cause.

Representations of the Vital Functions

In the ayurvedic system, the totality of the transformations undergone by the seven organic substances (*dhātu*) is governed by the combined play and balance of wind, fire and water, present and active in the body in the form of three vital principles. Indeed, wind, the essential motive force of the Universe, is also that of the body in which it is represented by the 'vital breath' or *prāṇa*, which is localized mainly below the navel. 'Fire' is represented by a principle which collects in the form of 'bile' or *pitta*, which is localized between the heart and the navel. As regards water, it is found in the form of *kapha* or *śleṣman*, 'phlegm', a substance common to all the bodily serous fluids and secretions, which is localized in the chest. Each of these three principles acts by assuming five secondary forms which correspond to the different vital functions. Their action works towards a complex and autonomous process of balancing which maintains the organism alive (by the constant renewal of its constituents) and in good health. These Indian ideas are very close to the notion of *homeostasis*, already anticipated by Claude Bernard during the nineteenth century and which Walter Cannon (1871–1945) described as the totality of organic processes which act to maintain the stationary state of the organism, in its morphology and in its internal conditions, despite external disturbances.

Of the three principles, it is the organic wind, under its different forms, which is considered the most important vital element. According to the *Carakasaṃhitā* (Sūtrasthāna, XII, 8), it ensures by its action the ingestion, digestion and assimilation of food, the differentiation of the organic substances and their distribution, as well as the internal circulation of the fluids, respiration and movements, covering in this way a number of aspects of functioning attributed today to the nervous systems. The seven *dhātu* contain a liquid principle which makes them alive and which is named *ojas*, i.e. to say 'strength'.

Psychological Conceptions

Psychological conceptions play a fundamental role in the teachings of Āyurveda (Rosu 1978). The connection between the body and the mind is asserted in the most direct manner by the Sanskrit medical texts: 'The body is governed by the psyche and the psyche by the body' (*Carakasaṃhitā*, Śārīrasthāna, IV, 36).

It is interesting to note that, according to Āyurveda, the psyche represents the contribution of the previous existences of the incorporated soul. This is entirely in conformity with the Indian theory of *karman* (karma) which has become the central dogma of Hinduism. The word *karman*, derived from the root *KṚ*, 'to do', means 'action', but denotes also the results of the good and bad actions in the form of merit or demerit, the inexorable consequence of acts accomplished in previous lives. By affecting the *sūkṣmaśarīra* or 'subtle body', or in other words the psychic individual, the 'Self' (*ātman*), the permanent and unconscious substratum of the human being, *karman* obliges him indefinitely to undergo a new birth in a human or other form, determined by the quality of his past acts.

The observation of the relationship between the body and the mind has led Indian physicians to notions of personal temperament and physiognomony. Ayurvedic biotypology is based on two criteria, one constitutive and the other psychological. The first typology describes three kinds of temperaments based on the predominance of one of the three vital principles: the 'windy', the 'bilious', the 'phlegmatic'. The second typological system of Āyurveda categorises the individuals according to the properties (*guṇa*) of the mind. The ideal standard of behaviour is that which corresponds to a predominance of *sattva*, 'purity', according to the *Sāṃkhya* philosophy.

Diseases and Pathology

According to Āyurveda, diseases (*roga*, *vyādhi*) are of two kinds, exogenous and endogenous (Sharma 1992). The former are caused by damage from outside (blows, injuries, bites, falls, burns, etc.). All the others represent an

> imbalance of the *dhātu*' (*dhātuvaiṣamya*), or in other words disturbances in the normal balance of the elements which constitute the substance of the body and which animate it. 'Wind, bile and phlegm, in the normal state, enable a man to have a long life, with his faculties intact, endowed with vigour, good appearance, and health… But, if they become abnormal, they lead him to great adversity…' (*Carakasaṃhitā*, Sūtrasthāna, XII, 14).

That is why this triad of vital elements has been given the name of *tridoṣa*, the 'three vitiating factors'.

The conditions of perturbation of their functions are complex in most cases. The alteration of just one of these elements or just one of its secondary forms can unleash a disease by virtue of the disturbances resulting in the functioning of the others. Often two among them or even all three of them are simultaneously involved, in varying degrees, in the production of different ailments. Hence there are a very large number of pathogenic combinations. The perturbations of 'wind', 'bile' and 'phlegm' can in their turn affect the *dhātu*, the joints or the vascular system. The elements, the tissues and the organs interact, and imbalance of the ones leads to imbalance of the others. Some parallels have often been drawn between ayurvedic ideas and some of the data from Greek medicine. The text *Airs* of the Hippocratic Collection describes a pathology by the association of blood and 'wind', which brings to mind the theory of the *Suśrutasaṃhitā* relating to the pathogenic role of 'wind–blood'. Furthermore, there is a remarkable analogy between the doctrine of the *tridoṣa* and a theory described by Plato at the end of his *Timaeus* (Filliozat 1964).

The perturbations in the functions of wind, bile and phlegm are themselves related to multiple causes called *nidāna* which are looked for mainly in the behaviour of the patient and his food, having regard to external circumstances. Dietary deviations are often criticised.

Nosology is highly developed. It categorises the diseases sometimes according to their supposed origin and sometimes according to the nature of their symptoms. We also find them divided in another way, according to whether they affect the chyle, the blood, the flesh, the fat, the bones, the marrow or the semen.

Diagnosis and Prognosis

To identify an ailment, to know its stage of development as well as the part which should be ascribed to each *doṣa* in its production, the ayurvedic practitioner must undertake a minute examination not only of the body of the patient, but also of his mental state. The methods of examination must bring into play all five senses.

The practice of the examination of the pulse, common today in ayurvedic medicine, does not seem to have appeared before the twelfth century. The idea of examining the pulse might have been borrowed from China, but the technique attested in India is different and what one expects to learn out of this examination is not what the Chinese physicians look for. Indeed, by taking the pulse the Indian physician claims to recognise the disturbances in the equilibrium of the three vital principles, 'wind', 'bile' and 'phlegm' and in this way he diagnoses all the ailments. The interpretation of the various pulses is connected therefore to the ayurvedic theory of the *tridoṣa* (Kutumbiah 1967).

The palpation is done by bringing the tips of the index finger, the middle finger and the ring finger close to each other and applying them on the radial artery of the right wrist for men, and the left wrist for women. The texts distinguish several types of pulse according to the amplitude of the pulsation (strong, weak or very weak pulse), the frequency (regular, rapid or slow pulse) and the temperature (hot or cold pulse), whose variations are presumed to reflect the activities of the three *doṣa*.

Questioning the patient and his family circle complements the various examinations. The purpose of this questioning is not only for the physician to gain information about the circumstances in which the first symptoms appeared and the development of the ailment, but also about the personality of the patient, his activities, his food and his appetite, having regard to the season, the climate and, of course, the psychological context in which the sickness began, for Āyurveda cares for the whole human being, both his soul and body. According to these ideas, each patient should be treated holistically. Today, however, it is rare to find ayurvedic practitioners who will prepare remedies specific to particular patients. The *Carakasaṃhitā* indicates that the patient should also be questioned about his dreams.

In ancient times, the establishment of the prognosis concerning the curability or the incurability of a disease depended more often on the divining art than on medical science. Thus, one claimed to foretell the outcome of a disease according to the language, the clothes and the attitude of the messenger who came to fetch the doctor, or else according to the direction of the wind blowing at his arrival, or else according to the dreams of the patient. The anomalies that may be noticed in the sensations of the patient were generally regarded as bad signs. Other fatal indications could be drawn from the change in his complexion.

Preventive Medicine

Of all the ancient medicines, it is probably ayurvedic medicine which, from its origins, has accorded the greatest importance to hygiene, to diet, to physical exercises and to massage, both as means of prevention and as curative methods. The rules of hygiene and of diet were already extremely numerous and elaborate in the treatises of Caraka and Suśruta who devote several chapters to them. These rules take into account not only the climate, the season and the circumstances, but also the temperament of each individual.

In the chapters relating to prevention, the *Carakasaṃhitā* (Sūtrasthāna, VII, 31–34) emphasizes the benefits of physical exercise (*dehavyāyāma*). It is said there that gymnastics makes the body light, increases its capacity for work, diminishes the *doṣa* and stimulates the 'digestive fire'. But it must be practised with moderation.

The oldest Sanskrit texts lay stress on the importance of a well-balanced diet, both from the quantitative and the qualitative points of view. According to the *Carakasaṃhitā*, the quantity of food depends on the capacity of digestion (*agnibala*, literally 'strength of the fire'), so much so that even foods considered as very easy to digest must not be consumed in excessive quantities. The medical texts systematically enumerate all varieties of edible products indicating their different properties, according to the temperament, behaviour and state of health of each individual, having regard also to the season, the time of the day, the quality and the quantity of the food taken. Thus, some foods recommended for cold and rainy weathers are strongly inadvisable during summer; a drink that is safe for a healthy individual carries the risk of complicating an already morbid condition, etc.

Āyurveda emphasizes also the benefits of tonics and stimulants, the *rasāyana*, and of aphrodisiacs, the *vājīkaraṇa*. The *vājīkaraṇa* are believed to increase the strength of those who are weakened and whose virility is low. These are most often preparations based on sesame, broad beans (*Phaseolus radiatus* L.), sweet potatoes (*Ipomea digitata* L.), sugarcane juice, long pepper (*Piper longum* L.), emblic myrobalan and milk, in combination with the testicles of goats, buffaloes or donkeys. The roots, bark, buds and fruits of the *aśvatha* tree (*Ficus religiosa* L.) are also used. As regards the *rasāyana*, they are elixirs which are expected to confer long life, health and youth. The *Carakasaṃhitā* gives very detailed instructions for their preparation. One of the most famous is the *Cyavana Prāśa* in the compounding of which more than 30 ingredients figure.

The choice of a therapy depends not only on the disease diagnosed, but also on the causes which are attributed to it in relation to the excessive activity or improper functioning of the three vital principles (wind, bile and phlegm), the temperament and the environment of the patient. Ayurvedic treatments are therefore individualised and they give great importance to prescriptions of diet and hygiene.

'Pañcakarma' Therapy

Pañcakarma therapy is considered the method of treatment *par excellence* for restoring the normal balance of the three vital principles. Under this name are grouped 'five procedures' (*pañcakarman*): the administration of emetics (*vamana*), purgatives (*virecana*), enemas (*basti*), errhines (*nasya*) and bloodletting (*raktamokṣana*).

Vamana consists in orally evacuating the *doṣa* in excess by prescribing emetics in cases of ailments attributed to disorders of the 'phlegm'. They are contraindicated in the case of consumptive disease, in case of weakness and for children, the aged and pregnant women.

Purgatives are administered for eliminating by the lower tract the impurities accumulated in the intestines. Purging is indicated in the case of diseases that result from an imbalance of the 'bile': fever, skin disease, digestive disorders, urinary disorders, eye diseases, etc. It is contraindicated for children and old people, as well as for pregnant women. Enemas are intended to purify the organism. The process owes its name to the bladder (*basti*) used for introducing various medicinal preparations into the body. Rectal injections are especially indicated in case of fever, diarrhoea, constipation, colic and flatulence.

Āyurveda recommends taking medicinal preparations through the nose (*nasya*) to rid the head and the neck of the problems which are located there. The prescriptions are powders and nasal drops whose choice, time of administration and dosage depend both on the condition diagnosed and the vital principle (wind, bile or phlegm) involved in its production.

Bloodletting is for ridding the organism of 'polluted' blood and for combating in this way various diseases for which blood is thought to be the seat, or the source, in particular diseases of the skin. Anaemia, pregnancy, fatigue and old age constitute the major contraindications. Bloodletting can be carried out by means of lancets or by the application of leeches.

Besides these five 'principal measures' (*pradhānakarman*), *pañcakarma* therapy also includes preliminary measures (*pūrvakarman*). Patients are prepared by being oiled and sweated.

Drugs of Natural Origin

Most of the drugs recommended by Āyurveda are plant-based. In the course of the centuries, ayurvedic medicine has used more than 3,000 plant species of which a good thousand still enter, in various forms, into the composition of the remedies prescribed today. One notes also the use of a certain number of substances of animal or mineral origin. Among the animal products figure foods of animal origin, meats, fats, milks and derivatives, as well as blood, bones, nails and horns. The medical texts speak highly also of the beneficial effects of human urine and that of different animals. Goat's urine, for example, is particularly recommended in cases of cough, breathlessness, icterus, anaemia or haemorrhoids. Horse's urine, pungent, caustic and warm, is especially indicated in cases of perturbations of wind or phlegm. As regards human urine, it has been used in salves for treating certain eye affections. The mineral products of the ayurvedic pharmacopoeia comprise notably bitumen, arsenic, copper sulphate, gold, silver, lead and iron. The last mentioned was used very early, in the form of powder, in the treatment of anaemias.

All these natural substances have contributed to the manufacture of thousands of remedies often involving very complex formulas. This complexity of the compositions is explained simultaneously by ayurvedic pathology, by the complexity of the cases to be treated and by the concern for combining the different ingredients in such a way as to counterbalance, increase or prolong the effects of some by the properties of the others.

The forms of drug delivery are varied: powders, infusions, decoctions, macerations, electuaries, pills, liniments or ointments. Apart from aqueous preparations, the usual vehicle is oil or clarified butter (*ghṛta* or ghee), but milk and honey are also used. As regards the methods of administration of these remedies, they depend on the nature of the medicine and/or the location of the disease. A certain number of preparations are administrated orally, through the nose or through the rectum (enemas, suppositories). Others are reserved for external use.

In order to explain the properties of the different substances and their effects on the organism, Indian physicians of antiquity developed theories which apply as much to food as to plants and to the substances of animal or mineral origin in the pharmacopoeia. For that reason they were very early led to establish correspondences between the vital principles and the simplest perceptible properties of these substances such as their consistency, their odour, their colour and above all their savour (Meulenbeld 1987; Mazars 1995a).

According to Āyurveda, there are six basic savours: sweet, sour, salt, pungent, bitter and astringent. For a long time modern physiology only recognised four of them (sweet, sour, salt and bitter), but no one ever thought of verifying their primary character experimentally. In fact we know today that there is no basic savour. Ayurvedic medicine teaches that substances with a sweet, sour or salt savour calm the wind but irritate the phlegm. On the contrary, those which are pungent, bitter or astringent combat the harmful effects of the phlegm but excite the wind. As regards the activity of the bile, it is reduced by sweet, bitter or astringent substances and increased by sour, salt or pungent substances.

Of the six savours distinguished by Āyurveda, the sweet savour appears to be most important, for it has been thought to contribute to long life. But an excess of remedies or foods with sweet savour, by perturbing the 'phlegm', provokes obesity, promotes laziness, weakens the power of digestion and leads to all kinds of diseases.

Observing that some foods and remedies do not provoke the effects proclaimed by the theory of savours, the theoreticians of Āyurveda sought other explanations to account for the properties of all the substances. They were thus led to establish for each substance:

1. Its 'post-digestive' [*vipāka*, literally 'after cooking' (by the 'digestive fire')] effect, which flows from its savour.
2. Its 'quality' (*guṇa*). There are 20 *guṇa*, one opposing the other, as follows: heavy or light, dull or sharp, cold or hot, unctuous or not unctuous, smooth or rough, solid or liquid, soft or hard, stable or fluid, subtle or gross and non-slimy or slimy.
3. Its 'potency' (*vīrya*). Drugs are divided into two categories depending upon their potency: heating or cooling. Substances having 'hot' potency produce heat in the body. On the contrary, the substances having 'cold' potency have a cooling effect.

Finally, to explain the exceptions to these rules, the notion of *prabhāva* or 'specific action' was developed. These different conceptions conditioned the methods of choice, recommendation and preparation of foods and the medicines.

Āyurveda is the result of long medical observation, speculation and practice, and has exerted a great influence far beyond the frontiers of the Indian world. The underlying concepts of this system relating to health and disease are not devoid of interest. The examination of the data collected in the earliest Sanskrit medical texts shows that the physicians of ancient India visualised living beings in a way that we might qualify today as *systemic*. Humans (as well as animals) are considered an open system according to a concept fairly close to that developed by Ludwig von

Bertalanffy (1901–1972), a system exchanging matter, energy and information continually with its environment (von Bertalanffy 1968). Ayurvedic medical practice is also marked by systemic thought. Its overall objective is to maintain the normal balance of the vital principles responsible for the proper functioning of the organism or to re-establish this balance when it is disrupted. Thus, Āyurveda appears as a system which gives greater weight to prevention than to treatment, giving great importance to hygiene, food and environment whose decisive role in triggering certain diseases is being discovered today.

See also: ►Nyāya, ►Medicine in China

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Medicine in Islam

M

Husain F. Nagamia

Preservation of life is mandated by the following verse of the Qurʾān: "The saving of one life is as if one has saved humanity."

From the earliest times in the history of Islam, medicine has played a vital role. The importance of seeking treatment was emphasized by the Prophet himself in his sayings, which are known as the Ḥadīth: "Allah never created a disease for which he did not create a cure. So seek treatment." "There is a cure for every malady (except old age). If the right treatment is administered, Allah willing the malady is cured."

All the religious scholars agree that a medical doctor is ordained to find a cure for a disease and if one is not found, he should continue to do research until it is found. Thus in Islam disease is not looked upon as a curse from God to be endured and suffered but as an affliction for which a cure has to be sought and administered, with patience and perseverance.

Ethics of Medicine in Islam: The Physician and the Patient

Very early in the history of Islamic civilization (second century after Hijra or the beginning of the Islamic calendar[1]), Islamic medical ethical standards of practice were established set, and the relationship between a physician and patient was defined.

The physician was always held to the highest professional standards and ethics in treating his patient. One of the earliest treatises written on medical ethics was *Adab al-ṭabīb* (Practical Ethics of the Physician) by Isḥāq Ibn Ali al-Ruhāwī, a ninth century physician practicing under the Islamic Caliphate. In this philosophical treatise Ruhāwī examines not only the relationships between a patient and a physician, but also a physician's personal standards of behaviour, conduct of daily activities, morality and even his relationship with God. A physician was expected not only to perform to the best of his capacity in treating his patient, but also to be a model citizen in his society.

In Islam certain rules have to be observed when administering treatment (Mohammed 1980). With advances in medical sciences the ethics of a particular treatment have to be examined in light of Islamic tenets and beliefs *the Shariah*.

History of Medicine in Islam

Medicine as a science and art was cultivated during the development of the Islamic civilization (Hamarneh 1983). The advancements made were limited only by the development in the associated fields of physics, mathematics, chemistry, pharmacology, pharmacy, and philosophy. The Muslims gathered material together from extant sources added their own observations and compiled it into encyclopaedic works (Savage-Smith 1994). Medical knowledge disseminated to all corners of the expanding Islamic empire.

The Early Era of Islamic Medicine and the School of Medicine at Jundishapur

Jundishapur or "Gondeshapur" was a city in Khuzistan founded by Shāpūr I (241–272 CE). In present day western Iran the site is marked by the ruins of Shahbad near the city of Ahwaz (Seyyed 1976). The town was taken by Muslims during the caliphate of Hadrat Umar. At this time it already had a well-established hospital and medical school.

Many Syrians took refuge in the city when Antioch was captured by Shāpūr I. The closing of the Nestorian School of Edessa by Emperor Zeno in 489 CE led to the Nestorians' fleeing and seeking refuge in Jundishapur under the patronage of Shāpūr II. The Greek influence was already predominant in Jundishapur when the closing of the Athenian school in 529 CE by order of the Byzantine emperor Justinian drove many learned Greek physicians to this town. A university with a medical school and a hospital was established where Greco-Syriac medicine blossomed. To this was added medical knowledge from India brought by the physician vizier of Anushirwan called Burzuyah. On his return the latter brought back from India the "Fables of Bidpai", several Indian physicians and details of Indian medical texts. Thus at the time of the Islamic invasion the school of Jundishapur was well established and had become renowned as a medical centre of Greek, Syriac and Indian learning. After the advent of Islamic rule the university continued to thrive.

It is likely that the medical teaching at Jundishapur was modeled after the teaching at Alexandria with some influence from Antioch. This hospital was to become the model on which all later Islamic medical schools and hospitals were to be built. The School thrived during the Ummayid caliphate and medical and philosophical works of both Hippocrates and Galen were translated into Syriac. These were later to be translated into Arabic.

It was during the Abbasid Caliphate that Caliph al-Manṣūr, the founder of the city of Baghdad, invited the head of the Jundishapur School to treat him. This physician was Jurjis Bukhtīshūʿ, a Christian. He treated the Caliph successfully and was appointed to the court. He did not stay permanently in Baghdad, returning to Jundishapur before his death, but the migration to Baghdad had begun. His son, Jibrīl Bukhtīshūʿ, established a practice in the city and became a prominent physician. By the second half of the second century after Hijra (eighth century CE) the fame of Baghdad began to rise. Many hospitals and medical centers were established and tremendous intellectual activity was recorded.

Resources for the Development of Islamic Medicine: The Bayt Al-Hikmah or "The House of Wisdom"

Al-Maʾmūn is usually credited with having made the translation of the Greek sciences systematic and institutionalized in the form of the Bayt al-Hikmah. This institution has been variously referred to as an academy, translation centre and library. Its principal activity was the translation of philosophical and scientific works from Greek/Syriac into Arabic.

Scholars have recently begun to doubt some of the assumptions and the interpretations that have been made about the nature and function of this institution. To start with, no date can be established for its foundation, so although the earliest reference to it is in the time of Hārūn al-Rashīd, it may have existed with the caliphs al-Manṣūr or al-Mahdī (r. 775–785). Regarding its function, there are references in the sources to

[1] The Islamic calendar began 16th July 622 marking the migration of the Prophet of Islam from Mecca to Medina.

translation activity, but these are about work from Persian to Arabic, and there is nothing to suggest that there was any translation at the *Bayt al-Ḥikmah* from Greek into Arabic. Perhaps this can explain some of the confusion over its function. The main reason may be that by the time Ibn al-Nadīm was writing his biographical history the institution had assumed legendary qualities, which have continued to impress subsequent commentators (Attewell 2002).

The most celebrated translator of Greek learning into Arabic is Ḥunain ibn Iṣḥāq (d. 873 or 877). Born in Hira, Ḥunain was the son of an apothecary. He soon translated the entire collection of Greek medical works, including Galen and Hippocrates. He was more scientific and interpreted the original text by cross-reference, annotation and citing glossaries. His original contributions included 10 works on ophthalmology. He rose to the highest honor by being appointed the director of the House of Wisdom by Caliph al-Mutawakkil.

Yuḥannā ibn Masawayh (Mesuse senior) was an early director of the House of Wisdom. He wrote about gynecological problems.

The House of Wisdom had enormous effects on Islamic science, philosophy, art, architecture, agriculture and government. Some of the Islamic physicians had available to them much of the knowledge of ancient Greece, Syria, India and Persia and in turn they contributed their observations and originality.

Hospitals During the Islamic Era

The idea of a hospital as an institutional place for the caring of the sick has not been recorded in antiquity. There were sanatoria and "travel lodges" that were attached to temples where priests attended to the sick. Most of the therapy in these sanatoria consisted of prayers and sacrifices to the gods of healing.

A large number of hospitals were developed during the Islamic era. They were called *bīmāristān*. The early Caliphs adopted the idea of a hospital as a place where the sick could get attention. The first hospital is credited to Caliph al-Walid I (86–96 AH 705–715 CE). At first it was considered no more than a leprosarium because it allowed the segregation of lepers from others. It did have on staff "salaried doctors" to attend the sick.

The first true Islamic hospital was built during the reign of Caliph Hārūn al-Rashīd (170–193 AH 786–809 CE). Having heard of the famous medical institution at Jundishapur the Caliph invited the son of the chief physician, Jibrīl Bukhtīshūᶜ to come to Baghdad and head the new *bīmāristān*. It rapidly achieved fame and led to the development of other hospitals in Baghdad. It is claimed but not established that one of these, the "Audidi" hospital was built under the instructions of the Islamic physician al-Rāzī. At its inception it had 24 physicians on staff, including specialists such as physiologists, oculists, surgeons and bonesetters. When Djubair visited Baghdad in 580 AH/1184 CE he recorded that this hospital was "like a great castle" with water supplied from the river Tigris and all the appurtenances of royal palaces.

One of the largest hospitals ever built in the Islamic Empire was the Mansūri Hospital in Cairo. It was completed in 1248 CE. It had a total capacity of 8,000 people. The annual income from endowments alone was one million dirhams. Irrespective of race, religion and creed or citizenship (as specifically stated in the *waqf* documents, see below) nobody was ever turned away. There was no limit to the time the patient was treated as an inpatient. There were separate wards for men and women, and medicine, surgery. Fevers and eye diseases also had separate wards. It had its own pharmacy, library and lecture halls. It had a mosque for Muslim patients as well as a chapel for Christian patients.

The waqf (an inalienable religious endowment in Islam) specifically stated:

> The hospital shall keep all patients, men and women until they are completely recovered. All costs are to be borne by the hospital whether the people come from afar or near, whether they are residents or foreigners, strong or weak, low or high, rich or poor, employed or unemployed, blind or sighted, physically or mentally ill, learned or illiterate. There are no conditions of consideration and payment; none is objected to or even indirectly hinted at for non-payment… (Ahmad 1939).

Some of the hospitals, especially those established by princes, rulers and viziers, were luxurious; some were actual palaces that had been converted to hospitals. The annual income of Jibrīl Bukhtīshūᶜ was 4.9 million dirhams (Rahman 1989). His son, also a doctor, lived in a house in Baghdad that was air-conditioned by ice in summer and heated by charcoal in winter. For comparison, a resident, who was supposed to be on duty for two days and two nights a week, was paid 300 dirhams a month.

The Great Physicians of Islamic Medicine

The era of Islamic medicine produced some very famous and notable physicians. These physicians were not only responsible for getting all the existing information on medicine together, but also for adding to this knowledge by their own observations, experimentation and skills. Many of them were skilled in medical writing and produced encyclopaedic works which became standard texts and reference works for centuries. Some of these tenets form the basis of instruction of students of *ṭibb* and *ḥikmah*, traditional

Islamic medicine still practised in India and Pakistan today, under the name 'Unani or Tibbi' medicine. For the sake of classification, the historic periods of the Islamic physicians can be divided into three parts (1) *the period of Islamic Renaissance*: This started from the beginning of Islamic era and ended with the end of the Abbasid dynasty; (2) the period of Islamic Epoch: when all sciences including medicine reached the pinnacle of development; and (3) *the period of decline*: during which the knowledge of Islamic medicine declined in the Islamic state but was translated into European languages and became the basis of further development and discoveries.

The Bukhtishu Family of Physicians

The oldest in this family was Jurjis Bukhtīshūᶜ who was the Chief Physician at the Hospital in Jundishapur. He came from a Christian family and was summoned to the court of Caliph Maʾmūn (148 AH/765 CE) when the latter fell ill. It was his son Jibrīl Bukhtīshūᶜ who was later invited by Caliph Hārūn al-Rashīd to come to Baghdad to treat him (171 AH/787 CE). He was Chief until he died in 185 AH/801 CE.

Masawayh

Another family that migrated from Jundishapur to Baghdad was the family of Masawayh who went at the invitation of Caliph Hārūn al-Rashīd. One became a famous ophthalmologist. Most famous amongst his three sons who were physicians was Yuḥannā ibn Masawayh (Mesue Senior). He wrote prolifically; 42 works are attributed to him. He is known for having a sarcastic temperament but commanded great respect because of his medical expertise.

Ḥunayn ibn Isḥāq

Ḥunayn ibn Isḥāq, who was a student of Ibn Masawayh, became the greatest translator of Greek and Syriac medical texts during the third century AH/ninth century CE. He was responsible for masterly translations of Galen, Hippocrates and Aristotle into Arabic. He also improved the Arabic medical lexicon giving it a rich technical medical language to express medical terminology. He was himself a physician and wrote two original works on ophthalmology.

Al-Rāzī

The most famous physician of this time and perhaps of the entire early Islamic era is Muḥammad ibn Zakariyya al-Rāzī (born 251 AH/865 CE; died 312 AH/925 CE), called Rhazes by his Latinized name. He was born in Rayy in northern Persia not far from modern Tehran. Although not much is known about his early life or his medical education, his fame started with the establishment of a hospital in Baghdad of which he was the chief. The story of how he picked the site of the hospital when asked to select one has become one of the classical legends of Islamic medicine. He had pieces of meat hung in various quarters of the city and had them examined for putrefaction and recommended the site where the meat had decayed the least as the most suitable site. This made him one of the first physicians to infer indirectly that there was an element of bacterial putrefaction in the degradation of meat, and suggested the environmental role that contaminated air plays in the spread of infection.

Al-Rāzī is known for numerous other original contributions to the art and science of medicine. He described the differences between smallpox and chickenpox and gave an in depth description of measles. He described allergy to roses in one of his classical cases. The Islamic historian and scientist al-Bīrūnī listed 56 medical works of al-Rāzī, the most famous being *al-Ḥāwī*, an encyclopaedia of medical knowledge based on his personal observations and experiences. A Copy preserved in the National Library of Medicine in Bethesda Maryland is described as the third oldest medical manuscript preserved in the world today.

Besides these and other original contributions of which many have been published, al-Rāzi devoted a lot of his time to teaching, bedside medicine and attending to the royalty and court. The impact of these publications on Islamic medicine was tremendous. His books became an invaluable addition to the armamentarium of a medical student of the time and remained standard texts until the appearance much later of texts by al-Majūsī (d. 994) and Ibn Sīnā, who authored such monumental works as *al-Qānūn fī l-ṭibb* (The Canon of Medicine).

Al Majusi

In the fourth century of Hijra, tenth century CE another Islamic physician gained prominence in Baghdad. His name was 'Alī ibn al-'Abbās al-Majūsī (d. 384 AH/994 CE). (Latinized Haly Abbas). He became the director of the Adud-dawlah Hospital. Al-Majūsī dedicated his medical work *Kitāb al-Malakī* (The Royal Book) to its founder. This book is very well systematized and organized. It is divided into two volumes, one covering theory and the other practical aspects. Each of these has ten chapters. The first volume deals with historical sources, anatomy, faculties, six primeval functions, classification and causation of disease, symptoms and diagnosis, urine, sputum, saliva and pulse as an aid to diagnosis, external or visible manifestations of disease and internal diseases like fever, headache, epilepsy and warning signs of death or recovery. The second volume deals with hygiene, diet, cosmetics, therapy with simple drugs, therapy for fevers and diseases of organs. There is a chapter on surgery, orthopaedics, and finally treatment by compound medicaments.

About the second century AH/eight century CE a great centre of knowledge learning and culture had been developing in the western part of the Islamic empire. This was in Spain or "Andalusia" as the Arabs called it. Spain was invaded and conquered by the Muslims in 93 AH/714 CE. When the Ummayad dynasty ended in Baghdad the last of Ummayad princes escaped to Spain where they established the Western Caliphate. The rulers of this dynasty laid the foundation for the Muslim rule of Spain that was to last for seven centuries. During this time Cordoba, also called "Qurtuba", became a great centre of international learning. A great library containing more than a million volumes was established.

Al-Zahrawi

Perhaps the most famous physician and surgeon of the era was Abū l-Qāsim al-Zahrāwī, known to the west as Albucasis (318 AH/930 CE to 403 AH/1013 CE). He gained great fame as a physician. He wrote a 30-volume compendium called *al-Taṣrīf*. The initial volumes dealt with general principles, elements and physiology of humours and the rest dealt with systematic treatment of diseases from head to foot. The last volume deals with all aspects of surgery. It was the first textbook of surgery with illustrations of instruments. He emphasized that knowledge of anatomy and physiology was essential prior to undertaking any surgery:

> Before practicing surgery one should gain knowledge of anatomy and the function of organs so that he will understand their shape, connections and borders. He should become thoroughly familiar with nerves, muscles, bones arteries and veins. If one does not comprehend the anatomy and physiology one can commit a mistake which will result in the death of the patient. I have seen someone incise into a swelling in the neck thinking it was an abscess, when it was an aneurysm and the patient died on the spot.

He described operations on varicose veins, reduction of skull fractures, dental extractions, forceps delivery for a dead foetus to mention just a few. His work raised surgery to a high level.

Ibn Sina

However the greatest physician of the Islamic era was *Abū ͨAlī al-Ḥusain ibn ͨAbdallāh ibn Sīnā*, Avicenna or Ibn Sīnā. Some historians of medicine call him one of the greatest physicians that ever lived. That is because Ibn Sīnā was not only a physician, but also his knowledge and wisdom extended to many other branches of science and culture including philosophy, metaphysics, logic and religion.

Ibn Sīnā was indeed a prodigy. At the age of 10 he had memorized the whole Qurʾān. By age of 16 he had mastered all extant sciences that appealed to him including mathematics, geometry, Islamic law, logic, philosophy and metaphysics. By age 18 he taught himself all there was to learn at that time in medicine. Born in the city of *Būkhārā* in what is now central Asia in the year 370 AH/980 CE, he rapidly rose in ranks and became the vizier (prime minister) and court physician of the Samanid ruler Prince Nuh ibn-Mansūr. The Royal Library was opened to him and this enlarged his knowledge. He began writing his first book at age 21. In the short span of 30 years of writing he wrote over a 100 books of which 16 were on medicine. His magnum opus is *Qānūn fī l-ṭibb* (The Canon of Medicine). This voluminous compendium of medical knowledge rivaled one written earlier by al-Rāzi and al-Majūsī and indeed surpassed both of these in content and originality. It was composed of five volumes: general principles, simple drugs, systematic description of diseases from head to foot, general maladies and compound drugs. The Canon was translated into Latin by Gerard of Cremora and Andrea Alpago and remained the standard textbook of medicine in Louvain and Montpellier until the seventeenth century.

Ibn Nafis

Islamic physicians not only possessed excellent knowledge of anatomy, but also they added some challenging new concepts that were revolutionary to the then understanding of anatomical concepts laid down by the "ancients". The example that has now become well known is that of the discovery of the lesser or pulmonary circulation by Ibn Nafīs (d. 687 AH/1288 CE). The description he gave of pulmonary circulation challenged the fundamental concept held by Galen. In fact it suggested that there existed a pulmonary capillary bed where the blood was "purified" before being brought back to the heart by the pulmonary artery, thus predating the discovery of pulmonary capillaries long afterwards, made possible by the discovery of the microscope by Antony van Leeuwenhoek. Al-Zahrāwī emphasized that the knowledge of anatomy was a prerequisite for the surgeon.

> Now this is the reason why there is no skillful operator in our day: the art of medicine is long and it is necessary for its exponent, before he exercises it, to be trained in anatomy as Galen has described it, so that he may be fully acquainted with the uses, forms, temperament of the limbs; also how they are jointed, and how they may be separated, that he should understand fully also the bones, tendons and muscles, their numbers and their attachments; and also the blood vessels both the arteries and the veins, with their relations.

The physiological concepts embodied in Islamic medicine were based on the Hippocratic and Galenic concepts of elements, natures and humours. In this theory harmony in the body prevails when all the humours are in proper balance and it is their imbalance that creates disease. Under this principle, disease is a state of imbalance of humours and needs the restoration of balance to bring the organism back to its normal healthy state. Islamic medicine also expounds the concept of elements and temperaments. The basic elements are earth, fire, air and water, and each of these is given a temperament: earth is dry and cold; water is humid and cold; fire is hot and dry; air is humid and hot. Each of the four essential body fluids – blood, phlegm, yellow bile and black bile – is assigned a respective temperament. Each dietary food, medicine or climatic environment can thus then modify or temper the humours of the body and it is an interplay of these that can restore health from sickness or cause the sickness to worsen.

It was the fundamental belief of a Muslim physician that the organic body alone cannot manifest life, being innate and devoid of a life force. It was the instillation of a life force, *Ruh*, which gave it vibrancy and vitality of spirit. Thus without the Ruh, no function of the body is possible. It is the Ruh which descends from God to mix with the anatomic and physiologic body to make a complete human being. It is thus essential when treating a diseased state to take the Soul or 'Ruh' into consideration. Laying the foundation of Holistic Medicine.

Pharmacy, Pharmacognosy, Materia Medica and Therapeutics

One of the sciences that had an impetus on Islamic medicine was the development of pharmacy and pharmacognosy. Most Islamic physicians and scholars studied chemistry or alchemy. This study was furthered by the concomitant development of techniques to refine drugs, medications and extracts by processes of distillation, sublimation and crystallization. Pharmacists became commonplace in Islamic lands, and their proliferation ultimately required the institution of licensing.

Pharmacological drugs were classified into simple and compound drugs. The effects of these were detailed and documented. The earliest Islamic works on pharmacognosy, such as "Treatise on the Power of Drugs, Their Beneficial and Ill Effects" and "The Power of Simple Drugs" were written in the third and fourth century AH/ninth century CE. Most medical texts contained chapters on the use of both these types of remedies. Rāzi's *al-Ḥāwī* mentions 829 drugs.

Materia medica and texts containing compendia of drugs and their effects appear frequently during the era of Islamic medicine. Notable amongst these is the contribution of Abu Bakr ibn Samghun of Cordoba, *The Comprehensive Book on Views of the Ancients as Well as the Moderns on Simple Drugs*. Ibn Juljul made a commentary on drugs and plants described by Dioscordes and added a number of newer ones. Al-Zahrāwī's *al-Taṣrīf* mentioned earlier in reference to its surgical volume also had a section on plants and drugs. The second book of the *Canon* is devoted to the discussion of simple drugs and their powers and qualities. One of the most authoritative books on drugs was written by al-Bīrūnī, entitled *The Book on Drugs*, which contains a huge compendium of drugs, their actions and their equivalent names in several languages.

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Medicine in Japan

William D. Johnston

When considering the Japanese history of medicine, it is important not to project our ideas about medicine today onto the past. Whereas modern medicine worldwide is based on the language and methods of natural science, the medicine of premodern Japan consisted of many different languages and practices. Moreover, the historical development of medicine in premodern Japan must not be thought of as following a linear development that inevitably ended in the adoption of Western medicine. It is, rather, the story of theories and practices that unfolded according to their own historical logic, often in competition with each other and without theoretical or practical consistency. The fact that the Japanese did adopt Western medical ideas and practices during the premodern period simply reflects the ways in which some Japanese medical ideas and practices developed.

Throughout the premodern period, which in the case of Japan spans all of history until the mid-nineteenth century, numerous medical theories and practices, many of which were mutually contradictory, coexisted. Until modern times, most people depended primarily on folk remedies to treat their ailments. These consisted mostly of shamanistic rituals whose remnants can be found today in a small number of Shinto shrines and Buddhist temples. Physicians with a textually based theoretical training were rare in rural areas, where most Japanese people lived as peasants or fishers. However because few documentary sources exist on which a history of folk medicine could be based, historians have made the textual tradition the focus of their research. Hence it is also necessary to focus on this textual tradition here, but this is, of necessity, only a partial history.

Within these limits, the history of Japanese medicine can be divided into four periods: ancient, medieval, early modern, and modern. The ancient period spans from prehistory to the late twelfth century; the medieval period reaches from the beginning of the thirteenth century to the late sixteenth; and the early modern period encompasses the years from the late sixteenth until the mid nineteenth century. Because in many respects the history of Japanese medicine during the modern period parallels that of the Western world, this article deals primarily with the premodern period.

Prehistoric and Ancient Medicine

Based on skeletal remains, it is clear that the prehistoric inhabitants of the Japanese islands developed rudimentary medical practices. Some bone fractures, at least, were treated so that they healed cleanly. The earliest written records, which date from the early eighth century, recount the use of herbal remedies for some illnesses. However the same records also reflect the belief that most diseases were divine retribution for offending a deity or spirit; they were treated through exorcism, ritual ablution, and purification rituals. Some diseases, such as leprosy and tuberculosis, were also associated with ritual pollution, a belief which has found currency into modern times. Because this pollution was thought to be hereditary, these diseases often made it difficult for the persons who had them and members of their families to find marriage partners. When a disease reached epidemic proportion, it was thought to be caused by the more powerful deities that controlled forces of nature throughout the land, deities that the emperor or empress attempted to assuage with national purification rituals.

It is unclear when Chinese writing first reached Japan, but by the late fourth or early fifth century scholars from the Korean peninsula were tutoring members of the imperial family in the Chinese classics. The real rise of literacy came with the Japanese adoption of Buddhism from the sixth century; it can be surmised that the advent of textually based medicine in Japan also dates from this time. By the seventh century, Buddhist monks from the continent were both practicing medicine and training Japanese monks to become practitioners themselves. Until the seventeenth century most trained medical practitioners retained the trappings, if not always the formal status, of Buddhist priests.

From the late seventh century the Japanese state adopted the legal codes of Tang China. These included provisions for government posts that specified the employment of various medical specialists, including internists, surgeons, acupuncturists, masseuses, exorcists, obstetricians, dentists, and pharmacologists. Although in China these posts were filled with scholars who passed required examinations, in Japan they soon became hereditary and remained so until the nineteenth century. This did not, however, preclude the adoption of new developments in medicine from the continent. Constant interaction with both Korea and China, where numerous Japanese Buddhist priests went to study, kept them informed of changing theories and practices, although the process of change was far slower than during more recent times.

Medicine during the Nara (710–794) and Heian (794–1185) periods remained the domain of court physicians and Buddhist priests. As in premodern Europe, internal medicine and surgery remained distinct practices. Internists had a high level of education and relatively high social status; surgeons, who mostly treated skin lesions, wounds, and fractures, had comparatively little theoretical training and low social status. These remained distinct until the late eighteenth century.

Internal medicine was based entirely on Chinese texts; the first Japanese medical text did not appear until the year 984. This was the *Ishimpō* (literally, Methods at the Heart of Medicine), which was written by the court physician Tanba Yasuyori (912–995) and remained an important text among some schools of medicine until the nineteenth century. This 30-volume work contained information on internal medicine, pharmaceuticals, preventive practices, and other topics, and was based on over eighty Chinese texts written during the Sui (581–617) and Tang (618–907) dynasties.

Until the eighteenth century, anatomy envisioned the human body as containing five organs and six viscera, and physiology focused on their relationships with each other and the meridians found on the surface of the body. Visual observation of the internal organs played little role in the classical Chinese model of the human body, and organs including the brain, pancreas, thyroid, and adrenal glands played no role in the treatment of disease. Indeed, there was no word for the latter three organs, and visual depictions of human anatomy did not appear in the Japanese medical literature until the fourteenth century. Rather this model was conceptual, based on the Chinese notion of the five elements of fire, metal, water, wood, and earth. These were, respectively, associated with the heart, lungs, kidneys, liver, and spleen, and each organ was in turn associated with five colors, tastes, and seasons, the spleen being associated with the time of changes between seasons. Physicians interpreted diseases as resulting from imbalances within this system and treated them with herbal medicines, acupuncture, moxibustion, massage, and restrictions on diet and behavior. Yet this model did not completely replace ideas of disease as being caused by spirit possession, and the literature of the Heian period abounds in examples of Buddhist priests attempting to cure maladies through exorcism, a common practice until modem times.

Because the diagnostic criteria and disease categories of premodern Japan were so different from those used today it is difficult to establish with any accuracy in modern terms the diseases from which people suffered at the time. Yet it is certain that the most common epidemic diseases of premodern Japan, beginning with the Nara and Heian periods and continuing through the nineteenth century, were smallpox, measles, influenza, and enteric infections. Tuberculosis, malaria, and parasitic infections remained endemic during the premodern period. Despite a myth of cleanliness attributed to the Japanese, bathing and the regular washing of clothes were not common practices, making skin diseases common until modern times. In addition, kitchen areas frequently were far less than sanitary, and latrines and even graves were sometimes located close to water sources, contaminating them.

Although most medical folk beliefs are poorly documented, much is known concerning some popular beliefs related to what probably was tuberculosis. During the twelfth century, Chinese Daoist priests thought that a disease they called *zhuan shi* (*denshi* in Japanese), literally "transmission of the consumption bug," was caused by minute worms. According to Daoist texts, this disease passed through a cycle of six phases with turning points on certain calendar days, when the worms metamorphosed from one phase to the next; in the sixth phase they were thought to be highly contagious. A popular belief in these worms took root in Japan from the Heian period as part of the Kōshin folk religion. They were considered a deity's agents that reported a person's sins on the days of *kōshin*, which occurred once every 60 days in the calendar cycle. If a person abstained from sleep on those nights, the worms would remain dormant; otherwise they would divulge their host's sins to the deity, who punished people by causing consumption (*denshi*). At first, only the Heian-period aristocracy abstained from sleep on those nights, but the ritual spread throughout the country and was practiced in rural villages until the twentieth century.

Medieval Japanese Medicine

During the Kamakura period (1185–1333) warrior culture eclipsed the culture of the imperial court, but changes in medical theory and practice remained slow. The hereditary posts of court physicians remained in place, and the physicians who filled them were sometimes dispatched to treat the leaders of the military government in Kamakura. However these physicians had little opportunity to keep abreast of the changes in medicine that occurred in China, and in most of Japan Buddhist priests dominated medical practice.

The most important medical text of the Kamakura period was the *Don'isho* (which is untranslatable), written by Fu-jiwara Shōzen (1266–1337) in 1302. This work was significant for its visual representation of human anatomy, the first in Japan. Like previous Japanese medical texts, the *Don 'isho* was also a compilation of Chinese sources, except for the section on leprosy, which was based entirely on Buddhist thought. This reflected current Japanese ideas concerning this disease. From the Heian period, leprosy was called a karmic disease (*gōbyō*), the result of sins committed in past lives. As in medieval Europe, leprosy was common during the middle ages in Japan and had much the same stigma; persons who developed leprosy became outcasts, shunned by their families and communities alike, finding succor only in the care of Buddhist monasteries. The stigma attached to leprosy did not change even into modern times. (The plague, another representative disease of medieval Europe, did not reach Japan until the late nineteenth century and was never a significant cause of mortality.)

The Muromachi (1333–1468) and Warring States (1468–1600) periods witnessed considerable changes in the theory and practice of medicine. During the Muromachi period Buddhist monks became increasingly knowledgeable in Confucian thought, and were influenced by the rise of Neo-Confucianism during the Song dynasty (960–1279) in China. This new current in Confucian thought emphasized the role of *qi* (vital force; *ki* in Japanese) and *li* (principle; *ri* in Japanese) in the order of nature, states, and individuals alike. The ideas of Neo-Confucianism entered the mainstream of Chinese medicine in the theories of Li Dongyuan and Zhu Danxi, who were active during the Yuan dynasty (1279–1368). Li and Zhu understood disease according to interrelationships between an individual's vital energy, environment, and behavior. In therapeutics they placed a new emphasis on emetics, purgatives, and medicines that caused a person to sweat. The ideas of Li and Zhu became influential in Japan from the early sixteenth century, primarily through the works of Tashiro Sanki (1465–1537), who studied medicine for 12 years in China. They then became established in the mainstream of Japanese medicine through the works of Manase Dōsan (1507–1574), who had studied under Sanki. Dōsan's descendants and followers remained highly influential, treating the warlords and hegemons of the Warring States period. Following the establishment of the Tokugawa *bakufu* in 1603 Dōsan's medical theories and practices became government-sanctioned medical orthodoxy (*hondō*). As such they remained at the core of some schools of medicine until the end of the premodern period, and had virtually no competitors until the beginning of the eighteenth century.

Dōsan and his followers had a powerful influence on diagnostics, which they standardized. Later and competing schools of medical thought only supplemented the diagnostic procedures delineated by Dōsan, which remained standard until the advent of Western diagnostics during the nineteenth century. He based diagnosis on a four-step method. Visual observation focused on the patient's skin color, weight, strength, condition of the hair, and inspections of sputum, feces, and urine. Aural observation included listening for responses indicating pain when the patient was examined, for the type of cough, and for sounds in the chest. The physician questioned the patient concerning appetite, waste elimination, emotional disposition, and the circumstances preceding the illness. Finally there came pulse diagnosis, a technique without parallel in Western medicine, which analyzed the strength, speed, location, and other aspects of the pulse.

Endemic warfare during the Warring States period stimulated new approaches to surgery, with a widespread need for specialists who could treat battle wounds. The arrival of the Westerners in East Asia during the sixteenth century was soon followed by the spread of firearms, whose wounds called for new forms of treatment. This led to the adoption of Portuguese surgical practices during the second half of the century in what was called the *Nanbanryū* (Southern Barbarian School). At this time, however, the Japanese adoption of Western medicine remained limited to practical measures for treating wounds, skin lesions, bone fractures, and dislocated joints, and contemporary European medical theory made little headway into Japanese medicine.

Early Modern Japanese Medicine

The defeat of the last major opponents to the hegemony of the warlord Tokugawa Ieyasu in 1600 marked the end of the Warring States period and the beginning of the Edo period (1600–1868), a time of peace and gradually increasing prosperity. The seventeenth century was a period of political, economic, and cultural stabilization and consolidation during which medical theories and practice changed little, dominated by the orthodoxy of Manase Dōsan and other established schools. A century of peace, however, ushered in a period of intellectual and cultural ferment that began during the last decade of the seventeenth century and continued into the nineteenth.

During the last half of the seventeenth century, Confucian scholars started to reject Neo-Confucian interpretations of the Chinese classics and focused instead on direct textual analysis. This trend appeared at the same time in medicine, with a number of physicians rejecting Song and Yuan dynasty interpretations of medical texts, emphasizing instead the direct reading of ancient Chinese medical works. Most of the leaders of this movement, which came to be called the School of Ancient Medicine (*Koihō*), lived in Kyoto, and included Gotō Konzan (1659–1733), Kagawa Shūan (1683–1755), Yoshimasu Tōdō (1702–1773), and Yamawaki Tōyō (1705–1762). Practitioners of the School of Ancient Medicine were by no means unified in their interpretations of either texts or phenomena, but most did emphasize practical methods to establish the validity of their ideas and methods. This was of momentous importance to the changes in Japanese medicine that followed during the rest of the premodern period.

Yamawaki Tōyō, a physician at the imperial court, was central to those changes. Tōyō questioned traditional Chinese interpretations of human anatomy and attempted to replace them with a view based on a passage in the *Zhou li* (Rites of Zhou), one of the early Chinese classics, which described the body as containing nine organs. To verify his view, Tōyō conducted the first public dissection of a human body in Japan in 1754, and published the results in the *Zōshi* (Anatomical Record) in 1759. Although Tōyō's nine-organ theory did not gain currency, his method of examining the body through dissections did. Thereafter, physicians in various parts of the country performed dissections and advanced other anatomical theories, none of which, however, replaced the Chinese theory of five organs and six viscera.

In 1771 three physicians, Sugita Genpaku (1733–1817), Maeno Ryōtaku (1723–1803), and Nakagawa Jun'an (1739–1786), witnessed the dissection of an executed criminal's corpse in Edo (Tokyo). Discussing the results afterward, they concurred that they could not consider themselves medically qualified without a true understanding of the structure of human anatomy, and that such an understanding could be gained only by translating the Dutch anatomy text which Genpaku and Ryōtaku had brought to this dissection. In 1774 they published the *Kaitai shinsho* (New Book of Anatomy), their translation of the *Ontleedkundige Tafelen*, or "Illustrated Anatomy," by the German physician Johann Adam Kulmus (1689–1745). This both started the study of Dutch medicine (*Ranpō*) in Japan and opened the door to European ideas by making the Dutch language widely accessible; after finishing this translation Ryōtaku then compiled a Dutch–Japanese dictionary.

During the first half of the nineteenth century, growing numbers of Japanese physicians studied Dutch medicine under Dutch and German physicians who offered instruction in Nagasaki. Until after the Meiji Restoration in 1868, when Western medicine became mandated as the sole basis for medical practice, various schools of Chinese medicine coexisted with Western medicine in Japan, but the door to Western medicine and science had been opened because of indigenous Japanese developments that had taken place during the eighteenth century, and in this respect the history of premodern medicine in Japan is unique in the world.

The spread of vaccination from the mid-nineteenth century the marks the beginning of modem medical practice in Japan. By the 1850s, vaccination had become common in many parts of the country. However it was not until after the Meiji Restoration in 1868 that modern medical education became instituted. Tokyo University was established in 1877, with its Medical School one of the initial departments. Thereafter, numerous Japanese students traveled to Europe, and particularly to Germany, to study medicine. Some continued to work in Europe as researchers and several, including Kitasato Shibasaburō (1852–1931), who codiscovered the tetanus antitoxin and plague bacillus, became internationally renowned; he was nominated for the first Nobel Prize in medicine. By the late nineteenth century modern medical schools had been established throughout the country and medical practitioners were required to hold state licenses.

During the twentieth century Japanese physicians have remained on the cutting edge of medical research in many fields. Since World War II, national health insurance has made medical care available to the entire population, helping to make the average life span the longest in the world.

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Medicine in Korea

Don Baker

"Oriental Medicine" is the English name Koreans prefer for what is known in most of the rest of the world as Chinese Medicine. Among themselves, Koreans call it "Korean medicine." They believe their traditional medicine is as much Korean as it is Chinese, since for around 2,000 years they have adapted medical theories, practices, and even prescriptions from China to fit Korean needs (Fig. 1).

Koreans probably acquired elements of Chinese medical theory and practices for the first time a little over two millennia ago, after China's Han dynasty established four outposts in and around the peninsula late in the second century BCE. Not long after the last of those outposts disappeared early in the fourth century, Buddhist monks from China and farther West began arriving and teaching not only their religion but also the more advanced civilization of China, including its medical theory and practice.

Exactly how much Koreans learned about Chinese medicine from those outposts and from those monks is not clear, since we have few written records from that period. The oldest extant history written by Koreans, the *Samguk sagi* (History of the Three Kingdoms), dates back only to the twelfth century. However, statements in that book, as well as scattered references in Chinese and Japanese records from centuries earlier, indicate that Koreans were reading Chinese medical manuals and applying what they read in them during the Three Kingdoms period (300–668) as well as during the Silla period (668–936).

The Kingdom of Goryeo (918–1392)

Substantially more information is available on medical theory and practice under the Goryeo, which followed Silla and ruled over the Korean peninsula for four and a half centuries. We know, for example, that Goryeo used Chinese-style civil service examinations to identify qualified candidates for government medical posts. Applicants for Goryeo medical posts were tested on their knowledge of the basic principles of internal medicine and pharmacology, as found in the same Chinese medical classics studied in China. They were also tested on their knowledge of external medicine (as defined in Oriental medicine), primarily acupuncture, moxibustion, and the treatment of wounds. That section included questions on material introduced in more recent medical texts, including at least two books from China's Sui (581–618) dynasty.

Medicine in Korea. Fig. 1 A Chinese herb market in Seoul. Photo copyright Korea National Tourism organization.

Although China was the primary source of medical concepts and practices, Koreans had to adapt Chinese prescriptions to fit what was available on the Korean peninsula. For most of the Goryeo dynasty, Korea was blocked from direct land contact with China by hostile non-Chinese states in southern Manchuria. This forced Goryeo to develop *hyangyak*, Koreanized versions of Chinese prescriptions in which herbs, animal parts and minerals found on the Korean peninsula replaced ingredients from China. The oldest Korean medical text still extant, published in 1245, is called *Hyangyak gugeupbang* (First Aid Prescriptions Using Native Ingredients). Not only did the prescriptions in this medical manual use ingredients available locally, but some of them were drawn from local folk medicine and therefore called for only one or two ingredients, in contrast to the multitude of ingredients in prescriptions which originated in China. This was just one of several medical manuals produced in the latter part of the Goryeo era which emphasized locally available ingredients as well as prescriptions of local origin (Kim 1981: 137–141)

The Joseon Dynasty (1392–1910)

The Joseon dynasty which followed Goryeo, influenced by recent developments in Chinese thought, embarked on a restructuring of Korean government and society along Neo-Confucian lines. That restructuring embraced medical institutions as well as medical practice.

The Neo-Confucian influence on medicine during the Joseon dynasty was seen in two areas: the creation of a national network of medical facilities and the certification of physicians through civil service examinations. The greatest concentration of physicians was in

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and around the capital city. The government established clinics inside Seoul to provide medical care for the royal family and top officials. It also opened medical clinics for commoners just outside the city walls so that those with infectious diseases would not have to enter the capital itself (Kim 1981: 196–199; 408–416).

In addition, the Joseon government established medical facilities in various regional centers, primarily to deal with outbreaks of epidemics among the general population as well as to collect materia medica from local areas. A Confucian scholar normally led the higher-level medical offices. Under him would be physicians who had passed the civil service medical examination.

Joseon Korea was a highly stratified society and privileged a distinguished ancestry and knowledge of Confucian philosophy and literature ahead of technical expertise. Only those with a good family background and a passing grade on the Neo-Confucian civil service exams could be appointed to the highest posts, such as director of a major medical clinic. Consequently, the heads of central government medical agencies were usually Confucian scholars with more expertise in Chinese poetry and ancient Chinese history than in the details of medical practice.

Professional physicians ranked one step below Confucian scholars on the social ladder. There was a separate civil service examination for those who aspired to such a post. Though there was no legal requirement that those sitting for that examination be descended from a previous exam passer, the emphasis in the Joseon dynasty on hereditary status meant that a few families dominated the list of medical exam passers. For example, ten families produced almost 30% of all officially certified physicians between 1498 and 1894 (we lack reliable records on medical officials for the first century of the Joseon dynasty) (Yi 1997; Kim 1999).

Only physicians who sought an appointment to a civil service position were required to pass the medical examination. Until 1900, medical practitioners among the general population did not need any official certification of their medical expertise. Nor were they subject to government oversight. However, even among those with informal credentials, family background was still important. A popular saying during the Joseon dynasty warned villagers, “Do not accept medicine from a doctor who is not at least a third-generation physician.”

Joseon Korea was a patriarchy and restricted most government appointments, including medical appointments, to men. However, some women were employed as medical technicians because of the constraints of Confucian ethics. Uncomfortable with the idea of a male physician examining the body of a female patient, which would violate the Confucian directive calling for a rigid separation of the sexes among upper-class adults, King Taejong (r. 1400–1418) ordered that a few women be selected for training in acupuncture, moxibustion, and pulse measurement (an important diagnostic tool). Male pharmaceutical specialists could prepare medicines for an upper-class woman who was ill, but they were not allowed to place the acupuncture needle or moxa on her skin nor could they place their male fingers on her veins to feel her pulse. After 1406, such tasks therefore were assigned to a small core of women medical practitioners at court (Heo 1992: 214–217).

Localized Chinese Medicine

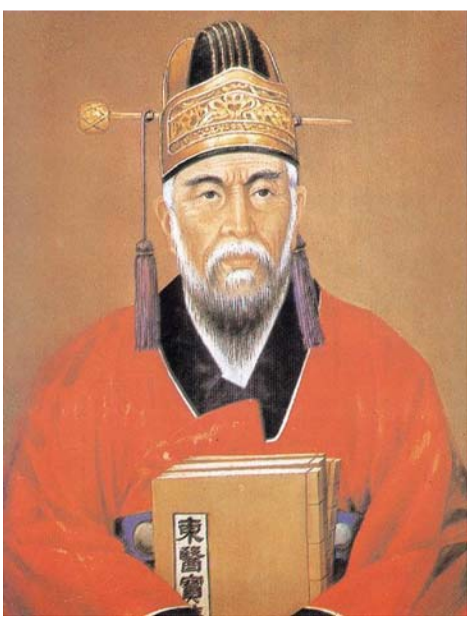
Official medicine in Joseon Korea was based primarily on the canonical texts of Chinese medicine. Koreans supplemented the medical theory and clinical advice in those classical works with more recent Chinese publications as well as with Korean texts that provided local counterparts for the Chinese ingredients in Chinese prescriptions. Both trends are particularly evident during the reign of Joseon’s fourth and greatest King, King Sejong (r. 1418–1450). Among the many volumes compiled and published under King Sejong’s direction, two are particularly important for the history of Oriental medicine in Korea.

The first is the 85-volume *Hyangyak jipseongbang* (Great Collection of Native Korean Prescriptions). Completed in 1433, this encyclopedic pharmaceutical guidebook identified 959 different diseases, arranged under 57 different categories. It described 703 different mineral, vegetable, or animal medicinal products available on the peninsula, told how to identify them, when to collect them, and what diseases they were effective against. Many of its prescriptions were extracted from Chinese medical manuals. However, whenever possible, it substituted native ingredients for expensive or rare Chinese ingredients (Kim 1976: 70–73). In addition, this work listed almost 1,500 ways acupuncture and moxibustion could be used, some based on local experience.

To ensure that his physicians had access to the best advice Chinese medicine had to offer, even if all the prescribed ingredients were not readily available, in 1445 King Sejong also had his officials compile the *Uibang yuchwi* (Classified Collection of Medical Prescriptions). Totaling 365 volumes, this massive reference work listed over 50,000 separate prescriptions, drawn from Chinese sources and arranged according to the symptoms they were believed to alleviate. It also included separate sections on treating childhood illnesses and mental disorders, on childbirth, on first-aid remedies, and on treating fractures (Kim 1976: 80–83).

Both the *Great Collection of Native Korean Prescriptions* and the *Classified Collection of Medical Prescriptions* were compiled for the use of physicians at court and were too large to be made available to the general public. However, in 1613, a more concise guide to medical theory and practice appeared. Koreans consider the 25-volume *Dongui bogam* (A Treasury of Eastern Medicine) their greatest original contribution to the development of Oriental medicine. Compiled by royal decree under the direction of Korea's most revered physician, Heo Jun (1539–1615) (Fig. 2). *A Treasury of Eastern Medicine* provided an encyclopedic overview of Oriental medicine from a Korean perspective. At only 25 volumes, it was more compact than either of King Sejong's two massive medical encyclopedias and therefore could be more easily distributed to government offices throughout the peninsula. Read by Confucian scholars as well as physicians, it shaped medical thought and practice in Korea for the rest of the Joseon dynasty and remains influential today.

A Treasury of Eastern Medicine opens with explanations of the basic concepts of Oriental medicine. Heo placed particular emphasis on *jeong* (Chinese *jing*), *ki* (C. *qi*), and *shin* (C. *shen*). Those three Sino-Korean terms are used in such a wide variety of contexts with such a wide range of meanings that it is difficult to find English equivalents for them. As Heo uses them, they refer roughly to essential bodily fluids, bodily energy, and refined bodily energy, respectively. All three terms refer to the fundamental cosmic energy that animates the universe. Within the human body that vital energy takes three different forms, distinguished according to differences in visibility, tangibility, and density. Jeong is visible vitalizing energy, such as semen or blood. Ki is invisible but palpable vitalizing energy, discerned when a doctor feels the pulse of a patient to determine the state of his or her internal energy. Shin is ethereal vitalizing energy, so rarefied that it provides the physiological basis for consciousness. Heo places fostering and reinforcing that vitalizing energy at the core of his approach to Oriental medicine.



Medicine in Korea. Fig. 2 Heo Jun, the chief author of *A Treasury of Eastern Medicine*. Reprinted courtesy of the Association of Korean Oriental Medicine.

After introducing *jeong*, *ki*, and *shin*, Heo discusses various external windows into the state of vital energy within, including blood, phlegm, saliva, dreams, and the sound of the patient's voice. Only in his third chapter does he turn to the coagulation of vital energy into the five major governing organs (liver, heart, spleen, lungs, and kidneys) and the six supportive organs (gallbladder, stomach, large intestine, small intestine, bladder, and triple burner). He follows that discussion of the inside of the human body with a discussion of the outside, from head to foot. He complements this analysis of the basic components and processes of the body with a detailed analysis of the various ways those components can become dysfunctional and as a result damage the body's other components, preventing them from functioning the way they should. He also included a catalogue of the medicinal substances available in China and Korea, where they could be found, how to prepare them for human consumption, and when to prescribe them. His final chapters are a detailed description of when and how to use acupuncture and moxibustion.

The basic principles of both Heo's medical theory and his practical suggestions for health and healing were derived from the Oriental medicine of China. What made Heo's book different, and so influential, was the way he presented those theories and techniques. Earlier medical handbooks were primarily compilations of medical texts which did not evaluate the relative effectiveness of the various prescriptions and other medical strategies those texts recommended. Heo provided an interpretative framework for understanding which healing and health-enhancing techniques were likely to work better than others. He also provided evaluations of which medicines or procedures were likely to be the most effective in specific situations.

Despite the contributions of *The Treasury of Eastern Medicine*, medical problems increased rather than decreased over the next three centuries. The first serious new threat to Korean health was syphilis. Introduced onto the peninsula early in the sixteenth century, it became a major medical problem during the Japanese invasions at the end of that century. That deadly sexually transmitted disease was joined soon afterwards by one even more deadly because it spread from victim to victim through more casual contact. Sometime in the seventeenth century a new virulent strain of measles appeared in Korea, taking the lives of thousands in periodic epidemics from the late seventeenth through the nineteenth centuries. The nineteenth century brought one more new biological brake on population growth. Cholera reached Korean shores in 1822, returning again several more times that century, each time killing tens of thousands.

The impact on population growth was striking. Instead of growing rapidly, as it had in the first part of the Joseon dynasty, the Korean population first stagnated and then began shrinking. The Korean government counted almost a million fewer Koreans in 1850 than it had found a half a century earlier. That 1800 figure itself was only a slight advance, of less than 100,000, over the census figures for 1750. Both epidemics and famines were taking their toll (Baker 1990).

The response of Korea to this demographic decline was a popularization of Oriental medicine. *The Treasury of Eastern Medicine* was too large for distribution among the general population, so much smaller pamphlets dealing with prescriptions for specific diseases were printed and distributed to meet the growing popular demand for medical information. Such publications designed for the masses were not the only evidence of the popularization of Oriental medicine in the second half of the Joseon dynasty. The opening of Oriental medicine markets in four Korean cities, starting in the mid-seventeenth century, indicates that more and more Koreans were beginning to trust prescriptions more than the shamans and monks they had relied on in the past. By the middle of the eighteenth century there was enough demand for Oriental medicine that a new occupation appeared in Korea-pharmacists. Koreans began to frequent private shops run by men skilled in diagnosing disease according to the categories of Oriental medicine who would then prepare prescriptions in accordance with their diagnosis (Kim 1998: 190–92).

This growing popularity of Oriental medicine among the general population stimulated not only the greater use of indigenous materia medica but also the indigenization of medical theory. Near the end of the nineteenth century, an amateur physician supplemented the medical theory imported from China with some additional reflections on the relationship between differences in individual physical constitutions and differences in responses to medical treatment. Lee Je-ma (1838–1900) suggested that every human being could be assigned to one of four separate and distinct physiological categories, depending on which of four emotions (sorrow, anger, joy, and pleasure) dominated that individual's personality. He recommended that physicians determine which of those four constitutional types best described a patient before they treated him or her, since he believed that the same outward symptoms were manifestations of different internal malfunctions in different physiological types. The physiological category applied to a patient was determined by the emotion that patient tended to display to excess. Someone prone to sudden outbursts of anger, for example, would damage his liver and would therefore have a physiology different from someone who was too quick to indulge in sensual pleasure and would therefore have damaged lungs (Lee Je-ma).

Lee's unique "Four Constitutions" approach to diagnosis and treatment has become increasingly popular in Korea in recent decades. However, before Koreans could create a Koreanized Oriental medicine based in part on Lee Je-ma's hypotheses, they first had to overcome a drastic fall in status for Oriental medicine in Korea at the end of the nineteenth century and the first half of the twentieth (Fig. 3).

In 1884, Christian missionaries from North America entered Korea carrying both Bibles and doctor's satchels. Within a decade, government legitimation of Oriental medicine through state civil service examinations had ended and a hospital practicing the new biomedicine from the West had opened in Seoul with support from the Korean government. Korea's rush to modernization threatened to leave behind Korea's traditional medicine.

Practitioners of Oriental medicine did not vanish from Seoul. There were so few physicians trained in biomedicine on the Korean peninsula that the government found that it had to assign Oriental medicine doctors as medical officers for the modern army it began trying to build in 1896. Moreover, Oriental medicine physicians remained on the staff on the Royal

Medicine in Korea. Fig. 3 Yi Jema. Reprinted courtesy of the Association of Korean Oriental Medicine.

Clinic and the Directorate of Medicine, since the royal family was still more comfortable with traditional medicine than with the new medicine from abroad. In addition, since most of the general population was also more comfortable with Oriental medicine than with biomedicine, and also because there were very few Koreans trained in biomedicine, the Joseon government decided to include Oriental medicine in its plans for the modernization of its public health system. In 1899 it opened the Gwangjewon (Seoul Public Hospital) which it staffed primarily with specialists in Oriental medicine. The next year, the government inaugurated a licensing system for all practitioners of Oriental medicine on the peninsula. This was the first time in Korean history that medical specialists who operated outside of the civil service had received any official certification of their expertise (Heo: 293–301; Shin 1999).

Oriental Medicine in Twentieth-Century Korea

In 1905, however, the Joseon dynasty lost most of its power to make its own decisions when the rising imperial power of Japan imposed Japanese advisors on the Korean government. Five years later, in 1910, the last vestiges of Korean autonomy ended when Japan turned Korea into a colony under direct Japanese control. The Japanese immediately embarked on a campaign to change Korea into a society more closely resembling modernizing Japan. That included changing traditional Korean medicine into the form of medicine Japan considered more compatible with the modern world, the biomedicine imported from the West. Oriental medicine had to wait until the Americans defeated the Japanese in 1945 and Korea recovered its autonomy before it could regain anything close to the respectability it had enjoyed prior to Japanese colonial rule.

The end of Japanese colonial rule created two competing governments on the peninsula, with different policies toward Oriental medicine. The Communist government of North Korea redefined Oriental medicine as the traditional medicine of the Korean people and therefore worthy of government support. An Institute for the Study of Eastern Medicine was established within North Korea's National Medical Science Center in the 1950s, decades before a similar research center received government funding in South Korea. North Korea also incorporated Oriental medicine into the national public health system long before South Korea assigned Oriental Medicine doctors to its rural health centers (Fig. 4).

In pro-Western South Korea, Oriental medicine had to overcome the assumption among South Korea's Westernized elite that Oriental medicine represented a past Korea needed to leave behind to win respect as a modern nation. A shortage of medical practitioners during the Korean War forced the government in 1952

Medicine in Korea. Fig. 4 Medicine Cabinets used by Korean Oriental Medicine Specialists. Copyright: Korea National Tourism Organization.

to formally recognize Oriental medicine doctors as physicians. This paved the way for official recognition of Oriental medicine clinics, as well as a state licensing examination for new Oriental Medicine Doctors (Yi 1977: 316). Formal recognition, however, did not win Oriental medicine doctors the high status and high incomes biomedical physicians enjoyed. Given the traditional Korean respect for educational credentials, parity with biomedicine had to wait until there were respected medical schools for Oriental medicine in Korea.

The first college in independent South Korea dedicated to preparing doctors of Oriental medicine opened its doors in 1953. Four years later it opened an attached Oriental Medicine Hospital. However, it ran into financial difficulties and was absorbed by Kyunghee University in 1965, which created an Oriental Medicine College within the Kyunghee University medical school. Kyunghee University quickly inaugurated a graduate program in Oriental medicine and in 1971 opened South Korea's first large Oriental medicine hospital as part of a newly opened Kyunghee University Medical Center. A year later Won'gwang University, also privately run, opened South Korea's second medical school for Oriental medicine. Won'gwang University added its own affiliated Oriental medicine hospital in 1975 (Yi: 317–319).

There are now 11 medical schools for Oriental medicine in South Korea, all established by private universities. There are also 147 Oriental medicine hospitals, all privately run, and over 8,000 Oriental medicine clinics. As yet, there are no schools of Oriental medicine at public universities, nor are there any government-run Oriental medicine hospitals. However, the growing respectability for Oriental medicine led the South Korean government to open the Korea Institute of Oriental Medicine in 1994 to coordinate research on the theory and practice of Oriental medicine.

That growing respectability has also been reflected in changes in the 1990s in South Korea's laws regulating providers of medical care. Graduates of colleges of Oriental medicine are now allowed to fulfill their obligatory term of military service as medical officers in the South Korean military, just as graduates of colleges of other medical colleges have done since the establishment of the Republic of Korea in 1948. They may also be assigned to responsible positions in public health centers, something not permitted before the 1990s. In addition, in 1996 the law regulating pharmacists was changed to recognize those who had graduated from a pharmacology department of a college of Oriental medicine as certified specialists in Oriental pharmacology. In 1992 South Korea's national medical insurance system recognized this increased respectability of Oriental medicine by adding coverage for a few basic prescriptions to the coverage established in 1987 for acupuncture, moxibustion, and vacuum cupping.

One way Oriental medicine has regained respectability in the last decade of the twentieth century is through modernization. Korean Oriental medicine has become more compatible with modern urban life by adopting such markers of modernization as standardization and mechanization.

Traditionally, an Oriental medicine physician or pharmacist would modify prescriptions to meet the particular needs of a particular patient. It is still possible to obtain individually tailored prescriptions in South Korea today, but it is also possible to walk into a drug store and purchase packages of Oriental medicine prescriptions in mass-produced pill, granular, or liquid form, no different in appearance from many medicines produced in the factories of Western pharmaceutical companies.

Similarly, patients who visit an Oriental medicine hospital for a physical examination might find that their blood pressure is checked the same way it would be checked in a biomedical clinic, although they may also have their pulse checked by a machine which will produce a result framed in terms of the traditional 27 measures of the pulse in Oriental medicine. In addition to an electrocardiogram evaluating how well their heart is functioning, they may encounter another mechanical device that will evaluate the flow of vital energy through their hands and feet.

Not only diagnosis but also treatment, particularly acupuncture, has been modernized as well. The traditional insertion of needles into specific points along the vital energy channels is still practiced, but now those needles sometimes are electrified to provide additional stimulus to vital energy. Lasers are also used to enhance the effectiveness of acupuncture needles. For the treatment of pain, sometimes bee venom is injected into an acupuncture point in a treatment called "medicinal acupuncture." Tapping is another variant on traditional acupuncture. Tape is pasted over an acupuncture point, stretching the muscles and stimulating the vital energy flowing through that point.

Whether Oriental medicine in Korea is a unique Korean approach to health and healing or whether it is a Korean variant of traditional Chinese medicine, it is nonetheless seen by Koreans today as a legacy of their traditional culture worth preserving. Oriental medicine has not been supplanted by biomedicine in twentieth-century Korea. On the contrary, Oriental medicine flourishes alongside biomedicine, in a complementary rather than an antagonistic relationship. That complementary relationship is revealed in the presence of family practice biomedical physicians staffing the emergency rooms of Oriental medicine hospitals. It also appears in the advice of a biomedical physician to a patient recovering from a stroke to visit an acupuncturist, or in the advice of an Oriental medicine physician to a patient suffering from appendicitis to hurry to the emergency room of a biomedicine hospital. For most Koreans today, biomedicine remains the medicine of choice for acute medical problems or for problems requiring surgery. However, Oriental medicine remains the medicine of choice for chronic pain, fatigue, or the ravages of old age. If recent past history is any guide, it is likely that Oriental medicine will remain a viable and vital partner of biomedicine in Korea for decades, if not centuries, to come.

Extra 1

Some nationalists claim that needle-shaped bits of stone found in excavations of Neolithic villages on the Korean peninsula prove that Koreans rather than the Chinese invented acupuncture. Other nationalists cite references to mugwort and garlic in the ancient myth of Dan'gun as "proof" that what non-Koreans call Chinese medicine arose independently in Korea over four millennia ago. Few scholars outside Korea accept such claims. (Kim. *Han'guk uihaksa* [A History of Medicine in Korea] Seoul: Tamgudang 1981: 14–28.)

Extra 2

Recently, one Korean claims to have greatly simplified acupuncture. Yu Tae-u, the founder of hand acupuncture, claims that he discovered in the 1970s that all the acupuncture points on the body have counterparts on the hand and that stimulation of those points on the hand is just as effective as stimulation of the corresponding points on the other parts of the body. Few mainstream doctors of Oriental medicine in Korea accept Yu's restriction of acupuncture to the hand, though hand acupuncture had become popular among the general population as a form of self-medication. It has also gained adherents in Japan and North America (Yu Tae-u 1988).

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Medicine in Meso and South America

Ruben G. Mendoza

Ancient America provides a unique case study for examining the independent development of medicinal practices and technologies in non-Western societal contexts (Majno 1975). Initial European contacts with New World cultures of the early sixteenth century made clear that aboriginal medical systems and technologies embodied principles of a holistic – mental, somatic, spiritual, and supernatural – approach to healing (Classen 1993; Guerra 1971; Lopez Austin 1971; Huber and Sandstorm 2001). While the great centers of New World civilization provide our most complete record of medical practices and technologies, many localized native populations contributed to the extensive body of technical knowledge and expertise associated with herbal, chemical, surgical, extrasomatic, or ritual approaches to healing and public hygiene (Ankl 2002; Gall 1997; Kunow 2003). From South American gold and other metal-based dental fillings, cranial trephination, postcranial surgery, and coca-based anesthetics, to Mesoamerican intramedullar nails, medicinal enemas, surgical sutures and cauterization, caesarean sections, topical anesthetics, poultices, and birth control, the list of ancient American medical practices and technologies is as impressive as it is extensive (Mendoza 2003).

Because of the breadth and diversity of these practices in the Americas, we can only examine a narrow sampling specific to ancient Mesoamerica and Peru. The following discussion will move from a consideration of basic Native American concepts pertaining to the causes of disease to the examination of specific case studies concerning the development and sophistication of Native American practices. The perspectives in question are drawn from contact era sixteenth-century accounts of the Aztec and Inca civilizations. One should bear in mind that the New World Inquisition inhibited and condemned the exercise of Native American medical practices. Through the entire duration of the colonial era (ca. AD 1521–1824) these practices were thought to be the work of sorcerers and other native practitioners in league with the Devil (Cobo 1990). European colonials actively sought to destroy ancient medical works, along with pagan practices and practitioners, throughout the contact era. While early chroniclers attempted to document such practices, they openly disparaged them, and every effort was made to minimize their significance by comparison with European practices of the time by way of blatantly ethnocentric and racist assumptions about the mental life and intellectual contributions and potential of America's aboriginal inhabitants. In those few instances where a concerted scientific effort was made to collect information on the medical practices of such groups as the Aztec (Sahagun 1932), the distribution or publication of such works was prohibited for centuries (Cruz, Bylan and Gates 2000).

Much of our knowledge of contact era medical practices is derived from the detailed chronicles compiled to document the cultural history of the Aztec

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and Inca civilizations. For example, medical anthropologist Bernard Ortiz de Montellano (1990) has subdivided Aztec concepts pertaining to the causes and treatment of disease into three categories: supernatural or religious, magical, and natural or physical. He indicates that the Aztec held a holistic world view pertaining to the causes and cures of disease, and refers us to the work of Mexican ethnohistorian, Lopez Austin: "the origin of illness is complex, including and often intertwining two types of causes: those that we would call natural – excesses, accidents, deficiencies, exposure to sudden temperature changes, contagions and the like – and those caused by the intervention of nonhuman beings or of human beings with more than normal powers. For example, a native could think that his rheumatic problems came from the supreme will of Titlacahuan, from the punishment sent by the tlaloque for not having performed a certain rite, from direct attack by a being who inhabited a certain spring, and from prolonged chilling in cold water; the native would not consider it all as a confluence of diverse causes but as a complex" (Lopez Austin 1974: 216–217). This complex view required that the physician reconcile a variety of conceptual, spiritual, and physical dimensions in the course of diagnosis and treatment. Aztec doctors were required to balance herbal and other chemical treatments with interpretive models of causation ranging from the supernatural and magical to the natural, or a complex mix of both (Cichewicz and Thorpe 1996). The supernatural and magical, encompassing astrological interpretations such as those prevalent in sixteenth-century Europe, were of the greatest interest to early contact-era European chroniclers (Majna 1986).

Botanical Knowledge

While the botanical repertoire of New World peoples is discussed elsewhere within this encyclopedia, the relative significance of botanical specimens and knowledge to New World medical traditions necessitates brief consideration. It should be noted that recent research in this area makes clear the great contributions made by Native Americans (Schultes 1994; Lux 2001; Lopez Austin 1974). The surviving Aztec herbal known as the *Codex Badianus* provides one of the most extensive listings of botanical specimens identified with the medication and treatment of a variety of ailments (Cruz Byland, and Gates 2000). However, in his efforts to make the herbal, authored by the Aztec doctor Martin de la Cruz, palatable to a European audience, Juan Badiano, the chronicler who prepared the document for submission to King Charles, modified it to incorporate European medical beliefs regarding the role played by temperature in illness, diagnosis, and treatment.

The large body of medicinal knowledge identified with the Americas, and subsequently adopted by European-based medical systems, included such ancient Native American medicinal and hallucinogenic substances as coca (*Erythroxylon coca*), mescaline (*Lophophora williamsii*), nicotine (*Nicotiana tabacum*), quinine (*Quina cinchona*), psilocyben (*Psilocybe mexicana*), dopamine (*Carnegiea gigantea*), anodyne analgesics (*Solandra guerrerensis*), the ergot alkoloid D-lysergic acid (*Ipomoea violacea*), and genipen-based antibacterial agents (*Chlorophora tinctoria*). To this list may be added medications and related chemicals and supplements ranging from *N*-dimethylhistamine to atropine, seratonin, tryptamine, kaempferol, prosopine, pectin, and camphor – to name but a few. These served Aztec physicians in a variety of capacities. Ortiz de Montellano (1990) has documented the medicinal properties of many of the herbal and chemical treatments administered by Aztec physicians. Included in that listing are diuretics, laxatives, sedatives, soporifics, purgatives, astringents, hemostats, hallucinogens, anesthetics, emetics, oxytocics, diaphoretics, and anthelmintics. Furthermore, there were a variety of antibiotic or antiseptic treatments for treating wounds, medicating infections and fractures, and performing surgery. These included the herbal vasoconstrictor *comelina pallida,* maguey or agave sap, for its hemolytic, osmotic, and detergent effects, hot urine in lieu of other available sources of sterile water, and mixtures of salt and honey which have been determined to provide enhanced antiseptic functions.

Recent studies of the "hidden chemical wealth of plants" used by the Native American tribes of the Amazon rain forest provide but one more point of departure for gauging the range and extent of pre-Columbian medical traditions (Schultes 1994). In his summary of the pharmacology of the Kofan and Witoto tribes of the Amazon Basin, ethnobotanist Richard Evans Schultes has observed that "the forest peoples' acquaintance with plants is subtle as well as extensive. The Indians often distinguish "kinds" of a plant that appear indistinguishable, even to the experienced taxonomic botanist." This taxonomic acuteness extends to the level of being able to distinguish chemovars, or the basic chemical constitution of a specific subvariety, by visual inspection alone. Despite an estimated 80,000 species of higher plants in the Amazon, fewer than 10% have been "subjected to even superficial chemical analysis (Schultes 1994)." Such a store of indigenous botanical knowledge recently prompted Schultes to ask "why not regard the Indians of the Amazon Basin as a kind of phytochemical rapid-assessment team already on the ground?"

Medical Specialists and Personnel

While it is clear from all accounts that herbal specialists existed in all regions of pre-Columbian America, the existence of a broader corps of trained medical specialists and personnel is less evenly documented. So intent were early contact-era European chroniclers on disparaging and discouraging pagan forms of medicine that much was done to reduce the role of medical specialists from Native American communities. In most instances, medical specialists ranging from herbalists to physicians were simply characterized as sorcerers or charlatans. Given the relatively impoverished state of European medicinal practices of the early sixteenth century, it is no wonder that most European chroniclers of Native American medical traditions expressed outright contempt for Native American physicians and their medical practices and traditions. Despite deliberate errors of omission and commission, surviving documents provide indications of the broad sophistication in Native American medicinal practices.

As for the documented existence of a scientific tradition with trained practitioners specialized in specific forms of surgical treatment, we are informed by archaeologist Burland (1967) that, in a region above Lima, Peru, there existed an ethnic enclave known as the Yauyos with whom the Inca collaborated in the training of specialists in the art of cranial trephination or skull surgery. The patient was drugged, and pain was alleviated by way of the application of direct pressure to nerve endings in the affected area. In such instances, trephination was used only as a last resort, whereby the diseased or smashed bone was cut away from the skull. Other forms of surgery included the "removal of a torn spleen, cleaning out of ulcers, and the cleaning and after-care of wounds" (Burland 1967). Professional alliances between the Inca and Yauyo allowed for the exchange of technical knowledge and technicians. Accounts of the work of Yauyo physicians indicate that they were highly trained and had developed a formal discipline based on a corp of specialists. Apparently, herbal specialists of highland Peru were organized into "local confraternities," while medical specialists and physicians – *camasca* or *soncoyoc* – were sponsored by the Inca state and "highly trained within their own kind of collegiate discipline." This latter point is of paramount significance in establishing the existence of a specialized corps of medical personnel, and as such, the makings of a formally constituted and state-sponsored scientific tradition specialized in the treatment and trephination of the human cranium.

According to medical historian Gordon Schendel (1968), technical distinctions were made between "old" and "new" school physicians. At European contact, old school physicians were thought of as more traditional and more adept at conveying medical and spiritual beliefs pertaining to the art of healing, whereas the physicians of the new school engaged specialized methods and medical procedures. Among the Aztec, medical specialists included the *tlana-tepat-ticitl* or healer who "cured with medicines which were digested or applied on the skin" (Guzman Peredo 1985), the *texoxotlaticitl* or surgeon whose skills included bloodletting, and the *papiani-papamacani* or herbalist. Other terms utilized to identify Aztec medical specialists included *texoxtl*, or surgeons, and the *tlamatepatli* or medical interns of the *texoxtl* surgeons. The *tecoani* were the bloodletters; the *temixiuitiani* were the midwives. The *papiani* were the pharmacologists or herbal pharmacists. The *panamacani* are identified with pharmacognosists, or those individuals specialized in the identification; collection, and dispensing of herbal remedies, a specialty not unlike that of the plant pharmacologists of the Amazon Basin. Schendel has also documented the existence of a variety of specialists and areas of medical specialization, including internists, psychiatrists or psychotherapists, anesthesiologists, dermatologists, dentists, obstetricians, gynecologists, orthopediatricians, ophthamologists, urinogenital surgeons, and other practitioners specialized in the administration of tonsillectomy and embryotomy. In all areas of medical endeavor, specialists were held accountable for their actions and practices by their peers, as well as by the community at large.

Other specialists included those who used chiropractic methods, whereby "these doctors, in the case of falls, usually strip the patient and rub his flesh; they make him lie face downwards and step on his back. I have seen this myself, and I have heard patients say that they felt better… the pity of it is that there are even Spanish men and women who believe them (Aztec physicians) and are manipulated to serve their needs and evil" (Cervantes de Salazar 1936, as cited in Guzman Peredo 1985). Spanish Friar Bernardino de Sahagun commended the technical expertise of Aztec physicians and noted that they "had great knowledge of vegetables; moreover, they knew how to perform bloodletting and to reduce dislocated bones and fractures. They made incisions. They healed sores and the gout. They cut the fleshy excrescence in cases of ophthalmia (inflammation of the eyes)."

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Surgical Practices

As our discussion of medical specializations makes clear, pre-Columbian medical practices, particularly those pertaining to surgical methods, were comprehensive and sophisticated in scope. According to conquest period chronicles, "Aztec battle surgeons tended their wounded skillfully and healed them faster than did the Spanish surgeons … [and] … one area of clear Aztec superiority over the Spanish was the treatment of wounds. European wound treatment at that time consisted of cauterization with boiling oil and reciting of prayers while waiting for infection to develop the 'laudable pus' that was seen as a good sign" (as cited in Ortiz de Montellano 1990). Medical historian Miguel Guzman Peredo (1985) cites Fray Bernardino de Sahagun: "Cuts and wounds on the nose after an accident had to be treated by suturing with hair from the head and by applying to the stitches and the wound white honey and salt. After this, if the nose fell off or if the treatment was a failure, an artificial nose took the place of the real one. Wounds on the lips had to be sutured with hair from the head, and afterwards melted juice from the maguey plant, called meulli, was poured on the wound; if, however, after the cure, an ugly blemish remained, an incision had to be made and the wound had to be burned and sutured again with hair and treated with melted meulli." This citation makes clear the availability of prosthetic or cosmetic devices, the use of sutures, and the application of maguey or agave sap as an antibiotic ointment.

The Aztec also maintained a complex typology for mapping human anatomy and physiology. They identified specific body parts, organs, and their respective biological functions, and employed anatomical terms for the articular surfaces and attachments of limbs, as for instance in the use of the terms *acolli, moliztli, maquechtli,* and *tlanquaitl*, for the articulation of the shoulder, elbow, wrist, and knee, respectively. According to Guzman Peredo, "those physicians had more than elementary concepts of the different organic functions. They knew, for example, of the circulation of the blood. They even became aware of the throbbing at the tip of the heart; this they called tetecuicaliztli. The radial pulse was called tlahuatl." Armed with such knowledge, the Aztec "used traction and counter traction to reduce fractures and sprains and splints to immobilize fractures" (Ortiz de Montellano 1990). Perhaps one of the most significant medical innovations concerns the use of the intramedullar nail. Bernardino de Sahagun (1932) noted that in instances where bone fractures failed to heal, "the bone is exposed; a very resinous stick is cut; it is inserted within the bone, bound within the incision, covered over with the medicine mentioned." The intramedullar nail was not rediscovered by Western medicine until well into the twentieth century.

The most outstanding example of the empirical reliability and effectiveness of a pre-Columbian medical tradition centering on surgical applications was the use of cranial trephination or skull surgery (Mendoza 2003). Examples of the practice have been documented from throughout South, Middle, and North America. An extensive review of this practice can be found elsewhere in the encyclopedia.

Our review of pre-Columbian medicinal practices raises many more questions than can be addressed in this essay. Clearly, the European predilection for accommodating only that which suited prevailing eurocentric modes of thought contributed to the uneven documentation of significant Native American medical innovations and practices. A selected recounting of significant innovations should take into account practices centered on (a) holistic concepts of health, (b) state-sponsored public health programs, (c) an extensive body of anatomical terminology, (d) the existence of confraternal medical associations and state-sponsored medical corps, and specific practices centered on medical innovations such as those pertaining to (e) cranial trephination, (f) prosthetic and cosmetic devices, (g) antibiotic and antiseptic ointments and medications, (h) intramedullar nails, (i) formal procedures for the maintenance of dental health and hygiene, (j) psycho- and logo-therapeutic, or image-based, psychological approaches, and not surprisingly, (k) the largest pharmacological repertoire of effective and affective herbal and chemical remedies ever documented in the ancient world. Ultimately, any assessment of pre-Columbian medical traditions and innovations will need to contend with the fact that scholars have only just begun to scratch the surface of this New World of lost science and tradition.

See also: ►Trephination, ►Ethnobotany

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Medicine of Native North Americans

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American Indian men and women practiced the first medicine in the Americas, and Native North American medicine took many forms. Some of the Native medicine ways worked much like modern biomedicine, but other forms of traditional Indian medicine differed greatly. The Indian medicine practiced in various communities was different among the thousands of tribes, bands, and groups of American Indian people. Thus, no "generic" Indian medicine ever existed, but most Native American medicine was holistic and practiced by men and women who drew on medicinal plants, prayers, power songs, and experience to heal people. Indian doctors varied in their approaches to curing, but most addressed the physical, mental, and spiritual relationship of humans to the larger world. The differences between Native American and Western medicine are important considerations for health care providers working with First Nations people who often think differently from non-Natives about disease, power, spirits, prayers, and the meaning of medicines.

Native North American Indians believe that medicine emerged with the creation of Indian people, and creative forces gave Native people the first medicine. Indian medicine took many forms, including spiritual medicine that entered the world in the form of positive and negative powers, forces, thoughts, and actions. For example, among some Indians, such as Navajos and Apaches, lightning is a positive force that can bring healing, but it is also a negative, harmful force. One Navajo woman once explained that she had suffered from a large sore on her thigh, which affected her entire body and brought her to the brink of death. A "hand trembler" diagnosed the young woman, explaining that she had become ill because a few days before her own birth, her mother had witnessed the awesome power of lightning that struck and killed an entire herd of sheep. The ill effects of the lightning manifested themselves in the girl and nearly killed her. A medicine man among the Diné (Navajos) performed a Lightning Way ceremony on the girl, and she lived to tell this story. Her sore disappeared, and she became *hozho* or whole, healthy once more.

Indian people brought medicine power with them from other places or "worlds" where they had once lived. In the creation stories of many tribes, the people moved about from one place to another, bringing with them both positive and negative power that they placed in the present world where it is still extant. Sometimes, they used this medicine power to recreate mountains, valleys, rivers, and lakes. As a result, the medicine power of former worlds can be found at certain places in the Americas. Members of some tribes still make pilgrimages to sacred places to pray and sing, make offerings, and hold ceremonies. Sometimes tribal members or medicine people go to these places to gather plants or collect soil for their medicine bundles, taking home with them a portion of the sacred earth that once had been brought here from former lands. Indian people know about these places, their histories, and their uses through ancient stories and songs. Sometimes, medicine people repeat these stores and songs as part of contemporary ceremonies that link the people of today to the ancient ones. In a sense, medicine ceremonies link people with the ancient times, rituals, and medicine, all of which is part of the healing ways of Indian people.

Thus, creation in American Indian medicine is critical to an understanding about the way Native Americans perceive of and use medicine. In addition to bringing soil from other lands and creating sacred space, many Native people believe that at the beginning of time, creative forces set aside certain places on earth and put healing power at the site. Many believe the power is still there in caves, rivers, mountains, stone formations, and other natural occurring places. In the past medicine men and women – or Indian doctors – harnessed this power and usually used it to help and heal their people, although some people could use the power to harm or kill. This concept of power usage is common among American Indians today, and it can be compared to medical doctors and other health officials using their medical knowledge to heal patients or harm them, depending on how they use their talents, skills, and knowledge. The "laws" governing the use of medicine power among American Indian peoples vary considerably from tribe to tribe and region to region.

But in general, Indian doctors, like Western doctors, are expected to use their power for the benefit of others, not to enhance themselves and their place in society.

No discussion of Indian medicine can discuss adequately the many aspects and ramifications of Indian medicine, because they vary considerably among tribes. However, a few shared concepts of Indian medicine exist in North America. First, people living within Native American communities – past and present – believe in unseen forces, powers, or strengths. The people believe that medicine power exists everywhere and within everything, animate, and inanimate. Thus, given the ability to access power, Indian doctors and others may draw medicine strength from rock formations, rivers, valleys, mountaintops, caves, trees, clouds, animals, oceans, fire, and wind. Indian people believe in such power and doctors harness the power to cure disease and prevent illness. The general belief in unseen forces helped Native American people bridge the gap between Indian beliefs about disease causation and Western medicine when Native people first learned about microorganisms that caused disease. American Indians understood bacteria and viruses in terms of unseen enemies, like the ones they had learned about in oral traditions. During the 1940s and 1950s, Navajo nurse Annie Wauneka used traditional beliefs about invisible power to inform her people about the tuberculosis bacterium, a new unseen enemy that had entered their communities.

Second, Native Americans generally believe that all things in the universe are connected and influenced by all other things. Just as the moon influences the tides and the slant of the sun effects the changing seasons, so does the cosmos influence Indian medicine. Destruction of a river by a man-made dam can influence the health of Indian people, and the treatment of one person by another can also affect wellness within an entire community. Third, Indian people believe that their heath and wellness depend on the continuance of prayers, songs, ceremonies, sacrifices, ritual acts, offerings, daily actions, and humor. Tribes often direct prayers for the benefit of the entire universe, not just their own people, because they are part of an enormous system. Every tribe has songs intended for the good of communities and individuals, and medicine people enjoy medicine songs given to them by unseen powers. Fourth, Indian doctors are respected within their own communities and among other Indian groups who know of the person's powers and use of medicine. In English, we refer to these men and women as priests, medicine people, Indian doctors, chiefs, shamans, and caciques. Fifth, all of these Indian doctors possess special medical knowledge and they can communicate with healing powers, summoning them for help during curing sessions and ceremonies. They often employ prayers, songs, stories, and material items such as feathers, tobacco, sage, sweet grass, pipes, and prayer sticks during their curing sessions. They have knowledge about these items or instruments of health, and they know when and how to use them. Sixth, medicine people have a deep understanding of the "laws" governing their communities, and they often interact with patients in discussions to discover the root cause of physical and psychological afflictions. When shaman cannot engage in such discussions because of the patient's condition or inability to communicate the problem, then the medicine people use their special ability to "see" deep within the person's mind and body to find the cause of the health problem. Scholars and contemporary Indians often refer to these laws as rules, customs, and taboos. Seventh, most Indian people commonly believe that everything in heaven and earth has a soul or spirit, because everything is part of the creation and thus related to everything else. The Great Mystery, Great Spirit, Creative Force, or God made all things, and so all things are interrelated and have power, including medicinal power.

Most American Indian communities would agree that medicine is interdisciplinary and woven into their specific cultures in unique ways. The medicine ways of one tribe or group may not be the same as another group. For Indian cultures, medicine is integrated into many aspects of culture, including religion, psychology, economics, and government. Traditionally, Native people lived their medicine every day because they believed it to be alive. Some Native Americans still think this way. Harmony and balance became the objective of Indian medicine in most communities in order to prevent and cure disease. Indians tied Indian medicine closely with seen and unseen forces that existed inside humans and throughout the universe, so that medicine involved the relationship of people to plants, people, places, animals, celestial bodies, and other elements of the natural world. For Indian people "medicine" could bring order and structure to the cosmos and control the forces, powers, and strengths that could influence the health of individuals and communities. In other words, outward forces – beyond humans – influence sickness and death, but so did activities of the individual and community. For example, among the Ajumawe of northern California, the people believe that only holy people or Indian doctors can ascend the heights of Akoyet or Mount Shasta, a sacred mountain that contains within its peak a basket holding all of the goodness of creation. If members of the tribe break this "law,", they place themselves, their families, unborn children, and communities in jeopardy of earthquakes, avalanches, fires, diseases, and death. Among the several tribes composing the Houdenosaunee, commonly called the

Six Nations of the Iroquois, men desiring to cut a false facemask from a live tree must complete prescribed rituals before harming the tree. Otherwise, the health of the carver and others could be compromised. According to an Iglulik woman named Nanoraq from Baffin Bay, "The sickness is due to my own fault. I have not performed my duties well. My thoughts have been bad and my actions evil." And Navajo people could become ill if they shook a tree imitating a bear or by stabbing a knife into a piece of meat. Both of these actions by Navajo people could bring on violent behavior and cause illness among their people. Pima shaman Juan Gregorio once explained that his people could become ill if they did not pray properly before killing an animal, did not handle eagle feathers correctly, or failed to be respectful to desert tortoises. Every American Indian community had "laws" given to them at the time of creation, and they had to obey these laws or suffer disease, natural calamities, or death. Bringing individuals and communities back into balance with the laws occupied some of the duties of medicine people.

Indian medicine helped control forces that could harm the people, and it invited the good strengths to provide the people with abundant harvests, favorable weather, game animals, long lives, and freedom from diseases. The medicine offered Indian people social order, healthy directions, and prevention from illness in an uncertain world. As a result, Native Americans elevated the place of medicine into the realm of the holy and sacred, and those who successfully practiced medicine earned a special place within every community. Different levels of Indian medicine developed with various names, depending on the group, tribe, and region. Some medicine people danced, while others sang, created sacred art, diagnosed, offered herbal remedies, prayed, or helped conduct ceremonies. Indian people knew two larger forms of disease. Communal disease was caused by the transgressions of community members who did not obey the laws functioning within the tribes. Traveling disease included communicable diseases like measles, mumps, smallpox, chickenpox, influenza, and others, and was brought by newcomers. Indian doctors effectively controlled community disease, but they had a more difficult time addressing the new diseases that traveled from tribe to tribe, killing millions of Indian people after 1492.

Among the Indian tribes of North America, two larger categories or levels of Indian medicine existed and still exist today: common medicine and shamanistic medicine – both of which Indian doctors used to address community based diseases and traveling diseases. Within most Indian communities, family elders – particularly women – had a detailed grasp of herbal medicines. Among most Indian communities of the Eastern Woodlands, elders understood the medicinal qualities of sassafras root, which they used to make a tea and prevent and cure colds. The Eastern people along the Atlantic seaboard also used the fronds of the white cedar to make a tea that cured scurvy and relieved some of the painful symptoms of syphilis. Indian people across the West used creosote branches to create a tea to relieve sore throats, and they used the same remedy in larger doses to relieve constipation. Paiute–Shoshoni elder Dorothy Joseph once stated that as a child she never suffered from poison oak because each spring, her mother picked the new leaves of poison oak and had all her family consume a small number of the leaves, creating a temporary immunity. Indian families everywhere knew some of the uses of plants and how to prepare them properly. However, some of the elders knew botanical science far better than others, and they used their in-depth knowledge to help the people.

Very special individuals among all American Indian groups practiced another form of Indian medicine labeled "shamanistic" medicine. Shaman is a term derived from the Tungus people of Siberia, and in the twentieth century, scholars have applied the term to Native Americans. All American Indian languages had words for different kinds of shamans, medicine people, or Indian doctors. Several different types of shamans exist today, just as they did in the past, although their numbers have been reduced over time. Shamans know herbal medicines as well as anyone within their communities, but they also know how to diagnose and cure their patients through spirit medicine. The people expect shamans to work for the good of the community and to help restore the balance within individuals, families, and communities. Most often, Native people pay for the services of a shaman, and sometimes a fee is negotiated before the healing takes place. In the past, families paid for the skills of shaman with trade items, food, furs, wampum belts, and other items. Today, this practice continues in some parts of North America, but more often, people pay Indian doctors in currency.

While most Indian people learned to appreciate and understand some aspects of medicine, Indian doctors had special knowledge of the Native medical field. Indian doctors became familiar with the unexplainable light and knowledge of unseen forces, and opened their minds to receive healing power. They usually gained such knowledge through prayers, songs, dreams, visions, and experiences that brought them into a new realm of understanding and power to heal the sick, control the weather, find lost objects, prophesize, interpret future events, and see into the minds and bodies of their people. Shaman received their power at sacred places away from human habitations, deep in the forests, within the depth of hot springs, in caves, and on mountains. They received power at these sites and converted the powers into energy to heal others. Each medicine person had his own power or powers. In the late nineteenth century, a spring and water bugs gave Wenatchi elder Texanap her power and song, which became so uncontrollable that as a young woman, Texanap could not walk. Her father, a powerful shaman, built five fires, set a post in the middle of the village, and sang. In a community ceremony, Texanap controlled her spirit power, used the pole to stand, and threw her hair into each fire without it burning. In this way, she gained control of her medicine power, which she used to heal others.

The first shaman among the Iglulik came forward to help his people when they were starving because of the lack of game animals. According to oral tradition, he traveled to the bottom of the ocean to visit Arnaluk takanaluk, "the woman down there,", the controller of the animals. He spoke with her, pleaded his case, and asked for animals to visit his people again to save them from certain death. The mother of marine animals responded kindly to his request. The animals came to the people and gave of themselves so that the Iglulik could survive, and they did. This shaman used his power to bring the animals back to the people so they would not die. Indian doctors from other tribes also helped their people in other unique ways, including an Indian doctor among the Mojave of western Arizona and eastern California. He helped his people who were suffering from a tuberculosis epidemic in the late nineteenth century. He reported that even before his birth, he knew he was destined to be a shaman because he had traveled in dreams to the sacred mountain of Avekwame to meet the creator and power source, Kumastahmo. After tuberculosis arrived in the Mojave villages along the Colorado River, the Indian doctor dream-traveled to the mountain where he found Kumastahmo spitting up blood. The creator told the shaman to suck his chest, and so the Indian doctor did so, learning directly from the god how to become a "consumption doctor.". This technique of sucking out poison, foreign objects, and negative power found within a patient's body is a common technique among many shamans. The Mojave doctor reportedly could suck out the disease and destroy it in Mojave patients, and his story is a unique adaptation of a traditional medicine technique used on "traveling" or infectious disease.

Less well known are the smoke doctors who use tobacco smoke to find illnesses, and breath doctors who use their breath and labored breathing technique to open up air and blood blockages in the mind and body. Without surgery, the breath doctors enter the body, find blockages, and use their breath to penetrate the body and remove the objects obstructing the flow of oxygen and blood. Some doctors also rely on dreams and trances that take them inside the body where they locate and destroy disease through thought energy. Such techniques of Indian doctoring may seem fanciful to people accustomed to or trained in Western medicine, and shortly after the arrival of non-Natives, some newcomers described Indian shamans as fakes, frauds, and "witchdoctors,", a representation that tied Indian medicine to Satan and the occult. For Indian people, however, many mysteries surrounded the methods used by their shaman who enjoyed sacred spiritual medical knowledge. However, most Native North Americans believed in the medical techniques of shamans and many still do today.

Wintu shaman Flora Jones of northern California died recently, but her work is well recorded by Indians and scholars alike. She earned a positive reputation as an Indian healer. She used many powerful spirits in her healing ceremonies, including star spirits, moon spirits, and mountain spirits. Other powers also came to her, but she had to order and structure them in order to travel to the site of the sickness and remove them. Like some other Indian doctors, Flora fell into a trance or altered state of consciousness, and spirits spoke through her to diagnose and establish a plan of curing. In severe cases, Flora conducted a Soul Dance, bringing greater power to and through her to help heal her patient. She had her own healing songs, procedures, and material items, which she used in her healing.

In their healing ceremonies, shamans often use a variety of material items to further their healing rituals, including feathers, plant pollens, pipes, tobacco, and other leaves, sand paintings, fans, prayer sticks, soils, crystals, and other items, depending on their power and instructions received from helping spirits. The power vested in these sacred objects also may speak to the shaman instructing the doctor to use particular herbal remedies or specific techniques, such as "roasting" the patient. In this form of treatment, doctors dug holes into the ground, built fires to heat the area, then covered the fire with soil and blankets so that the patients could be buried in the warm pit with their heads above ground. The patient sat or lay down in the ground while the doctor sang and prayed, allowing the warmth of the earth to help the person with blood flow and reproductive problems. In addition to the warmth of the earth, the patient received the spiritual security of the earth wrapped around his body, and some patients felt a rebirth as they stepped out of the pit.

Some shamans worked their medicine in secular sites, while other took their patients to sacred places. In the early twentieth century, Serrano Martha Manuel stepped on spirit power set out by Cahuilla shaman Ignacio Ormego who had warned Martha and her cousin, Vincent Morongo, not to play in the area. Martha became violently ill and could not speak or walk; she ran a high temperature. Her family first took her to Dr. John Evans who placed Martha in a hospital in San Bernardino, California, but after a few days of not being able to diagnose her sickness, Martha's family took her by wagon to Palm Springs, California, where *pul amnahwet* or the highest-ranking Cahuilla shaman, Pedro Chino, doctored Martha. He lay the girl in the sun to help expose her illness. Chino used the power of the hot springs to diagnose Martha's problem, which took him considerable time. He found her sickness in her leg, which he sucked, drawing out a white worm that he showed to his family before destroying it. Martha's fever declined and she gained her ability to walk. She recovered fully, telling Chino and her family of Ormego's warning, and she also said that during her ordeal, she saw several tiny men dressed in black suits, all the same person, running about her leg. The family believes that Martha had seen her relative Pakuma or Santos Manuel, another powerful shaman who had died years before.

Among many Indian people of Southern California, Indian doctoring took place in the Big House or Ceremonial House, and this is still true in central and northern California where tribes have active Dance or Ceremonial Houses. Indian people throughout North America build special lodges for healing ceremonies, including the Medicine Lodge for the Sun or Thirst Dances, tipis for the peyote church, and pole and mat longhouses for the Nez Perce, Yakama, Umatilla, and other tribes of the inland Northwest. Navajos use female hogans for their healing ceremonies, and the people of the Northwest Coast use cedar plank houses for healing ceremonies. Other tribes construct wickiups, log longhouses, kivas, earthen lodges, wigwams, brush shelters, and other dwellings, creating a man-made environment or sacred spaces for their medicine ceremonies and rituals. Nearly all tribes in North America also used sweat lodges to purify minds and bodies, a place to invite the spirits to visit, inform, and heal. Shamans used the lodges and special places as part of their medicine, drawing on various means to follow, find, and eliminate the sources of illness.

Generally, Indian doctors learned from others and pragmatically employed new plants, techniques, and ideas in dealing with the sick. When they found that new ways improved the health of their people, they often adapted and adopted the new medicine. After the Columbian encounter of 1492, Indian people throughout the Americas suffered high death rates because of the lack of natural immunities to contagious or "traveling" disease brought to the Native universe. Since Europeans could barely control diseases, American Indian shamans could not benefit greatly from the medical knowledge of the newcomers. However, contact with the newcomers helped medicine men and women understand more about infectious diseases and to fear the spread of epidemics. Indians in some parts of North America became more familiar with Western medicine after the United States and Canada established forts in Indian country where medical doctors first interacted with some Indian patients. Varying numbers of Indian people sought relief of their ailments from medical doctors. Some doctors, like Washington Matthews among the Navajo and James Walker among the Lakota, learned well from Indian people and their Indian doctors. Others denigrated Indian doctors, referring to them as quacks and charlatans. Still, by the late nineteenth century, Indian and non-Indian medicine began to converge, most often with Indians listening and learning about infectious disease causation and spread.

In 1879, the United States created its first off-reservation boarding school at Carlisle, Pennsylvania, where children became ill and died of infectious diseases, especially measles and tuberculosis.[1] As part of the curriculum at Carlisle and other Indian schools, students learned the cause and prevention of tuberculosis, particularly about the importance of isolating people known to have the disease. Through lectures, slide presentations, and pamphlets, students learned about diseases, and they took their knowledge home to share with their people. During the late nineteenth century and early twentieth century, Indians living on the reservations of Canada and the United States suffered greatly from tuberculosis, measles, influenza, smallpox, chickenpox, mumps, trachoma, accidental deaths, and a host of gastro-intestinal diseases. These diseases also ravaged the Native populations of Mexico and the other countries of Latin America. In the United States, the Office of Indian affairs had a medical division that relied on a few medical doctors often contracted to conduct part time work with Indians. In Southern California during the 1880s and 1890s, for example, the Indian office hired one medical doctor to serve thousands of Indians from the Chumash villages surrounding the Santa Barbara region east to the Colorado River and south to the Mexican border. Neither the Congress nor the Indian Office funded Indian health, and in Canada, the federal government often contracted missionary doctors to serve Native

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[1] The horror of the Carlisle and other Indian schools is not dealt with in this article, but we urge the reader to read more. See Jessica Enoch, "Resisting the Script of Indian Education: Zitkala Ša and the Carlisle Indian School." *College English* 65.2 (2002): 117–142. See also Clifford E. Trafzer, Jean Keller, and Lorene Sisquoc, eds. *Boarding School Blues*. Lincoln: University of Nebraska Press, forthcoming 2006.

populations. Thousands of Indians died as a result, in spite of the heroic efforts of traditional medicine men and women as well as some medical doctors.

National reforms focusing on Indians during the 1920s and 1930s led the United States and Canada to direct more money to Indian health and the high mortality – including high infant mortality – caused by tuberculosis. Medical personnel also tackled trachoma, often resorting to radical grattage (scraping the eyes with a stuff brush) on Indian patients. Both countries hired more doctors, established more hospitals, and built sanatoria for Indian patients. Both countries also hired public health nurses who became the front line forces of Western medicine, treating Indian people on reservations, reserves, and remote regions of the Arctic. From the 1920s to the 1970s, field nurses traveled thousands of miles each year in automobiles, hydroplanes, dog sleds, wagons, horseback, and on foot to visit reservation populations. Like the teachers in boarding schools, they taught people to identify signs of tuberculosis. Nurses isolated Indian patients, drove Indians to hospitals, conducted clinics, informed mothers at "well baby clinics,", directed Indians to X-ray screenings, and visited families on nearly all the reservations. Their efforts may have influenced the decline of Indian deaths caused by tuberculosis in the late 1930s and early 1940s, before the Indian offices began to use antibiotics in its treatment of tuberculosis.

The Office of Indian Affairs did not provide Indians in the United States with high quality medical care as stipulated by treaties and the laws of Congress. In 1954, the Public Health Service took over the duties of providing Indian medical care through the Indian Health Service. The change proved significant to Indians in the United States, as the Public Health Service provided far better care than the Indian Bureau. Still, Indian health lagged behind that provided to most Americans, Canadians, and Mexicans. In both rural and urban areas, Indian people continue to suffer high infant mortality rates and deaths caused by infectious diseases. However, after World War II, a new trend emerged within Indian communities as more Indians began dying of man-made degenerative diseases such as heart disease, cancer, kidney problems, and complications due to type 2 diabetes, alcoholism, and suicides. Although health services for Indians improved during the late twentieth century, few Indians received first-rate medical care, and most still do not. However, the emergence of high stakes gaming among some tribes has made it possible for some Native Americans to buy their own health insurance and for tribes to partner with highly skilled physicians and the top medical institutions to offer tribal members better medical care. In 2003, Loma Linda University Medical Center, one of the nation's leading medical research institutions, launch a new American Indian health and wellness center and is currently working closely with the Chinook of Shoalwater Bay in Washington state, Shoshoni–Paiute of Fallon, Nevada, and Chemehuevis of the Twenty-Nine Palms Band. Although the Indian Health Service continues to play the significant role in Indian health today, the new partnerships of Indian nations with medical institutions and physicians shows great promise to improve the health of Native Americans throughout North America.

Today medicine among most Native Americans is a combination of traditional Indian medicine and Western medicine. While most Indians consult Western doctors and nurses and use hospitals, they continue to view disease, health, and medicine much like their ancestors. Shamans still perform healing ceremonies in many parts of Indian country and Indians still use common medicine taught to them by elders. Some Indians believe that the combination of Indian and Western medicine will lead to "new medicine" that relies on medical sciences and spirit medicine, particularly the power of prayer and material items taken from the earth.

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Medicine in Native North and South America

Åke Hultkrantz

"Medicine" is an ambiguous word in American Indian connections. The first European missionaries and settlers learned that in the aboriginal languages the word corresponding to medicine could also be translated as supernatural power. A "medicine man" could be a man who healed a human being, but also a kind of a miracle man who through his connections with the supernatural world of gods and spirits was able to prophesy the future, locate lost articles or persons, bring on rain, attract game animals, call on the spirits, escort the newly dead to the other world, and many other things. In short, he was, and still is, a mediator between humankind and the spiritual world. It is through his equipment of supernatural power that he can cure the sick. In this article medicine will be understood as the way of curing and as a medicament, except in the compound medicine man, which will retain its old composite meaning. The role of the medicine man in curing will be further elucidated below.

All medical measures depend upon the ideas of the character of the disease. Slight injuries and mild diseases are not interpreted so much in terms of supernatural agencies at work, but dangerous diseases – or diseases considered to be dangerous – are mostly referred to supernatural intervention. Ghosts, unknown spirits, disease demons, witches, or taboo infringements are supposed to be responsible for cases of illness. The supernatural causation is a consequence of the fact that the basic harmony between humankind (or parts of humankind) and the sacred Universe has become upset. Prayers and propitiatory rituals may enclose all kinds of healing procedures but are more common where more grave diseases are concerned.

Whereas the supernatural element in curing is clearly present in the serious cases of disease and damage, natural knowledge plays a dominant role in the curing of ordinary wounds and diseases. Medicine men and women could relieve the pain and remove the diseases of this latter kind, but it was also common for old men and women to take care of them, at least in North America. These old people who had learned their medical arts during a long life and furthermore had particularly observed the traditional healing systems of the tribe, to a large extent used herbal medicines. They could, therefore, be called herbalists. It is not too much to say that herbs, for external or internal usage, were the most common medical cures in aboriginal America.

There were many different kinds of treatments. In Algonquian New England the colonists found that people who had been scalded had their sore skin washed with a strong decoction of tobacco, and thereafter a powder made from dried tobacco was sprinkled on to the wound. More to the south, in North Carolina, seeds of *Datura* were used for the same purpose. Bleeding was arrested with spiderwebs in large parts of North America. James Adair, who was a well-known trader among the Southeastern North American Indians in the latter part of the eighteenth century, reports that every Cherokee carried a variety of herbs and roots such as snake-root and wild plantain in his shot pouch as a remedy for the bites of poisonous snakes (Adair 1775). The Indian chewed the root, swallowed a part of it, and applied another part to the wound. After some pain and contortions the man was relieved of the poison. Here we see how everybody was his/her own doctor.

From the same area the well-informed anthropologist Swanton (1928) reports that the Creek drank a cold decoction of "Devil's shoe-string," or catgut (*Tephrosia virginiana*), to relieve themselves of bladder trouble. They also boiled the roots of sassafras (*Sassafras officinalis*) into a hot drink to get rid of bowel and stomach ache. Sassafras seems to have been a health medicament wherever it occurred. Venereal diseases were also cured with herbal decoctions.

Herbalism was a subject in Aztec schools, and some herbalists were even examined in the priest schools, the *Calmecac*. They were known for their empirical approach to health. Ortiz de Montellano (1989) writes that "the efficacy of Aztec wound treatments has been validated, as well as their accurate knowledge of the physiological activities of plants. Their extensive ethnobotanical knowledge and accurate taxonomy indicates that herbals may have existed and were taught in school, although no genuine pre-Columbian herbal has survived." As the same author points out, it would, however, be wrong to postulate a distinction between empirical and supernatural knowledge among the Aztecs, for "good doctors also included those who used mixed therapies and psycho-religious techniques." In this respect the old Mexican doctors remind us of North American medicine men.

In South America herbalism is mainly thought of as a medical subfield of the medicine man. Herbalist specialists among the Araucanians might know up to 250 medicinal plants. Ackerknecht (1949), an authority on South American Indian medicine, has next to nothing to say about herbalism there. He points out, however, that such measures as massages, drugs, baths, bloodletting, diet and enemas do occur, and are "objectively effective." At the same time, the causation of such diseases, indeed, all diseases, is supernatural, he claims. Another expert, Métraux (1949), insists that "light and common ailments and the sicknesses introduced by the Whites often were regarded as natural and were treated with drugs rather than by

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shamanistic means." He admits, however, that most diseases were attributed to supernatural causes. It is obvious that these questions have not been satisfactorily investigated. Several works indicate that herbalism was very widespread in South America, but whether there were – and are – herbalists who could be classed as inspirationally initiated medicine men is not clear.

A herbalist is, as seen in this article, a person who primarily deals with herbal medicine for internal or external usage. Secondarily he or she also handles stimulant drugs, emetics, and, in some cases, surgical operations. In North America the *peyote* (*Lophophora williamsii*), a cactus growing in the vicinity of the Rio Grande, is supposed to cure all kinds of diseases when eaten, drunk, or smoked. Peyote is hallucinogenic but not narcotic; it is not habit-forming. A particular Peyote religion was formed at the end of the nineteenth century and spread over large areas of North America. The taking of peyote against disease occurs frequently in individual cases. In the cultic connections peyote is consumed because it gives supernatural blessings, including a medical cure. Peyote is powerful for many purposes, not just for medicine, although the medical reasons have been strongly supportive in the diffusion of the Peyote religion. It is very possible that other "herbs" have also had such a general effect because of their supernatural qualities. In South America narcotic beverages such as the *ayahuasca* prepared from the plant genus *Banisteriopsis* and the decoctions of *Datura arborea* are used in or after shamanic curing séances. Also here the drugs are active because of their spiritual force, and not because they have a specific medicinal content.

Some drugs have been favored since they have emetic qualities. In both North and South America poisonous or impure substances in the body are expelled from the mouth via emetics (and from the rectum via cathartics). The most well-known emetic is prepared from a particular holly, *Ilex vomitoria*, that grows in the southeastern part of North America. This drink, called "black drink" by the Whites because of its color, but "white drink" because of its supposed purifying qualities among the Indians of the Southeast, contains caffeine. Drunk in large quantities it provokes violent vomiting. This emetic was taken as a brew to produce purity before social and religious ceremonies – as ritual sweat baths in other areas – and in connection with diseases. The disease belonged to the impurities that were removed through the black drink.

There are some reputed cases of surgery in the old days; however, amputation seems to have been scarce. Scarification occurred in many places in North America. Thus, according to Frank Speck, the northeastern Algonquians tried to relieve pain by creating an exit for it. Skull surgery, or trepanation, is mentioned from both Americas. Some scholars have tried to find rational reasons behind such operations – head injuries, unconsciousness, and so on. Since they were performed in pre-Columbian times it is impossible to get a definite answer. However, it seems more in conformity with American Indian thinking to presuppose an animistic model of explanation: the surgeons wanted to relieve the sick person from the spirit that plagued him. The most common method was, however, to put some herb or bark on the wound or over the aching area.

If there is much uncertainty concerning the ideas of etiology and the nature of the healers in herbalism, there is more certainty of the medicine men and their disease ideology. As stated above, the medicine men and women, or those medicine men and women who are doctors, function as such when through their own or other healers' inspiration it can be stated that the disease is of supernatural origin. The medicine person was chosen by his/her guardian spirit to conquer the malign spiritual influence behind the disease. His or her healing is dependent upon the power with which he/she was entrusted in the course of his/her calling.

The supernatural aspect of religious causation can mean many things, for instance, that witches on account of their supernatural powers, or sorcerers because of their magical manipulations, upset the normal health of individuals. Or it can mean that transgression of tabooed places or actions, displeasing of the powers, or imbalance in the cosmic harmony cause the same result. Sometimes spirits and divinities introduce disease and wounds without any apparent reason. The immediate outcome of this supernatural line of action may be intrusion into a person's body of objects or spirits (which could be the same thing since objects may be inanimate manifestations of spirits, or instruments of spirits), and the loss of the soul which may be wandering around, or has been stolen by some witch or some spirit(s), usually the spirits of the dead. In the latter case the lost soul may be taken to the realm of the dead from which it is difficult for the medicine man to retrieve it and take it home. The soul entity that has been lost is usually a separable soul, mostly the free-soul, or the soul that sometimes distances itself from the body in dreams and trances. As long as the soul of vitality or, where it exists, the ego-soul remains with the body, the individual is alive; where all the souls (usually two souls, the free- and the body-soul) remain with the body the person is also alive. This is the general program, but many exceptions from this rule have been found among North and South American tribes.

There is a particular tendency among Native Americans to distinguish two definite systems of diseases behind the two causation theories. When the "intrusion" diagnosis is resorted to attention is directed to the body and its diseases. We can say that the patient's physical pain conducts the doctor. In "soul loss," however, it is the sick person's mental state that stands in focus. His intellectual power fades away, fever or absent-mindedness rule, he languishes away, loses his consciousness, and so on. Scholars have until fairly recently tried to show that intrusion was more common in America, and therefore is an older diagnosis, whereas soul loss has had a more spot-like distribution and is therefore a younger diagnosis. As will soon be seen, the latter diagnosis corresponds to more difficult healing procedures. However, the more field research has proceeded the more cases of soul loss have been discovered. The present distribution of diagnoses confirms the generalization made here. Of course, in some regions we find intrusion as the dominating complex, in others, soul loss. But the presence of both diagnoses – for different types of disease – seems to be the original pattern. In our days soul loss is missing in many places, but the memory of its application by capable medicine men some decades ago is living.

In some places, for instance among the Navajo, the decision of the nature of the disease is left to particular diagnosticians who, in an inspirational state, are capable of finding out the roots of the disease. A serious disease to them is always referred to as being a break with the invisible world and its spirits; the diagnosis is never concentrated on the biological state of the individual, but on the acting spiritual forces. Among the Navajo the disease means that the afflicted person has fallen out with the balance and harmony of the Universe, so he has to be reintroduced by being identified with the supernatural powers in nocturnal rituals of up to nine nights. The officiant is a sacerdotal singer, not the diagnostician. The former could be termed a priest, the latter a shaman.

Shaman is a Tungusian word denoting those medicine men who perform their services in a trance or ecstasy. The word has since the eighteenth century become a technical term for medicine men who communicate with supernatural beings in states of trance. The Natives in America rarely have a term for differentiating shamans from ordinary medicine men; usually a shaman is said to be a stronger healer than others. Shamans occur, or have occurred, over most areas in America. The large majority of them, but far from all of them, handle diseases. When the recovery demands contacts with or intervention from supernatural powers, the shaman appears on the scene in order to meet these powers in a trance situation.

All medicine men, shamans included, receive their doctor's powers through inheritance, spiritual calling, or vision quest. In the question of inheritance it is often possible to see who is going to become a doctor; he or she has a nervous psychic constitution or is reminiscent of a deceased medicine man. In South America it is not uncommon for a doctor to transfer his profession to his own sons or nephews. The calling of the spirits is more or less attached to the inheritance idea since the guardian spirits of a shaman try to find his successor in the same family. In The American Great Basin, California, and Gran Chaco are areas where shamans are called by the spirits. Sometimes this calling follows very aggressive lines, for instance, among the Mapuche of Southern Chile. Vision quests are used in the areas in eastern North America where ordinary individuals also seek guardian spirits in order to procure their powers and their protection. Shamanic spirits are stronger and more specialized in healing than other visionary spirits. The acquisition of spirits is connected with fasting and several days' staying out in the wilderness with the dangers of climate and wild animals. In South America the candidate smokes strong cigars and consumes *ayahuasca* wine in order to attain shamanic ecstasy. The novice also joins a medicine man school, or an experienced older shaman, in order to learn shamanic procedures and tricks.

The medicine man heals the patient partly through herbalism and partly through suction, blowing, massage, and wafting with feathers, to remove the disease object or disease spirit. In South America the medicine man may attain some degree of ecstasy by drinking *ayahuasca*, whereupon he blows thick clouds of tobacco into the patient's mouth. The disease object – an arrow, a dart – is sucked out by the medicine man and then regurgitated by him. In both Americas the medicine man often produces a little thing that he claims to have sucked out of the patient and that is supposed to have caused the disease.

In cases of soul loss the healing procedure is often more difficult and more dramatic. Let us, however, first of all state that the usual background of soul loss, the serious change of consciousness, in some places can be healed without too much difficulty on the part of the acting medicine man. Thus, sometimes the soul may be called back by the medicine man, or sought by him and his associates in the neighborhood of the camp or village. According to Karsten (1955), the Jivaro Indians at the sources of the Amazon River know no remedy for fever diseases but destroy their own villages and leave them, apparently in the belief that not soul loss, but attacks of disease demons have hit the patients. In North America, for instance among the Yuma, it happens that soul loss is cured through blowing and suction, a proof that the intrusion model of disease diagnosis has formed a general curing pattern here.

The most common cure of soul loss is that the medicine man – who in this case operates as shaman – sinks into a trance to transgress the boundary between this and the other world. In North America this entrance into ecstasy is mostly brought about through autosuggestion and drumming, and in South America narcotics such as tobacco and ayahuasca effect the same state. The shaman's soul, and in some cultures his guardian spirit (it also happens that he is transformed into his guardian spirit) then departs on the long road to the land of the dead. Sometimes he manages to catch up with the fleeing soul and can then return it to its owner. If however the soul of the sick patient has reached the land of the dead, the shaman has to risk his own life by seeking the fugitive soul in that realm and trying to persuade it to come back with him. In such cases the shaman has to fight violently with the mass of the departed who want to retain their newly arrived visitor. Usually the shaman wins the struggle and brings the patient's soul back home. He presses the soul against the patient's head or some other place, and after a short while the patient wakes up again. The shaman, who in most cases has been lying down as if he were dead during the soul journey, now also comes back to life.

Sometimes many shamans cooperate in a ritual drama in a so-called imitative shamanistic séance. An example of the latter is the voyage of shamans in a symbolical canoe to the land of the dead among the Puget Sound Coast Salish. The medicine men are equipped with boards which represent a canoe and paddles and act out the events of the voyage: the hardships on the journey, the battle with the dead, the release of the imprisoned soul, and its transporting home. Here it is not the question of a deep trance, but a dramatic performance in the inspired state of an actor.

Collective medical contributions are also given in some agricultural societies, such as the Pueblo societies in New Mexico and Arizona. They have curing organizations constituted of people who have once been ill and healed by the same organizations. Animal spirits, so-called Beast gods, are the patrons of the medical societies among the Zuni Pueblo Indians. The societies are specialized in curing particular diseases, and use the methods adopted by medicine men healing patients suffering from "intrusion" diseases.

See also: ►Religion and Science, ►Ethnobotany

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Medicine in Oceania

Cluny Macpherson

Accounts often portray 'indigenous' or traditional medicine as a culture-bound set of knowledge and practice, rooted in superstition and indigenous religion, which will eventually be displaced by a more powerful scientific biomedicine (Strathern and Strathern 1999). A study of traditional medicine in Oceania (and probably anywhere else) reveals that it is, in fact, a dynamic body which routinely incorporates new forms of medical knowledge, material and practice which have been shown to be effective, and which, in the process, becomes progressively more useful. The extent of this incorporation is often missed because its practitioners soon come to regard innovations as part of tradition, and because users often assume that since a traditional healer dispenses the medicine it derives from some indigenous medical repertoire. This makes it difficult to reconstruct traditional medical knowledge. It is, however, possible to reconstruct the trajectory of the incorporation and to identify the sources of new knowledge and the circumstances in which it occurred. In the Oceanic case, the late introduction of Western illnesses and medical knowledge, and the circumstances of their arrival, have meant that scientific biomedicine is considered a useful adjunct to, rather than a replacement for, traditional medicine and the two systems sit alongside one another as complementary elements of a healing system.

Some 5,500 years ago, people moved out of South China and, along two routes, into Oceania. Descendants of the original settlers moved steadily eastward, pausing only briefly while they developed the naval architecture and navigational knowledge to make the steadily longer voyages between ever more scattered easterly islands possible (Goetzfridt 1992). They eventually settled the furthest reaches of the last uninhabited region on earth with voyages to Aotearoa (New Zealand), Rapanui (Easter Island) and Hawaii some 900 years ago.

The path, progress and timing of the settlement of the Pacific have been confirmed by oral history, and by steadily growing volumes of linguistic, archaeological (Kirch 2002), anthropological (Kirch and Green 2001) and, more recently, DNA evidence. Studies of voyaging and navigation techniques and, more recently, a series of voyages in replica sailing vessels (Finney 1988) have confirmed that the required journeys could have been made with available nautical knowledge and technology, and have dispelled the earlier view (Sharp 1957) that these were accidental or drift voyages. Findings of ongoing research in each of these fields confirm this theory of easterly settlement and typically refine dates or clarify processes. There are now accepted explanations for the presence of the few elements which led to consideration of the possibility that Oceania had been settled from South America.

On the surface at least, it should be possible to trace continuities in the knowledge and practices of the settlers. There was little which would have been expected to transform established knowledge and practice as the explorers moved from west to east. The settlers, who were agriculturalists, carried a limited range of cultigens and technologies necessary to farm these. Beyond what is now New Guinea, they encountered no other peoples on their way eastward, and settlement occurred within a restricted range of terrestrial (Muller-Dombois and Rapaport 1999) and marine ecosystems within a relatively limited range of latitudes. Once settled, the Oceanic settler societies were only infrequently visited and then, typically, by Oceanic neighbours. This situation persisted until European explorers reached the region some 2,500 years later and limited the external influences on these Oceanic cultures. Despite thousands of years of separation, similarities are evident in the lexica of the Oceanic languages, and these have been recognized in the designation of an Austronesian language family (Pawley 1999). There is also evidence of the passage of some cultural traits from west to east, and explanations of why these might have taken various forms in different places (Kirch 1989; Kirch and Green 2001).

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Yet despite that, there is little evidence of the passage of a body of medical knowledge and practice from west to east.

That does not, however, mean that there was not a body of Oceanic medical knowledge and practice, but rather that it was not documented at contact, which had more to do with the worldviews of those who were in a position to record it. The earliest traders and missionaries typically dismissed the knowledge of indigenes as insignificant, and as artefacts of a worldview which they sought to modify or replace. By the time better educated missionaries and settlers became interested in documenting indigenous knowledge, much of what had existed had been either lost, transformed by, or fused with the introduced worldviews with which it had collided. Introduced material and beliefs had found their way into traditional medicine and, in some cases, even the practitioners were unaware of the extent of these incursions.

It has, as a consequence, become difficult to reconstruct the autochthonous medical knowledges of Oceania. There are numerous studies of traditional practices in contemporary Pacific societies (Feinberg 1979; Connell 1980; Parsons 1985; Whistler 1985, 1992, 1996), but few comprehensive reconstructions of pre-contact Pacific medical knowledge and practice. One exception is Samoa (Macpherson 1985; Macpherson and Macpherson 1990) which lies near the geographical centre of Oceania. This case is significant because of Samoa's place in the settlement of Oceania, and because it provides some insights into the dynamic nature of traditional knowledge.

Samoa was settled some 3,500 years ago, and a distinctive society developed over some 1,000 years before the bearers of this culture set out to settle the eastern reaches of Oceania. This case is culturally significant because Samoa lies at the boundary of Eastern and Western Polynesia, contains elements of western Polynesian culture, and is widely acknowledged as the birthplace of eastern Polynesian cultures. From the point of view of cultural reconstruction, Samoa is also significant. By the time European contact and settlement occurred in Samoa, there was more systematic interest in indigenous knowledge and practices, and a more comprehensive record, from authors with diverse personal and professional interests. These provided a more reliable basis for historical reconstruction. This study is used here as the basis of an account of what might have existed in Oceanic societies.

Samoans referred to health as *soifua mālōlōina* which means "life rested" and refers to a form of biosocial equilibrium.[1] It embodies the idea of balance in relations between individuals, the social entities to which they belonged, the physical environment in which they lived, and the supernatural realm within which all humanity existed. An individual exists at the intersection of a number of related realms. These linkages were called *va* and had to be consciously maintained, *teu,* by individuals who wished to maintain good health. Such relationships were ideally balanced and reciprocal, or *fealoa'i*, which implied mutual respect of rights and obligations which attached to related roles. This balance existed when norms of conduct for people in related roles were observed. Health was attained, and maintained, when a person attended to his or her relations with others and with the spiritual agencies, *atua* and *aitu,* which controlled human activity. An ordered society is one in which relations between the realms were in a form of equilibrium and is known as one in which relationships are balanced, *va fealoaloa'i*.

Conversely, ill health occurred where people violated the norms and rules of social and spiritual relations. Ill health was the consequence of offences against either social or supernatural agencies and the causes of everything from physical trauma to mental illnesses were sought in these areas of social and supernatural relationships (Turner 1983). These gods' influence was so pervasive, and their powers so extensive, that they were held to be the principal authors of all human illness. Gods generally created illnesses to punish people under their protection for a lack of appropriate respect or for acts of meanness to them. Various people, known as *taulāaitu* or *taula ole aitu,* or anchors of the spirits, acted as mediums and identified social and supernatural sources of an illness (Moyle 1974). In the case of supernatural causation, the medium sought to identify the offended spirit or god, to clarify the cause and offer the appropriate form of conciliation.

In other cases, offended living persons could call on another class of gods, known as *taula-aitu-vavalo-ma-fai-tu'i,* to make the offender ill. The resulting illness could take several forms, and the form gave some clues to the nature of the offence which, in turn, focused enquiries on people who might have committed it. Where social offence was suspected, a process of systematic enquiry led eventually to the offended person who had engaged in the sorcery which had created the illness, and to the form of social activity which would lead to its removal. This consisted of incantations directed at the identified spiritual agencies (Moyle 1974). Only when these causes were identified could the process of intervention commence, and only when this was completed and accepted, could relationships be restored.

The focus of activity in each case involved the identification of the relationships which had been

[1] It was also referred to as *la'oifua*, or "to be recovered from sickness", and in the language of chiefs, as *laumālie*.

disturbed, and the activity necessary to *teu le va* or heal the relationship. In most illnesses, the human body was simply the site in which the offended party had sought to demonstrate their displeasure. To complicate matters, the person who became ill was not always the one who had caused the offence, and so diagnostic inquiries had to extend to the conduct of those around the victim in case this person was a surrogate.

The level of agreement on an essentially social intervention process in the writings of a range of early observers of Samoan society was unexpected: traditional models of physiology, aetiology and epidemiology, an extensive, and apparently thriving, body of plant-based medicines and forms of massage are in use in contemporary Samoa (Macpherson and Macpherson 1990). This paradox led to consideration of the possibility that those who documented it were led by their religious and social agenda to focus on these elements of practice,[2] and to overlook either accidentally, or deliberately, other elements of Samoan medical practice. However, an examination of both religious and a number of secular authors' works suggested that there were only very rudimentary indigenous models of human anatomy and physiology and little in the way of biomedicine. Early missionary authors, such as Dr. George Turner, who sought information on medicinal uses for Samoan plants, reported that relatively little medicinal use was made of the local flora and fauna (Turner 1983). This was confirmed by other missionaries, and surprised them as they were themselves regular users of herbs and simples. Comprehensive and well-regarded dictionaries compiled by early missionary linguists (Pratt 1862) contained extensive lists of flora and fauna but few terms for medical implements or procedures, and few annotations of medicinal plant uses. Relatively few indigenous terms or concepts relating to human physiology or biology were discovered by these linguists. Early plant collections contained extensive notes on various practical uses of plants, but little evidence of medicinal uses (Powell 1868). Comprehensive studies of Samoan material culture located no implements used in medicine (Hiroa 1930).

This finding was remarkable, given that there is an extensive traditional knowledge and thriving traditional practice, and that Samoans make regular use of both traditional knowledge and practitioners, and flora and fauna in their search for health (Macpherson 1985; Macpherson and Macpherson 1990; Whistler 1996, 2000). The finding raised the issue of how missionaries and other settlers, who had so assiduously documented other areas of Samoan life, could have missed a body of traditional medicine.

One possibility canvassed was that the medicinal material and knowledge was, for various reasons, not revealed to early missionaries. Other forms of sacred knowledge, such as navigation, had been hidden from visitors to Oceania (Lewis 1972). In this case, the missions had sought to undermine belief in Samoans' traditional gods, and had ostracized those who had expressed continued support for them. The close association between the family and village gods and health and illness might then have been systematically hidden from missionary eyes by those who sought to retain their affiliation with the mission. This does not appear to be the case. Missionaries, who lived on mission stations with numbers of Samoans, were well placed to obtain this information but did not, and secular settlers who lived close to the Samoans (Pritchard 1863–1864; Pritchard 1866) also found little evidence of an extensive indigenous medical knowledge and practice. They were able to obtain information on and document a range of other sacred practices, and did so in the belief that their activity would be more successful where missionaries understood Samoan culture. Nor is it clear that Samoans were as completely dominated by missionary power as this explanation requires. At the turn of the nineteenth century, Samoans were reluctant to share medicinal knowledge, not out of fear of the missionaries, but out of suspicion that others might use it. The German naval physician, and pioneer ethnographer, Dr. Augustin Krämer, reported that Samoan healers would not share their knowledge with him because they believed he might expropriate it and incorporate it in his own medicine (Kramer 1994: 134).

Another, and more likely, possibility is that Samoans, living in relative isolation in the middle of the Pacific Ocean with few disease vectors, suffered a relatively limited range of recurrent illnesses (Kramer 1994). Those could be adequately explained by a paradigm which placed more emphasis on the social and supernatural causes of illness, and rather less on the biological and physiological ones. This seems probable: Samoans lived in that archipelago for some 2,800 years until European contact occurred in the late eighteenth century. During that time, and after an epidemic which followed a visit by an Oceanic neighbour, Samoans prayed daily to deities to prevent 'sailing gods' from landing, and physically repulsed those who sought to land to prevent further epidemics (Turner 1983; Stair 1983). The presence and absence of illness could be explained by reference to humans' relationships within social, natural and supernatural realms. In the circumstances, there was no need for a

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[2] These missionaries were dependent on their supporters in Britain for the resources for the mission. Their records and tracts tended often to focus on areas of activity which showed the enormity of their task of conversion and which generated the most interest and most generous support on the part of British congregations.

paradigm which systematically linked illness to biological vectors and or physiological processes.

This would also explain why in a relatively short period, between the early nineteenth century and the present, Samoans incorporated new medical ideas and practices which are now widely regarded as traditional. If this is indeed so, the Samoan case demonstrates that traditional Oceanic medicine is not static but dynamic, and is constantly expanding as new materials and ideas become available and are incorporated. The problem then becomes one of explaining the conditions under which an indigenous medical paradigm might expand and of identifying the factors which might influence the shape of the neo-traditional paradigm.

The commencement of contact between Samoans and people from beyond the archipelago provided a motive to rethink the pre-existing paradigm. Contact resulted in the immediate introduction of new diseases which struck indiscriminately at a population with little resistance or immunity to them (Macpherson and Macpherson 1990: 54–58). Ironically, the isolation which had produced the relative epidemiological stability before contact (Kramer 1994) had prevented the Samoans from developing immunity and ensured that each of the illnesses introduced between 1830 and 1918[3] would have significant impacts on Samoan society. Traditional aetiological and epidemiological models could not explain the new forms and patterns of illness. This inadequacy led Samoans to seek new explanations for the new experiences.

The growing frequency of contact with visitors and settlers from beyond Samoa also provided opportunity to expand their models of illness. Settlers from Britain, Germany, the United States, Australia, New Zealand, visitors from elsewhere in the Pacific, indentured labour from Melanesia, and later, from China took up residence in increasing numbers just as the Samoans' new health problems were emerging. Bearers of new models provided the knowledge necessary to augment the Samoan explanations and, in some cases, new material and practices to expand their medical repertoire.

Some of this knowledge transfer was deliberate. The missions sought to undermine polytheistic Samoan religion by providing alternative explanations for illnesses. This involved, ironically, persuading Samoans to replace many gods who caused and healed their illnesses with a single one with similar powers. But not all missionary effort was driven by a religious agenda. The London Missionary Society, in an attempt to provide comprehensive theological education for Samoan missionaries, translated and published works on zoology and biology including, in 1886, a 330 page tome entitled, *O le Tala i Tino o Tagata ma Mea Ola eseese: e iai fo'i o tala i manu ua ta'ua I le Tusi Pa'ia* which is, literally, an account of the bodies of people and various animals and of animals mentioned the Bible (Powell 1886). The manual was provided to pastors who were encouraged to use the information to improve the quality of their teaching. The missions may not have fully appreciated the ways in which Samoans would use the explanations in these to supplement, rather than supplant, their own earlier ones. Some other manuals found even wider readerships.

But their efforts were duplicated by those concerned with public health. In 1912, Cottle, the Health Officer at the US Naval Station at Tutuila, translated a health care manual for school children in American Samoa entitled, *O le Tusi e a'oa'oina ai i le Tausiga o le Soifuaga o Tagata Samoa,* sub-titled *Health Care for Samoans* (Cottle 1912). A final, and influential, example was the comprehensive 1937 work by Downs and Turbott entitled, *Health for Samoans* (Downs and Turbott 1937). It was subsequently translated by Drs Ielu I'iga and Atimalala Mama as *Maloloina Mo Samoa* or *Health for Samoans*, in a text which contained side-by-side translations of the original material. The Samoan language version was widely distributed to upper school students, teachers, native medical practitioners (NMPs), nurses, and women's health committees in villages and copies are still found often in the possession of healers and others. From the time that new health problems confronted the Samoans they had access to a series of texts which opened up new ways of thinking about the human condition and managing illness.

Not all health knowledge transfer was deliberate. Some transfer was incidental and occurred as Samoans observed and availed themselves of the health practices of those who increasingly lived among them. Missionaries and others noted that Samoans were very interested in the visitors', often experimental, use of herbs and simples, particularly since they had access to the power of an omniscient and omnipotent god, to whom Samoans expected them to turn for remedies for their illnesses.

Some transfer was deliberate. Early in the twentieth century, the German administration and the US Naval Administration sought to reduce the costs of administering their Samoan possessions by training Samoan paramedics to minister to Samoans. Similar programs were later extended by the New Zealand Administration in Western Samoa. The training programs were based at hospitals and graduates were given medical kits, texts and basic equipment. The Samoans embraced the programs and villages often sent for training people who had shown a disposition for healing. These were often traditional healers, known as *fofo* or *foma'i samoa,* who on graduation returned to their former practice with an expanded medical repertoire.

[3] The 1918 influenza pandemic resulted in the death of some 23% of the population of Western Samoa.

The availability of new knowledge led to the expansion of both explanations and treatments. For instance, the highly influential teachings of Christian missionaries taught that an omniscient and omnipotent God could and would bestow on faithful followers the ability to heal. The gift of healing, given to Jesus and later to his apostles, and demonstrated in a series of acts in a sacred text, which rapidly became central to the Samoan worldview, was also available to the faithful and was, arguably, more powerful than other forms of human intervention. This led to the early incorporation of the belief that the most devout Christians might receive god-given healing powers, and of such practices as prayer, singing and fasting into Samoan healing.

From the mid-1800s, Samoan pastors became central in the missionary activity as the mission sought to convert the peoples of western Oceania. Samoan pastors trained in Samoa and served with distinction in Western Polynesia and Melanesia. In the mission fields, they were often left to their own devices, and became in many cases dependent on their congregations for food, shelter and medicine. There, and particularly on high islands with abundant flora and fauna and often separated from support, they became familiar with a range of local medicinal plants and learned local uses for plants. The Samoan pastors, duty bound to eradicate heathen practices, tended to ignore forms of intervention which invoked supernatural agency and to focus instead on plant-based medicine.

These practices and the associated plants were often repatriated at the end of their mission service, and are now found so widely in Samoa that they are supposed to be indigenous. It is not unusual to come across gardens of introduced plants from Melanesia in Samoan villages, and to find that their medicinal value and uses were originally acquired by missionary relatives who had served in those regions as much as a century earlier. This may explain why some Samoans assume that the plants and their medicinal uses are indigenous. This trend is evident in the steadily growing range of medicinal plants documented in Samoa. The ethnobotanist, Whistler, for instance noted that of 59 plants used in Samoan medicine, about 53% were native, 30% were Polynesian introductions and 17% were recent or European introductions (Whistler 1992: 64), and that similar mixes were found in the Tongan islands to the south.

Despite white colonial administrators' attempts to prevent it, fraternization between the Samoan, Chinese and Melanesian populations occurred during the first half of the twentieth century (Shankman 2001; Field 1984). Intermarriage and cohabitation made the medical knowledge and practices of these groups available to Samoans with whom they lived. Melanesians, who also came from high islands with similar flora and fauna, extended the Samoans' appreciation of medicinal indigenous flora, and there are cases where the Melanesian origins of contemporary Samoan uses are marked linguistically and or acknowledged by those who use them. However, it is also true that the use of certain Melanesian practices connected with sorcery, and known as *fa'alauatau,* was banned by missions. Medical concepts and practices also undoubtedly derive from Chinese medical models used by the 2000 plus Chinese labourers who worked in Samoa, some of whom later married into and lived in Samoan society. Again, the Chinese origins of some contemporary medicinal ideas and practices are marked linguistically and or acknowledged by practitioners who use them. It is, however, impossible to establish the exact extent of these influences since only systematic questioning of those who know of the origins of their practices could determine this. In some cases, information on origins, which is not usually central to competent healing, has simply been lost in transmission.

The practice of incorporation continues. As Samoans have become more mobile, and despite increasing biosecurity measures at Samoa's borders, new plants are regularly introduced, established and soon incorporated into traditional medicine. The dynamic nature of Samoan medicine is not always apparent to Samoans since most patients seek relief and do not routinely ask their healers about the origins of either the plants or practices in use. Contemporary practitioners do not always know the origins of knowledge and practices which were incorporated into traditional medicine two or more generations earlier. Occasionally, the source of plants is marked linguistically, as in *'ava fiti, 'ava toga* and *'ava niukini* which distinguish varieties of *Piper methysticum* from Fiji, Tonga and New Guinea, respectively, but this is often not so. However, systematic inquiry about exotic plants can yield interesting material on sources of exotic plants and ideas in use in traditional Samoan medicine where these are known. A Samoan rigger who had worked in Papua New Guinea in the 1970s and had hunted pigs with local tribesmen, had brought to Samoa a plant used by hunters to relax cramped muscles. He had given the plant and instructions for its use to his mother's sister who had incorporated it in her repertoire. A Samoan Mormon missionary had brought back to Samoa a plant from New Mexico used as a nasal decongestant by native Americans which is now in use in her mother's sister's practice in Samoa.

Nor is the incorporation confined to plant materials. A number of traditional medicines are prepared in different strengths for babies, children, adolescents and older adults, respectively. This practice, a healer explained, derived from the filariasis eradication program carried out in Samoa in the 1960s on which she had served as a liaison person. She explained that the connection between body mass and dosage was obviously effective and she had subsequently adopted a variant in her own practice.

The Samoan case offers evidence of two other forms of medical dynamism. Several studies have pointed to the declining use[4] of certain plants where either the plants become scarce, or other more efficacious materials and treatments have become available (Macpherson and Macpherson 1990; Whistler 2000). Whistler, for instance, reports that of the 130 plants which have had medical usages reported for them, only some 84 are currently in use, and that of the latter group some are now used by only small numbers of healers. Other plants, however, have been found in an extended range of medicines. Significant numbers of the plants recorded by Kramer at the turn of the twentieth century are now used in a wider range of medicines. In these cases, new uses are sometimes the consequence of experimentation and, more commonly, of a growing awareness of alternative uses as a consequence of contact. Unusual uses of particular plants in some healer's repertoires were usually tracked to the presence of migrants from either Asia or the elsewhere in the Pacific, and occasionally, to the practice of western-trained medical professionals who recommended readily available local plants as effective alternatives to more expensive imported medicines.

This search for new ideas and practices has not, however, led to the abandoning of pre-existing models, which have, after all, served Samoans well over some 3,000 years of residence, but rather to their augmentation. The new illnesses, which were determined to be a distinct category of illnesses, and the property of the visitors, became known as *ma'i mai fafo,* sicknesses from outside, and included *ma'i papālagi,* the illnesses of Europeans, *ma'i saina,* the illnesses of Chinese, *ma'i meauli,* the illnesses of Solomon Islanders. Their diagnosis and treatment required additional medicinal knowledge which was supposed to be possessed by those who had brought them. Just as Samoans were supposed to be familiar with the causes and management of *ma'i Samoa* or 'Samoan illnesses', the visitors were supposed to be familiar with the nature and management of these new illnesses. The people who brought the diseases were supposed, by the Samoans, to be well-versed in their management, and versions of visitors' explanations and management became incorporated into augmented Samoan models of illness and management. This meant that there was no obvious reason to establish empirically which, if any, of the available medical paradigms was more effective than another. This way of thinking about illness and its management opened the way for the co-existence of a set of complementary medical paradigms which continues today.

In these circumstances, there is no obvious reason why healers would not continue to expand traditional medicine or for patients to discontinue the use of traditional medicine since its use does not prevent them from using other forms of treatment where this may appear appropriate.

This case, outlined in greater detail elsewhere (Macpherson and Macpherson 1990), shows that Pacific indigenous medical systems need not be unchanging, culture-bound paradigms which depend solely on cultural and religious logics for their power. They can be dynamic systems in which both knowledge and practice are routinely augmented as observation and experience of new models and practices suggests additional and more effective ways of approaching health. It also suggests that attempts to reconstruct truly indigenous medical knowledge and practice in such circumstances confront real problems. Because of the ways in which the sources of these ideas, materials and practices are constantly expanding, and because these are incorporated into traditional medicine without drama it becomes difficult to tell which part of today's traditional medicine was yesterday's introduction.

[4] The empirical evidence must be considered carefully, because of the difficulties of accurate sampling of the usage of plants in healers' repertoires which is compounded by the difficulties of doing longitudinal comparisons where plant names change over time. However, anthropological studies routinely reveal the dynamic nature of the process and Whistler's ethnobotanical work is the very best available for Samoa.

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Medicine in Sri Lanka: Traditional Medical Knowledge, Its History and Philosophy

Arjuna de Zoysa, C. D. Palitharathne

A Framework for Medical Histories

The study of Sri Lankan history recognizes four distinct periods (Bandaranayake 1990) from prehistoric times (ca. 125000 BCE) to a proto-historic era, when settled agriculture and Iron Age technology began. The historical period begins with the growth of advanced irrigation systems for food production and the surplus created by this results in the emergence of a flourishing civilization centered on cities such as Anuradhapura, Sigiriya, and Pollonnaruwa in the north central province. These city-centered civilizations spanned a period of one and a half millennia, from around 300 BCE to 1250 AD (De Zoysa and Palitharatne 1992). From 1250 AD onwards one sees a number of "centrifugal" tendencies, with fragmentation of centralized power to the periphery. With the arrival of the Portuguese (sixteenth century), a period of colonization by European powers followed and ended only after the Second World War. Modern Sri Lanka was heavily influenced by this colonial period (ed. note: see the article on Colonialism and Medicine in Sri Lanka).

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From Proto-Histories to Civilizational Periods

Living evidence of conditions in the pre- and proto-historic periods exists among the Veddha community, an indigenous people who retain most of their hunter–gatherer past even today (Spittel). The Veddhas possessed sufficient medical knowledge for their survival needs. They had knowledge of medicinal plants to treat wounds and used python fat for fractures. They practiced exorcism, which is still practiced today and reputed to have great value in an appropriate socio-cultural context. There is however no evidence of any attempts to build a connected knowledge system out of these curative practices, and their life spans were short (Sagara 1995).

With the coming of the city-centered civilizations (ca. 300 BCE), there was rapid development in all fields of knowledge. Historical information of this period is derived from several sources (Bandaranayake 1990; Uragoda 1987):

1. Written material, which was recorded on Ola leaves. The *Mahavamsa* a collection of historical information, is such an example (Guruge 1989);
2. Rock inscriptions at religious and archaeological sites;
3. Artifacts and buildings from archaeological sites.

A reasonable picture of what constituted medical knowledge in Sri Lanka during this time can be derived from these sources (De Zoysa and Palitharatne 1992). By the end of the proto-historic period, curative medicines and practices were locally found and available, but it was probably not until the early historic period that Āyurveda and Siddhi (Classical Indian) and Unani (Classical Middle Eastern) systems were extensively used and integrated with local regional (*Deshiya Chikitsa*) practices or folk practices. Āyurveda forms the major practice of traditional medicine in Sri Lanka. The well-known texts on Āyurveda such as the *Carakasaṃhitā* and the *Suśrutasaṃhitā* were known and read in Sri Lanka from before the historical period. The *Arkaprakāśa* an early book on Āyurveda, supposedly written by a king, Ravana, is still available (Buddhadasa 1960). The *Carakasaṃhitā* refers to a legendary conference on medicine held in the Himalayas (ca. 6000 BCE), where a number of *Rishis* (meditating recluses), worked out the fundamentals of Āyurveda in consultation with divine beings. The Rishis are named, and one of them, Pulasthi, was from Sri Lanka, an emissary of Ravana who was supposed to have returned with the principles of medical knowledge to Lanka (Buddhadasa 1960: 1–2). Āyurveda was probably first introduced to Sri Lanka during the time of king Ravana.

Āyurveda had the character of a well-connected knowledge system (De Zoysa and Palitharatne 1992). There were for instance sections describing fields similar to surgery, toxicology and ear, nose and throat diseases. The *Suśrutasaṃhitā,* a book on surgery from India, describes 121 surgical instruments (Pilapitiya 1982), many surgical practices using them, and dissections on dead bodies for surgical practice. Surgical procedures show knowledge of the infective power of microorganisms too small to be seen by the human eye. The underlying paradigms of Āyurveda were very different from biomedicine and form a powerful alternative to such a system.

During the city-centered historic period, extensive state sponsorship was given for medical practice and science. Some kings, such as Buddhadasa (fourth century), Aggabodhi (eighth century) and Parakrama Bahu (twelfth century), were actual practitioners and scholars of Āyurveda. The *Mahavamsa* records the existence of hospitals (Guruge 1989), dispensaries and medical halls during this period, and archaeological excavations are supportive of these claims. Medical practice at this time was in line with Ayurvedic practices; as such it would have been comprehensive, covering both preventive and curative measures which extended even to the care of animals.

With the decline of the city-centered civilizations one sees the emergence of a number of regional centers of administration around the sea port cities such as Kotte, Jaffna and in the hill country Kandy. Although a large body of medical knowledge was preserved and passed down through generations, no notable achievements were recorded during this period (De Zoysa and Palitharatne 1992).

The Colonial Period to Modern Times

Colonial conquests started with the Portuguese in 1505 and continued for nearly four and a half centuries. This period saw also the rapid growth of modern science in Western Europe and its introduction to Sri Lanka by the conquering colonial powers, in particular the British.

Both the Portuguese and Dutch had a great respect for local medical knowledge and used it at times to treat even their own sick and wounded (Uragoda 1987). The Portuguese are reputed to have used local knowledge to cure dysentery and snake poisoning among soldiers. They did however reject culture-bound practices such as exorcisms on religious grounds. The Dutch, who captured the coastal towns from the Portuguese in the seventeenth century, are credited with building many hospitals in Sri Lanka (Uragoda 1987), where herbal medicines were used alongside drugs imported from Europe. Towards the latter part of the eighteenth century they even appointed "native" physicians proficient in Āyurveda in all their hospitals. During the Dutch period there was a brief renaissance in the study of traditional medicine. King Narendrasinghe (1707) translated a thirteenth century palm-leaf manuscript, the *Bhesajja Manjusa,* on medicine and was also responsible for compiling a *Vattoru Vedapotha,* a book of traditional medicinal prescriptions. Paul Hermann, a surgeon attached to the Colombo hospital, was interested in botany; he was at that time in contact with Linneaus and sent collections of local plants to him. It is said that Linneaus used these as part of his famous plant classification (Goonatilake 1985).

The British colonial period in Sri Lanka started from 1796 and lasted 150 years. During this period the rapid industrialization of Europe and North America and its domination of the rest of the world took place. Not surprisingly, Western medical science was introduced and it established a dominant position in Sri Lanka. Āyurveda and traditional medicines were generally discouraged under British rule and the colonials learnt little from it. There were however notable exceptions. Sir Henry Blake, a British Governor in Sri Lanka, translated parts of the *Suśrutasaṃhitā* using Buddhist scholars; he claimed in a lecture delivered to the Royal Asiatic Society in 1905 that malaria was recognized as a vector borne disease (Uragoda 1987). This was never accepted in Europe, but it is difficult to envisage how an irrigation-based civilization flourished if it did not understand even the causative mechanisms of such a devastating disease like malaria. Another notable exception was the establishment of a College of Indigenous Medicines in 1929 with state sponsorship. These instances of support were however, very much the exception.

In spite of heavy state support for Western allopathic medicines and the marginalization of traditional practices, the latter survived and were used by a majority of people; even the urbanized middle classes, who were heavily "westernized" in outlook, continued to use them. What were the reasons which made these traditional systems of medical knowledge so resilient? We will in the following text investigate the world-views behind the two knowledge systems of Āyurveda and allopathy (biomedicine). To do so, we will first touch on some developments in the philosophy of modern science.

A Philosophical Note

The term *incommensurable* first introduced by Kuhn (1970) and later developed by Feyerabend (1978) refers to the impossibility of comprehending a theory "A," based on a paradigm "A," by using concepts and terminology of a theory "B" based on a different paradigm "B." By paradigm we mean,

> On the one hand it stands for entire constellation of beliefs, values, techniques, and so on shared by the members of a given community. *On the other, it denotes one sort of element in that constellation, the concrete puzzle – solutions which, employed as models as models or examples, can replace explicit rules as a basis for the solution of the remaining puzzles of normal science.*

Numerous examples can be taken from the history of science itself as evidence for incommensurability between theories. Relativistic and Newtonian physics form two of the best-known examples. In Newtonian physics, mass, time, and energy are observer-independent entities, existing in absolute space. In relativistic physics, they depend on the relationship between the observer and the observed, have no fixed value and lose all absolute meaning. In fact the concepts are so radically different that the use of the same words – "mass," "time," etc. – leads to confusion. A student used to years of reference to "Newtonian mass" finds it difficult to comprehend and adjust to "relativistic mass." Perhaps it would be easier to make the gestalt switch if different terminology were used.

Werner Heisenberg (1952) provides a rather striking, but less well-known example of incommensurability. Heisenberg shows the almost total incommensurability between Newton's and Goethe's theories on color. Newton's theory of color was mechanistic, precise and with later modifications proved to be useful for all kinds of practical purposes. Goethe's theory of color was based on symmetry and complimentarity. Its purpose was very different from Newton's; it described a sensory world of color which was relevant and proved useful for aesthetic purposes.

Differing Worldviews

The worldviews or broad paradigms on which the two medical knowledge systems are based are different and incommensurable. The ontology of classical Western science takes for granted the existence of subatomic particles which form atoms, and these arrange themselves into chemical compounds growing in complexity to form organic molecules and hence life. In Vedantic philosophy, material form is described by five fundamental attributes, the Pañcamahābhūta. These attributes can be understood metaphorically by use of commonly encountered substances, such as Air (motion), Water (fluidity), Earthiness (solidity), Agni (fire), or energy in thermal form and Voidness (or emptiness). The above list of metaphors exhausts the discourse on materiality, and there can be no further additions to this particular classification. One can only go for an alternative form of classification which may contain as many as 12 properties. The substance-based element theories in modern science are different. They refer to "elements" which exist "out-there" in material form. The discovery of additional elements to the original 92 is therefore expected. It is important to realize this difference; as the foundational base of Āyurveda is unchanging, its pharmacopoeia and curative techniques are dynamic. Health in the human body in turn is described as a balance between three metaphoric properties, known as the *tridoṣa*: *Vata, Pitta and Kapha*. The substance metaphors for these are often given as Air, Bile, and Phlegm. These metaphors should not be mistaken to mean the same as these actual substances. However, a *Kapha* imbalance would lead to a preponderance of phlegm in the body. These properties in turn are connected to conditions in the natural environment, age and disease. The knowledge system is thereby connected as a whole. A superficial understanding of this could lead to "fuzziness." With the modern focus on quantitative exactness and reductionism many prejudicial viewpoints could result, if one views these ancient sciences with a simplistic lens. In understanding these concepts, language itself is an impediment, as they are difficult to translate. A proper understanding can only be derived by an appropriate gestalt switch from knowledge system "A" to knowledge system "B" (De Zoysa and Palitharatne 1992).

Let us examine the paradigms underlying the theory of disease causation in the two systems.

In Āyurveda, there are four reasons for disease: *Aganthuka* (external factors such as injuries), *Sharirika* (Physical), *Manasika* (mental), and *Swabhavika* (natural, such as old age, hunger, thirst). Disease itself is defined as contact with *dukkha* (Pilapitiya 1982). The meaning of *dukkha* is very comprehensive and includes unsatisfactory physical as well as mental states, both temporary and permanent. Negative emotions such as anger and jealousy are considered to be disease states. We can at once see why such a system has to deal with both physical and spiritual treatments. *Āyurveda* recognizes the existence of microorganisms, however, the main causative factor lies in an imbalance within the human body. Using such a theory, it would be easy to explain the occurrence of influenza and to adopt preventive measures against it. Cold temperatures, moisture, food described as cooling, all enhance *Kapha*, leading to an imbalance, which makes the body susceptible to a viral invasion. Person "A" may contract it in autumn and not in summer and so forth. The virus after all presents itself constantly, but it is only sometimes and only some people who are affected. The *tridoṣa–vada* of balance and imbalance can be thought of as a comprehensive theory of resistance and susceptibility to disease. Its real benefits lie in disease prevention. There is also the recognition of *Kamma* (karma; ethical acts), either done in this life or in a previous life, which impact on disease. In fact if negative *Kammic* effects are dominant (*Kamma Roga),* special acts are specified to nullify these before or during medical treatment (Buddhadasa 1960: 63–64). In the *Carakasaṃhitā* there are diseases mentioned which cannot be cured by clinical means alone. It is said that people who think that one is born purely by the coming together of man and woman are supposed to have limited vision (Buddhadasa 1960: 337). The worldviews between allopathy and Āyurveda are thereby fundamentally different.

In South Asian traditional systems, the emphasis is on health, not disease; the re-establishment of a diseased body to health is extensively dealt with. The cure in biomedicine might sometimes be worse than the disease. For example some chemotherapies and radiation treatments for cancers could be worse than the cancer itself and might lead to a disabled existence or death for the treated person. In South Asian medical processes such "cures" are no "cures" as they do not lead the patient's body to health. Much could be learnt from the practice of Āyurveda, and a reasonable cross fertilization of knowledge systems could be beneficial to all.

Ayurvedic medical treatment is considered to be both a science (*Shashtra*) and a craft (*Shilpa*). The practitioner takes a personal interest in the patient and ethical norms are built into the very development of the *Shashtra.* For instance, animal experimentation is not allowed in Ayurvedic research.

On Validation

I will here use a particular example which brings the problem of validation into sharp relief. The double-blind test for the efficacy of drugs is a special case of a control widely used to determine the solely physical effects of drugs. In Āyurveda we find a category of herbal medicine known as *Khema,* in which a "wanted" physical component interacts with the "unwanted" psychological action. A *Khema* is always accompanied by an intricate story of its origin, and ritualistic preparations are used before administration. The patient is made to believe in these, and although the herbal medicine has a physical effect, its value is substantially enhanced by psychosomatic interactions. The two effects may not be separated out and studied, because in general their interaction is nonlinear, affecting the whole human body rather than the merely diseased parts of it. A double-blind test would be irrelevant in such a case (De Zoysa and Palitharatne 1992). Validation of Ayurvedic efficacy should be taken as a whole treatment regime, and validation is a process, not a single medicine, which in any event is a *Sanyojanaya* (compound mixture) and not a chemically extracted active ingredient.

Quantification in classical systems is personalized. For instance Āyurveda gives three major measures – *Anguli, Anjali, and Matra* – with reference to the patient's body size (Balasubramaniam 2005). In the Western medical system measurement is with reference to abstract quantities. This difference means that any validation of classical medicines should be quantified accordingly.

The Future

Both Ayurvedic and Western medical practice claim to rest on a firm "scientific" basis. These claims are only partly true. The practice in a number of cases does not flow naturally from a theory based within a broad paradigm. In a Kuhnian sense, we cannot say that both are fully "mature sciences" flowing from broad generally accepted paradigms of theory to practice. There are many practices and medicines, in both

Western and Ayurvedic systems, which are used simply because they work. Some times ad hoc practices which do not deeply penetrate the respective knowledge systems are used. Vaccinations were used in Europe for smallpox long before any theory of immunity had been accepted as a specialist discipline. Smallpox inoculation is mentioned in the ancient Indian text, *Atharvaveda,* and was practiced in Ancient India by introducing "inoculated pustules of the previous year" to healthy persons (Pilapitiya 1982). Again it is unlikely that Ayuvedic theory prompted such treatments. Treatment of many common ailments, such as back pain, is treated on a "try and see" basis in biomedicine, and often the patient knows what course of action would be best for him. Many other examples can be taken to show this disjointedness between theory and practice in both systems (De Zoysa and Palitharatne 1992).

Western medical scientists interested in creative work have a fertile field in traditional systems of medical knowledge. They can learn much from the history of Western science itself, in particular from its major creative periods, to develop an openness and methodology for fruitful cross-fertilization of knowledge with traditional knowledge systems. A healthy respect for alternative knowledge systems would be a liberating force for science.

See also: ►Medicine in India: Āyurveda

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Medicine in the Talmud

Samuel S. Kottek

Although whole books have been devoted to the study of talmudic medicine and quite a number of studies to specific related topics, only a small number of scholars in the field of medical history are aware of this rich corpus of knowledge. The core of the Talmud (the authoritative body of Jewish law and tradition), called *Mishnah* (divided into six tractates), was compiled between the second century BCE and the second century AD. Two extensive commentaries and glosses were added to the basic text. One is the so-called Jerusalem Talmud, which was completed in the fifth century AD. The Babylonian Talmud, which was much larger, was sealed in the sixth century. No medical texts from the ancient Hebrew–Jewish period have reached us, so the wealth of medical knowledge that is interspersed in the Talmud is the sole source of documentation in these matters. It should be made clear that these medical data are recorded by talmudic scholars in the midst and for the sake of legalistic discussions. In most cases few details are provided and only those that are relevant to the specific point under consideration.

The spectrum of medical knowledge covered in the Talmud is very wide. The field of anatomy (mainly of animals) is impressively represented, particularly in the tractate *Ḥullin* which deals with dietary laws. The inspection of slaughtered animals is one of the remarkable institutions of Jewish law, as it related to public health. In order to decide whether an animal was acceptable for consumption (*kasher*) or not (*taref*), anatomy and pathology had to be mastered to a considerable degree. Two examples will be given here.

The number of bones is considered in the context of uncleanliness: it is ruled that everything contained in a tent (or room) in which there is a number of bones amounting to more than half of a corpse becomes unclean. The body is comprised of 248 bones (it says "members," *evarim*), corresponding to the number of days of the lunar year, and 365 "sinews" (*gidim*) corresponding to the solar year [bab. Makkot 23b]. The Talmud mentions that once research was done on the corpse of a young female prostitute who had been executed by the (Roman?) authorities, and it was found that there were 251 bones. The Sages opined that the discrepancy was due to the fact that this was a young woman [bab. Bekhorot 45a]. Another opinion was that the number of bones may vary from 200 to 280 [Tosefta, Oholot 1: 7]. Osteology was not very exact, even in "academic" medicine. Galen speaks of "more than 200 bones" [De Form. Foet., Bk. 6]. Interestingly enough, Ibn Sīnā (Avicenna) and al-Zahrāwī (Abulcasis) both accepted the number 248, most probably in accordance with the lunar analogy and the macrocosmos/microcosmos similarity.

The second example is related to neuroanatomy. The case history featured a lamb which dragged its hind legs along, and the question was, "What kind of lesion does it have?" One sage said, "This is a case of sciatica" (Hebr. *shigrona*). Another replied, "Possibly this is a lesion of the spinal cord" (Hebr. *ḥut ha-shedrah*). The text then says, "They examined it (i.e., they performed an autopsy), and the second diagnosis was authenticated." This shows a remarkable experimental approach. The sages decided that if an animal dragged its legs it would be said to have sciatica, and such an animal would be permitted for consumption [bab. Ḥullin 51a]. This is a very typical example of talmudic casuistry. The sages not only allow, they even advocate thorough examination of the case, but the decision is based on the opinion of the majority and on the most frequent occurrences.

The Talmud, in both versions, is full of observations of medical and historical interest pertaining to internal medicine, gynecology and obstetrics, dermatology, neuropsychiatry, surgery, traumatology, and most other specialties (including otology, ophthalmology, and dentistry). Other fields such as dietetics, preventive medicine, forensic medicine, public health, and materia medica are also widely represented. Instead of listing a catalog of items, we shall give a number of examples that stand out for their detailed description and/or for their originality.

Commenting on the scriptural verse [Deut. 7: 15] which reads, "And the Lord will take away from thee all sickness…," the Talmud asks the question, "What is sickness?" A number of answers are provided by the Sages in both versions of the Talmud [bab. Baba Mezia 107b; jer. Shabbat 14: 3]. In both versions we find three cardinal causes of diseases. One pertains to scientific medicine: the bile; one is related to popular medicine: the cold (or cold-and-warm); and one belongs to magic lore: the evil eye. Other agents that appear only in one version include: air (or wind); fever; abnormal or superfluous secretions; climatic factors (the *sharav* wind); obsession (one who is persuaded that he is sick), and carelessness (which is particularly stressed, thus enhancing the preventive aspects of medicine). Two other factors are mentioned elsewhere in the Talmud. One is blood (i.e., plethora): "At the head of all (causes of) diseases am I, the blood" [bab. Baba Bathra 58b]. The other is changes in one's habitual way of life [ibid. 126a]. Another version mentions changes in one's usual diet [bab. Kethubot 110b]. This particularly developed topic is characteristic of talmudic lore, as it includes popular beliefs, empirical notions, and scientific aspects. Humors (blood, bile), specific symptoms (fever), environmental causes (winds, cold), magical aspects (evil eye), psychic factors (obsession), and a heedless way of life (carelessness): these are part of a broad spectrum of the agents of sickness.

Gynecology and obstetrics are well represented in the talmudic corpus, particularly in the tractate *Niddah*. Menstruation (during, and 7 days after which a woman cannot be approached by her husband), vaginal bleeding, recognition and duration of pregnancy, as well as a wealth of details related to embryology, sterility, and abortion, are only examples of the topics considered by the Sages. We shall again select two items: cesarean section and embryotomy. Regarding cesarean section, it is stated [bab. Arakhin 7a], "If a woman dies during labor, the operation is performed even on the Sabbath day and the child is ripped out of the womb." A decree of this kind was already extant in the early Roman *Lex Regia* of Numa Pompilius. More challenging is the question of whether cesarian section was performed on a *living* mother in talmudic times, a procedure that has not been documented in adjoining contemporaneous cultures. We read [Mishnah, Bekhorot 8: 3]: "A child born through the (abdominal) wall (Hebr. *yoze dofen*), and the one who comes (i.e., is born) after him, none of them are considered (legally) as being first-born." It seems that it was acceptable in the times of the *Mishnah* (second century AD) that a woman gives birth by cesarean section, recover, and gives birth later to another child in the normal way. Such a possibility seemed quite strange to Maimonides [see his commentary ad loc.], who tried painstakingly to devise a case that would make sense. There has been a lively and prolonged discussion among historians of medicine and talmudic scholars regarding the definition of *yoze dofen*. Some think it could mean extrauterine pregnancy; others advocate abnormal birth through a perineal tear, or even through the anus. I am among those who think that this was a theoretical case based maybe on animal pathology [see ibid. Bekhorot 2: 8], but the question is still open to discussion.

Embryotomy is mentioned in the *Mishnah* as well: "In case a woman experiences difficulty in labor (her life being in danger), her fetus should be cut to pieces inside her womb and extracted limb by limb" [Mishnah, Oholot 7: 6]. It is clearly stated that the life of the mother has preference over that of the fetus. However, once his head, or the majority of his body, is out of his mother's body, the fetus may no longer be harmed, for one life cannot be put aside for the sake of another.

Circumcision was, according to the biblical narrative, first performed by Abraham, and was henceforward to be performed on every male child at the age of 8 days [Gen. 17: 10–14], The technical details of the surgical procedure are nowhere mentioned in the Bible; they are, however, discussed in the Talmud. What interests us here are some of the complications of the operation. It is stated that if two children of the same mother have died (from hemorrhage) as a result of circumcision, the third child should not be circumcised. It says further that if two children of one mother or one child each of two sisters dies, the third should not be circumcised.

The sages remark that there are families in which the blood is "loose," whereas in others it is "tied up". This is most probably the first historical description of hemophilia and of its genetic transmission [bab. Shabbat 134a and Yebamot 64b].

The operation that should be performed on a newborn baby which presents an imperforated anus is described in detail [Shabbat, ibid.]. It says that the membrane should be opened crosswise. This is noteworthy because a circular incision would indeed have been ineffective.

In accordance with Hippocratic medicine, the Talmudic sages considered that an eight-month baby could not be viable [bab. Shabbat 135a]. A baby was usually breast fed for 2 years. Therefore if a nursing mother lost her husband, she was not allowed to marry again until 2 years (at least 18 months) had elapsed, for fear that she might become pregnant again and her milk production could be stopped [bab. Yebamot 42ab]. In order to prevent a nursing mother from becoming pregnant (which could stop lactation), some sages advocated the use of a pessary (*mokh*) during intercourse. Others promoted withholding intercourse altogether during lactation, which was repeatedly urged in ancient medical lore. Wet nurses were hired in case the mother could not nurse her child. The wet nurse was supposed to tend this nursling exclusively; she could not even nurse her own child [bab. Kethubot 60b]. The use of non-Jewish nurses was permitted. Some sources granted this permission without any condition [Tosefta, Niddah 2: 5]; others asked that the nurse be under the parents' close supervision [Mishnah, Avodah Zarah 2: 1]. Moreover the use of milk from animals, even from unclean beasts, was permitted, as the child was considered in deadly danger if he got no milk whatsoever.

Even a brief abstract of talmudic medicine cannot disregard the topic of public and personal hygiene. Dietetics is not exclusively centered on dietary laws. Several axiomatic statements, based on empiric and popular lore, are recorded. One should eat simply [bab. Shabbat 140b], slowly (carefully chewing food) [bab. Berakhot 54b], moderately [Shabbat 33a], and regularly. "Any change in one's usual diet is the beginning of bowel disease" [bab. Sanhedrin 10la]. Wine and meat are characteristic of a festive meal [bab. Pesahim 109a]. Excess of meat is considered harmful; the priests in the Temple suffered from bowel diseases, as they consumed too much meat (from the offerings). There was even a "specialist" for these diseases; his name was Ben Ahijah [Mishnah Shekalim 5: 1–2].

Fasts were instituted by the sages to commemorate great calamities such as the destruction of the Temple. The only fast that is of biblical foundation is the Day of Atonement (*Yom Kippur*). Fasts were also initiated in case of oncoming epidemics, wars, floods, or drought. Such fasts did not usually exceed 24 h [Mishnah, Ta'anit 3: 3–5].

Personal hygiene included cleanliness as reflected in the laws of purity. Women took a ritual bath after menstruation and observed an additional 7 days purification period. General hygiene is featured in a number of regulations on water supply, lavatories, bathing, care for the dying and burial, and the Sabbath rest.

Even after all this explanation, we can still ask the question: Is there actually a specifically talmudic medicine? I prefer the view that there is definitely a fascinating topic labeled "Medicine in the Talmud." These rich and multifaceted data should take their legitimate rank in the history of both medicine and culture.

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Medicine in Thailand

VIGGO BRUN

There exists in Thailand a medical tradition based on local disease concepts, the use of natural products and certain magical rituals which have been practiced by local doctors for centuries. This local wisdom has been passed on both orally and through manuscripts from teacher to pupil for generations. Traditional Thai medicine exists in two versions: a village variant, containing many regional and personal variations, and a court variant influenced by Indian (Ayurvedic) medicine, which has been standardized to a certain extent.

Since around 1900 the official medical system in Thailand has however been solely based on biomedicine, and biomedicine is now widely accepted by the Thai public. But even without any official support, traditional Thai medicine has survived quite well in the rural areas, and in present-day Thailand, the public makes use of both traditions – predominantly the official cosmopolitan medicine, and, to a lesser extent, traditional medicine. Since the beginning of the 1990s the attitude of the state towards traditional medicine has changed, and the official policy is now to integrate traditional medicine into the public health system.

The Village Tradition

In villages all over Thailand one finds people referred to as traditional doctors (*moo phaen booraan*) who mainly use medicinal herbs (*samunphraj*) and other natural substances to cure diseases. The sum of knowledge and practices of these experts is labelled "traditional Thai medicine". There is no traditional doctor who knows the entire body of traditional medical knowledge, and there are many local and individual variations of traditional Thai medicine within Thailand, both in the way plants and diseases are labelled, in the way disease terms are understood, in the way concrete cases of illness are diagnosed, and in the way plants and other materia medica are used in the curing process.

Traditional Thai medicine includes knowledge about the identification of plants (and minerals and animal components) and their curing properties, about diagnosis, cause and development of diseases, about prescriptions and about relevant incantations and ceremonies. The prescriptions, which exhibit the concrete relationship between diseases and the plant world, are – together with the incantations – considered to be the essential and most valuable part of the tradition and are surrounded with a certain amount of secrecy. The prescriptions contain any number of ingredients, normally from five to ten, but sometimes less and often more, even comprising as many as 50 different ingredients. For each ingredient the prescription will ideally specify which part of the plant should be used – root, leaf, bark, fruit, etc. – and normally in what quantity. While much of the medical knowledge is transmitted orally, the prescriptions are written down. There are a vast number of medical manuscripts in Thailand, both in temple libraries and in the care of the herbalists, and almost all of these manuscripts are merely collections of prescriptions.

In order to access the information in the manuscripts as well as to copy them and write down the prescriptions, it was necessary to be able to read and write. In former times these skills were taught only in temples to boys, so the traditional doctors were exclusively male. Monks and former monks were central in the transmission of all written traditional knowledge, including medicine, and Buddhism has – as we shall see below – left a deep imprint on the way traditional medicine has been organized.

To a certain extent, the general public also possesses medical experience and knowledge which people use to talk about diseases, to chose between available curative alternatives, and for self-medication. There are a number of simple traditional remedies known to villagers, commonly referred to as "household remedies" (*jaaklaangbaan*).

The traditional doctors are often called to a career in medicine after they themselves have been sick. They will seek out a traditional doctor, get cured, and thereafter ask to be accepted as a student of that doctor and learn the prescription that cured them. After that they start treating people with this particular disease. If the treatment is successful, and if the new doctor feels he has a knack for traditional medicine, he seeks out more knowledge from other teachers, and thus gradually expands his curing range. Another path is to learn the trade from a practicing relative. Few traditional doctors become true generalists, though, and few become full-timers. For most of them, curing provides them with supplementary income, although a successful traditional doctor will be respected and obtain higher social status.

Traditional Thai doctors neither perform surgery, except for lancing abscesses, nor do they undertake dissection. Thus they do not have a very precise or systematic knowledge of the human's interior organs and how they function. A certain amount of anatomical knowledge is gathered from partitioning animals, and Buddhist scriptures do enumerate body components.

Some traditional doctors perform bone setting. The broken bones are pulled back into place – no painkiller! – and the area around the fracture stabilized with sticks of wood tied together, after which incantations are blown onto the fracture. Traditional bone setting may result in the bones growing together at unusual angles, so most people prefer to go to Western-style hospitals to be treated for fractures.

Massage and midwifery are separate branches of the local medical tradition. Traditional midwifery is fast disappearing, while Thai massage has become tremendously popular – also outside Thailand. A number of drawings of the human body in Wat Pho, the largest and oldest temple in Bangkok, pertain to Thai massage, indicating points on the exterior of the body on which applications of pressure have a therapeutic effect for specific ailments. Other drawings of the human body show lines (*sen*) connecting various points on the body. The meaning and practical application of these lines and how they connect up with the rest of traditional medical theory and practice are not clear. One homepage, ►http://www.bomi.info/books/thai_massage.htm, lists 12 books on Thai massage which have been published within the last decade – some accompanied by videos – mostly practical introduction written by people who operate clinics for Thai massage in various countries.

Traditional saunas, where steam from herb-steeped water is directed into a small, closed room, are also used. These steam baths are regarded as generally healthful but are also used specifically to cure certain skin or respiratory diseases.

In the countryside people used to rinse their mouths with water after eating, and they used toothpicks and sometimes rubbed their gums with salt. Now most people use toothbrushes and toothpaste. Previously toothache was simply considered to be bad luck. When the pain became intolerable, the tooth was pulled out. Until recently there were peddlers appearing in the villages trying to convince people that their toothache was caused by small worms eating the teeth – they could miraculously produce such worms from the mouth of any bystander with toothache – and that their bottles of medicine would kill these worms. This medicine was very popular. The bottles they sold merely contained a simple plain painkiller.

Transmission

The medical tradition in Thailand is said to have been transmitted through a chain of teacher–pupil relationships which goes back to the tradition's original teacher, Jivaka Komarabhacca, the legendary physician of the Lord Buddha, and each practitioner pays respect to his teacher at annual rituals. On every occasion in which he uses the knowledge from the tradition, he should ceremonially invoke the whole chain of teachers – living and dead – to be present and thus infuse his actions with their sacred power. Medical knowledge is in principle restricted to those who have been ritually initiated into the tradition, and thus every potential doctor has to find a teacher who will accept him as a pupil and share his knowledge with the student. The teacher is important because the tradition consists of both oral and written information. The written manuals contain the essence of the tradition – the prescriptions – but the manuals contain almost no information about each particular disease or plant, beyond their names. All the background knowledge and detailed information which the manuals presuppose are transmitted orally. The student needs a teacher to give him this oral information and from whom he can observe the finer points of medical practice.

The ideal would be if the complete primordial knowledge was passed on verbatim through faithful repetition and copying. Still, time involves change and decay, and it is recognized by everyone that losses, fragmentation, external additions and copying mistakes have occurred all along the transmission chain. Medical manuals are no longer complete and homogeneous, but fragmented and heterogeneous. The actual transmission of knowledge is no longer only faithful copying but also a continual process of selection and reorganization, and new knowledge may even be added to the tradition. The standard way of justifying additions is to present them as revelations, often referred to as *tamraa phii book* (manual told by the spirits). In other words, additions and innovations are permitted as long as they are received directly from the "other world", i.e. as long as they are disguised as restoration, rediscovery or reestablishment of something original.

Traditional Pharmacy

There are probably several thousand plants (and ingredients from the mineral and animal kingdoms) in traditional Thai medical prescriptions, and these should – alone or in combinations – have a curing property of one kind or another. There are a number of herb stores in the larger towns where the traditional doctor can buy the ingredients he needs. Still it is convenient if he has the plants he uses most frequently ready at hand. Many traditional doctors therefore grow medicinal plants in their gardens and possess some botanical knowledge.

A number of monks also practice as traditional pharmacists or doctors. In Buddhist temples one can sometimes find extensive gardening of medicinal plants.

There are also a number of traditional pharmacists who produce homemade traditional medicines for sale at markets and fairs or through local stores. With the increasing popularity and growing demand, the traditional medicines – and herbal-based cosmetics – are now also being produced industrially by a number of firms. Thus people have easy access to ready-made traditional medicines, which are cheaper than the available biomedical medicines, and although it is widely viewed that they may take a longer time to produce results, it is also claimed that they have fewer side effects than cosmopolitan medicines.

The Ministry of Public Health stipulates that traditional drugs should be approved before public sale, but this law is not strictly enforced.

Botanists and pharmacists in Thailand have published a large number of books on Thai plants and their claimed curative properties. There is also a "pharmdatabase", ►http://www.medplant.mahidol.ac.th/index.asp, where one can search by plant name (English or Thai), genus, or biological activity.

Etiology

Many of the disease causes recognized by traditional Thai doctors are also causative factors in modern medicine. Some diseases are, for example, regarded as contagious and some as inherited; some as caused by changes in the climate and others by contact with external agents such as metal chains or washing powder, resulting in skin eruptions. Some are caused by insect or animal bites and others by spoiled food, or bad smells. There are natural causes for fracture, dislocation, contusion, burns, or wounds.

The close relationship between food and disease can be seen in the monastic rules (*Vinaya pitaka*) where medicines are classified as "non-substantial food". Many of the most common medicinal plants are also ingredients in food. Food prohibitions are, moreover, integral to the treatment of many diseases. Such prohibitions might be against meat, frogs and fish with skin, seafood, pickled food, certain vegetables, eggs, liquor, or foods with certain tastes – all depending on the disease in question. There are also specific dietary rules for the post-natal period. Adding and withdrawing certain foods from the diet can also function as preventive measures.

A causative factor specific to the medical tradition of the court is "imbalance in the elements (*thaat*)", i.e. imbalance between wind, water, earth, and fire. These are the elements of which our body (and indeed all matter) is composed.

In addition, traditional Thai medicine operates with other types of causes, which modern science summarily dismisses as superstition. These can be classified as spirits, black magic, and *karma* (past actions). If the diagnosis is that a patient in some way has offended and angered a spirit, who in retaliation has caused the offender to fall sick, then the curing process may consist of ritual offerings only.

There are cases characterized by sudden violent and abusive behaviour, which may be attributed to possession by an inferior, evil spirit. A specialist is then called upon who will talk to the spirit and ask it who it is, where it lives and what it wants. If the spirit does not want to leave the body after offerings have been given, it is mercilessly beaten out – the spirit apparently feeling all the pain, while the possessed person feels nothing.

Another type of mental disturbance may, after all other treatments have proved fruitless, be attributed to a superior, good spirit who wilfully has inflicted this kind of suffering on the patient to force her to become its medium. When the person accepts mediumship, the spirit immediately withdraws the ailment, and the person recovers.

Piercing or lancing pains in the joints, abdomen, or chest may, if unresponsive to treatment, be attributed to black magic. This means that an object – like a nail or a lump of skin – has been inserted into the patient's body by a doctor using special incantations and acting on the instructions of an enemy of the patient. The only solution for the victim is to find a doctor who has even stronger incantations to counteract the original ones and can thus remove the object or even send it back to attack its owner. The Northern Thais say that the Karen and the Khamu hill tribes harbour powerful incantations, in Northeastern Thailand they may blame the Khmer for the black magic, and in Southern Thailand the Malays.

The Buddhist concept of karma may also be used as an ultimate causative factor, but normally only after all other explanations have failed. Using karma as the cause implies that the disease is a deserved and inescapable result of a previous action by the patient. People do not favour this explanation, because it means that a cure is impossible and that a person simply must endure his or her fate. However, people confronted with the inevitable deterioration and malfunctioning of their bodies, such as the elderly and those with incurable diseases, use karma to indicate that they have accepted the inevitable. This resignation can also be a relief for relatives, who no longer need to feel obliged to search for new remedies and pay even more bills.

The recitation of holy words plays an important role in many contexts in Thailand, and there is a strong belief that recitation of holy stanzas (*weedmon khaathaa-aakhom*), if performed by the right persons, produces power and that this power is transferable. Incantations are an integral part of traditional medicine and are in many cases recited over or blown on to the medicines and the patients by the traditional doctor.

Magical practices are a central part of Thai culture and thus also of traditional Thai medicine. Still this must not overshadow the fact that traditional Thai medicine is basically a rational tradition based on experience. The traditional doctor will first seek a natural and rational explanation to a disease. Only if this does not work will he resort to other types of explanations and treatments. And if one accepts the premises of magic, such as the existence of spirits and other levels of existence, it too possesses its own rational logic.

Heterogeneity

A central feature of the Thai medical tradition is its heterogeneity: it generates many different answers to the same question. This is true at all levels of the tradition.

The names for one and the same plant may vary from locality to locality, and one and the same name may be used for different plants in different places (which is nothing peculiar to Thailand, of course).

The claimed medical properties of plants in isolation vary from informant to informant, and do not necessarily conform with the prescriptions in which the plant actually occurs. When one, for example, asks, "What are the curative property/properties of plant P?" the first informant says, "It cures disease A", the second informant says, "It cures disease B", and when we check the prescriptions we have collected, we find that plant P does not occur in prescriptions against diseases A and B, but in prescriptions against diseases C and D.

The content of the local disease names varies according to the informant. Furthermore, disease names known by one expert may not be known by another even if they live in the same area. And finally actual diagnosis varies a lot.

One could speculate that a likely reason for this heterogeneity is a slow and erratic process of crystallizing experience, which again could be due to the lack of communication (i.e. competition) between the herbalists and the lack of records of the experiences of the individual herbalist. Furthermore, the lack of standardization of disease concepts and the lack of an explicit epistemological framework could well be factors which have hampered the crystallization process of the popular medical tradition and contributed to its continued heterogenic character.

But there exists another branch of the medical tradition in Thailand emanating from the royal court with an explicit and rather elaborate theoretical framework.

The Court Medical Tradition

At the Thai court royal physicians (*moo luang*), who held official positions within the Medical Department (*krom phaet*), were responsible for the well-being of the king and his court. The knowledge of the court medical tradition was kept within the court, and transferred in many cases through certain families. Rama III decided to make public parts of the traditional knowledge harboured within the court when he restored the Wat Pho (Wat Chetuphon) temple in central Bangkok from 1834 onwards – including medical knowledge, especially related to massage (stone inscriptions) and physical exercise (stone statues).

In 1870, during the reign of King Chulalongkorn (=Rama V, 1867–1910), a committee of royal physicians was appointed to collect and edit old medical manuals. The result of their work became known as *tamra luang*, the Royal (Medical) Treatise, and was kept in the library of the palace, available to court physicians only. When Siriraj Hospital was established in 1887, the patients could choose between cosmopolitan and traditional treatment, and likewise the curriculum at the Siriraj Medical School (1889) included instruction in both cosmopolitan and traditional Thai medicine. To standardize the teaching of traditional medicine, a printed version of the *tamra luang* was introduced as textbook at Siriraj Medical School with the title *tamraa phaetsaat songkhro*. Thus the court medical tradition went public, and became the official medical tradition until the teaching of traditional medicine was discontinued around 1906 (some say in 1913). Some 50 years later, in 1957, the Association of the School of Traditional Medicine was established at Wat Pho (Bangkok), and both the teaching and the officially supervised examinations there were based on reprints of the *tamra phaetsaat songkhro*. The Wat Pho school later established schools at a number of temples in major towns. Since 1957, in order to practice traditional medicine legally one has had to pass examinations from these schools, where courses in traditional pharmacy, midwifery, and general medical practice are offered. As an innovation women have been allowed to participate on equal footing with men.

In the court medical tradition we find a theoretical framework which is based on the four elements (earth, water, wind, and fire), the three humours (bile, wind, and mucus), and the ten tastes (hot, cool, mild, astringent, sweet, poisonous, bitter, oily, salt, and sour). The fact is, though, that the theoretical framework lacks internal coherence and consistency, and that its relationship to actual medical practice is weak: it is not readily applicable to diagnosis and treatment of concrete cases of diseases. One could say that the theoretical framework we find in the court tradition is divorced from practice and functions only as a frame of reference, a model. This framework legitimates practice, but does not dictate it.

During the Aythaya period, the capital was a lively international trading port with many foreign communities from various Asian as well as European countries. A number of these foreigners were employed in the King's service. It is quite likely that these foreigners left an imprint on the court medical tradition, although it is not clear how and to what extent this actually happened. It is quite obvious, on the other hand, that there is an element of Sanskrit influence in the court tradition. A number of court medical manuscripts on which the *tamra luang* is based have Sanskrit names – although no one has yet been able to identify these names with titles of Sanskrit medical manuals in India – and many of the concepts and the disease names are borrowed from Sanskrit. Still, no comprehensive comparative studies on this matter have, to my knowledge, been undertaken, so it is difficult to ascertain the extent and exact nature of Ayurvedic influence on the court medical tradition in Thailand. Even now, there are separate institutions for Ayurvedic medicine, such as the Ayurvedic Society of Thailand (*samaakhom ajuraweed haeng pratheedthai*).

Many Thais regard the court medical tradition as more advanced than the village tradition, and thus accord it the status of *the* Thai medical tradition, considering the village tradition but a crude simplification with many local variations (cf. Somchintana 1989: 280). This attitude is unfortunate because it glosses over the fact that even if the royal tradition has an explicit theoretical framework which the village tradition lacks, the medical practices of the two are still very similar.

Furthermore, there have not been any court physicians proper practicing traditional medicine for the last 100 years, so that the oral tradition that goes with the court medical tradition has been broken. Today there are therefore hardly any people who can explain the theories, concepts, organization, and the quite numerous unintelligible passages in the court medical manuals with authority.

Buddhism and Traditional Medicine

Buddhism is a crucial factor in Thai culture, but still there is no study of the influence of Buddhism and Buddhist medical lore on the Thai medical tradition.

In his study of the development of Buddhist medical knowledge within a broader Indian medical tradition, Kenneth Zysk points out that Buddhist monks at the time of the Buddha already acted as healers for their fellow *bhikkhus* (monks), and that "from around the mid-third century BCE monk-healers and the monasteries extended medical care to the population at large" (Zysk 1991: 41). Portions of the medical knowledge and experience of the Buddhist bhikkhus were recorded in a chapter on medicines (*Bhesajjakhandhaka*) in the *Mahavagga* of the *Vinaya Pitaka*, the monastic rules, thereby giving rise to a Buddhist monastic medical tradition.

Medicines were part of the five requisites a monk could possess, and originally the monks were allowed only a very limited number of basic medicines. As time went by the list of medicines allowed was increased and became in principle open ended. Furthermore,

> Medicines of the Buddhist monastic materia medica were considered to be foods but classified as nonsubstantial nourishment, allowing them to be consumed at any time (Zysk 1991: 73).

The medical knowledge in the *Vinaya* is organized in the form of case histories, where Buddha tells about the disease of a certain person and the remedies used to cure that person:

> The section on medicines in the *Mahavagga* (of the Vinaya Pitaka)… is characterized by reference to actual cases, and functioned as a handbook and guide for the treatment of common afflictions… The medical importance of these Buddhist records, however, is their recounting of patients' medical problems and the corresponding treatments. The academic medical treatises of classical *ayurveda* offered no such case-by-case medical instruction… Between those two traditions [i.e. the Buddhist Pali records and the classical Indian medical treatises] many similarities, but also numerous differences, exist – significantly, the Buddhist emphasis on practical application *devoid of the theoretical considerations of disease etiology* (italics added) that dominate the [non-Buddhist] medical books. This difference supports the view that codified Buddhist monastic medicine, with its emphasis on materia medica and case-based therapies, represents an early attempt to provide a manual of medical practice and in some sense legitimated the formalized collections of prescriptions… (Zysk 1991: 71–72).

As for knowledge of anatomy we find that:

> In the *Mahasatipatthanasuttanta* of the Dighanikaya (in Sutta Pitaka), the four intents of contemplation (*cattaro satipatthana*) are detailed. The first

of these was the human body (*kaya*) in all its parts, aspects, and impurities. The monk was to endeavor, through persistent contemplation, to realize the fundamental impermanence of his physical and mental constitution by meditating on the body:

> And in addition, O monks, a monk contemplates this very body, up from the soles of the feet (and) down from the crown of the head, bound by skin (and) full of manifold impurities. "There is in this body (the following): hair of the head, hair of the body, nails, teeth, skin, flesh, sinews, bones, bone marrow, kidney, heart, liver, pleura, spleen, lungs, bowels, intestines, stomach, excrement, bile, phlegm, pus, blood, sweat, fat, tears, grease, saliva, mucus, serous fluid, and urine..." There is in this body "earth element, water element, fire element, and wind element" (Zysk 1991: 34).

This list includes anatomical parts, but does not give any further descriptive details, neither how they function and relate to each other nor how they relate to diseases. The four elements are mentioned, but only to underline that the body, like all other matter, is ultimately composed of these elements.

Buddhist medical knowledge encompasses concepts such as the four elements, the three humours, and the 32 constituents of the body, and shows a very practical attitude to the curing process, but it does not attempt to construct specifically medical theoretical frameworks. Thus when Zysk concludes that, "The medical doctrines codified in the monastic rules probably provided the literary model for the subsequent enchiridions of medical practice" (Zysk 1991: 118), it is not difficult to agree that this has indeed also been the case for traditional Thai medicine.

Traditional and Cosmopolitan Medicine

If we look at patients' choices of curing methods in the countryside nowadays, we find, according to some statistics, that 95% prefer cosmopolitan medicine as a first choice, while only a small minority chooses traditional medicine. Furthermore, traditional medicine is in many cases resorted to only after treatment with biomedicine has failed. This means that patients who no longer can afford modern treatment or people with terminal, incurable, or chronic diseases will resort to traditional medicine. But there are also certain illnesses where traditional medicine has a reputation of being more efficient than biomedicine. These include haemorrhoids, kidney stones, and diseases with "wind" as the prominent symptom. In addition, the simple fact that traditional doctors are local people who know their patients' social situation, speak the local dialect, talk in a way the patients understand, and have more time to listen may give them an advantage over the more sterile and impersonal relationships the patients have with the Western-trained physicians and hospitals.

From the patient's side, it is not an either–or situation. Many patients will choose both traditions. People who are sick often go to several doctors and several pharmacies at the same time, both biomedical and traditional, and thus follow parallel treatments. This may have the consequence that they stuff themselves with too many drugs, thus rendering it impossible to decide which medicine actually cured the disease.

While cosmopolitan-trained doctors are quite sceptical of the efficacy of traditional medicine, the reverse is not true. Traditional doctors recognize quite readily the qualities of cosmopolitan medicine, such as the surgical skills and the value of vaccination and antibiotics for example. They also in some cases refer patients to modern doctors and they may (re)sell certain Western drugs they find useful. Ideologically they also feel akin to biomedicine in that, as one traditional doctor put it,

> Diseases are a terribly complicated business, so traditional doctors must use the same method as the Western trained ones, namely the trial-and-error approach: If one prescription does not work, I will try another, and yet another, until I have found one that works, just like the pharmacists and the modern doctors.

But cosmopolitan medicine does indeed also take an interest in traditional pharmacopoeia, trying to identify and extract medically active chemical components from traditional medical herbs in the hopes of being able to design new drugs. Transnational – and Thai – pharmaceutical firms are involved in this search, and the Government Pharmaceutical Organization has in fact for years been producing herbal remedies for sale based on their own research.

Cosmopolitan medicine in Thailand is also adopting traditional Thai disease terms for modern diseases, thus eroding the traditional concepts and causing some confusion. Modern medicine has, for example, adopted the traditional term *mareng* for cancer, while the term originally was a vague disease term covering various skin diseases with itching eruptions. So it seems rather far-fetched to claim – as some traditional doctors do – that traditional prescriptions against certain skin diseases (*mareng*) also cure cancer (*mareng*) in general, simply because the names for the two diseases coincide. Also, some traditional doctors are claiming to have found or invented herbal medicines which can cure other "new" diseases, such as diabetes and AIDS, and herbal mixtures have also been used to cure heroin addicts.

Current Developments

Over the last decade or so, the Thai government has radically changed its policy towards traditional medicine.

The general context for this change has been the new WHO policy to encourage governments to incorporate traditional medicine into their official medical systems. Furthermore, public expenses for medical care have continued to increase at an accelerating rate, and so has the bill for imported medicines and medical supplies. Thai politicians and bureaucrats also see the possibility for export of traditional Thai drugs, and that Thai medicine can play an important role in transforming Thailand into Asia's health service centre.

There has also been a growing awareness of and pride in one's national heritage and local wisdom and knowledge, and "nature", "ecology", and "holistic approaches" have become very popular concepts and part of the current discourse on health. Some even feel that there is an incongruity between modern technology and the Thai way of life and indigenous culture. All these factors have contributed to strengthening the hand of traditional medicine and also in changing the attitude of the bureaucracy. One of the first official steps in this direction was the Seventh National Economic and Social Development Plan for 1992–1996, which stated that:

> The promotion of people's health entails the efforts to develop traditional wisdom in health care, including Thai traditional medicine, herbal medicine and traditional massage, so as to integrate it into the modern health service system.

The Thai government has followed up on this plan, by adopting the goals of the plan in its official health policy and by establishing in 1993 the National Institute of Thai Traditional Medicine (NITTM) under the Ministry of Public Health. Its first director was the energetic and knowledgeable Dr. Phennapa Subcaroen. The basic aim of the NITTM is to integrate Thai Traditional Medicine (TTM) effectively into the National Health Service system. To achieve this aim, NITTM must, according to a brochure it has published, "systematize and standardize the body of TTM knowledge" and thus "gather knowledge, revise, verify, classify, and explain TTM knowledge" as well as "compare and explain the philosophies and basic theories of TTM and to produce textbooks on TTM".

Thus in order to revitalize traditional medicine and make it acceptable to the official medical system, the NITTM has deemed it necessary to create a new traditional medicine with a coherent medical theory, a consistent diagnosis and a consistent use of medical herbs, as well as a safe and efficient medical practice, or in other words, to replace heterogeneity with homogeneity. The result is no longer called "traditional Thai medicine" but simply "Thai medicine", "traditional" having been dropped because it sounded too outdated.

This recreation of tradition is supposed to be done in cooperation with traditional doctors, NGOs, and other interested parties. But, according to Rancarati:

> Not all health care workers, academics and traditional healers are content with official views of TTM… since they (particularly those in peripheral regions) feel that it is just another form of homogenization and domination of Central Thai culture within national boundaries… Standardized Ministry of Public Health TTM exams favour the Central Thai model, particularly by adopting Central Thai names and concepts related to medicinal herbs (Roncarati 2003: 209).

Another important step taken by the NITTM has been to protect Thai traditional medicine from being appropriated and exploited by foreigners. Thus the NITTM drafted the Traditional Thai Medicinal Wisdom Protection Bill which, after several years of discussion, was approved and came into effect in May 2000. This bill makes Thailand one of the first third world countries to regulate foreigners' access to all aspects of traditional medical knowledge. The law drew quite irate comments from the US embassy in Bangkok but was lauded by the local media. In a commentary in the *Bangkok Post* of 18 June 1997 for example, the editor Sanitsuda Ekachai praised this initiative to "defend our indigenous plants and age-old knowledge of their use from being hijacked by richer countries". She deplored the fact that rich countries with advanced biotechnology and sophisticated laboratories can use the genetic resources of developing countries free of charge, extract the effective chemicals, patent them and sell them back as expensive Western medicines. She also referred to the unfair global trade laws, and concluded, "The Traditional Medicine Bill is a small effort by Thailand to defend itself against such injustice. No one can rob us of this right".

The increased awareness about the value and potentials of traditional medicine in Thailand and the attempts to revitalize this tradition will hopefully contribute to a better and more self-reliant public health system, but it has also made traditional medicine a highly political issue.

Chinese Medicine

Chinese medicine is quite visible in Thailand, especially in the towns, where drugstores sell Chinese herbs and where acupuncture treatment is offered. Still, Chinese medicine remains quite a distinct tradition used mainly by the Sino-Thai population. Although the use of certain Chinese herbs and prescriptions – as well as massage theories – may have entered the Thai medical tradition over the centuries, no systematic study has been made to verify the extent of such influence. The popularity among the Chinese – be it in the Mainland, Taiwan, or parts of Southeast Asia – of using the horns, bones, or bile of certain animals as aphrodisiacs has contributed to the endangering of mammals like the rhinoceros, tiger, wild boar, bears, and certain snakes, among others.

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This bibliography includes works on Thai traditional medicine defined narrowly, thus works on botany, pharmacy, medical practice in general as well as contemporary health problems and policy issues have not been included. I have also left out numerous studies on rituals and religion, many of which have a bearing on traditional medicine. Furthermore, the bibliography confines itself to Thailand and does not include relevant works from neighbouring countries, and it contains only works in Western languages, thus omitting a number of studies in the Thai language. For further bibliographic references to works on traditional medicine in Thailand, including works in Thai, see Shigeharu Tanabe, ed., *Religious Traditions Among Tai Ethnic Groups: A Selected Bibliography.* Ayutthaya (Thailand): Ayutthaya Historical Study Centre, 1991 (which contains special sections on Traditional Medicine).

The bibliography below reveals that most studies in Western languages on traditional Thai medicine are articles on specific aspects of traditional medicine. There exist only a few more comprehensive studies: Golomb (1985) gives a broad anthropological view of medical practices in Southern Thailand; Bamber (1987) studies disease classification from a linguistic point of view; Brun and Schumacher (1987) concentrate on medical practice in Northern Thailand using the traditional doctors as informants; Mulholland (1987) studies traditional paediatrics based on manuscripts from the court tradition; and Somchintana (1989) studies the concepts and system of traditional court medicine in Bangkok from a cognitive anthropological point of view.

There are but few works on the historical development of traditional medicine in Thailand for the simple reason that there is very little material in Thai which has survived from before around 1800. Scattered evidence can be found, but thorough and critical studies are extremely time-consuming and would not necessarily yield substantial results. Furthermore, detailed and critical comparative studies, both historical and contemporary, between the Thai medical tradition(s) and similar traditions in India, Sri Lanka, Burma, Cambodia, Laos, and China have yet to be undertaken. Thus how and to what degree these traditions have influenced each other is still an open question. What role Buddhism and the Buddhist *sangha* have played in the development of Thai traditional medicine awaits further studies. There is also a huge number of medical manuscripts which are in need of critical study which would also deepen our understanding of regional variations – just to mention some obvious areas of study which are needed to give us a better understanding of traditional Thai medicine.

Today Thai scholars conduct most of the research on traditional medicine, with basically two aims: to preserve tradition and to make it applicable to the health needs of contemporary Thailand.

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Medicine in Turkey

CHRISTOPHER DOLE

Turkey comprises a territory that has long been a crossroads for numerous empires, religions, and cultures. The medical and healing techniques that are practiced and utilized in contemporary Turkey reflect this diverse history. While cosmopolitan medicine has been practiced in Turkey for centuries and patients overwhelmingly prefer it when available, there exists a rich set of health care options for problems not defined as treatable within medical settings, in instances where one has no access to or cannot afford medical treatment, or, most commonly, alongside biomedical treatments. Despite a history of opposition toward nonbiomedical forms of healing (Dole 2004, 2006), traditional healing practices are still widely practiced and used within both urban and rural settings. As with any social practice, these healing practices change in relation to ongoing political, economic, historical, and social transformations.

The majority of traditional healing practices are closely related to Turkey's dominant religious orientation, Islam. Of these religious forms of healing, four general categories or types of healing can be identified. While there is a significant degree of regional, local, and individual variation, these categories reflect the most widespread practices and can be distinguished based upon their respective conceptualizations of therapeutic efficacy, of how each form of healing is understood as affecting a cure.

The first form of healing, *kurşun dökme*, roughly translates as "the pouring of lead" and consists of a lead pouring specialist (*kurşuncu*) who treats patients who have been struck by the *nazar*, or evil eye. The evil eye can manifest itself in a variety of forms – fever, sweating, "fright," bad luck, pimples, skin rashes, and nightmares, to mention but a few (Maloney 1976; Çelik 1974). Although practiced exclusively by women, both men and women go to this specialist for treatment. Women and children (both male and female) are, however, the most frequent visitors. The primary ritual feature of the *kurşuncu* is the pouring of molten lead into a basin filled with water over which the patient, with a scarf or covering of some sort over her or his head, leans. While the lead is being poured, the *kurşuncu* recites prayers and commonly says, “It is not my hand, it is the hand of our mother Ayse Fatma.” After the lead has been poured – which creates a cloud of steam that passes over the patient’s face – the *kurşuncu* removes the solidified piece of lead and reads it to divine the source of the evil eye. This is typically repeated three times.

Outside of this basic ritual formulation, there is remarkable variation, particularly in the many additional items that accompany the lead pouring and what the *kurşuncu* instructs the patient to do with them. For instance, items such as onions, bread, salt, oil, coal, keys, soap, strainers, brooms, forks, and gold rings can be utilized within *kurşun dökme* rituals. After finishing the lead pouring, the patient can be given specific instruction about what should be done at home and what should be done with each item. Instructions can include such things as not talking with or kissing anyone, not telling anyone that their condition has improved, throwing the water where no one will walk, tossing the onion behind oneself without looking, feeding the bread to a dog or cat, burying the bread at a crossroads, and so forth.

Women who specialize in the pouring of lead commonly learn the practice from older female relatives. As children, they assist their elder relatives with the ritual, thus learning the ritual variations of each healer. In this regard, the relationship between female elder and daughter or granddaughter is central to the succession of healers. In addition to passing on the specifics of ritual practice, this relationship is significant in that the ability to heal is passed through the female line of a family. The actual passing on of the ability to heal is described as *el vermek* – to give one’s hand. As compared to other forms of healing, this has perhaps shown relatively little historical change (Dole 2002).

A second category of religious or ritual healing widely practiced is that of the *ocaklı*. The practices of the *ocaklı* are incredibly broad and overlap with *kurşun dökme*. This form of healing, however, is not defined so much by the ritual style of its healing, but its association with holy or sacred ancestors. The term *ocak*, the root of *ocaklı*, while having many connotations (furnace, hearth, fireplace, mine, political body, guild, fraternity), is associated here with the notion of “family line.” To be *ocaklı* – literally, “with the *ocak*” – connotes someone having special powers to heal based upon their relationship to an ancestor. The *ocaklı* is thus usually linked to a particular tomb, that of his or her dead ancestor, which is generally located near his or her home village.

While different *ocaklı* may perform very different rituals, they all tend to be marked by a considerable specialization in regard to the problems treated. There are respective *ocaklı* who, for instance, treat specifically warts, rashes, arthritis, shingles, and jaundice. In addition to these more localized ailments, some *ocaklı* were known for their ability to cure alcoholism, to miraculously induce fertility for those who were unable to conceive, and provide good fortune in general.

Although the ritual techniques of the *ocaklı* vary considerably, the recitation of Quranic verses appears to be consistently present. Many, as well, utilize particular verses from the Qurʾān known as *şifa ayetler* (curative Quranic verses) that are recognized as being particularly effective in treating specific problems. While these verses are supposed to be effective no matter who reads them, the *ocaklı* is regarded popularly as having special powers in the realization of the verse’s intent. Beyond this, there are some common but less ubiquitous ritual components to the practice of the *ocaklı*. Drawing or scratching (*çizmek*) on the skin is one such practice, particularly for skin related ailments.

As with the *kurşuncu*, the efficacy of the *ocaklı* is attributed to their inheritance of a special gift or power to heal from an ancestor to whom miraculous or extraordinary powers are accredited. Similar to the *kurşuncu* as well, the training of the *ocaklı* typically occurs through assisting an elder *ocaklı* as a child. Although like the *kurşuncu* the *ocaklı* is customarily elderly, unlike the *kurşuncu* both men and women can be *ocaklı*. Likewise, both men and women go to *ocaklı*. Similar to the *kurşuncu*, the practices of the *ocaklı* seem to have changed little over the years and there appears to be little difference between *ocaklı* practicing in rural and urban settings.

While the *ocaklı* may be popularly ascribed titles like *ana* (lit. “mother”) or *dede* (lit. “grandfather”), mention should be made here of the distinct category of *dede* among Turkey’s Alevi Muslim minority (comprising approximately 20–25% of the total population). For the Alevi, *dede* is a title used to describe someone whose lineage can be traced back to Muḥāmmad through one of the Twelve Imams. While a given village, or group of villages, may be headed by a *dede* recognized as having spiritual and moral authority, there are commonly many more *dede* who do not perform the customary judiciary, ritual, and religious functions of the *dede* who heads a village or group of villages. These individuals are *dede*s principally in name only. On occasion, however, particular *dede*s – in their association with their lineage, or *ocak* – are considered to have the ability to cure illness or fulfill wishes. While at times referred to as an *ocaklı*, they may also be described as a *dede*. The Alevi *dede*, however, is distinct from the *ocaklı* discussed earlier, although the latter may also be referred to as a *dede*. Among Turkey’s Sunni Muslim majority, there is no figure that precisely resembles the *dede*, as it is understood among the Alevi. In terms of the more general category of *ocaklı*, however, there were few discernable differences in how the Alevi *ocaklı* and the Sunni *ocaklı* practiced.

The third form of healing, that of the *cinci hoca* or *üfürükçü*, treats a range of illnesses and problems which typically involve people being struck, harassed, or possessed by spirits (*cin*) or fairies (*peri*). Hence the title *cinci* (exorcist) *hoca* (teacher, or more specifically Muslim teacher or cleric). The *cinci hoca*, however, does not only treat those who have already been affected by *cin*. They may also work to control *cin*, and thus bring harm upon others. In this regard, such cinci hoca are considered practitioners of magic (*büyü*). Furthermore, their characteristic ritual blowing over either the patient while being prayed for or over the object being made serves as the basis for the title *üfürükçü*, itself a derivative of the verb *üfürmek*, to blow on someone or something. Although they address an incredible range of problems, the most common ones are epilepsy, nightmares/fright (*korku*), adultery, and a host of relationship problems.

Rather than an emphasis upon the inheritance of a sacred gift, such as with the *ocaklı* and the *kurşuncu*, the capacity of the *cinci hoca* to heal centers upon training and the learning of specific ritual formulas. Correspondingly, many *hoca*s base their practice on such texts as *Gizli İlimler* (Secret Sciences), *Havasu'l-Havas*, and *Kenzü'l-Havas*. These books, which are readily available at many religious bookstores, contain extensive lists of ritual prescriptions that are said to have been passed down from the distant past. A given treatment is typically the result of computations based on the Arabic equivalent of the letters of a patient's and that patient's mother's name, the patient's birth date, and the presenting illness, problem, or intention (*niyet*). Based upon these, the book then provides the appropriate ritual formula. This ritual formula can include not only the appropriate prayers to be recited a specific number of times and at specific times, but also instructions for the production of different ritual objects or talismans (*tılsım*).

The *muska* is by far the most recognizable object produced by the *hoca*. A *cinci hoca* may also be referred to as a *muskacı* – a writer of *muska*. The *muska* is a sheet of paper over which a Quranic verse, a ritual prescription, the patient's name, the patient's mother's name, and/or the object of the spell's intent has been written in Arabic. The paper is then folded, frequently into a triangle, and put into a pouch. This pouch can either be worn or placed on the body of the patient (e.g., around the neck, in one's pocket), or can be placed in prescribed locations to realize the desired effect. For example, there are numerous accounts of *muska* being placed under a bed so as to block the sexual drive of a person. Alternatively, the *muska* can be burned or soaked in water, after which the water is consumed (Eyuboğlu 1987, 1998). Although there are instances of female *cinci hoca*, male *cinci hoca* are far more prevalent. Both women and men, however, visit the *cinci hoca*. The *cinci hoca* is a highly controversial figure and the target of considerable animosity (Dole 2006).

In many a neighborhood mosque, or *cami*, the local imam may treat members of the community for various problems using some of the same practices as the *üfürükçü*. While any imam, or *cami hoca* as they are sometimes distinguished from the *cinci hoca*, would fervently disagree with being compared to the *cinci hoca*, many imams utilize similar rituals treatments for the ill, assign enormous importance to the *şifa ayetler*, and incorporate the ritualized blowing over the patient while reciting prayers. There are however drastic differences. The imam does not utilize the astrological and numerological aspects of the *üfürükçü*'s practice. Outside of perhaps writing out the *şifa ayet* for the patient, the imam also does not utilize talismans such as the *muska*. Finally, the *cami hoca* tends to treat minor ailments and does not venture into the realm of magic and witchcraft. On theological grounds, imams categorically denounce the work of the *üfürükçü* as not part of Islam. The *cami hoca* is relatively rarely utilized and not typically conceived of as representing a specific tradition of healing.

The fourth, and far less prevalent tradition of healing, is that of the *evliya*. Although the meaning of the term is most closely approximated with the English concept "saint," one should be careful not to assume a homogeny between Christian and Islamic notions of sainthood. Nonetheless, an *evliya*, as with a saint, is broadly definable as a person acknowledged as possessing extraordinary spiritual powers, which in turn connotes exceptional status. An *evliya* is commonly defined as a possessor of *keramet*, the God-given power to perform miracles. Unlike the *ocaklı*, the saint's power does not necessarily have to be the result of being a descendant of a holy person; they are the holy person from whom the *ocaklı* will be descended and to whom a *türbe*, or tomb, will most likely be dedicated. *Türbe* visitation is an extremely popular tradition in Turkey and commonly coincides with requests for cures (Olson 1991, 1994). It could possibly be viewed as its own form of traditional medicine, although no designated healing practitioner is commonly associated with tomb visitation.

Although there are no specific passages in the Qurʾān that authorize the recognition or veneration of saints, saint worship is nevertheless extremely popular. The existence of those recognized as living saints is however still rare. It should be noted that unlike Christian sainthood, particularly in Catholicism, there is no formal system of canonization when discussing the *evliya*. *Evliya* are, in many regards, "self made" (Faroqhi 1979:658). As with the Christian saint, though, the principal task or duty of the *evliya* is to intercede with God on behalf of petitioners or supplicants. While being able to heal is one of the commonly ascribed God-given powers of the *evliya*, they are not solely healers. Because the centrality of their efficacy revolves around an ability to perform miracles and speak directly with God, training is of little significance for the *evliya*'s authority. Though there is supposed to be only one *evliya* on earth at any given time, scattered throughout Turkey are nonetheless rumors of numerous saints appearing and disappearing.

Other than the principally religious based forms of healing discussed earlier, there are also prominent forms of healing for which there is limited scholarship. For instance, the use of herbal remedies is widespread in Turkey. In addition to frequently being self-prescribed, one can find individuals in both urban and rural areas who have received special training in mixing medicinal herbs. Additional healing specialists that were in the past particularly widespread in rural areas of Turkey are the *kemikçi* (bone-setter) and the traditional midwife (Önder 2005).

The traditional healing practitioners described earlier constitute significant aspects of local health care systems, and people (from all backgrounds) seek their assistance for a variety of reasons. Most commonly, they are utilized alongside biomedical treatments. With the exception of perhaps the *evliya*, such practitioners are not leaders of religious groups or organizations. They are individuals who, like others, assume a variety of social positions – neighbor, greengrocer, butcher, relative – but have acquired a body of specialized knowledge that bestows upon them a certain degree of reverence.

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Medicine Wheels

LAWRENCE TYLER

The Indians of the North American Plains, because of their nomadic ways, were not dependent upon permanent settlements and structures. Aside from rings of stone left after *tipis* were moved there is little evidence of construction left by these tribes. The noted exceptions to this generalization are the formations known as "Medicine Wheels". More than one hundred of these formations have been found in North America ranging through Saskatchewan, Alberta, Montana, North Dakota, Wyoming, and Northern Colorado. These sites are all located north to south, within a few hundred miles of the eastern boundary of the Rocky Mountains, suggesting the migratory patterns of the Native American culture of this area. They are distinguished from *tipi* rings and camp sites by their size and by the spokes or arms which radiate from a central cairn. These formations are found in isolated locations, inappropriate to community dwelling. Always of native stone, these "wheels" usually consist of a central hub of stone, and/or an inner circle, from which other stone lines radiate out toward the horizon. They are not meticulously constructed but rather seem like a design that a few workers could put together in a matter of days. However, the dimensions are sometimes substantial. The Bighorn Wheel in Wyoming, for example, has a central hub about 12 ft across; with radiating spokes 90 ft in length.

The existence of many of these stone formations has been known for at least a century. The Bighorn Medicine Wheel was reported in the 1880s by explorers and prospectors; by radio carbon analysis it has been dated AD 1600–1700. The first archaeologists to investigate the Bighorn site asked local Native Americans about its use or origin but initially none of the tribes claimed responsibility for its existence or knowledge of its use. Gradually stories emerged, but there is always the question of whether the informants were creating the sort of responses that they thought anthropologists wanted to hear. In point of fact, none of the indigenous groups, such as Sioux, Cheyenne, and

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Arapaho, have folk legends and traditions which either explain or validate the role of Medicine Wheels in their traditional cultures.

Until the 1970s, the generic explanation for Medicine Wheels was that they must have been of "ceremonial" use, though no one was forthcoming with any detailed account of just what ceremony. The Sioux and Cheyenne are known for their Sundance ceremonies, for which special circular medicine lodges were built. Some observers have been tempted to point out the spatial similarities between the circular medicine lodges built around a living tree used as the center pole with roof and walls radiating from that center and the medicine wheels with central cairn and radiating spokes. The symbolic similarity may be clear, but real intent and purpose remain unknown. So until the 1970s, Medicine Wheels were at most a curiosity of Plains Indian culture neither well known nor well explained. Then an integrative approach called archaeoastronomy, linking the previously separate disciplines of archaeology and astronomy, emerged as a new way of examining ancient phenomena. Basically its unifying theme is to examine megalithic and prehistoric formations for astronomical significance. One example of this is Gerald Hawkins' work documenting the astronomical alignments of Stonehenge in Salisbury, England. Soon practitioners of both astronomy and archeology were looking with renewed interest at ancient megaliths around the world, including Medicine Wheels.

The astronomer John Eddy is most closely associated with an archeoastronomical interpretation of North American medicine wheels. He, in collaboration with an archeological team, studied several medicine wheels, including the Bighorn Wheel in Wyoming and the Moose Mountain Wheel (radio carbon dating, AD 100–500) in Saskatchewan. His findings suggested that many such formations could have been used as landmarks in the rolling plains of an otherwise undistinguished terrain. The simplest of these seem only to point to other stone formations, in the same way guideposts mark long trails across isolated lands.

However, for both the Bighorn and Moose Mountain wheels, Eddy notes solar and stellar alignments that could have been used for solstice calculation. Normally solstice observation is associated with agricultural societies, but nomadic groups such as Plains Indians also needed techniques for anticipating the severe weather changes of the northern plains. While such an interpretation is not conclusive, various studies are now suggesting that the Plains Indians were very careful observers of the evening sky as well as the land. The Medicine Wheels may be indicators of their ability to use markings on the earth to note celestial changes in the sky and the corresponding journey of the seasons; all useful information for high plains travelers. In any case Medicine Wheels could have been of both ceremonial and astronomical utility since the world view of the plains tribes would have made no significant distinction between spiritual and stellar forms.

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Metallurgy in Africa

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A condensed discussion of African metallurgy is difficult because of the large size of the continent and the 3,000 years over which it developed south of the Sahara desert. Furthermore, several metals were produced and used in Africa, and metal production involved many technological steps which were not necessarily used for each metal type (i.e., iron, copper, gold, and tin). Iron production, for example, involved mining iron ore and smelting it to a bloom, a nonmolten mass of metal intermixed with a waste product called slag. The bloom was then forged into objects by hammering, welding, and other processes. Some preindustrial societies made cast iron, a molten form of iron, but there is little evidence for this technology in Africa. Copper and copper alloys, on the other hand, were often made by reducing ore into molten metal and pouring it into molds, or by hammer forging solid copper. Gold was hammered out from its original nugget form, or melted and cast. Pellets of tin were removed from the slag output of tin smelting and were then melted into ingots. Moreover, not all societies used the same metals or mastered the same manufacturing steps for any given metal. Some cultures specialized in iron smelting, while others forged iron blooms into objects. In copper producing areas, some societies had craftsmen who cast molten copper into molds, others hammered out unrefined copper, and still others specialized in drawing out copper wire.

Much of the current knowledge about African metallurgy concerns iron production. There are several reasons for this. Iron has the clearest presence in the archaeological record, iron ore is virtually ubiquitous across Africa, and, for centuries, it was a subject of interest to Greek and Arab travelers and, later, European explorers, missionaries, and scholars. Copper smelting and casting, as well as the production and use of bronze (an alloy of copper and tin), brass (an alloy of copper and zinc), and gold, have also received considerable attention. The more isolated occurrences of these technologies across Africa in the archaeological and ethnographic record, however, have resulted in less detailed reconstructions of their diverse histories and their significance to African cultures. Some tin production occurred in southern and western Africa, but this is the least studied indigenous metal and may have a relatively short history as compared to iron, copper, and gold.

The prehistory and history of African metallurgy come from several sources. Archaeological excavations often yield metal objects, and/or the physical remains of production centers (i.e., smelting furnaces containing slag, tuyères or blow pipes, and charcoal fuel; forging pits; casting crucibles; molds). Increasingly, archaeologists submit these remains to laboratory analysis to determine how an object was made, or the chemical and physical dynamics of an ancient metallurgical process, its environmental context, and its age by radiocarbon dating. Some scholars conduct collaborative research with village elders who still remember how to smelt and forge iron, or cast copper. Several projects have resulted in important films which underscore the complexity of many metallurgical operations, provide critical insights into poorly understood ancient practices in Africa and worldwide, and highlight the nontechnical aspects of production. Some researchers also perform experimental reconstructions of metallurgical processes to understand further the thermodynamics involved. A final source of information is the archival record of numerous visitors to Africa over the centuries. The reports from the early twentieth century first featured the nontechnical characteristics of African metallurgy, including esoteric knowledge, decorated furnaces, ritual, music, and taboos.

The following discussion begins with a brief overview of the prehistory of African metallurgy, then examines the technical diversity of metallurgical practices across Africa, and concludes with a look at its social and ideological components.

Although this review principally concerns Africa south of the Sahara desert, the earliest evidence of metal production and use was in Egypt. Copper was first used there around 5000–4000 BCE and was being smelted by 3000 BCE. Iron objects were rare through the Middle Bronze Age, but became more frequent during the New Kingdom after about 1570 BCE. Iron smelting was practiced by the eighth century BCE.

Ancient Egyptian metallurgy had no influence on the rest of the continent except to the immediate south in Nubia and the later kingdom of Kush, both in modern Sudan. An Egyptian outpost was established in Nubia to smelt local copper ores in 2600 BCE, and Egyptians exploited Nubian gold from an early time. By the next millennium, Nubian craftsmen worked copper, bronze, silver, and gold. At Meroë (ca. 500 BCE to AD 300), the capital of the Kushite state, there were craftsmen of copper, bronze, gold, and iron. The earliest iron slag from the site dates to the fifth century BCE; domed, brick smelting furnaces, possibly of Roman influence, were used after about 200 BCE.

There is controversy over two interrelated aspects of the origins of metallurgy in sub-Saharan Africa (1) whether it was invented indigenously or introduced from elsewhere and (2) which metal – copper or iron – was smelted first. Researchers looking for a "natural" progression of pyrotechnological knowledge (i.e., simpler copper smelting to more complex iron smelting) to prove indigenous origins have been thwarted to date. Copper smelting only seems to have preceded iron smelting in Nubia and, during the early to mid first millennium BCE, along the southern Sahara in Niger and Mauritania. Current evidence shows that iron appeared first or at the same time as copper in the rest of sub-Saharan Africa. Other than at Meroë, the earliest indications of iron smelting are in Nigeria (ca. 900–800 BCE), Niger (ca. 500 BCE), Rwanda/Burundi (ca. 700–500 BCE), and Tanzania (ca. 300 BCE).

Many archaeologists believe that knowledge of iron smelting was brought from abroad, but they cannot agree on the route of introduction. Several routes have been proposed (1) Egypt to Meroë, then west and south, (2) from the Phoenician or Roman coast of North Africa across the Sahara desert, and (3) via the Indian Ocean. The first has been ruled out because of the early evidence of iron smelting in West Africa. Little else can be resolved until issues over radiocarbon dating are settled, excavations are conducted in poorly explored regions, including the North African coast and Ethiopia, extensive historic linguistics are done, and the possibility that more than one route existed is carefully investigated. It is now recognized, however, that iron and copper were introduced to different regions of Africa at different times.

Iron working spread from the regions of early introduction in West Africa, Sudan, and East Africa to Southern Africa in 500–700 years. This rapid expansion was once thought to be linked to the movement of Bantu-speaking agriculturalists as they traveled south and east from their homeland in present-day Cameroon, over 3,000 years ago. Recent archaeological and historic linguistic evidence discredits this theory. Traces of early iron smelting have been found in modern Gabon and Congo, but not in northeastern Zaïre. Historic linguistics suggest that iron working in East Africa probably had northeastern, not western, origins. The earliest evidence of copper smelting to the south of Cameroon, on the other hand, occurs by the fourth century AD in copper-rich areas on the Congo coast and in northern Zambia/southeastern Zaïre at about the same time as iron working.

Intensified use of iron, copper, bronze, gold, and brass during the first and second millennia AD was connected to, but not the cause of, the rise of African states, urbanization, and the development of long distance trade routes in some regions. For example, the city of Jenne-Jeno in present-day Mali was well-developed by the third century AD. It did not begin to receive gold from across the Sahara desert until around the eighth–ninth centuries AD or brass (a known import based on the nonindigenous zinc present in the alloy) until the ninth–tenth centuries AD. Jenne-Jeno then became a major trade center in metals. In southern Africa, a long distance trade in gold developed between people living in modern Zimbabwe and those in coastal towns on the Indian Ocean by the tenth century, on the back of an earlier trade in ivory and skins. A powerful state with its capital at Great Zimbabwe (AD 1275–1550) prospered, in large part, by taxing the gold mined and traded from this region. Bronze, a golden alloy of copper and tin, also was developed in the area around this time, but little is presently known about the technology and its local significance.

In many other parts of Africa at this time, relatively small quantities of iron and/or copper were produced, used, and traded locally. The diversity of mining, smelting, and forging techniques that developed over the last two millennia is extensive.

Metal ores, such as specular hematite, malachite, and galena, may have been mined many millennia ago in sub-Saharan Africa, but they were ground to powders for cosmetics. Once ores were mined for smelting, several techniques were developed depending on the type of ore exploited and the physical and technical constraints encountered.

A similar array of mining techniques was developed for copper, iron, gold, and tin across Africa. Some copper and gold ores differed from iron and tin ores in one critical way, however: they could be found in their native metallic state. Mining for native metals involved picking up workable nuggets, panning for and concentrating metal flakes in watery contexts, or digging shafts along seams of metal. This was often labor intensive, such as in ancient Zimbabwe where gold mining involved considerable digging, crushing the matrix rock, and then amassing the gold by panning.

African miners exploited the oxide minerals of copper, iron, and tin at or near the earth's surface for smelting. They dug narrow shafts until the ore was exhausted, the shaft was unsafe, or they reached water. Large open ditches were also excavated. Both techniques required metal tools and, in the latter case, fire-setting was also used to break up the rock. Often, the matrix rock had to be crushed to concentrate the ore. Cases also existed of panning to concentrate rich iron ores dispersed in sandy matrices. While many aspects of African metallurgy were performed and controlled by men, the labor of carrying the ore, panning, and working in the narrow shafts was often done by women and, probably, children.

A facet of African metallurgy that has long intrigued scholars is the bewildering diversity of iron smelting furnaces over lime and across space. At a very general level, three types of furnaces were built: pit or bowl furnaces lacking walls and operated by bellows and tuyères; shaft or walled furnaces with a pit beneath, also operated by bellows and tuyères; and tall furnaces (ca. 2.5–4 m), often without a pit, that used natural draft to stimulate combustion. Within each general type, there was enormous variation based on whether or not slag was tapped from the furnace during smelting, numbers of tuyères, bellows type, pit depth and diameter, height and shape of the furnace walls, building materials, decoration on the furnace walls, and presence/absence of interior furnace features.

Some scholars have theorized a chronological sequence for these general furnace types, from "primitive" pit furnaces in which wrought iron was made to shaft furnaces in which low grade steel was produced to natural draft furnaces. Regional and local variations would have then developed over time. Recent findings reveal that the earliest furnaces all had walled shafts, and that a heterogeneous bloom, varying from soft wrought iron to high grade steels, could be produced in each furnace type. It is now generally thought that furnace variation was a response to certain local constraints, such as ore types, but primarily to the different sociocultural contexts into which iron smelting was brought or developed.

Less is known about African copper smelting because it was practiced less widely and has been the subject of less research and ethnographic observation. Most copper smelting furnaces were the shaft type, but considerable variation existed based on whether the molten copper was tapped directly from the furnace into molds or was melted in crucibles within a furnace. Pit size, building materials, wall height and shape, number of tuyères, bellows type, mold sizes and shapes, and wall decoration also varied.

Gold was not smelted, but melted in crucibles over an open fire. There is little evidence of gold extraction technologies in Africa except for occasional pieces of gold-encrusted crucibles from Zimbabwe and South Africa. Tin ore, like iron ore, had to be smelted or reduced in a furnace, but little is known about the processes used or when they were developed. An ethnographic account from Nigeria indicates that tin and iron ores were cosmelted and tin was removed from the slag. In South Africa, tin ore was smelted in tiny furnaces, pellets of tin were extracted from crushed slag, melted in crucibles, and cast in molds.

The fabrication techniques used to transform raw metal into objects were also diverse and varied by type of metal and region. Iron and steel, for instance, were always hammered into shape, but many types of hammers and anvils were used over the continent. Skill at welding together pieces of iron and/or steel and other joining techniques varied widely. Evidence that iron was drawn out into wire comes from East Africa and to the west in modern Angola, but the history of this technique is vague. Interestingly, no evidence of pre-colonial heat treatment of steel (i.e., quenching it in water) to harden and strengthen an object has been found.

Copper was manipulated in several ways: hammer forging solid metal into various forms; drawing out wire; casting molten copper into molds; and alloying copper with another metal, like tin to make bronze, and then casting the alloy (the ability to cast copper is improved by adding tin). Evidence to date suggests that a sophisticated lost-wax casting technology (intricate forms are made of wax and encased in clay; molten metal is poured into the mold which replaces the wax) was developed in West Africa by the ninth–tenth century AD. The site of Igbo Ukwu in Nigeria has yielded remarkable castings that were followed by later traditions at nearby Ife and Benin.

Igbo Ukwu also provides the earliest evidence of bronze which was used to make many lost-wax castings. Investigations into whether bronze alloying was an indigenous discovery in West Africa is ongoing. The only other region where bronze alloying developed was around present-day Zimbabwe, although little is known about the stimulus and dating of this technology. It probably arose after the beginning of the maritime trade along the Indian Ocean, perhaps in the eleventh–twelfth centuries AD, and was used to make wire, beads, and simple two-sided mold castings. Brass, the alloy of copper and zinc, on the other hand, was used extensively for lost-wax casting in West Africa beginning around AD 1000, although the metal itself was imported into Africa from across the Sahara Desert and along the West and East African coasts.

There is no evidence of lost-wax casting outside West Africa, although casting traditions did exist. Open-faced or one-sided molds seem to have been used to cast copper into bar shapes as early as the seventh century AD in present-day Zambia. In the Zaïre–Zambia copper belt region, cross-shaped molds were made by the ninth–eleventh centuries AD in northern Zambia, but not until the fourteenth century in southeastern Zaïre. These ingots were then traded. Objects were made as the ingots or raw metal were hammer forged into sheet, rods, ribbon, and other shapes. Drawing copper into wire, a fabrication technique found in Central, Eastern, and Southern Africa, was used by the mid-second millennium. The history of its development and spread is unknown, although iron/steel draw plates for wire were found at Ingombe Ilede, Zambia, dating to the fourteenth–fifteenth centuries AD.

Gold objects tended to be produced by the same techniques as copper in a given region. Lost-wax casting of gold in West Africa, such as among the Asante of present-day Ghana, is particularly exquisite. Wire drawing of gold was also practiced in West Africa. At ancient Zimbabwe, gold was usually hammered to shape beads, wire, and sheet. Finally, there is no evidence that any objects were made of pure tin in Africa. Occasional ingots cast of tin are found in South Africa, presumably for used trade.

A critical part of African metallurgy that has not been discussed is the nontechnical – the social organization of labor, the use of space, and the esoteric knowledge, rituals, taboos, special clothing, and music involved. The innumerable processes of African iron and copper smelting, in particular, were complicated mixtures of technique, special knowledge, and ritual controlled and designed by men to ensure success and circumvent danger and malevolence. This involved not only pleasing the ancestors, but countering the acts of sorcery that were perceived to be a threat to the process.

Central to this examination is the recognition that all social activity, including technology, must be explained and done so within a framework meaningful to the people involved. Questions concerning the sources of ore, how rocks become shiny metal, why some smelts are unsuccessful, and what slag is are answered in modern, Western societies by scientific principles of geology and engineering. In pre-colonial Africa, these questions were resolved through principles based largely on human physiology and social structure.

A compelling framework was offered recently to consider how many pre-colonial African societies explained metallurgical activities. This is based on two fundamental aspects of human experience – gender and age. Gender concerns the interaction of males and females through a life cycle, but focuses on one critical stage of life that is not shared. Women are capable of transformation and creation through their ability to give birth, a process that is interrupted by monthly periods of sterility and ends at menopause. The links between women, production, and reproduction are poignant. Male metal workers could only generate similar creative forces with which to transform rock into metal and then into objects by controlling and appropriating women's natural abilities through symbol, metaphor, and ritual.

The axis of age encompasses the relationships between youth and elders, as well as between the living and the dead. In many African cultures, the human life cycle involves the accumulation of wisdom and power through adulthood. Greatest power is acquired as an ancestor. Thus, elders have the expertise and knowledge to demand and exploit the labor of youth in most activities, including metallurgy; the ancestors have ultimate power over all significant activities of the living, particularly its reproduction. Integral to mining, smelting, and fabricating metal objects, therefore, was gaining and maintaining ancestral approval.

The cultural influences of gender and age were most obvious during iron and copper smelting – technologies of transformation and creation with many opportunities for failure. These influences were manifested in highly diverse ways. Often, smelting involved rituals and song that simulated significant times in the life of a productive woman, such as marriage, pregnancy, and birth. The Fipa of Tanzania, for example, adorned and treated a newly built iron smelting furnace as a bride who would have many children. The furnace was perceived as a "wife" to the iron smelters in many African cultures, such as the Phoka of Malawi. Furthermore, various parts of furnaces were often given the same names as female body parts, particularly those related to sexuality and birth. The Shona of Zimbabwe, the Chokwe of Angola, and others were more explicit and built their furnaces as women. They decorated the walls with breasts and scarification, denoting fertility, and the bloom sometimes came out between leg-like projections. Rituals also were used to consecrate new iron forges or tools which drew analogies between the anvil/hammer (the most important tool of a smith) and a second wife, such as among the Nyoro of Uganda, or a child, such as among the Ondulu of Angola.

Both age and gender strongly affected the roles played and choices made during metal working, including the significant influence of ancestral spirits, the technical and ritual expertise of elders, the work load of the youth, and the exclusion of women. Although women were often miners in cultures with labor shortages, all women, particularly pregnant or menstruating ones, were excluded from smelting operations. Prepubescent girls and postmenopausal women, however, sometimes participated in presmelting rituals or cooked and transported food to the smelters. Furthermore, strong taboos existed to prevent men from having sexual relations prior to a smelt. Such behavior represented infidelity to the furnace, and adultery was often thought to cause miscarriages in pregnant women. Furnaces were usually placed far away from villages to minimize this potential threat.

These rules of participation were designed to please the ancestors by preventing the presence of forces – uncontrolled fertility and temporary sterility – that might jeopardize a productive metallurgical operation. Young girls and postmenopausal women were not threatening because of their lack of fertility and active sexuality. The rules also served to separate metalworkers from the general public as people with special knowledge and capabilities. Many accomplished metal workers became wealthy members of their societies, as well as important political figures.

Other forces influenced how a smelt proceeded and how failure was explained, including visible problems with the materials or technical steps used. In less obvious circumstances, however, a common explanation for failure was sorcery by jealous villagers or by competing metalworkers. Since iron, copper, bronze, brass, and gold workers were often relatively rich and powerful men, they sometimes became foci of envy. Actions to avert evil spells, therefore, involved meticulous attention to the preparation and placement of medicines in and around a furnace and, sometimes, a forge. Ethnographic and archaeological evidence reveal that the placement of medicines inside furnace pits has been practiced for two millennia. As a result of this integral part of the metallurgical process, metalworkers were often believed to be sorcerers and/or people with special powers. Particularly skilled metalworkers were regularly in demand by the general public for their abilities to heal and divine.

Two significant lessons – actually two sides of the same coin – may be learned from the study of African metallurgy (1) a technology can exhibit tremendous variation through time and across a continent and (2) a technology is a system that is at the same time technical, economic, social, ideological, and political. A technological system affects and is affected by the culture and society in which it operates such that a great diversity of associated behavior and knowledge may result over time and space. Unfortunately, all the complexity and variation of African metallurgy will never be fully appreciated and known, particularly as the elderly experts die with much of their precious knowledge untapped.

See also: ►Technology and Culture

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Metallurgy in Ancient Eastern Eurasia

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Background

The development of metallurgy is considered fundamental to the emergence of complex societies in many regions of the ancient world. Until recently, little evidence could be obtained to explain the emergence and spread of metal technology in the third and second millennia BCE in the Eurasian Steppe where life was centered in kin-based, relatively independent pastoral or agropastoral communities. Archaeologists in central and eastern Eurasia have recently uncovered information about early metal use and production by residents of the steppe and the significance of this development in the area east of the Urals and west of the Yellow River. This is the area addressed in this essay.

Eurasia is a term given to the combined areas of Europe and Asia. Eurasia forms the largest landmass on the globe, or about 20,816,400 square miles. Many geographers claim that this is one continent and therefore that Europe is merely a peninsula of Asia. But whatever one's conception of continent, the area extends from the Balkans to the Yellow Sea and links Europe and Asia. Lying between the 40th and 50th latitude of this enormous land belt is a steppe land with a fairly uniform terrain with an average altitude of between 500 and 1,000 m. Like the prairie across much of the mid-section of the United States, this terrain is covered either by coarse grass or low woods. Only one mountain barrier with high forests, the Urals, crosses Eurasia in a north–south direction, giving rise to the nineteenth century conception of two continents of Europe and Asia divided at the mountains. The Urals are, however, merely an interval, rather than an interruption, in the vast sweep of the Eurasian steppes.

Decades ago studies on the beginnings of metallurgy envisioned the setting in the centers of early civilizations. Mesopotamia and Egypt in the west and China in the east, and early centers of production could be documented in West and East Asia, but not in between (Tylecote 1992; Moorey 1985; Knauth 1974). Both the intellectual climate and the evidence available conceptualized the advent of metal use as a spontaneous occurrence in a single ancient society. But, given the discrepancy in start dates and distance between the Near East (beginning as early as the fifth millennium BCE) and the Far East (beginning at the earliest about 3000 BCE), there has been much speculation about what role, if any, Eurasia had in the process of transmission. Researchers asked whether such a complex technology could be transmitted across the vast steppe to East Asia by the peoples of Eurasia or whether it was spontaneously generated in the Far East.

Sites excavated in Eurasia, that is in the border provinces of present-day northern and western China, the Republic of the Altai, Kazakhstan, Mongolia, and Russia east of the Urals, in the past two decades document the production and use of metals as early as the late fourth and third millennia BCE (Chernykh 1992: 190–234, 2000; Linduff et al. 2000; Linduff 2003). Based on a synthesis of the current Russian and Chinese chronological and metallurgical information from the area, it is possible that the entire area, including north China, might be better understood as part of a larger sphere of interaction that produced metallurgical traditions that emerged during the late fourth to the second millennium BCE. Technological as well as typological differences found across the area may be explained by noting the availability of ores, use of artifacts, and social complexity and even the environment of the generative societies. It is clear that many regional traditions abound, but that movement of ideas as well as artifacts, and people, perhaps technicians more than whole groups, was likely and was a stimulus for the transfer and invention of the variety of technologies now known to have been employed in this vast area.

The Problem

At the eastern edge of the Asian continent, analysis of metallurgy has figured centrally, for its development was thought to signal the advent of "historic Chinese civilization." In establishing ownership of the earliest bronze, priority was conventionally given to central China largely because it was where a high Bronze Age civilization eventually arose. The areas adjacent to ancient dynastic Chinese lands where early metallurgy was documented, even as distant as southern Siberia and Mongolia, were seen as peripheral to it as independent centers of invention. The direction of

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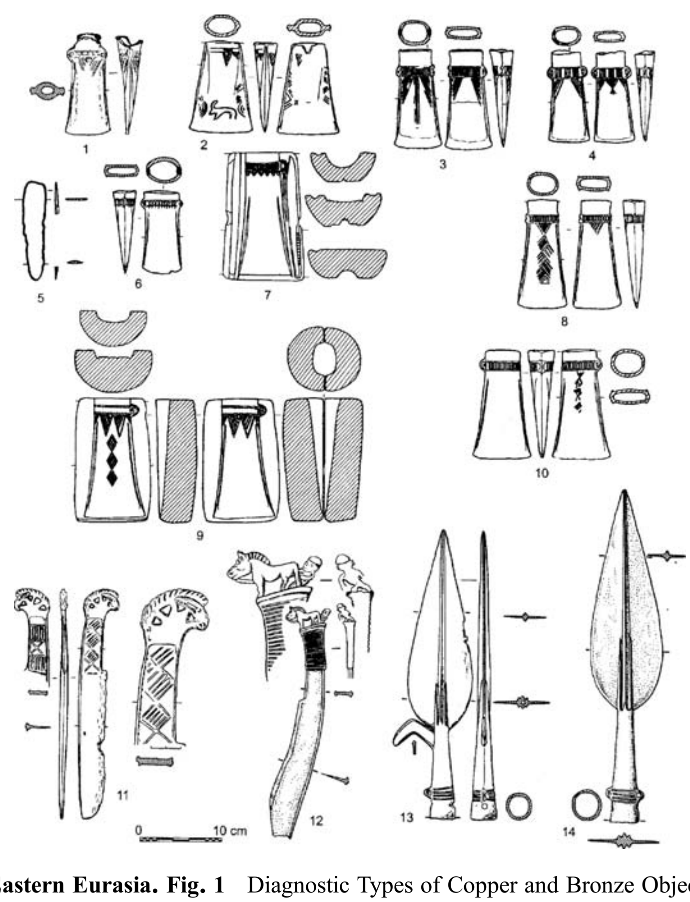
exchange of people, ideas, artifacts and/or technology in the area, was a topic hotly debated in the past, and is no better exemplified than by the dispute between Bernhard Karlgren (1945) and Max Loehr (1949a,b) over bronze daggers and knives. They described the differences in the weapon and tool inventories of each area and agreed that there were two distinct traditions represented by diagnostic artifacts known from a limited number of excavations and from museum holdings. China was represented by straight-edged bronze knives; outward curving, hafted knives; single-edged daggers with tangs decorated with conventional Chinese motifs, particularly *taotie* (animal mask) and dragon designs. The Eurasian (or Siberian) typology included socketed axes; curved knives with naturalistic images of animals on the pommels; and double-edged short swords, also often with recognizable animal designs on the handles (Fig. 1). The discussion was focused on issues of cultural primacy and the dating of the Siberian against the Chinese Bronze Age. Since no carbon dates were available then, the discussion rested on reasoning about typological sequencing. This debate has persisted in the literature for many decades.

Based on her own fieldwork and that of others in Russia and Kazakhstan, Legrand has recently reviewed the discussion, but not with an eye toward solving the debate over initial invention (2003). We now know that the "Karasuk" and "Andronovo" material does not represent the earliest use of bronze in either area and that the broadly defined dichotomous model developed by Karlgren and Loehr is far too simple to address the question of the emergence and spread of metallurgical technology, even in eastern Eurasia between the Altai mountains and the Yellow River.

Among Chinese and Russian scholars, study of the metal industry and proposals about who initiated the technology have been affected by mutual lack of information because of language barriers, and especially by modern political borders and nationalistic sentiments. The Chinese and Russian studies, as well as the now-dated debate between Profs. Karlgren and Loehr, presented judgments about the direction of



Metallurgy in Ancient Eastern Eurasia. Fig. 1 Diagnostic Types of Copper and Bronze Object Categories from the Seima-Turbino Complexes (Asian Centers). From: *Metallurgy in Ancient Eastern Eurasia from the Urals to the Yellow River*. Ed. Katheryn M. Linduff. Chinese Studies Vol. 31, Lewiston, Queenston, Lampeter: The Edwin Mellen Press, 2003. Fig. 1.10.

transmission for the technology that were based on comparisons of style of artifacts and on relative dating of each "host" culture. Their arguments, Karlgren as the champion of Chinese and Loehr of Siberian prototypes for certain artifacts and ultimately for the technology itself, were mounted at times when excavated, tested, and dated materials earlier than about 1250 BCE were lacking, so that only the fully developed phases of the second millennium BCE were studied. And, although archaeologists and metallurgists still debate the diffusionist and spontaneous generation models, new archaeological data, C14 dates and metallographic studies from both Russia and China (Chernykh 2000; Linduff 2003) permit a different way of thinking about the issue. After the break-up of the Soviet Union, both Kazakh and Mongolian Institutes of Archaeology have conducted their own investigations and some of those results have been reported as well (Goriachev 2003; Erdenebataar 2003). These studies are the first in English to document carefully the earliest known use of bronze in each area.

In the current literature, there is another problem worth mentioning. Field archaeologists, whether trained in the Russian or Chinese intellectual tradition, for the most part have defined cultures according to pottery types and styles and discussed the transmission of technology accordingly by these "archaeological cultures." The metallurgical scientists have looked at metallurgical traditions first, and then connected them with cultures. The application of a single term to identify a "culture" such as the "Andronovo" in much of Eurasia generalizes to the point where its descriptive meaning is useless since it often ignores regional cultures and perhaps even very different traditions altogether (Korochkova and Stefanov 2003).

For instance, bronze artifacts that follow the shape and style of ones called Andronovo or Seima-Turbino, such as trumpet-shaped earrings and socketed axes, have been excavated at a site called Huoshaogou, in Gansu Province in western China and date from between 1900 and 1600 BCE (Linduff et al. 2000: 15–19). Russian archaeologists might, on the basis of those objects, identify Huoshaogou as an Andronovo or Seima-Turbino culture site. One the other hand, no Chinese archaeologist has labeled it thus, but rather consider it as part of a western extension of the "Yangshao" culture because the painted pottery found at Huoshaogou, they say, is a variant of the Yangshao diagnostic type known from the central Chinese heartland. Not only is the terminology of archaeological cultures true to neither "type" in this case, the application of these labels obscures the nature of the local setting. The site, its organization and use, shows that this community both produced metal artifacts, and also imported metal items for burial. The issue here is not about to what "culture" they might belong, but how the local community was constituted and connected to traders, metal workers, and each other. Clearly the site and its regional neighbors absorbed peoples and information from both their west and east, but are quite self-sufficient and distinct.

Or, similarly, there is no doubt that the Semireiche region in Kazakhstan is an important one for the development and transmission of metallurgical materials and technology throughout its immediate region as well as to its east, especially into what is now western China. Although the several pottery traditions have been identified there have been variously labeled Andronovo or Fedorovo, the distinctiveness of these sub-areas is argued for by Goriachev while recognizing how important large regional networks might have been to them (2003). Such a network has been determined with the excavation of a site where a massive mining effort was recently identified and dated in the late fourth or third Millennium BCE at Kargaly (Chernykh 2003). Kargaly is now known, for example, to have supplied large numbers of artifacts and raw materials to peoples living to the west of the Urals. Another such network probably connected patrons and metal manufacturers living in areas to the west and east of the great tin loads in the Altai Mountains (Chernykh 1992). The territorial extent of these Eurasian trade networks are only beginning to be understood, but the amount of data now available allows us both to examine carefully local operations as well as to speculate on how individual societies might be connected others.

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The Data from Southern Siberia, Kazakhstan, and the Altai

Debates and assessments of incipient metallurgy and its consequences in the ancient world now consider several crucial factors:

1. Knowledge of the presence of ores and the corollary existence or creation of trade networks
2. The presence of knowledgeable local and/or itinerant artisans who knew metals and their properties
3. A community able to support such workers, with a degree of social and/or ritual complexity to create a demand for metal products
4. The ability to create high temperature furnaces for smelting and refinement of ores and final castings

The most sophisticated and earliest known metal-producing industries were located in or near the more complex societies in the Near East where these products were used for many purposes ranging from utilitarian to luxury items for use in everyday activities to solemn rituals. The Eurasian metal period is on the whole later than that in western Asia.

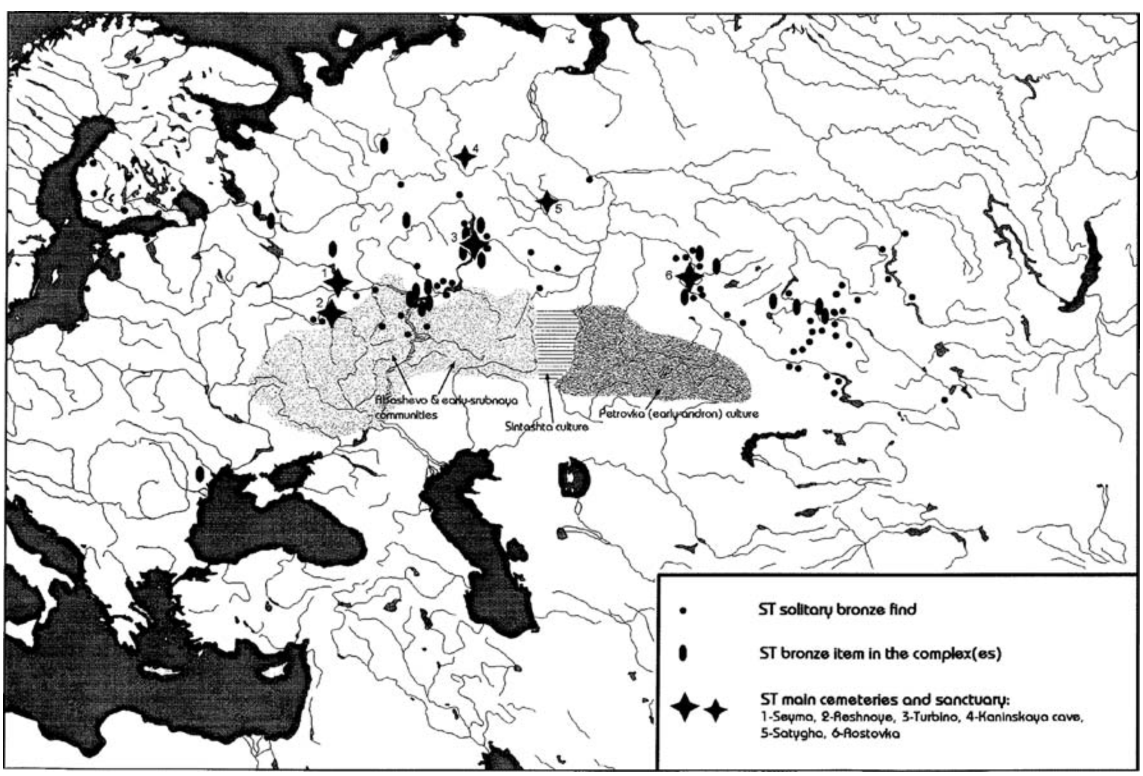
The publication of Evgenii Chernykh's texts and bibliographies on the early metallurgy in the USSR

(Chernykh et al. 2003; Chernykh 1992, 2000, 2003) and many reports on individual sites have provided data on excavated materials from the territories between the Near East and the current Chinese borders. In addition, more complete reports on copper- and bronze-using sites in Russia, especially those near the Ural Mountains, such as Arkaim and Sintashta-Petrovka (Gening 1992; Zdanovich 1997), have been published. Chernykh and his colleagues in Moscow have collected almost 2500 C14 dates from metal using sites across Eurasia (Chernykh et al. 2000). The map of the earliest known metal production from Chernykh's essay (2003) shows quite clearly that metals were part of village life in Eurasia no later than the late fourth millennium BCE (Fig. 2).

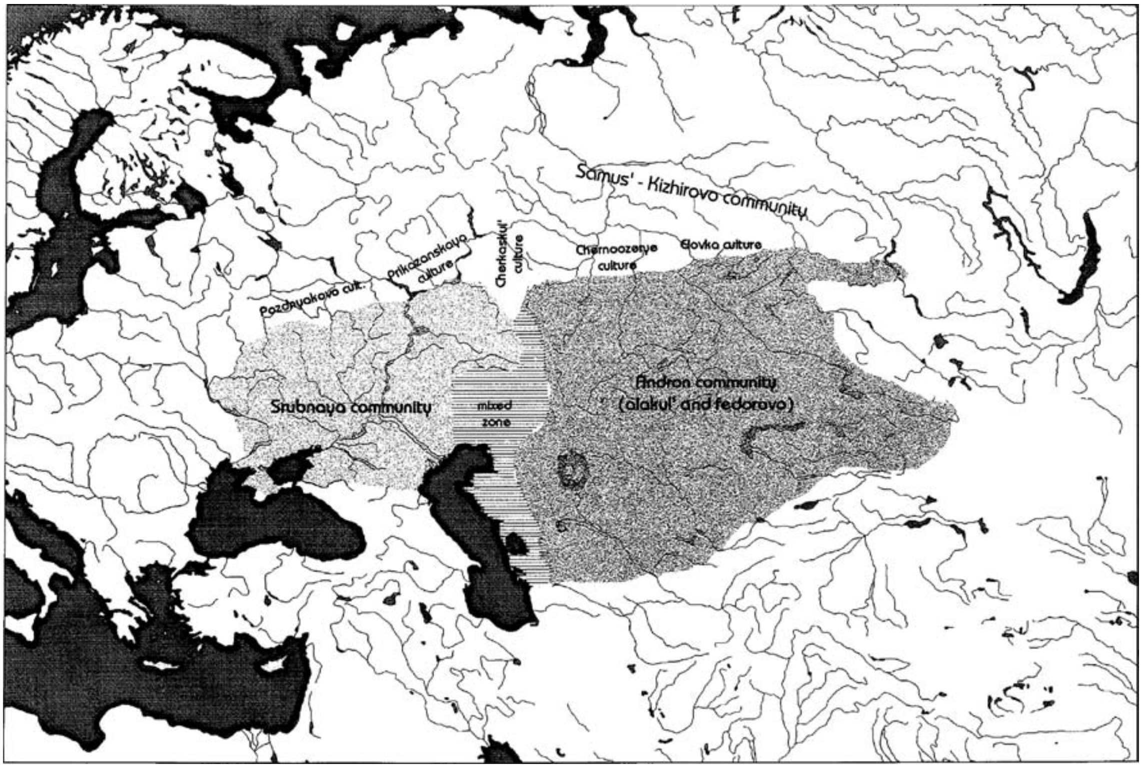
Chernykh defined "Metallurgical Provinces" as large contiguous regions linked through shared utilization of morphologically defined ornaments, tools, weapons; a common technology of metallurgical production; availability of or access to the same metallurgical resources often emerging into large trade networks; and comparable dating (Chernykh 1992: 7–16). These provinces cover distinct areas at different times and include discrete sub-areas of metallurgical knowledge and metalworking. What he calls the Eurasian Metallurgical Province (EMP) and its sub-category, called the Seima-Turbino chronological horizon, date from the late fourth and third millennia BCE, or Late Bronze Age, are the most relevant here (Chernykh 1992: 7) (Fig. 3). Some artifacts, such as fishhooks, awls, rings, and bracelets, are ubiquitous in the Seima-Turbino contexts.

Although Kuz'mina challenges the method and details of dating this complex against the Andronovo (2003: 37–84), there seems to be little argument about the importance of this metallurgical development. The disagreements over the dating of each sub-area complex depend at least in part on the methodology used to establish a chronology. Chernykh depends largely on C14 testing with calibration (Chernykh et al. 2000). Since carbon dates are never precise, Kuz'mina, for instance, proposes that the most reasonable dating can be derived from classification method using evolutionary-typological analysis (2003). Her system finds the Andronovo (and possibly the Fedorovo in Kazakhstan) and the Seima-Turbino synchronous in the seventeenth century BCE (2003). Many authors use a combination of both methods (Korochkova 2003; Legrand 2003; Goriachev 2003).

More recently, however, regions called foci, or distinct centers of production, were also identified within the EMP (Chernykh 1992). For example, the



Metallurgy in Ancient Eastern Eurasia. Fig. 2 Borders of the Eurasian Region and Main Archaeological Cultures (The Early/Initial Phase). *Metallurgy in Ancient Eastern Eurasia from the Urals to the Yellow River*. Ed. Katheryn M. Linduff. Chinese Studies Vol. 31, Lewiston, Queenston, Lampeter: The Edwin Mellen Press, 2003.



Metallurgy in Ancient Eastern Eurasia. Fig. 3 Borders of the Eurasian Province and Main Archaeological Cultures at the Second Phase (The Period of Stabilization). *Metallurgy in Ancient Eastern Eurasia from the Urals to the Yellow River*. Ed. Katheryn M. Linduff. Chinese Studies Vol. 31, Lewiston, Queenston, Lampeter: The Edwin Mellen Press, 2003.

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eastern region includes the Andronovo historico-cultural community and other archaeological cultures recognized previously by archaeologists in the southern Urals and central and northern and eastern Kazakhstan to the Altai and Tianshan mountains (Kuz'mina 2003: Fig. 2.5). The significance of these regional centers is very evident in the study of sub-areas just east of the Ural Mountains (Korochkovo 2003) and in eastern Kazakhstan (Goriachev 2003) where small Andronovo/Fedorovo type metal objects have been excavated recently; and in western China where similar metal items have also been uncovered (Han and Sun 2003; Mei 2000, 2003). Although separated in many cases by large distances, analogies in the shapes and décor of these metal objects can and have been noted. In each case, however, regional peculiarities such as pottery types or décor and/or metallurgical traditions clearly mark important distinctions which Chernykh claims constitute sub-areas of a larger complex. For instance, unique types such as socketed axes with hatched triangles and rhombuses, forked-shank spearheads, and curved knives with animal (sheep and horses) and human subjects on the pommel were made only in the eastern region in the Altai and Tianshan. Because these items were used sparingly in burial and were unique in décor, they have been labeled "princely" artifacts (Chernykh 1992: 218–219). Currently available materials make clear these differences, while recognizing that there is interchange throughout this region no later than the third and early second millennia BCE (Linduff 2003).

Spectrographic analysis was carried out on all dated metal items from the Seima-Turbino area and Chernykh attributes fundamental innovations in metallurgy and metalworking to this region at this time; his conclusions are based on analysis of the 422 metal objects and 30 casting moulds excavated from burials. In the "eastern focus" area (that is, up to the borders of present-day China), only two examples of arsenic–copper were found; all other examples were tin–bronze (all from Rudny Altai, Rostovka). The curved knives with horse figures on the hilts, for instance, are all high quality tin–bronze and were found by him only in the Altai. The vast quantity of tin ore in the Altai is given as the reason for such a concentration of tin–copper alloys in eastern and southern Siberia (Chernykh 1992: 224–226). By contrast, products typical of the western sub-area were made from "pure" and arsenical copper and billon found in abundance in the Urals. And, although tin–copper and tin–arsenic–copper products were found throughout the EMP defined by Chernykh, only certain shapes such as ornately decorated Seima-Turbino socket axes were excavated in the western region, suggesting that the axes were supplied in a finished state (Chernykh 1992: 224, 2003). Finally, Chernykh proposed that the Altai was the source of particular tool types and chemical compositions of tin–bronze and depictions of animals (Chernykh 2000). In addition, jade and flint, bone tools and protective armor are also exclusive to this area. The notion of an EMP can be extended to include Xinjiang, and even probably Gansu and various of the northern provinces in present-day China, given the materials found and analyzed there in the past couple of decades (Han and Sun 2000, 2003; Mei 2000, 2003; Linduff 1997; Linduff et al. 2000: 1–29).

The Data from the Northern Zone of China

Syntheses that investigate China usually view the archaeological landscape during the fourth millennium BCE as a mosaic of regional groups that interacted with each other (Chang 1986). When dealing with the period of early metal use however, most Chinese archaeologists have accepted a traditional model which regards the Central Plain of northern China as the dynamic center of social, political and technological change and proposes that complex societies emerged in Asia through a process of political expansion and cultural diffusion from the Yellow River Basin (An 1982). The elevated position of metal artifacts as well as the highly specialized and sophisticated multipiece mould technology developed to produce them in early Chinese society has led to the assumption/conclusion that the commencement of metallurgy in East Asia was to be found inside the early Chinese cultural, and/or even the political sphere. Now this conclusion must be reexamined because there is adequate information to show that metal artifacts were locally produced in enough volume to confirm their regular use all across the Northern Zone. Moreover, the types of objects found in this region as well as the component percentages of metals in the alloy corresponds to metal types and alloying formulae found in the EMP, including both arsenic- and tin–bronzes (Sun and Han 1997) and suggest that the advent of metallurgy in this region was not a separate occurrence.

Over the past two decades, articles about more than seventy sites that can be dated either by C_{14} and/or by archaeological context earlier than 1500 BCE have been published. These sites yielded metal artifacts and/or metal production materials such as crucibles or slag, and so forth. These sites date to the late fourth and third millennia BCE (Linduff 1997: 306–418; Mei 2000). The earliest metal-using communities are in Qijia/Siba sites in Gansu, with comparable sites in Xinjiang in the west, and others in Shandong, Liaoning and Inner Mongolia in the east and north, and in the Central Plain in the lowest levels at Erlitou. Because several levels of excavations are C_{14} dated and those dates have been matched up to ceramic types and styles, chronologies are more secure. An approximate chronological correspondence between the sites in the earlier eastern Eurasian steppe and China is now clear, and suggests that the emergence of metallurgy was supra regional (Linduff 2000 et al.).

Analysis of both the Chinese and Russian data, including metallic composition, casting technology, as well as types and uses in the period from about 3000 to 1500 BCE has led to some surprising observations about the advent of metallurgy in eastern Asia. (Barnard 1993: 3–48; Barnard 1987: 3–37; Linduff 1997, 1998: 619–643). First, we can see that one of the most striking, as well as usual, additions to late Neolithic village life in northeastern Asia as far east as the Russian Far East was the use of metals. Sites where metals (including copper as well as alloyed metals) were first used and manufactured are located across a large area, showing that the growth of the industry did not solely, or even primarily, occur in the Central Plain. Moreover, preliminary observations on the process and patterns of use of the technology are both shared and diverse (Siba versus Erlitou) (Sun et al. 2000).

Areas in China where metallurgical knowledge was in use emerged near ore sources of metals, especially copper in several combinations. For instance, arsenical bronzes produced in Gansu at Siba sites must have been manufactured by exploiting local arsenical copper resources still available in present-day Gansu. All areas developed a taste for items made from "pure" copper and copper alloys, and gold items have been found in the northeast and northwest China. Trumpet-shaped earrings, for instance, have been found all over eastern Eurasia and northern China and were made from copper, tin–bronze as well as gold and sliver according to the local preference. The lack of consistency in formulae suggests that that knowledge was gained from several sources and not through local invention (Han/Sun 2000; 2003; Mei 2003).

In contexts where manufactured metal artifacts have been found in China, excavated villages have yielded evidence of both cultivated crops and domesticated animals, as well as the continued practice of hunting with improved arrowheads made of bronze, especially in the northeast. Chernykh's fanciful speculation that the Seima-Turbino was formed though a fusion of metallurgists and warrior horse-riders of the forest zones of the Altai and eastern Siberian taiga mobile hunters (1992) is supported in the recent excavations of the village at Gorny (Chernykh 1998), Kargaly (Chernykh 1997, 2003), and many others including Arkaim and related sites (Zdanovich 1997). Located close to vast resources of ores in the Urals, these excavations reveal that isolated groups of miners and metallurgists worked in specialized communities for many generations supplying patrons across western, and possibly eastern, Eurasia.

General Observations

The many shared traits discussed above suggest that there was a "metallurgical network" of some type, however loosely connected. The region is linked through comparable artifact types, by closeness to ores, and by shared metallurgical technologies not easily transmitted without movement of craft workers or even groups of travelers. The consistently local character of pottery types and styles in sub-areas, as well as the appearance of metal items with affinities to cultural debris from Bronze Age southern Siberia, has suggested that there was movement into the area of western China, likely bronze producing peoples of Andronovo background from eastern Kazakhstan and/or Transbaikalia (Ke 1998; Linduff 1998; Mei 2000; Kuz'mina 2000). Although animal sacrifice signified status and/or leadership in burial and metal items included tools, weapons and personal ornaments associated with individuating societies in the region of Gansu (Linduff 1997), metal items ultimately were used to identify only elite members of a centralized political unit at Erlitou in the center of early dynastic China (Linduff 2000). As Kuz'mina suggests (2003) the appearance of wheeled transport, metallurgy and use and/or breeding of horses signal not only movement of ideas, technology, and perhaps peoples, but also significant societal change, often to a more complex social order.

This change evidenced and discussed for the earlier to middle second millennium BCE was not a one-time affair. That was not the only period of interchange between the peoples of western China and points west. Continued stimulation, moving in both directions, can be witnessed in the later second and early first millennia BCE (Legrand 2003). Nor are the border regions of present-day western China the limit of that exchange system. Both local pottery and early metal artifacts suggest that knowledge of metallurgical traditions and artifact types extended into northeastern China (Linduff et al. 2000) and into what is now the Russian Far East (Konkova 2002).

Nevertheless, when considering the advent of metallurgy in the late fourth and third millennia BCE, all the criteria of the EMP defined by Chernykh are found in the "Chinese" contexts. If separated from modern nationalistic and centric views of ancient culture and considered as part of a larger metallurgical context, even the multipiece-mould casting method developed in the late second millennium BCE at Erlitou, seen as a hallmark invention of early dynastic China, may be seen as a local technological variation within the easternmost Eurasian territory made for specialized ritual use.

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Metallurgy of Ancient Indian Iron and Steel

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Early ideas about the Aryan migration theory and the introduction of iron into India from the West have now been proved to be incorrect. For example, Pleiner (1971) proposed that so-called Aryans had no iron production until the second half of the first millennium BCE, and that there was no iron export to the West from the area of the Aryans, whom he assumed to be "the Sanskrit speaking people." However, there are firm dates for the advent of iron in the Indian subcontinent before this period. The independent origin of iron has been convincingly argued by Chakrabarti (1992). Agrawal and Kharakwal (2002) have compiled radiocarbon dates of excavated iron manufacturing sites in the Indian subcontinent. The earliest available date, 3050–90 BP, is from Raja-Nala-Ka-Tila in Uttar Pradesh (Tiwari 2003).

The primacy of iron technology in the Indian subcontinent is well established and there are several published books on the state of ancient Indian iron technology (Neogi 1914; Chakrabarti 1992; Biswas 1996; Tripathi 2001; Balasubramaniam 2002). The metallurgy of iron and steel in ancient India is the topic of this article, which includes the working of iron, the extraction of iron and salient features of ancient Indian iron. Some objects illustrating the skill of the Indian blacksmiths are provided. The Delhi Iron Pillar (Fig. 1) illustrates the pride of Indian blacksmithy skills.

Metal Extraction

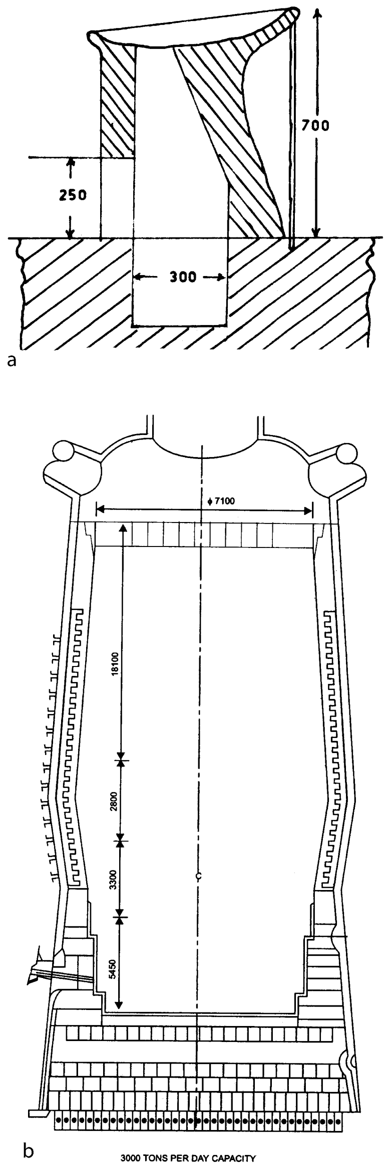
The direct reduction method of iron extraction was used for a fairly long period in India's history. Iron lumps were the starting material for the fabrication of most objects.

Iron melts at 1,540°C and the ancient Indian furnaces were incapable of attaining this high a temperature. The various aspects of construction and operation of ancient Indian iron furnaces (called bloomery furnaces because

Metallurgy of Ancient Indian Iron and Steel. Fig. 1 Delhi Iron Pillar located in the Quwwat-ul-Islam mosque in the Qutub Complex at New Delhi.

the end product was an iron bloom) have been discussed in the literature (see Tripathi 2001). The ore for extracting iron was carefully collected by the ironsmiths. Interestingly, specific ore was collected depending on the end application. Preheating facilitated breaking of the ores, and the fine dust was separated by washing or by wind. The preheated iron ore and charcoal were charged in alternating layers, the furnace ignited and slowly heated to the reduction temperature (1,000–1,200°C). Different designs of iron extraction furnaces have been described in the literature. Their heights ranged between 5 and 20 ft. A typical ancient Indian bloomery furnace is schematically compared with a modern blast furnace in Fig. 2.

Bellows placed at the bottom of the furnaces were operated at a controlled rate. The iron ore had to be reduced in order to obtain the iron. Iron ore is essentially oxide of iron and it is reduced by the carbon monoxide (CO) that is produced by the burning of charcoal in the bloomery furnace (or coking coal in a modern blast furnace). The other unwanted oxides, like silicon dioxide (SiO_2), which is commonly found in iron ores, have to be removed and this was possible by the creation of a liquid slag called iron silicate or fayalite $FeSiO_4$ or $2FeO{\cdot}SiO_2$. While some of the liquid slag flowed out of the bloomery furnace during the reduction of iron ore to iron, some of the liquid slag still remained when the hot iron lumps were taken out of the furnace. Therefore, the hot lumps that were extracted from the bloomery furnace at the end of the heat (typically lasting for about 6 to 8 h) were immediately hammered. In this process, most of the entrapped liquid fayalitic slag flowed out of the solid reduced iron mass. However, it was not possible to remove all the entrapped liquid slags and ancient irons produced by the direct reduction process will always contain entrapped inclusions. The inclusions are essentially composed of fayalite, some iron



Metallurgy of Ancient Indian Iron and Steel. Fig. 2 Comparison of (a) modern and (b) ancient furnaces for extracting iron from ore.

oxides (for example, wüstite FeO) and glassy phases (due to calcium silicon phosphates). As a result of entrapped slag particles and iron oxides in the structure, the specific gravity of ancient irons is lower than that for the purest form of iron (Fe).

The slag present in ancient irons is generally microscopic in nature with a few in larger sizes. As the solid-state reduction resulted in a fine distribution of slag particles, it was difficult to completely hammer the slag out of the metallic matrix. The resulting sponge iron always contained some amount of entrapped slag inclusions and unreduced FeO. These are not of uniform size and also not strictly uniform in composition.

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Viewing the production of iron lumps from a powder metallurgical viewpoint, the ancient Indians produced iron "pre-forms" directly from iron ore which implied that the powder production, powder consolidation, and sintering[1] processes were combined into one operation (Dube 1990).

The end product of the extraction process was a lump of iron that was subsequently used for a wide variety of applications, either directly or after further heat treatments. One important heat treatment that was successfully conducted was controlled carburization of iron in specially designed crucibles. The carbon content of steel (i.e., an alloy of iron and carbon) was carefully controlled by subsequent decarburization treatments. It is important to control the carbon content in steel because the mechanical properties of steel are critically dependent on the carbon content. As a rule of thumb, the higher the carbon content, the higher the strength of steel.

The relatively small iron lumps produced in the bloomery furnace were the starting materials for the manufacture of large iron objects. The lumps were also used, after suitable heat treatments, for manufacturing agricultural (hoes, spades, sickles, and weeding forks), household (knives, ladles, spoons, sieves, saucepans, cauldrons, bowls, dishes, saucers, and tripods), building (nails, clamps, staples, sheets, door handles, and spikes), tools (anvils, hammers, scissors, saws, chains, and smithy tools), and warfare (swords, javelins, armor, helmets, and shield bases) items. A marvelous example of a forge-welded object is the gilded Buddha head from the Gupta period (320–600 AD) (Fig. 3).

With the advent of the carburization of iron, a special type of high carbon steel was produced in India from as early as the fourth century BCE. This steel was known as *wootz steel* and it was much prized by warriors because tough swords could be wrought from wootz steel (Srinivasan and Ranganathan 2004). There were several applications for wootz steel, like the manufacture of tough swords (see Fig. 4), helmets (see Fig. 5), and armor (see Fig. 6).

Classification

Ancient Indians were masters in the production of iron and steel. The method of production of wrought iron directly from the ore by the process of direct reduction continued for a fairly long time, up to the end of the eighteenth century AD. The Indians knew fairly early about the beneficial aspect of carburizing iron to increase its strength. The earliest evidence for

[1] Sintering is a process in which fine solids are combined into a porous mass that can then be added to the blast furnace. These include iron ore fines, pollution control dust, coke breeze, water treatment plant sludge, and flux.

Metallurgy of Ancient Indian Iron and Steel. Fig. 3 Gilded wrought iron Buddha image of the sixth Century AD, now in Lucknow State Museum.

Metallurgy of Ancient Indian Iron and Steel. Fig. 4 Typical watered blade manufactured from wootz steel.

carburization of iron dates to about 800 BCE (Ghosh and Chattopadhaya 1982). The second urbanization of India (i.e., settlements along the Ganga) was strongly influenced by the steeling of iron.

Three principal varieties of iron were recognized based on the carbon content. Each of these was further subdivided into other varieties depending on the composition and properties (Prakash 1991). Sanskrit literary sources (for example, *Rasa Ratna Samuchchaya* dated to the eighth to twelfth century AD) classify iron into three basic categories: wrought iron (*Kanta Loha*), carbon steel (*Tikshna Loha*), and cast iron (*Munda Loha*). *Rasendrashār Samgraha* also mentions these three classifications and states that "*munda* is ten times better than iron rust, *tikshna* hundred times better than *munda*, and *kanta* million times better than *tikshna* iron." These three basic categories were further classified according to the carbon content, heat treatment, and end use. *Munda* was again subdivided into three varieties: *mridu*, which easily melts and does not break and is glossy; *kuntha*, which expands with difficulty when struck with a hammer; and *kadāra*, which breaks when struck with a hammer and has a black fracture surface. Six varieties of *tikshna* were provided: *khara*, *sāra*, *hrinnāla*, *tārābatta*, *bājira*, and *kālaauha* (black metal). One variety is rough and free from hair-like lines and has a quicksilver-like fracture surface, while another variety breaks with difficulty and presents a sharp edge. Five different varieties of *kanta* were recognized: *bhrāmaka*, *chumbaka*, *karshaka*, *drāvaka*, and *romakāntā*. The variety of iron which makes all kinds of iron move about was called *bhrāmaka*; that which kisses iron was called *chumbaka*; that which attracts iron was called *karshaka*; that which at once melts iron was called *drāvaka* and *romakāntā* was the kind which, when broken, shoots forth hair-like filaments.

Metallurgy of Ancient Indian Iron and Steel. Fig. 5 A typical medieval Indian helmet fabricated out of wootz steel.

The ancient Indian iron furnaces were capable of producing iron of consistent (low) carbon content-containing entrapped slag inclusions (Tripathi 2001). Iron meant for corrosion-resistant applications contained higher phosphorous (P) contents. Therefore, it is reasonable to conclude that the ancient Indian metallurgists possessed the art of manufacturing iron and steel according to the desired application and corrosion-resistant steel was one among them. The excellent corrosion resistance of ancient Indian iron can be attributed to its relatively high phosphorus contents. This is due to the absence of CaO (calcium oxide, i.e., limestone) in the charge of the bloomery furnace.

Microstructures

In materials engineering, the close correlation between structure and properties is well known. Structure indicates arrangement of the material. When one views the arrangement of electrons, neutrons, and protons, we call it atomic structure. On a microscopic scale, in the order of micrometers, the grain structure of engineering

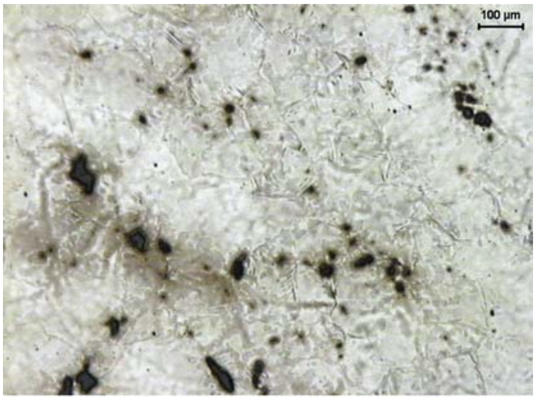
Metallurgy of Ancient Indian Iron and Steel. Fig. 6 Typical medieval Indian body protection gear wrought out of wootz steel.

materials is understood. Finally, the macrostructure refers to observations made in the range millimeters. Structure affects the properties of engineering materials.

The microstructures of ancient irons are highly heterogeneous; the iron normally possesses nonuniform grain structures.

In the unetched condition, the specimens generally reveal slag inclusions irregularly distributed in the microstructure. The end product of the bloomery furnace was a lump of direct reduced iron, which contained phosphorous as the major alloying element. The end product of the ancient Indian direct process of extracting iron can be called phosphoric iron. The end product of modern blast furnaces is pig iron, in which carbon is the major alloying element. In contrast to macrosegregation of P in pig iron, microsegregation of P is realized in ancient phosphoric irons. Fig. 7 shows an optical metallograph obtained after polishing an ancient Indian iron sample to a mirror-like finish and etching it with Oberhoffer etchant. The particular etchant reveals the distribution of P in the microstructure. The dark areas in Fig. 7 are the regions where the P content is less, while the bright areas are indicative of higher P contents. Notice that P is depleted from the grain boundaries and from the regions surrounding the entrapped slag particles. There are several fascinating insights that can be obtained from the study of microstructures but this is beyond the scope of this article.

The forge-welding method of manufacturing iron objects continued for a long time. Indians did not quickly adopt the cast iron technology that was becoming popular in Europe from the beginning of the sixteenth century. They continued with their traditional method of forge welding to manufacture large objects like cannons. One typical example of a massive cannon manufactured by forge welding is seen in Fig. 8. This cannon was fabricated in the early part o the seventeenth century and is located at Thanjavur. There are several other massive forge-welded cannons from the medieval period (Balasubramaniam 2007).



Metallurgy of Ancient Indian Iron and Steel. Fig. 7 Microstructure of Gupta period (320–600 AD) iron revealed using Oberhoffer etchant. The regions depleted in P appear darker in contrast. The dark structures are entrapped slag inclusions.

Death of Indian Iron

Indian metal crafts flourished until the end of the Mughal period (1526–1705). After the establishment of the British Empire, restrictions were imposed by them in the form of production taxes and bans on export. It was natural that this industry should die. This disappearance of the ancient technology during the eighteenth to nineteenth centuries was aggravated by the discovery of new scientific principles and development of new industrial process of metal production in Europe.

The direct reduction process of iron making declined after the advent of the processes for making liquid steel in large-scale in the middle of the nineteenth century. The iron and steel trade from India declined and the ancient method of extraction and processing became extinct by the beginning of the twentieth century.

The British in India made attempts to work on iron ores on a large-scale by modern methods. Several iron and steel works were set up in the country. For example, the Bengal Iron Company was established at Barakar in 1874. It employed 821 people in 1891 and produced 12,000 ton of pig iron (Jaggi 1989). However, these iron works depended on the availability of charcoal and this necessarily meant the destruction of forests and depletion of charcoal supplies. Another factor was also at play. By the end of the century, indigenous iron ceased to be produced because of the import of iron.

Another factor in iron's decline is the fact that certain essential steps were not shared by the master smiths with anybody except their favored apprentices. Traditional artisan communities in India never reveal full

Metallurgy of Ancient Indian Iron and Steel. Fig. 8 The massive forge-welded iron cannon called *Rajagopala* located at Thanjavur.

details to outsiders and when the communities disappeared, so did the methods. Other factors include the use of the same age-old furnaces, processes, and blowers (*bhathi*) by many tribes. This shows that these process secrets were well guarded and any change in the process or equipment was considered a bad omen. Probably this is one of the reasons for the loss of metal technology like wootz steel manufacture.

In the twentieth century, the condition had become so bad that the memory of ancient glory remained only in the form of stories narrated by old men. After independence in 1947 India had to borrow the modern technology from western countries to set up steel plants. The situation is now changing with India again rising to the challenge and hoping to be one of the largest producers of iron and steel in the twenty-first century.

The wishful thinking of Neogi in 1914 is worth recollecting.

> We hope we have been able to give a trustworthy account of the process of the manufacture of Indian steel, which was an object of envy of all nations but successfully imitated by none and which supplied the materials of many a true blade of warriors both in the East and the West. It is sad to reflect that an ancient indigenous industry which attracted merchants from Persia, as narrated by Dr Voysey, barely a hundred years ago, is on the point of extinction; but as even the darkest cloud is not without a silver lining, a distinct ray of hope is visible in the not very distant horizon presaging that India will yet regain her lost iron industry under modern scientific conditions together with other attendant industries depending upon iron.

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Metallurgy in Arabia

Gerd Weisgerber

Geology

The Arabian Peninsula as a whole is rich in metalliferous ores and minerals, especially in gold, lead and silver, and copper. In the North there are the copper deposits of Feinan and Timna (Hauptmann 2000; Weisgerber 2006); the Yemen also has many. There are many ore bodies in the Hedjaz Mountain range in the west of Saudi Arabia that are nearly archaeologically unexplored. In the early 1980s three visits to ancient mining and smelting sites were undertaken (Hester et al. 1984).

So far only the copper deposits of Oman and their exploitation during the last 5,000 years have been studied (Fig. 1). There is not only the Early Bronze Age production of the third millennium connected with the Sumerian copper country of Magan, but also the Iron Age and the Early Islamic productions represent real industrial scale production.

Copper ores occur in two occurrences of ophiolite in the Oman mountains: in the Semail Nappe formation and on Masirah Island (Peters 2000). Copper deposits are formed by irregular mineralization at the transition zone of peridotite to gabbro. Of the 44 locations studied until 1975 more than the half comprise shear zones with secondary copper minerals in gabbro and peridotite (Goettler et al. 1976: 47; Hauptmann et al. 1988). Other copper deposits occur in ophiolitic pillow lavas. These stratified deposits sometimes are indicated by gossans, a rusty-red mineralization originating from the weathering of massive cupriferous sulphides (Coleman et al. 1979, 1981; Hauptmann 1985). In total the entire mountain chains of Oman and those in the Masirah Island have more than 150 copper ore deposits (Goettler et al. 1976; Hauptmann et al. 1988; Peters 2000). They were newly discovered

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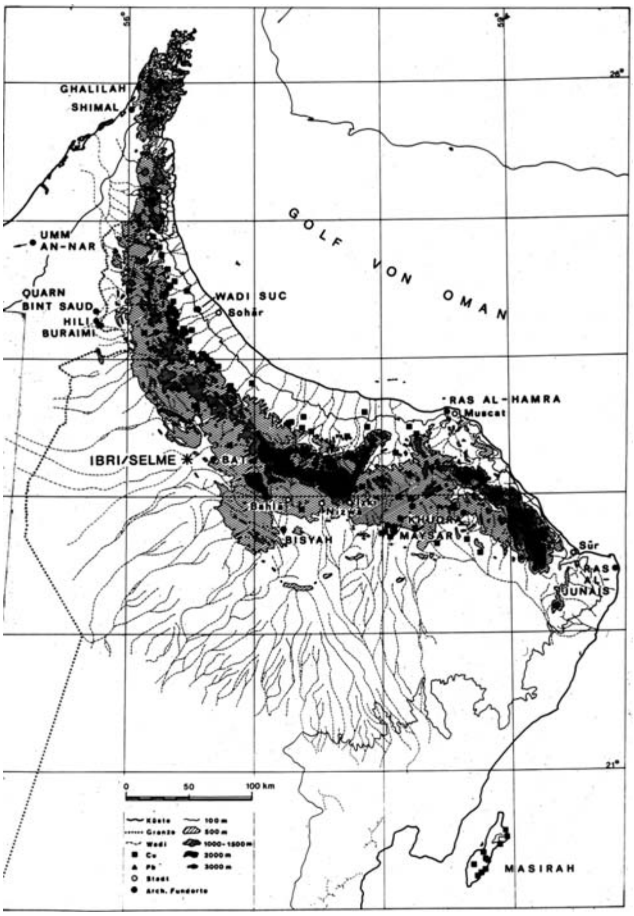

Metallurgy in Arabia. Fig. 1 Copper deposits (squares) and important Bronze Age (third to second millennium BCE) find spots (dots) in Oman (scale 100 km).

Metallurgy in Arabia. Fig. 2 ʻArja. The red gossan on top of the copper deposit results from the weathering and oxidizing of mainly chalcopyrite. This ore body recently has been completely removed by modern opencast mining.

either by copper slags or by the red colour of their gossan (Fig. 2).

Except for a few big ones, most of the deposits in Oman are small. Small green showings indicate veins of the copper ore, e.g. malachite. They were mainly exploited during the Chalcolithic and the Bronze Age, between 3000 and 1300 BCE. During the Iron Age and probably during medieval times, the large deposits under the gossans were preferred, perhaps mainly in the enrichment zones.

Therefore most copper production sites show more than one period of production. But today no site shows the whole spectrum of ruins – from mine to cemetery.

The Chalcolithic

There are some rare metal finds in the shell middens of the Neolithic found of Oman. But in the following Hafit period more metal occurs in the tombs. During this time copper production started. The oldest slags come from Batin in the Wadi Nam near Ibra (Fig. 3). They indicate local metal production (Yule and Weisgerber 1996). In the new burial cairns all over the country metal finds are standard but beside the new metal finds flint tools still occur. In a not plundered tomb under the Umm un Nar fortress at Maysar-25

Metallurgy in Arabia. Fig. 3 Batin in Wadi Nam near Ibra has the oldest slag. As is typical for the third millennium, the slag had to be crushed to expose and collect the copper drops and prills (scale 10 cm).

Metallurgy in Arabia. Fig. 4 Maysar-25, grave 1. Beside a typical Hafit vessel the grave contained two caramel coloured flint flakes, two copper needles, and beads.

Metallurgy in Arabia. Fig. 5 Nujum near Bidbid. These Bronze Age stone tools were lying around a trench mine.

Metallurgy in Arabia. Fig. 6 Wadi Miadin. A most impressive several hundred metres long trench mine in the Wadi Ma'aidin is a good example of shallow mining in the Bronze Age.

(Weisgerber 1981: 198) there was an untouched burial with two metal needles (Fig. 4).

The Early Bronze Age

Sumer in Mesopotamia from 2500 to 1800 BCE received a large portion of its copper from a country called Magan. Business transactions were written on cuneiform clay tablets. Ships from Dilmun/Bahrain, Magan/Oman, and Meluhha/India at the time of king Sargon (about 2400 BCE) docked at Akkad were unloaded, reloaded, and prepared to start for the next several months' journey. For their exports the merchants intended to exchange, in addition to copper, Afghani lapis lazuli, gold, cornelian, and exotic kinds of wood from India (Heimpel 1987). From Magan came copper and black diorite. Usually the ships would make a stopover in the trade emporium at Dilmun/Bahrain, a well-known source of fresh water, which probably had full control over the seafaring in the Gulf (Bibby 1970; Cleuziou 2003; Potts et al. 1986, 1992, 2003; Weisgerber 1983, 1986).

From Dilmun ships connected Magan for the first time probably at the small Island of Umm an-Nar off the coast of today's Abu Dhabi. Here the inhabitants of a small village had become extremely rich by transit trade, at least if one regards their large tombs with collective burials. They probably controlled the export of Magan's copper. But the ships may have had stopovers also at other islands in the south (Carter 2003). Bands of porters and caravans of donkeys brought the copper from the Oman mountain range to the island.

During the Early Bronze Age oxidic and carbonate ores were exploited. The Magan miners used stone hammers but had also metal chisels to break the rock. Good examples for mines of this time are the trench mines at Wadi Miadin and Nujum near Bidbid (Figs. 5 and 6). In addition to the local metal it seems that foreign copper was also in use (Prange 2001; Weeks 2003a).

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Metallurgy in Arabia. Fig. 7 Maysar-1. Furnace fragments with fragmentary holes indicate the use of bellows to increase the heat for smelting.

Metallurgy in Arabia. Fig. 8 Maysar-1. The mass of furnace fragments (left) in comparison with the few pottery sherds, both are the content of the same excavation square.

The ores had to be reduced by charcoal with heat above 1,100°C. Smelting happened in small free-standing pear-shaped and knee-high furnaces built of clay. In the walls these furnaces had holes for artificial ventilation probably by bellows. The copper ores became reduced in the heat by the charcoal to metal (Figs. 7–9). All remains such as fist-sized crushing stones, slag, ash- and fireplaces, holes beside them, fragments of furnaces and of crucibles, metal scrap, and an ingot hoard were excavated in the 4,000-year-old al Maysar-1 in the Wadi Samad south of the oasis village al-Maysar (Weisgerber 1981; Hauptmann 1985). The copper finds were made of local metal but not the ingots (Prange 2001). Inside of one house stood a large anvil stone surrounded by several fireplaces (Fig. 10). Finally the fluid metal had to be poured in a flat hole in the ground, and after cooling the ingots got their typical planoconvex shape (Fig. 11).

The site of Maysar-1 produced more than copper. There were also a pottery kiln, manufactories for soft stone vessels (steatite, chlorite), and evidence of agriculture. The oasis garden of Maysar-1 is the oldest preserved oasis in all Arabia. The dams to improve irrigation must also be mentioned (Hastings et al. 1975; Weisgerber and Yule 2003).

Building towers, organizing mining, smelting, and trading of copper depend on competent leaders and led finally to an elite which used seals (Fig. 12). Tower tombs are the monuments they built to house themselves after death.

In trade with Mesopotamia and the Indian subcontinent copper from Oman played a key role. But, Magan also became dependent on these contacts. When it lost the market both because of a competitor with higher technology resulting in a much cheaper copper production at Alashia/Cyprus and when the Indian partner ceased to arrive because of their own internal political, social and cultural decline, then the end of the Magan civilization arrived.

Metallurgy in Arabia. Fig. 9 Based on many fragments a pear-shaped smelting furnace could be reconstructed for the third millennium BCE. But in contrast to this artist's view the bellows most probably were simple skin bellows.

The Middle and Late Bronze Age

Traces of second millennium smelting are rare. But they show that the same types of ore and smelting furnaces were used as before. The best information comes indirectly from the rich metal finds. Villages are nearly unknown (Cleuziou 1981; Velde 2003). But

Metallurgy in Arabia. Fig. 10 Maysar-1, House 6. Fireplaces and an anvil stone indicate a workshop.

Metallurgy in Arabia. Fig. 11 Maysar-1, House 4, Locus 31. Between two fireplaces in a small depression a hoard of 6 kg of copper ingots was found in 1981. Only one ingot was complete.

Wadi Suq tombs among Late Iron Age cemeteries indicate some kind of occupation of the same oasis areas also during that period.

The rich community grave of Al Wasit (Wadi Jizzi) had 50 soft stone vessels and 16 swords and daggers and 42 spearheads. They probably are of local production as proved by the many tons of slag between the houses of today's village. But as most of the weapons are of pure Omani copper it is obvious that in those days tin for bronze was hardly available even for elites (Fig. 13) (al-Shanfari and Weisgerber 1989: pl. 5; Weisgerber 1991; Prange 2001).

Some hundred years later the evidence had changed. In a thirteenth century warrior tomb at Nizwa the types of weapons correspond to those of that time elsewhere in the Near East, but now they are of bronze (al-Shanfari and Weisgerber 1989). Tin had become

Metallurgy in Arabia. Fig. 12 Impressions of a three-sided 4,000-years-old prism seal from the debris of house 4 of Maysar-1. The impressions show sheep, goat, dog, ibex, and scorpion, but most interesting is the humped bull in the middle (Indian zebu).

Metallurgy in Arabia. Fig. 13 Al Wasit in the Wadi Jizzi. This collection of swords and daggers of copper were found in an extremely rich community tomb.

available again as demonstrated by some hundred bronze bangles of the Ibri/Selme hoard (Yule and Weisgerber 2001).

The Iron Age

Beginning during the twelfth century BCE, large copper production restarts most probably with new kinds of ores possibly from the enrichment zone of the massive ore bodies (Weisgerber 1988; Prange 2001; Weeks 2003b). The Cyprus multiple step chalcopyrite smelting technique which made Cyprus what amounted to a 'global copper player' in those days arrived in Oman (as it did also in the Alps). Cyprus lost its predominance and in Oman copper production continued or restarted on a large-scale. There is no large medieval smelting site without a predecessor of that period because both partly used the same ore bodies. The smelters are situated near the ore body but never as close as the later medieval ones. The smelting debris results in large tapped slag cakes of up to 10 kg. Only furnace fragments were found in Wadi Qatof (Fig. 14). We know no details about the Iron Age smelting processes.

The largest and highest slag heap of that period is at Raki 2 near Yankul (Fig. 15). The site is located near the gossans of two large copper deposits, but they mainly used another ore location at Loch Bab. The large settlement site Raki 2 specialized in the production of copper from around 1200 until 800 BCE (Table 1).

Metallurgy in Arabia. Fig. 14 Wadi Qatof. On the rather low Iron Age slag heaps well-fired fragments of furnaces could be collected.

Metallurgy in Arabia. Fig. 15 Raki 2 near Yankul. Here a more than 4-m high slag heap represents the highest Iron Age dump of smelting waste.

Slag cakes were used like stone slabs for constructing house walls. These often were built on top of slag piles (Yule and Weisgerber 1996; Weisgerber and Yule 1999) (Fig. 16). At Semdah or Lasail the Iron Age slag heaps cover areas near the entrance to the sites. At Wadi Miadin a fortification building of that period controls the mining and smelting activities as does the fort of Qarn al Muallaq at 'Arja. Fortresses all over Oman controlled the new villages which had been created after the installation of a new subterranean system of water supply – the qanat or falaj system. The typical stone built hut tombs often survived near smelting sites, e.g. the largest cemeteries known with more than 100 hut tombs lay at the copper sites near Gebel Saleli and Bilad al Maaidin, but they also occur at Mullaq. The tombs give a strong indication for a long lasting Iron Age copper production, although scanty habitation remains.

After the first half of the first millennium BCE copper production in Oman seems to have been interrupted for a while. For the Samad period only weak hints exist. But at ʿArja there are indications of possible Sasanian occupation.

The Early Islamic Period

On first view nearly all smelting sites checked in Oman date to the Early Islamic period, because this was the latest metallurgically active period, and the ruins are therefore rather undisturbed (Weisgerber 1993). This provides a great opportunity because in other parts of the world, like Central Europe and in the Mediterranean, hardly anything is known about mining and smelting techniques of that period.

When the new mines at Lasail and 'Arja in the Wadi Jizzi were reopened at the beginning of the 1980s insights into the old mines became possible (Fig. 17). At a depth of 65 m a gallery supported by wooden props was detected. Fragments of windlasses in that depth showed that the medieval mines were entered and ores were hauled up through vertical shafts; this was also true at 'Arja.

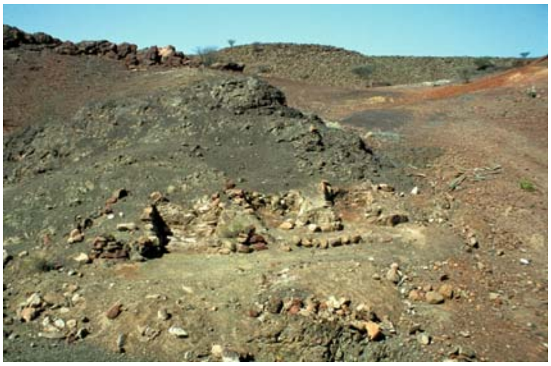
Excavations in 'Arja and Bayda yielded an interesting infrastructure (Costa and Wilkinson 1987) – a relatively well-preserved battery of three roasting pits to burn the sulphur out of the ores and two smelting furnaces. The roasting pits consist of three or more chambers which apparently were used in turn (Weisgerber 1987) (Figs. 18 and 19). Parallels can be found in the book by Georgius Agricola from 1556 (Agricola 1950). The backs of furnaces stood up to 1.40 m in height and had an interior diameter of 0.60 m. They were operated probably with natural wind draught by means of clay nozzles (tuyères). At their front metal and slag were tapped into pits (Figs. 20 and 21). In front of many furnaces, which show traces of several repairs or

Metallurgy in Arabia. Table 1 Generalized chronology

Chalcolithic	(Hafit Period)	3200–2500 BCE
Early Bronze Age	(Umm an-Nar Period)	2500–1800 BCE
Middle Bronze Age	(Wadi Suq Period)	1800–1300 BCE
Late Bronze Age/Early Iron Age	(Nizwa Period)	1300–1200 BCE
Iron Age	(Lizq/Rumeilah Period)	1200–300 BCE
Late Iron Age	(Samad Period)	300 BCE–AD 600
Early Islamic Period	AD 600–1100	
Middle Islamic Period	AD 1100–1500	
Late Islamic Period	Since AD 1500	

Metallurgy in Arabia. Fig. 16 Raki 2, near Yankul. Ruins of a house on top of a stratified heap of crushed slag.

Metallurgy in Arabia. Fig. 17 ʿ the small gossan of Bayda became exploited by a large opencast mine. In the walls several medieval galleries can be seen.



Metallurgy in Arabia. Fig. 18 ʿArja-Bayda. Battery of roasting installations. Three chambers are cut in the rock and framed by local stones.

Metallurgy in Arabia. Fig. 19 Artist's view of a three-chambered early medieval roasting installation.

reconstructions, up to 6,000 tons of slag may occur (Fig. 22), giving an idea of the thousands of tons of copper produced in medieval Oman (Weisgerber 1978a, 1980a, b, 1981; Hauptmann 1985).

One may imagine that the long mining and smelting activities of the Early Islamic period over centuries led to a complete devastation of Oman's vegetation because millions and millions of trees were needed both in underground mining and in the roasting and smelting work on the ground (Eckstein et al. 1987).

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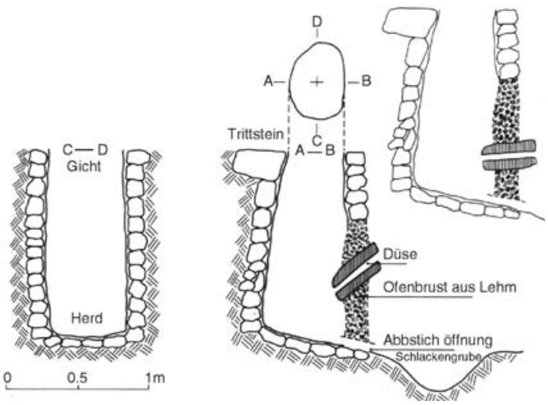
Metallurgy in Arabia. Fig. 20 ‘Arja. Early medieval smelting furnace ‘Arja 103 after excavation. Note the closed forefront above the opening which probably had to be opened and re-closed for each smelting process and the ramp to the right for going to the top of the furnace to fill in charcoal and ores.



Metallurgy in Arabia. Fig. 21 Scheme of an early medieval smelting furnace.

Metallurgy in Arabia. Fig. 22 Tawi Raki. More than 60,000 tons of smelting remains at many production units prove that here an extremely successful mining venture had taken place. The slag heaps are clearly separated from each other. Individual smelting firms have their own smelting furnace and roaster. Between them a lot of houses can be seen.

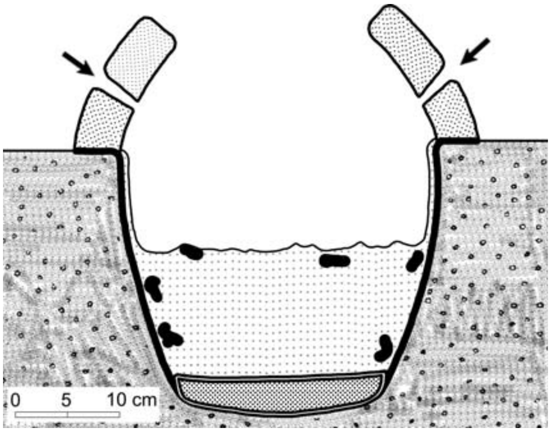
Metallurgy in Arabia. Fig. 23 ‘Arja. In the plain around Tawi ‘Arja flat fields of bowl slag indicate the late and post-medieval production of copper.

Metallurgy in Arabia. Fig. 24 ‘Arja. At Tawi ʿArja some complete slag cakes helped to reconstruct the bowl furnace. To remove the copper ingot the lower edge of the slag had to be smashed away.

The Middle and Late Islamic Period

In the area around the old well of ʿArja fields of slag cover the plain. There are no heaps or dumps but flat covers (Fig. 23). The complete slag pieces have a diameter of about 25–30 cm. The bottom is concave, the sides curved. This slag of 13–16 kg was produced in a bowl furnace dug into the ground (Figs. 24 and 25). Copper smelting in bowl furnaces took place from the Middle Islamic times to the nineteenth century (Weisgerber 1978b).

There is no mining activity which could be attributed to these periods. But all the Early Islamic slag heaps are marked by more or less circular depressions irregularly scattered in the dumps. Slag analyses confirm that they are high in copper (1–4%; Goettler et al. 1976: 47). Remains of copper and copper–matte in the Early Islamic slags were the target of this secondary digging work. And these were reduced in the bowl furnaces.



Metallurgy in Arabia. Fig. 25 Scheme of a late medieval bowl furnace. The upper part is still unclear. The 4–5 cm wide holes for the air of skin bellows were found in specially formed wall fragments. Charcoal occurs in most bowl slag cakes. Only the copper ingot below has been reconstructed.

Recent Copper Production in the Sultanate of Oman

From 1983 to 2003 Oman is once again exporting copper to the world market. Modern mines have been opened at Lasail, ‘Arja, and ‘Arja–Bayda in the Wadi Jizzi west of the old town of Sohar; a copper smelter has been constructed nearby. The mining and smelting work is connected with a new modern town, named ‘Magan’. And it is this name which gives a hint to the 5,000-years long history of copper production in the Sultanate of Oman (Mobbs 2003).

See also: ►Irrigation

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Metallurgy in China

HUA JUEMING

The earliest metal relics ever found in China are two brass artifacts from the Yangshao Culture Ruins in Jiangzai Village, Lingtong County, Shaanxi Province. They date as far back as 6,000 years ago, providing strong evidence that metallurgy germinated in China during that period. Considering that studies of possibly earlier metal relics are not done thoroughly enough, the problem of the origin of metallurgy in China has yet to be further explored.

By the latter part of the third millennium BCE, metallurgy had come into being in a number of regions, and many kinds of metal materials – red copper, primitive brass, tin bronze, and lead–tin bronze – were already used for small implements and ornaments.

The Xia Dynasty (twenty-first century to sixteenth century BCE) had evolved into the Bronze Age. In Erlitou Cultural Ruins, Yanshi County, Henan Providence, remains of foundry workshops have been discovered where bronze sacrificial vessels, weapons, implements, and casting moulds have been excavated. Apparently, the making of articles was done with casting as the main means.

The earliest copper mining and smelting ruins known in China are located in Tongling (meaning copper ridge), Ruichang County, Jiangxi Providence. Its mining can be traced back to the fourteenth century BCE. The shafts and drifts were supported by timber frames. Also excavated were ore-dressing troughs and wood winches for hoisting. Further study reveals that during Shang-Zhou Periods (Shang Dynasty: sixteenth century to eleventh century BCE; Western Zhou: eleventh century to 771 BCE; Eastern Zhou: 771–221 BCE) the mining of copper minerals had progressed to a rather large scale in the Liao River Valley and Yellow River Valley, especially in the middle and lower reaches of the Yangtze River. The smelting of copper was done in semicontinuous operation in shaft furnaces. By the late Western Zhou at the latest, copper sulfide minerals had been used to smelt copper.

The smelting technologies of lead and tin were mastered from the Shang Dynasty on. The lead vessels unearthed in Anyang have a purity of over 95%. Tin ore deposits were scattered in the Northeast, Northwest, and South China regions, especially in Jiangxi, Guangxi, and Yunnan, where tin reserves were very abundant. The early tin material must have come from these regions.

Alloying techniques improved greatly during the Shang Dynasty. The sacrificial vessels of imperial courts unearthed in Yin Ruins have a tin content of 18% or more. The book *Kao Gong Ji* of the Warring

States (475–221 BCE) recorded something about the alloy proportioning of *liu qi* (seven kinds of bronzes): *zhong* (bell), *ding* (cauldron), *fu* (hatchet), *ji* (halberd), *jian* (sword), *zu* (arrowhead), and *jing* (mirror). This indicates the craftsmen's clear understanding at that time that the mechanical performance of tin bronze varies with different contents of tin.

Shang-Zhou bronze culture was characterized by sacrificial vessels, complex in shape and delicate in design, which were mass-produced by casting. The key in achieving this characteristic without applying techniques such as the lost-wax process lays in the skillful use of composite pottery molds and various cast-joint technologies.

Beginning with the Spring and Autumn periods (771–475 BCE), it became in vogue to apply synthetically various shaping processes and decorating techniques: cast-joint, soldering, lost-wax process, forging, gilding, gold-plating, red-copper inlay, gold and silver inlay, engraving, etc. This significant change brought the manufacture of bronzes to a still higher level; the implements produced looked brighter and more colorful. As early as the late Neolithic Age, small-sized gold had already appeared. By the Warring States periods, there were more and more articles made from gold, and coins were first minted of silver. These may have been obtained by cupellation, a refining process in which metals are oxidized at high temperatures, and base metals are separated by absorption into the walls of a cupal, or porous cup made of bone ash. The production of mercury also reached a certain scale. It is recorded that a great amount of mercury used to preserve bodies from decay was found in the imperial grave of Emperor Qin.

It was far back in late Shang Dynasty that iron meteorites were used to be forged into blades and cast with bronze into weapons. This process was passed down all along to the end of Western Zhou, perhaps providing impetus to the origin of certain iron smelting technologies.

Archaeological excavations have shown that artificial ironmaking may have begun in the late Western Zhou in China. It is worth noting that the smelting and casting of pig iron began only about 200 years later, i.e., the late Spring and Autumn periods. Only another 100 years had passed before pig iron was in wide use for casting production tools, especially for farming implements, thus marking the beginning of the Iron Ages in China.

Correspondingly, a series of outstanding inventions related to pig iron came springing up one after another. Two of the most important were the iron mold casting and cast iron toughening techniques. In these, pig iron castings were changed into white-heart malleable cast iron or black-heart malleable iron through decarbonizing heat treatment or graphitizing heat treatment, respectively. Others were the later ones of puddling iron (Western Han 206 BCE–AD 8) and Guan-steel (made by smelting pig iron and puddling iron together, about the end of Eastern Han AD 25–220). These revealed a technological course of development, which, though markedly different from that in ancient Europe, led to the same goal. This unique instance in the history of technology is interesting and thought provoking.

In China, many of the most important inventions in ancient metallurgy were made before the sixth century BCE. After the fruits in the preceding times were digested and imbibed in the Tang Dynasty (AD 618–907) and Song Dynasty (AD 960–1279), metallurgical technologies in China took shape, leading to further prosperity and greater achievements. For example, in the southern regions there was full scale mining and smelting of iron minerals and others such as copper, tin, lead, gold, silver, and mercury. There were also large and extra-large castings and bronze or iron structures, etc.

It must be mentioned that the making of white copper (copper nickel alloy) was already mastered as early as the fifth century, and that during the Han and Tang Dynasties and later, metallurgy in China had exchanges with and mutual impact on the surrounding regions. Some examples are the westward spreading of iron-casting skills and the influences of Persian artistry on gold or silver wares in the Tang Dynasty.

In the Song Dynasty, wet metallurgy was put into large-scale practice to extract pure copper, annually yielding about 500 tons, which amounted to about one-third of the total copper produced in the whole country.

About 1620 in the Ming Dynasty, it was possible to smelt zinc, which was used in great amounts for minting coins. Antimony was smelted in the Ming Dynasty (AD 1368–1644), but it was not recognized at the time as a new kind of metal and thus was mistaken for tin.

Recently, some unexpected archaeological discoveries – such as the bronze culture of the ancient Kingdom Shu and the bronze groups of the late Shang in Xinggan, Jiangxi Province – indicate that there are still many mysteries in the metallurgy of ancient China which remain to be disclosed. Those disclosures would contribute greatly to academic studies.

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Metallurgy: Early Metallurgy in Mesopotamia

JEAN-FRANÇOIS de LAPÉROUSE

The development of metallurgy in ancient Mesopotamia and the surrounding regions of the Ancient Near East to the end of the Neo-Babylonian period (ca. 539 BCE) represented a largely unprecedented achievement that strongly influenced the evolution of technology in much of the ancient Old World. Although the alluvial plain of the Tigris and the Euphrates was lacking in the mineral resources and fuel required to extract metals, the rise of urban centers and long-distance trade networks allowed this region to benefit from raw materials and expertise gathered over a wide area from the Aegean Sea to the Indus River valley. This technology required an investment in labor and materials that reached beyond the constraints of earlier industries and enabled advancements in many fields including agriculture, transportation, armament production and the visual arts. Although much has been learned from archaeological exploration, the study of ancient texts and the application of scientific analysis to the study of ancient materials, many aspects remain to be elucidated in a field for which the following can serve only as an introduction.

The Nature of Metals

Cuneiform texts do not reveal any evidence that Mesopotamian craftsmen sought to develop a theoretical understanding of the nature of metals and their alloys. Nevertheless, the artifacts they produced bear witness to a considerable practical knowledge accumulated from centuries of experience manipulating the raw materials at their disposal. A brief consideration of metallic microstructure provides some insight into the medium with which they were working. The atoms of each metal species are arranged in one of fourteen possible crystal lattice configurations that can be visualized as closely packed spheres arrayed within larger crystals known as grains. Metals of the face-centered cubic configuration which include gold, silver, copper, and lead – all of which were used in the ancient world – are malleable at least in part because their compact geometry limits the friction encountered in slippage between atomic planes when stress, such as hammering, is applied. When the planes begin to interlock with continued working, heating the metal in a process known as annealing enables the atoms to reorder themselves thus restoring plasticity.

Impurities introduced naturally or by intentional alloying affect both grain size and composition and may result in the precipitation of immiscible inclusions at the grain boundaries. These discontinuities within the crystalline structure can increase an alloy's hardness and brittleness which are useful for certain utilitarian purposes but may render the metal unfit for forming by hammering. At the same time, alloying lowers the melting point of the more refractory constituent – a useful quality when casting and producing solders with melting points lower than those of the surfaces being joined.

When buried in the seasonally damp and salted soils of the Ancient Near East, metals, with the exception of gold, will begin to return to an oxidized state similar to the ore minerals from which they were extracted. As a result, the structure and appearance of many of the metal artifacts recovered from this region have been altered in some way since their original manufacture. Over time, corrosion as well as the precipitation of alloy components can cause embrittlement. Corrosion usually proceeds inward along the grain boundaries producing metallic salts that deposit on the surface and often cause internal fractures due to the expanded volume of oxidation products relative to that of the original metal. Nevertheless, careful cleaning and x-radiography can reveal surface details preserved within corrosion layers and a considerable amount of evidence about an object's manufacture, and subsequent history can be gleaned by analyzing cross sections prepared from small samples taken from artifacts.

Copper and its Alloys

While valid in broad terms, the tripartite division of human civilization into the Stone (ca. 7000–3000 BCE), Bronze (3000–1200 BCE), and Iron Ages (1200 BCE–present) proposed in the early nineteenth century CE has been extensively refined. It is now known that lithic, metal and even ceramic-based tools and technologies coexisted in the Ancient Near East both earlier and later than it would indicate. The earliest extant metal objects are beads and small tools such as pins, hooks and awls made of relatively soft native copper – i.e., geological deposits of metallic copper discovered near the earth's surface – that have been recovered from eighth millennium BCE contexts at sites in Anatolia, Iran and northern Mesopotamia. While knowledge of smelting during the following millennium is implied by the presence of a lead bracelet in level 1 of Yarim Tepe in Iran, it is not until the first half of the fourth millennium BCE that clear evidence from Levantine sites – such as the impressive hoard of 416 copper alloy objects discovered at Nahal Mishmar (Fig. 1) – indicates that the extraction of metal from ores was occurring on a significant scale.

Experimentation in the annealing and melting of native copper alloys as well as the accidental reduction of copper oxide pigments during the firing of decorated pottery may have prompted initial experimentation into the smelting of metal from copper ores. Early smelting furnaces, such as the late fourth millennium BCE example excavated at Timna in the southern Negev, consisted of a bowl or pit cut into the ground that was packed with dressed ore and charcoal – the latter providing both heat and carbon which combined with and removed oxygen. High temperatures were attained by drafts of forced air supplied by bellows inserted into the fire whose tips were protected from burning by refractory ceramic cones known as *tuyères*. At around 1,083°C – the melting point of pure copper – molten metal would puddle at the bottom of the furnace while the lighter, silicaceous impurities of the ore, known as the *gangue*, would separate out with the aid of a flux forming a layer of slag. Since both slag and *tuyères* were discarded in situ, they provide evidence of metallurgical activity at particular sites even in the absence of metal artifacts which were often hoarded and recycled.

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 1 Objects from the hoard found at Nahal Mishmar. Copper alloy. Levant, first half of the fourth millennium BCE (Israel Museum, Jerusalem). Roaf 1990 (Photo: David Harris).

Much of the initial smelting took place in the mountainous regions surrounding Mesopotamia that possessed mineral resources as well as extensive forests for producing charcoal. After an initial extraction, further refining could be achieved by repeated smelting in crucible furnaces at or near the workshops where artifacts were produced. Copper mines in the highlands of Iran, accessible by overland routes, appear to have been an early source of metal for the urban centers that arose in southern Mesopotamia – the heartland of ancient Sumer – during the period which is named after the important city of Uruk (ca. 3800–3200 BCE). With the expansion of seaborne trade fostered by the city-states of the Early Dynastic period (ca. 3000–2350 BCE), ore sources in Oman, which has been identified with the Magan of ancient texts, as well as the eastern lands of Aratta and Meluhha, both of which most likely received partially refined copper from various sources in Iran and Central Asia, increased in importance. The island of Dilmun – modern Bahrain – was well situated near the southern end of the Persian Gulf to serve as a mediator in this maritime copper trade particularly in the late third and early second millennia BCE. To the west, the copper mines in Anatolia supplied copper to production centers in the Levant and northern Mesopotamia from an early period and provided the raw materials for an indigenous tradition of sophisticated copper metallurgy exemplified by the late third millennium BCE objects found at the central plateau sites of Alaca Höyük and Horoztepe (Fig. 2). With the rise of important trading cities on the Levantine coast in the mid-second millennium BCE, the importation of Cypriote copper to the region also increased.

While bronze, an alloy of copper and tin, is attested in texts and objects dated to the beginning of the Early Dynastic period, modern analysis has indicated that for many centuries the copper used in Mesopotamia actually contained low concentrations of arsenic, nickel

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 2 Bull Standard. Copper alloy and electrum. Height: 48 cm. Alaca Höyük, Anatolia. Late third millennium BCE (Ankara Museum of Anatolian Civilizations, Turkey, 11850) Aruz 2003 (Photo: Bruce White).

and other elements (often referred to as arsenical copper) and that the use of tin only gradually increased toward a standard concentration of around 10% as that of arsenic decreased. Arsenical copper has often been viewed as bronze's inferior precursor – a soft alloy that was unfit for most practical purposes. However, ancient metalworkers appear to have been aware that this alloy could be effectively work hardened by hammering and cast more easily than pure copper, making it a useful alloy.

It has been suggested that the progression from native copper to bronze alloys reflected the nature of the ore deposits being exploited (Tylecote: 7–9). In many copper ore bodies, the layer closest to the surface and most easily exploitable consists of copper carbonates and oxides as well as native copper. Below lie two copper sulfide deposits which must be oxidized by "roasting" in an open fire before smelting. Of these, the uppermost layer, which is enriched by copper washing down with ground water from above, contains the highest concentration of impurities including arsenic, nickel and antimony. As these arsenic-containing deposits gradually became depleted by ancient miners, it is possible that the need for a new alloying metal promoted the use of tin. However, recent archaeological work indicates that the actual situation may have been less straightforward, as complex ores containing different mixes of impurities were cosmelted from an early period. In addition, the possibility that arsenic in some form was intentionally added remains a matter of debate.

Tin is not usually found as a natural impurity in copper ores and tin deposits are relatively rare. While evidence of tin mining in eastern Anatolia indicates that this area may have been a source of this metal at least in the Early Bronze Age, the primary source of this metal appears to have been the Badakhshan region of Afghanistan where oxidized tin is associated with alluvial deposits of weathered granite. Afghanistan is also thought to have been a primary source of the lapis lazuli, gold and semiprecious stones that played an important role in Sumerian art of the mid-third millennium BCE. This is seen most impressively in the finds from the Royal Tombs of Ur (Figs. 15 and 16), when bronze alloys increasingly were used. Like these prized materials, tin may have been traded initially as a precious commodity used in the production of highly valued objects. Early in the succeeding millennium, however, cuneiform texts indicate that large quantities of tin – presumably obtained in the East – were being transported up the Euphrates to the ancient city Mari from where they were distributed to other urban centers. During approximately the same period, merchants from Ashur, the historic and spiritual capital of the land of Assyria in northern Mesopotamia, established a merchant community (*karum*) at Kanesh in central Anatolia where tin and textiles were exchanged for locally obtained precious metals.

Gold and Silver

While gold and silver objects have been recovered from early contexts in northern Mesopotamia and Anatolia, it is not until the third millennium BCE that significant numbers of precious metal objects were being produced across the entire region. Gold, found in many of the lands encircling Mesopotamia, was retrieved from alluvial deposits in nugget form or gleaned from quartz veins by grinding and separation in water. Native gold usually contains some silver and copper or these metals could be intentionally added to achieve desired working properties and/or color. Natural or artificially produced gold alloys with high silver contents, such as the inlays in a copper alloy standard from Alaca Höyük (Fig. 2), as well as the jewelry and ingots found by Schliemann in Early Bronze Age levels at Troy, are known as electrum. Alternately, gold could be refined by the preferential oxidation and removal of the baser elements from the parent metal. This process, known as cementation, is alluded to in textual evidence dated to the first half of the second millennium BCE and may have been practiced even earlier. A recent study of a dagger from Ur suggests that a similar process of surface enrichment known as depletion gilding, which was independently developed in the pre-Columbian

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 3 Spouted cup. Gold. Height: 12.4 cm. Ur, Southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (The Trustees of the British Museum, London, BM 121346). Aruz 2003 (Photo: The Trustees of the British Museum).

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 4 Bowl. Gold. Length: 13.12 cm. Ur, Southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, B17693). Zettler 1998 (Photo: The University of Pennsylvania Museum of Archeology and Anthropology).

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 5 Tumblers. Silver. Heights: 16.5–17.4 cm. Ur, southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 (University of Pennsylvania Museum of Archeology and Anthropology, Philadelphia, B17072a–d). Zettler 1998 (Photo: The University of Pennsylvania Museum of Archaeology and Anthropology).

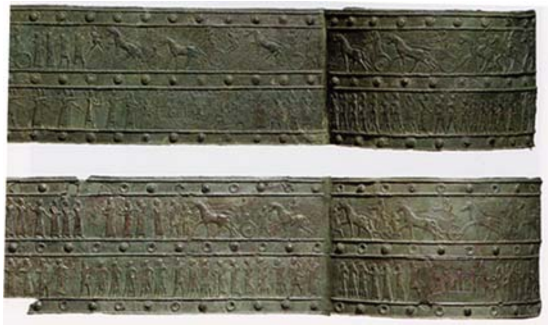
New World, was practiced by Sumerian metalworkers in the mid-third millennium BCE (La Niece 1999).

Although some smelting of silver ores may have occurred, most ancient silver appears to have been obtained by cupellation from argentiferous lead ores mined in mountains of Turkey and Iran – two regions that displayed an early expertise in silversmithing. In this process, the ore was heated in porous bone cups, or cupels, that absorbed oxidized lead, leaving behind silver droplets that were collected and melted together. The earliest archaeological evidence of this technology in the region has been found at the site of the Late Uruk city of Habuba Kabira which was located on the Euphrates River in what is now the country of Syria.

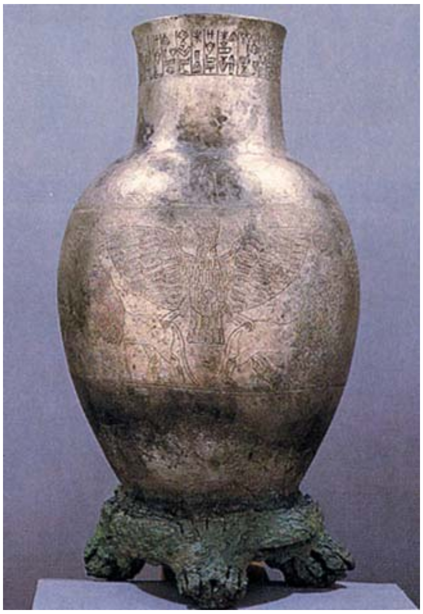
Metalworking Techniques

Forming objects by hammering and annealing, first attested in the earliest copper artifacts, remained an important manufacturing technique throughout the history of the Ancient Near East. Worked sheet was used to make simple tools, vessels (Figs. 3–5) and relief decoration (Fig. 6). Vessels were formed by sinking or raising which involved hammering in concentric circles on the inside or outside surface, respectively, of the container being formed sometimes with the aid of a form. Decorative reliefs and friezes were formed by repoussé in which figures were raised against a flat background plane by light hammering from the reverse. After forming, fine linear details were added by lightly tapping metal tracers with various shaped heads on the surface which displaced the metal forming lines and decorative patterns as seen in the figural decoration on a silver vase dedicated by Enmetena, a ruler of the city-state of Lagash, to the god Ningirsu around 2400 BCE (Fig. 7). A masterful example of all these combined techniques is also provided by in a cylindrical silver container attributed to western Central Asia of the late third–early second millennium whose surfaces virtually erupt with lions, bulls and wolves in extraordinarily high relief (Fig. 8).

Worked metal sections were joined to produce some of the earliest known metal sculptures in the round. The ability of ancient silversmiths to produce sensitively modeled, naturalistic figures on a small scale through the careful combination of separately formed components is demonstrated by an anthropomorphic kneeling bull attributed stylistically to the Proto-Elamite culture



Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 6 Details of two door decorations from the Balawat Gate. Copper alloy. Height: each 27 cm. Balawat, northern Mesopotamia. Neo-Assyrian period, ninth century BCE (The Trustees of the British Museum, London BM 124662 and 124661) Curtis 1988 (Photo: The Trustees of the British Museum).



Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 7 Votive vase of Entemena, ruler of Lagash. Silver on copper alloy base. Height: 35. Southern Mesopotamia, ca. 2400 BC (Musée du Louvre, Paris). Roaf 1990 (Photo: Service Photographique de la Réuion des Musées Nationaux, Paris).

Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 8 Cylindrical box and lid with lions, bulls and wolves in relief. Silver. Height: 23.1 cm. Western Central Asia, late third–early second millennium BCE (The Metropolitan Museum of Art, New York; Lent by Shelby White and Leon Levy L.1999.74.1). Aruz 2003 (Photo: Photo Studio, The Metropolitan Museum of Art).

(3000–2800 BCE) of western Iran (Fig. 9). Worked sheet was also used to create large freestanding figures with a minimal use of metal. The bull statues that originally adorned the façade of the Early Dynastic IIIB (2400–2250 BCE) Ninhursaga temple at Tell al Ubaid featured bodies consisting of worked copper alloy plates that were nailed onto carved wooden cores. Before its cladding, the wood was coated with a pliable

Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 9 Keeling bull holding a vessel. Silver. Height: 16.3 cm. Iran. Proto-Elamite period, ca. 3000–2800 BCE (The Metropolitan Museum of Art, New York, Purchase, Joseph Pulitzer Bequest 1966, 66.173). Aruz 2003 (Photo: Photo Studio, The Metropolitan Museum of Art).

bitumen layer in order to support the metal during its final chasing (Fig. 10).

Various casting methods also were employed according to the type of object being produced. Open-faced moulds may have been used to produce flat tools such as the sickles found in a hoard of mid-second millennium farming implements from Tell Sifr in southern Mesopotamia (Fig. 11). Bivalve moulds were used to cast solid objects of simple shape. Reusable moulds – which varied in complexity from the late third millennium BCE stone mold for casting trinkets and jewelry such as the example found at Sippar (Fig. 12), to a Neo-Assyrian multipart metal mould for simultaneously casting several arrowheads – were used to mass produce identical castings. Such easily portable molds, which may have been owned by itinerant craftsmen, enabled the widespread diffusion of cultural forms and metalworking expertise.

Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 10 Standing bull from temple. Copper alloy, wood and bitumen. Height: 71.2 cm. Tell al Ubaid, Mesopotamia. Early Dynastic IIIB period, ca. 2400–2250 BCE (The University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, B15886). Aruz 2003 (Photo: The University of Pennsylvania Museum of Archaeology and Anthropology).

It was the technique of lost-wax casting, however, that provided Mesopotamian craftsmen with their greatest opportunity to display their metallurgical and artistic skills. First attested by the intriguing "standards" and "scepters" of the Nahal Mishmar hoard, this technique was sufficiently advanced by the Akkadian period (ca. 2350–2100 BCE) to facilitate the production of the earliest large scale metal sculptures known from the ancient world including the head of an ruler and the lower half of a male figure on an inscribed base, both dated to the Akkadian period and found in northern Iraq (Figs. 13 and 14) (see Extra). Lost-wax casting begins with the sculpting of a model in wax or other thermoplastic material that is covered – or invested – with clay and fired, causing the wax to melt out through channels provided in the investment. During casting, these channels provide access for the molten metal to enter the mold and egress for gases evolved that could impede its flow. In order to reduce the amount of metal required as well as the risk of casting flaws, the model can be fashioned over a core of refractory clay that is held in place by metal supports inserted through the investment and into the core before the removal of the wax. After casting, the investment is broken away and the core supports are removed down to the surrounding surface.

Bronze – often with the addition of minor amounts of lead – is an excellent casting alloy, as tin can lower the melting point of copper by as much as 200°C and inhibit the oxidation of copper which can lead to casting flaws. Since the use of tin is so advantageous,

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Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 11 Farming implements from Tell Sifr in southern Mesopotamia. Early second millennium BCE Copper alloy. (The Trustees of the British Museum, London). Moorey 1971 (Photo: The Trustees of the British Museum).

Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 12 Mould form for jewelry, seals, and amulets. Stone. Height: 9 cm. Sippar, Mesopotamia. Late third millennium BCE (The Trustees of the British Museum, London, BM 91902). Aruz 2003 (Photo: The Trustees of the British Museum).

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 13 Head of a Ruler found at Nineveh. Copper alloy. Height: 36 cm. Mesopotamia. Akkadian period, ca. 2300–2159 BCE (Iraq Museum, Baghdad, IM 11331). Oates 1986 (Photo: Directorate-General of Antiquities, Baghdad).

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 15 Statue of Queen Napir-Asu. Copper alloys. Susa, Iran. Middle-Elamite period, fourteenth century BCE. Height: 129 cm. (Musée du Louvre, Paris, Sb 2731). Harper 1992 (Photo: Photo Studio, The Metropolitan Museum of Art).

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 14 Nude, belted figure found at Bassetki. Copper alloy. Diameter of base: 67 cm. Mesopotamia. Akkadian period, ca. 2300–2159 BCE (Iraq Museum, Baghdad, IM 77823). Oates 1986 (Photo: Directorate-General of Antiquities, Baghdad).

its absence in many of the copper alloy sculptures produced before the Iron Age has often been attributed to disruptions in the tin trade. That other factors may have influenced the composition of the metals used, however, is suggested by the sculpture of the Middle Elamite Queen Napir-Asu (ca. fourteenth century BCE) that was excavated in Iran at the site of the ancient city of Susa. The outer shell of this life-sized metal sculpture was cast by the lost wax method over a ceramic core using copper containing only 1% tin (Meyers 1996). For reasons that remain unknown, the ceramic core was subsequently removed and the void was filled with a bronze alloy containing 11% tin (Fig. 15). That the more intractable alloy was used for casting the outer shell even when tin appears to have been on hand may be due to the fact that a considerable amount of work was required to remove and/or patch casting imperfections and to add surface details and inscriptions with tracers after casting. Before the advent of hardened iron alloys that could engrave or cut into copper, this work may have been easier to execute on relatively pure copper rather than on bronze.

Although some casting of precious metals occurred, the rarity of gold and silver dictated that they be used more economically in sheet form to create vessels, jewelry and small figures. The numerous elements of gold sheet used in the elaborate headdress of Queen Puabi found at Ur undoubtedly created a striking visual and aural impression when worn (Fig. 16). Silver and gold also were also beaten into foil or very thin leaf that was used in the embellishment of baser materials in objects destined for elite or sacred use such as the lyres and rearing goat statues also found at Ur

Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 16 Queen Puabi's Headdress. Ur, Southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, B 16692–3, 17709–12). Zettler 1998 (Photo: The University of Archaeology and Anthropology).

Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 17 Great Lyre from King's Grave, Gold, silver, lapis lazuli, shell, bitumen and wood. Height of head: 35.6 cm. Ur, southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, B17694). Aruz 2003 (Photo: The University of Pennsylvania Museum of Archaeology and Anthropology).

Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 18 Rearing goat with flowering plant. Gold, silver, lapis lazuli, copper alloy, shell, red limestone and bitumen. Height 42.6 cm. Ur, Southern Mesopotamia. Early Dynastic IIIA period, ca. 2550–2400 BCE (University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, 30–12–702). Aruz 2003. (Photo: The University of Pennsylvania Museum of Archaeology and Anthropology).

(Figs. 17 and 18). Grooves for mechanically locking metal foils in place found on copper alloy sculptures – including that of Queen Napri-Asu – indicate that metal surfaces could also be partially or fully gilt.

In addition to mechanical joins involving nails, rivets, crimping and casting onto existing metal surfaces, metallurgical joins were made using solders of various compositions. The use of soft (i.e., lead/tin) solders, which melt at low temperatures and are difficult to control, was mainly relegated to joins in copper alloy objects that would not be readily visible. Metallurgical joins on precious metal objects were made either by carefully heating metal surfaces until they fused – a technique known as "sweating" – or by using hard solders containing copper which has a lower melting point than either silver or gold. Ancient metalworkers were very skillful at exploiting minor differences in the melting temperatures of these hard solders when constructing complex objects. For example, the seventeen sections of the Proto Elamite kneeling bull noted above were joined using silver solders containing increasing amounts of copper – and consequently lower melting points – as the figure was assembled, thus ensuring that previously made joins would not fail each time the appropriate amount of heat was applied. Elements in gold jewelry also could be affixed in place

Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 19 Necklace with pendants. Gold. Length: 43 cm. Dilbert, southern Mesopotamia. Nineteenth–eighteenth century BCE (The Metropolitan Museum of Art, New York, Fletcher Fund, 1947 (47.1a–h). Harper 1984 (Photo: Photo Studio, The Metropolitan Museum of Art).

using a colloidal hard solder consisting of an organic binder such as animal glue mixed with ground copper salts. When heated, the combustion of the glue provided a locally reduced atmosphere that aided the diffusion of copper ions into the adjacent gold to produce a strong and virtually invisible join that was ideal for affixing tiny gold grains in granulation work as well as other joins in complex jewelry constructions (Fig. 19).

The Advent of Iron

While iron oxide minerals and pigments as well as meteoric iron had been used for centuries, the use of iron alloys did not become widespread until the early first millennium BCE, following an early development in the region whose specific origins remain obscure. The late appearance of iron is ascribed to the relatively complicated processes required to obtain and fashion usable iron objects. Due to a melting point – almost 500°C. above that of copper – that exceeded the capability of early Mesopotamian pyrotechnology, iron could not be directly separated from its slag or melted for casting. (In the ancient world, only the Chinese craftsmen appear to have developed the technology for casting iron.) At about 800°C, the mass obtained from the furnace – known as the bloom – required repeated heating, folding, and hammering to squeeze out the slag and provide a metal that could be shaped by forging. While forging largely limited the use of iron to the production of utilitarian objects such as tools and weapons, skillful smiths could fashion complex shapes such seen by a the multipiece sword attributed to the Luristan region of southeastern Iran in the first half of the first millennium BCE (Fig. 20).

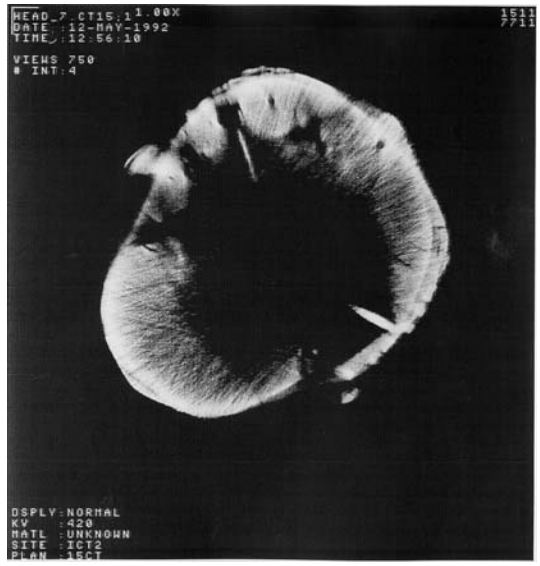
Metallurgy: Early Metallurgy in Mesopotamia.
Fig. 20 Multipiece sword. Iron. Length: 50.1 cm. Luristan, Iran. 750–650 BCE (The Metropolitan Museum of Art, New York, H. Dunscombe Colt Gift, 1961 61.62). Muscarella 1988 (Photo: Photo Studio, The Metropolitan Museum of Art).

Initially, wrought iron objects were relatively soft and it was only with the development of techniques such as carburization, in which carbon was introduced at the surface to form low carbon steel, and quenching, which preserved crystalline phases and structures normally found at high temperatures, that useful cutting edges harder than bronze could be produced. Although this technology was not completely mastered in early Mesopotamia, the relative abundance of iron ore deposits allowed for a dramatic increase in the use of this metal in the production of tools, weapons and armor from the Neo-Assyrian period onward (Fig. 21). Unfortunately, the extensive deterioration and loss of many early iron artifacts has often complicated a full reconstruction of early ferrous metallurgy.

As outlined above, almost all of the metalworking techniques used up to modern times were developed in the Ancient Near East. In addition, the long distance trade spurred by the demand for raw materials and metal artifacts resulted in the widespread dissemination of technical knowledge and artistic styles across the entire region. The study of recent archaeological discoveries such as the Early Bronze Age copper manufactory at Khirbat Hamra Ifdan in the southern Levant (Levy et al.), as well as the continued examination and analysis of artifacts, will undoubtedly broaden and revise our understanding of the interaction of culture and technology during this crucial period.

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 21 Helmet. Iron. Height: 30.8 cm. Nimrud, northern Mesopotamia. Neo-Assyrian period, eighth century BCE (The Trustees of the British Museum, London, BM 22496). Curtis 1988 (Photo: The Trustees of the British Museum).

Metallurgy: Early Metallurgy in Mesopotamia. Fig. 22 Head of a Ruler. Copper alloy. Height 34.3 cm. Mesopotamia. Akkadian period (?), late third millennium (The Metropolitan Museum of Art, New York, Rogers Fund, 1947 47.100.80. Aruz 2003 (Photo: Bruce White).



Metallurgy: Early Metallurgy in Mesopotamia. Fig. 23 Horizontal computed tomography cross section through the *Head of a Ruler* showing core supports (Photo: The Metropolitan Museum of Art, New York).

Extra: Head of a Ruler

Based on its style, purported Iranian provenance as well as the perceived ethnicity of its facial features and hair treatment, the *Head of a Ruler* now in The Metropolitan Museum of Art in New York has been attributed most often to the Elamite cultural sphere of the late third millennium BCE (Fig. 22). Whether or not it is a true portrait, this cast copper sculpture possesses a strikingly life-like presence that is enhanced by specific features such as the broad nose, deeply set eyes and prominent ears. The eye sockets, which are now empty, were probably inlaid with shell or stone. A tang projecting from the plate across the bottom of neck indicates that this head was attached to a body or other mount that may have been made of another material.

Long thought to be virtually solid, radiographic cross sections recently obtained by computed tomography revealed that this head contained a core and may be among the earliest examples known of life-sized hollow casting. In addition to locating the position of core supports, this examination found internal porosity associated with the casting flaw on the right side of the beard as well as voids around the ears which may indicate that they were made separately and joined to the wax model of the head before casting (Fig. 23). If such is the case, then this head bears some similarity in technique to an Akkadian period copper head found at Nineveh that is now in the Iraq National Museum in Baghdad (see main text Fig. 12 and Strommenger 1986).

See also: ►Beads

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Metallurgy in Egypt

Gregg De Young

Gold, silver, lead, and copper were among the metals exploited by Egyptians since the pre-Dynastic period (prior to ca. 3100 BCE). The main sources of these metals were the deposits in the ancient rocks of the Eastern Egyptian desert near the Red Sea and in the Sinai. Iron implements, although present in Egypt from the 26th Dynasty (ca. 665–525 BCE), did not become common until the Ptolemaic period (305 BCE–30 BCE), for Egypt had no access to major sources of iron ore. The most common metals for daily use were copper and bronze (a copper–tin alloy).

With no written descriptions of the mining or metallurgical operations we rely on vignettes of metalworking that appear in some funerary art for our understanding of the processes involved in procuring metallic resources. Of course, some nuggets of relatively pure metals can be found, but these were certainly used up very quickly, forcing the ancient Egyptians to learn the techniques for exploiting deposits of metal ores. Mines might be either open shallow pits or underground tunnels following promising veins of ore. The remains of ancient mine shafts and miners' stone tools, as well as heaps of waste, still indicate many of these sites. By the time of the New Kingdom (ca. 1550–1085 BCE), Egypt probably was relying more and more heavily on imports of copper, as well as tin and iron to meet its needs for metal implements.

There is some evidence to suggest that an initial extraction of the metal from the ore matrix took place in the vicinity of the mine itself. Extraction of the metal involved either roasting (heating the ore with charcoal in the open air) or smelting in closed furnaces using either the addition of coke and silicate particles to absorb impurities and aid in reducing the oxides to metallic form or a forced air blast through the molten slag to oxidize impurities and so free the metal. These effects require a high temperature that is only achieved though use of blowpipes or bellows to feed oxygen to a charcoal fire. Many ancient peoples knew the technical processes. In the context of ancient Egypt, however, we should not forget the geographical setting in which trees were not plentiful. Large-scale building projects, such as pyramid construction, therefore, which require extensive metallurgical implements, must have placed many strains on the natural economy and demanded complex administrative planning for their completion.

Pure copper is relatively soft, and so nearly useless for many implements. When hammered, it rapidly becomes harder and more brittle. This hardness may be removed by annealing (heating the metal above 500°C and allowing it to cool again). Many early edged implements were apparently shaped through repeated hammering and annealing, ending with a final hammering to harden the cutting edge.

Other metal products might be formed by casting (pouring molten metals into a pre-shaped stone or ceramic mold) and allowing the metal to cool and harden. For metallic objects not requiring solidity, the "lost wax" technique of casting used less of the precious metallic resources. In this process, the object was first modeled in clay or some other heat-resistant medium. This model was then coated with a layer of wax of uniform thickness. The wax, in turn, was completely surrounded by yet another layer of clay or plaster, leaving only a small opening into the wax-filled layer. The mold was then heated, melting the wax, which ran out through the drain provided. Through this opening, molten metal was then carefully poured in order to avoid formation of gas bubbles that might mar the finished product and allowed to cool.

The formation of gas bubbles is difficult to avoid with pure copper, since it absorbs gases which then produce bubbles that weaken the final product. If, however, a bit of tin is added to the copper, the results are significantly improved. Alloying copper with about 10% tin also produces a considerably harder and more durable metal, bronze. Bronze, therefore, was widely used for tools and weapons from the time of the Middle Kingdom (ca. 2150–1780 BCE) until replaced by iron implements late in the New Kingdom period (after ca. 1000 BCE). Since tin is not found in commercial quantities in Egypt, it is not certain whether bronze was imported as a semi-finished product or was internally produced with imported tin.

Metal tools such as chisels, knives, axe heads, and adzes are common in funerary collections and are often portrayed in Egyptian art. Another major use of metal was in the production of weapons: daggers, swords, spears, and battle axes. Defensive armor, such as mail coats (made by riveting small bronze plates onto leather jerkins) first became common during the New Kingdom period. Protective helmets also appear to be a relatively late innovation, although some tomb paintings from the Ramesside period (ca. 1290–1225 BCE) show foreign mercenaries equipped with protective headgear. A third important use of copper (and later, bronze) was in the production of domestic articles such as cauldrons, ewers, basins, and ladles. Mirrors of polished metal were common throughout the dynastic period. Excavators have also found pins, tweezers, and razors.

The gold deposits of the eastern Egyptian desert and Nubia were the largest in the ancient world, so perhaps the techniques for extracting gold and its alloys, as well as methods for working them, were discoveries of the inhabitants of the Nile valley. We cannot be certain, of course, for such knowledge was handed down from father to son and from master to apprentice without being recorded.

Sheets of metal, whether gold, silver, copper, or bronze could be worked by a variety of techniques to produce decorative effects. Repoussé is worked from the back of the metal sheet so that the design stands out on the front in raised relief. Chasing is relief worked from the front of the sheet by hammering down the background while leaving the desired figures raised in the foreground. Engraving, also worked from the front of the piece, means cutting a groove into the metal during which a portion of the metal is actually removed. Tracing, which leaves a similar effect, does not remove any metal from the piece.

Sometimes it is desirable to join together pieces of worked metal to form an object. The ancient Egyptians knew how to use a variety of soldering techniques effectively. In soldering, a metal or alloy with a melting point lower than that of the metal pieces to be joined is allowed to flow along the seam. On cooling, the two metal parts are joined together. Since the ancients rarely worked with pure gold or other metals, the choice of suitable solder was very important. For example, gold and copper melt at very nearly the same temperature (1,083 and 1,063°C, respectively). If 10 parts by weight of copper is added to 90 parts of gold, however, the mixture's melting point is only 940°C. Thus, if one were working with relatively pure gold, a gold–copper alloy might prove a suitable solder to use. A somewhat similar technique, sweating, involved coating the edges of the pieces with the solder, bringing the edges together and heating until the jointing compound melted, without adding further solder. This latter often makes a neater join than does soldering.

There has been considerable debate about whether the ancient Egyptians knew how to draw wires. There exist, both physically and in funerary art, numerous examples of what seem to be beads strung on wires. It is not clear, however, whether these were truly wires or merely thin strips cut from a sheet of metal using a chisel, for example, or whether friction with the beads of the jewelry might be the true cause for such strips to appear round like modern wire. Since Egyptian beads were manufactured by drilling a hole through stone or metal, there would be ample room for frictional forces to enter the manufacturing process.

Jewelry was an important adornment of both gods and humans. In ancient Egypt, people wore jewelry for a variety of purposes. Perhaps the most important was as amulets to protect the wearer from evil forces that seemed to surround human life on every side. Gold itself was considered magical, identified by some with the flesh of the gods since gold, among the metals known to the ancient Egyptians, was least susceptible to tarnishing and change. Precious stones were also used, along with natural objects such as the claws of a ferocious creature (who may have been considered to embody the powers of the god). Jewels could also be used, perhaps as an extension of their magical power, to enhance the sexual attractiveness of the wearer. They could also, as today, serve as symbols of status and wealth. We have reports of Pharaohs giving golden collars or other ornaments to their favorites as a mark of distinction. Jewelry was also essential to the burial customs of the Egyptians. Finally, jewelry could indicate the power to carry out royal prerogatives delegated by the Pharaoh. The man who held the king's signet ring or royal seal, for example, carried enormous responsibilities, both politically and religiously.

Jewelry making seems to have been an important activity in relatively few centers of culture and political power. Since gold was mainly the possession of royalty, it seems probable that jewelers who supplied the royal household with golden ornaments enjoyed considerable social and economic status. Three overseers of goldsmiths had tombs at Thebes, as did two goldsmiths, indicating a fairly high social status. Of course, the workers who actually carried out the designs of the jewelers must have had a lower social status, but they were not of the lowest social class. Skilled workmen in metals would always have been in demand, and this demand would translate into at least a modest level of social prestige and influence.

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Metallurgy in Meso and North America

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Native American metallurgical technologies held great attraction for sixteenth century European empires seeking to stake claims in the American New World. While the technical feats and mastery of Native American metalworks have only recently generated systematic scientific inquiries (Benson 1979; Lechtman 1979, 1984, 1991; Lechtman et al., 1982), the attraction of Mesoamerican and Andean precious metals has resulted in the plundering of massive quantities of these metals – often in the form of jewelry and other materials – from ancient centers where they served both ceremonial and funerary functions. Precious metals craftsmanship was an ongoing enterprise at the time of the Spanish conquest of the Inca state in 1532; heirloom items, ritual caches, and funerary offerings fed the raging smelters of European outposts in the New World for the duration of the colonial period. The crafted booty delivered to Fernando Pizarro by the Inca nobility, as ransom for the Inca Emperor Atahualpa, occupied nine forges for four months in 1533; this, in order to smelt the over 26,000 pounds of silver and 13,420 pounds of gold jewelry and other reliquary collected as tribute at that time. For the Spaniards, gold and silver were the fuel that propelled the expansion of the Holy Roman Empire; while for the Inca, gold, and silver symbolized the sweat of the sun and the tears of the moon, and thereby, the cosmologically ordained male and female principles, respectively.

Much of the precious metal processed by early European colonists in the New World was smelted from intricate works of art crafted into jewelry sewn into elaborate blankets, capes, shawls, and other clothing, as well as worked into ritual and funerary art and furnishings, weapons of war, and medical and agricultural tools (Easby 1974). Ancient and large-scale metallurgical workshops and industrial centers are known from the *patios de Indios* (native workshops) of Colombia, and from such ancient centers as Atzcapotzalco, Mexico, where craft guilds were a significant aspect of the economic and social landscape.

The growing international black market in antiquities has both hastened the looting of ancient sites containing pre-Columbian metal craft, and has, by extension, spurred the collection and preservation of these works as priceless relics of a bygone age. When one takes into account the fact that individual tombs from sites such as Batan Grande, Peru, contained as many as 200 gold objects, much of which consisted of tall – 30 cm – gold beakers, it is no wonder that much of this legacy has already been destroyed. Other funerary chambers, like that of Tomb 107 at Monte Alban, Oaxaca, Mexico, contained a veritable treasure trove of over 500 precious metal and stone objects recovered by Mexican archaeologists in the 1930s. Other archaeologically documented precious metals caches have been recovered from Zaachila, Oaxaca, and Coclé, Panama. Where bronze craftsmanship is concerned, individual tombs have produced upward of 500 kg of such metals worked from alloys of tin and arsenic–bronze. Given the notoriety of such discoveries among grave robbers and the general public, it should be of no surprise that looters persist in destroying ancient sites in search of treasures.

The recent discovery and subsequent excavation of the tomb of the warrior-priest of the ancient ceremonial center of Moche, Peru – which contained a collection of dynastic relics and funerary items of gold, silver, and alloys of copper and tin – was initially brought to the attention of the scientific community as a result of looting. Despite such destruction, archaeologists and other investigators continue to document the technical achievements of Native American metallurgists of Peru, Mesoamerica, Central, and North America (Shimada et al., 1983).

In 1921, Swedish ethnographer, Erland Nordenskiold began research into technical secrets made apparent through metallurgical analysis of ancient metal objects from South America (Linné 1957). Nordenskiold ascertained that pre-Columbian metalworks were far more technically sophisticated than imagined at that time. He made a number of observations concerning metallurgical problems, including those pertaining to the metallurgical composition of *tumbaga* (a complex alloy of copper and gold, or copper, gold, and silver), soldering with silver, and the welding of copper. The technical analyses completed by Nordenskiold were a precursor to the sophisticated analyses now undertaken by archaeologists, and metallurgists, using a variety of techniques ranging from replicative experiments – where the objects themselves are reproduced with known ancient methods and technologies under controlled conditions – to physical and chemical tests to ascertain the composition and construction of the alloys employed in the creation of pre-Columbian metal objects (Shimada 1988; Meeks et al., 2002; Lechtman 1991).

The body of ancient technical secrets relevant to the manufacture of pre-Columbian metal objects has grown considerably since the first European observations of Native American metallurgical techniques in the sixteenth century.

The Old Copper culture, which flourished from 3000 BCE to 1000 BCE along the shores of Lake Superior in North America, is credited with having introduced the earliest known metalworking tradition in the Americas. This tradition was the basis for later developments in the use of copper and related metals by Hopewellian and Mississippian peoples of the first-millennium CE. Old Copper culture sites have produced evidence of significant early metallurgical techniques, including cold hammering, hammer welding, annealing, and the production of socketed metal tools, conical points, knives, axes, chisels, awls, harpoon heads, and a variety of projectile point types derived from prototypes of stone, horn, shell, and bone. To this list we can add sheet metal, intricate sheet metal cut-outs, repoussé decoration, crimping, riveting, the gold sheathing of copper, gold and copper beads, and the hammer-welding of silver and copper, or "copper and meteoric iron to produce bimetallic objects" (Easby 1966, 1974). This demonstrates an early, independent, and regional tradition in the art and science of metal craft.

The lost-wax, or *cire perdue,* casting process was first employed in the region of Colombia by 100 BCE, but quickly spread into Ecuador, and lower Central America (Panama and Costa Rica), and was subsequently adopted in Peru and Mesoamerica by AD 800 (Hosler 1986). Ultimately, according to historian Easby (1966), lost-wax casting achieved "its highest development in the Oaxacan area of Mexico, where during the fifteenth and sixteenth centuries AD Mixtec master craftsmen produced little hollow castings that are unrivaled for delicacy, realism and precision."

Where Mesoamerica is concerned, the North American tradition of cold hammering and annealing, and that of South America, consisting of cold hammering, annealing, and casting, inspired the initial development of three distinct Mesoamerican metallurgical traditions. These traditions include those that emerged in the areas of upper Central America or southern Mesoamerica (including southern Mexico, Guatemala, Honduras, and El Salvador); the Pacific coastal lowlands including the Tarascan culture area, and the Mexican Gulf Coast lowlands and Yucatan Peninsula which encompassed the ancient Huastec, Totonac, and Maya cultures. Archaeologist Hosler (1986) argues that the relatively late adoption of metallurgy in Mesoamerica – after AD 700 – serves to explain the largely elite character of the Mesoamerican metallurgical tradition. While both South and North American metalcraft evolved from a utilitarian foundation centered on the manufacture of agricultural implements and other tools, trade and exchange in precious metals ultimately inspired the Mesoamerican metallurgical tradition. Hence, the wholesale and widespread adoption and exchange of metallic axe monies, tokens, and precious-metal objects.

While recent studies have yet to establish definitively the earliest dates identified with the origins of bronze metallurgy, Lechtman (1986) argues that arsenic bronze was in use in northern Peru by the fourth-century AD. Tin–bronze originated in highland Bolivia by AD 700, and, by the Inca era (ca. AD 1450) spread throughout the areas identified with the modern states of Peru, Bolivia, Chile, and Argentina. Finally, metallic money – in the form of copper axe blades and tokens – appeared in Ecuador by AD 1000 and quickly spread throughout South, Central, and Middle America.

The holistic nature, independent development, and antiquity of Native American metals craftsmanship are only now beginning to be clarified (Meeks et al., 2002). Metallurgical technologies that were developed by pre-Columbian craftsmen are far too numerous to discuss in any detail in this essay. However, a partial listing should provide some idea of the significance of this legacy. Those identified to date include (a) the *cire perdue* or lost wax casting process, (b) surface metallurgy, depletion gilding, acid pickling, and tumbaga, (c) the application of organic reagents and binding emulsions, (d) arsenic, copper–arsenic, and tin–bronze casting, (e) copper–arsenic, tin, and bizmuth alloys, (f) silver chloride coatings, (g) gilt copper sheeting, gold and silver sheathing, sheet metal processing and fabrication, mechanical crimping, gold-leaf treatments, hammer-welding, and the raising of sheet metal vessels, (h) silver/silver–copper/spot solder and soldering, (i) copper soldering, brazing, and spot welding, (j) electrochemical replacement plating, (k) complex annealing, cold-hammer and anvil, binary and ternary alloy processing, and ground and hammered meteoric iron implements, (l) charcoal-fed ore reduction and air-blast smelting/refining furnaces, (m) iron ore or hematite flux, and the reduction of sulfide ores, (n) open cast, multicomponent, and vented casting molds, and powdered carbon casting emulsions such as that of the Aztec *teculatl* (charcoal water), (o) mechanical and metallurgical joins including metal nails, rivets, staples, ribbon clips, strip clips, lacing, long sockets, short tabs, tab-and-slot and other metal fasteners, (p) repoussé and other embossed sheet metal applications, including cinnabar cloisonné, (q) solid-state diffusion bonding, sweat welding, fusion gilding or Sheffield plating, and cladding, (r) slush casting, (s) multicomponent sheet metal miniatures, (t) color surface and powder metallurgy, (u) technologies for the manufacture of thin cast rods, wire coils, strip wire, wire-work surfacing and filigree, metal sequins, quad metal mosaics, architectural cramps, agricultural blades and implements, socketed chisels and related tools; and copper and bronze axe blades, metallic monies and tokens, (v) arsenic and tin–bronze implements including fish hooks, eyed needles, pins, depilatory tweezers, and surgical instruments such as *tumi* knives and blades, (w) the standardization of metal ingots and tools, (x) platinum plating, ore processing, and the sintering of refractory metals such as platinum, and finally, (y) a variety of prospecting methods, including shallow shaft mining, the strip mining of exposed deposits, and the placer mining of alluvial gold and platinum. According to Lechtman, the tumbaga alloys alone "constitute the most significant contribution of the New World to the repertoire of alloy systems developed among ancient societies." It should be noted that the processing of platinum (which has a melting temperature of 3,000° Fahrenheit), was a feat accomplished by ancient Ecuadorian metallurgists by way of the "mixing of grains of platinum with gold dust" through a powder process identified with the "sintering of refractory metals" (Easby 1966; meaks et al., 2002).

Electrochemical replacement plating and depletion gilding, developed by the Moche of Peru nearly 2,000 years ago, allowed ancient Native Americans to plate precious metals on to semiprecious metals to a thickness of less than 1 μm. This electrochemical replacement process was not rediscovered until the twentieth century CE. Recent studies indicate that electrochemical replacement plating and depletion gilding or silvering "both involve sophisticated chemistry, and pre-Columbian surface metallurgy is surely as much chemistry as it is metallurgy" (Lechtman 1986). As Easby says, "the tale persists that the egotistical Benavento Cellini spent months trying to ascertain how an ancient Mexican craftsmen had fashioned a silver fish with gold scales and finally conceded that he was baffled." Unfortunately, as is the case with so many other aboriginal New World technological innovations, the very presence of such metallurgical traditions as that of the lost-wax casting process and tin and arsenic–copper bronze alloys was once taken to indicate that such technologies were introduced or diffused from the Old World.

Recent archaeological investigations underscore the paucity of information pertaining to metallurgy currently at our disposal, as well as the abundance of ancient archaeological materials that have yet to be studied in any systematic fashion (Lechtman 1986). Unfortunately, the relatively recent and highly specialized nature of publications pertaining to pre-Columbian metallurgy have led some scholars to suppose that even the most ingenious ancient Native American technologies were little more than isolated or accidental instances of technical insight and ingenuity. Such scholarly perspectives are clearly artifacts borne of the relative scarcity of and limited access to information. As the body of studies grows, it is becoming clear that innovations in metallurgy, such as depletion gilding and electrochemical replacement plating, were far more ancient and widespread than once thought.

While the wholesale destruction of the pre-Columbian world has closed an important window on the cosmology and beliefs of its metallurgists, we can nevertheless advance interpretations as to the social and ritual significance of metals based on contact-period and ethnographic accounts.

Both Inca and Aztec craftsmen, and Native Americans more generally, identified precious metals – gold and silver – with the male and female principles. The alloying of copper and gold, or, copper, gold, and silver, which produced a red, pink, or golden metal known as *tumbaga*, was in turn identified with the menstrual flow and ambered moon. Among the contemporary metals craftsmen of west Africa, smelters are designed to symbolize the female sexual organs, while the metals themselves are thought symbolic of the male principle embodied in semen and other bodily fluids. The cosmological message inherent in the metal itself, when combined with the supernatural and religious icons and images, must surely have served to enhance the power and prestige of the bearer, while at the same time providing clear indications of that individual's identification with supernatural and cosmic forces. The use of metals in personal adornment and ritual attire served to convey the associations of the bearer with universal principles, within which gender ultimately served as a distinguishing characteristic of the individual, and thereby, the cosmos.

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Metallurgy in the Near East

A Zooarchaeological Perspective on the Origins of Metallurgy in the Near East: Analysis of Stone and Metal Cut Marks on Bone from Israel

Haskel J. Greenfield

The Near East represents one of the earliest centers for the development of metallurgical technology and is crucial to the investigation of issues related to the development of metallurgy (Tylecote 1986, 1987, 1992; Muhly 1988; Wertheim and Muhly 1980). Metallurgy appears very early, with the recovery of cold-hammered copper artifacts from the Late Pre-Pottery Neolithic. With the development of smelting techniques, copper metallurgy spreads fairly quickly and widely during the Chalcolithic. Metallurgy spread ever more rapidly when it was discovered that the properties of copper could be improved by alloying copper with other metals such as arsenic, lead, or tin, to produce bronze. Bronze tools begin to be found in the Early Bronze Age (EBA). By the Middle Bronze Age, the use of bronze becomes more frequent (Maddin et al. 1999; Mellaart 1976; Moorey 1998; Redman 1978). However, it is impossible to document the introduction and spread of metallurgy into a region by simply using the frequency of metal finds. Metals, such as bronze and copper, are notoriously unstable. They decompose under most depositional conditions and/or are reused.

The objective of my research has been to investigate this issue from the perspective of Zooarcheology, or the analysis of animal bones from archaeological contexts. Slicing cut or butchering marks on bones can be used to identifying the nature of the raw materials which were used in the butchering of animals (Fig. 1). By distinguishing whether metal or stone tools make cut marks on animal bones, an independent measure of the relative importance of the different raw materials used for butchering or cutting of meat can be generated. The spread of metallurgy, as a result, can then be quantitatively monitored both across time and space within a region, and even within a single settlement.

Method

The method for distinguishing between stone and metal cut marks is based on experimental research conducted by the author and others and is discussed at length elsewhere. It will be only briefly summarized here (Greenfield 1999, 2000a, 2002a, 2002c, 2006; Olsen 1989). In order to identify bones with butchering marks on them, each bone fragment was individually examined. Most of the butchering marks were readily identifiable to the naked eye. A low power magnifying glass was used to survey each bone in order to enhance the potential for discovering butchering marks. Even though microscopic examination of the entire surface of each bone

Metallurgy in the Near East. Fig. 1 Cut mark on bone from site of Atlit Yam, sample 164 (Photo by Haskel J. Greenfield).

may have located a higher number of butchering marks, it was not deemed to be a realistic in terms of sample size, time, and finances.

Butchering marks are often relatively easy to distinguish in this period from tooth and other marks in later prehistoric bone assemblages. The nature of the activity leaves a relatively clear signature for even the naked eye – a relatively short straight incision in the bone. Many bones with potential cut marks were rejected when subjected to microscopic examination since they were deemed to be caused by nonbutchering sources. Once butchering marks were identified, the cut mark was examined under a light optical microscope and a tentative identification of the nature of the raw material of the implement was made – stone or metal.

Subsequently, a silicone mold of the incision was made in order to further study the mark in a scanning electron microscope. Each mold was subjected to further examination by the author and another assistant in the lab at the University of Manitoba. In this way, each mold was separately and repeatedly examined to determine whether a stone or metal blade had been used during butchering. This ensured a level of accuracy and repeatability of results rarely encountered in such analyses.

Several simple diagnostic criteria can be used to distinguish metal from stone tools. Metal tools have the following patterns (Fig. 2):

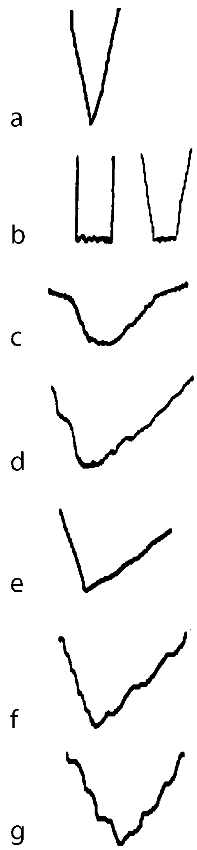
1. Metal knife blades sharp V-shaped or (Fig. 3) hard cornered |_|-shaped grooves (Fig. 4) that meet at a distinct apex at the bottom of the groove (Fig. 2a,b).
2. Metal tools make more uniform patterns on the bone, often removing material in the groove more effectively. They leave either no striations or striations of a more uniform depth and spacing than when stone tools are used (Fig. 5).

In general, metal knives produce a cleaner and more even slicing cut (except for serrated-edge blades – Fig. 2c).

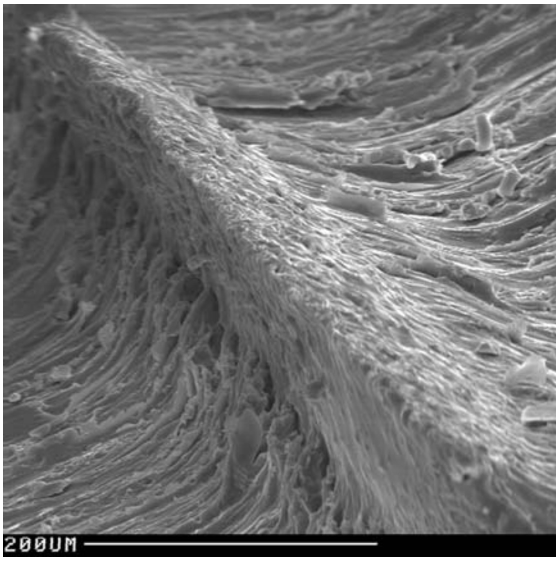
By contrast, chipped stone tools have different diagnostics, which can be summarized as follows:

1. Chipped tools (blades or flakes) create a groove with one side rising steeply and smoothly and the other side rising more gradually (Figs.6 and 1e), except for scrapers (Fig. 1d).
2. The gradually rising side will have one or more striae that run parallel to the apex of the cut, depending on whether it is retouched or not (Fig. 7).
3. Retouched tools may have lateral striations on both sides of the apex, depending on whether they are unifacially or bifacially retouched (Fig. 1f,g).
4. Stone tools produce a shallower, less even cut mark.

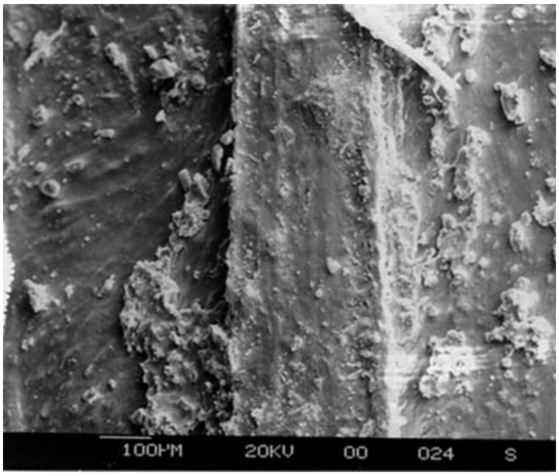
In sum, the type of raw material used in making a butchering implement can be distinguished on the basis



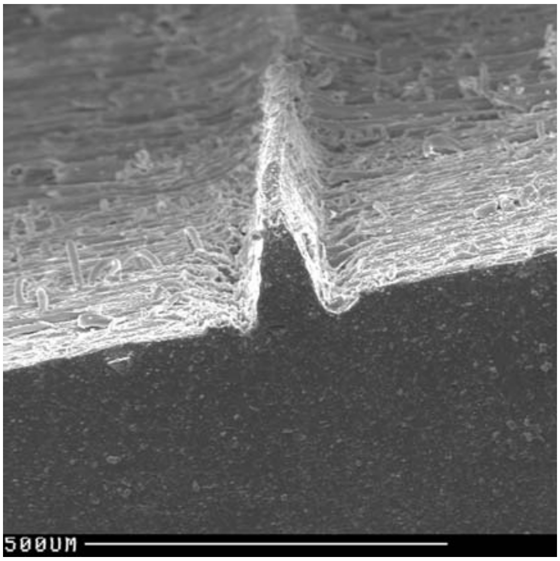
Metallurgy in the Near East. Fig. 2 Profiles of cut marks made by stone and metal blades.



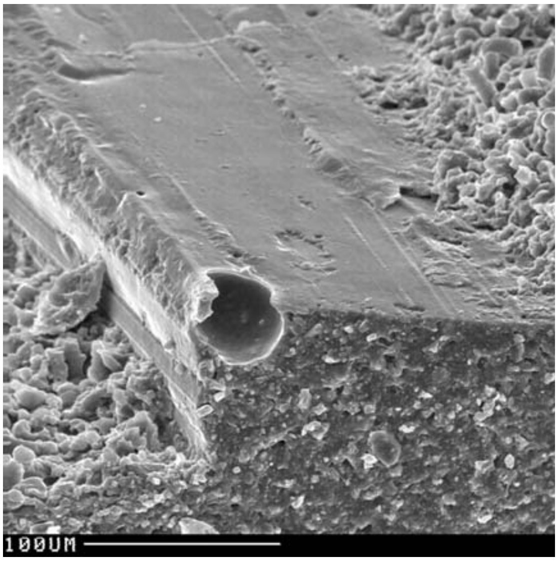
Metallurgy in the Near East. Fig. 3 Inverse mold of flat-sided metal knife (metal 9c) cut mark.



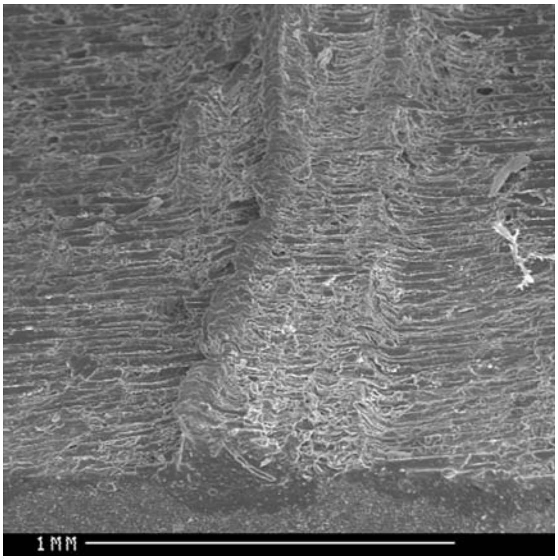
Metallurgy in the Near East. Fig. 4 Inverse mold of dulled metal knife (an236) cut mark.



Metallurgy in the Near East. Fig. 5 Inverse mold of flat metal blade (metal 4c).



Metallurgy in the Near East. Fig. 6 Inverse mold of unretouched stone blade (stone 125a) cut mark.



Metallurgy in the Near East. Fig. 7 Inverse mold of unifacially worked stone blade (stone 6a) cut mark.

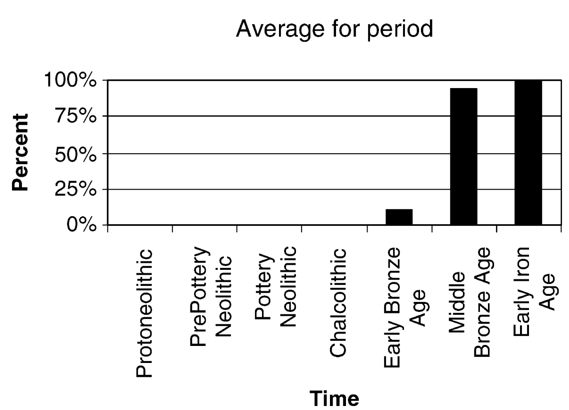
of its profile. In this illustration, typical profiles for different types of metal or stone butchering implements are presented.

Data

In order to investigate the origins of metallurgy in an area, sites from before and after the assumed starting point must be included in the analysis. Data from Israel were chosen since this is an area with early metallurgy (Levy 1998; Levy and Shalev 1989; Mazar 1990; Shalev 1994; Shugar 1999) and is one of the few areas of the Ancient Near East where many animal bone collections are easily accessible for analysis. At this point in time, data from over seventeen zooarchaeological collections have already been analyzed from sites excavated in Israel and the present Palestinian Authority areas (Greenfield 2004a,b; Greenfield et al., 2006; Saidel et al., 2006).

Data from the Proto-Neolithic through the Middle Bronze Age are included in the study. In this way, it is possible to monitor the possible introduction of metallurgy even the Chalcolithic, when the first metallurgy has been proposed to exist. Most of the sites

Metallurgy in the Near East. Fig. 8 Map of sites used in analysis.



Metallurgy in the Near East. Fig. 9 Histogram of percentage of metal cut mark frequency over time (average per period).

fall into the PrePottery Neolithic, Pottery Neolithic, and EBA. The other periods are more poorly represented. Over the next few years, more sites will be added to the database.

Results

A total of 857 bones with useable butchering related cut marks have been identified (to date) from the above sites. The data can mostly be analyzed from the perspective of time, although there are some inferences that can be made with regard to spatial divisions with the data.

Temporal Distribution of Butchered Remains

In the Proto, PrePottery, and Pottery Neolithic assemblages, there is no evidence for metal cut marks on bones (Fig. 9 and Table 1). This is not unexpected, but is important to demonstrate. A few metal cut marks were found at (Jericho in the PPNB sample), but these have been deemed to be from intrusive or improperly labeled specimens.

This pattern of stone tool dominance continues during the Chalcolithic. While the sample size of sites is much smaller than in the previous periods ($n = 1$, Gilat), there are a substantial number of cut marks from the site.

During the EBA, the pattern begins to change. Metal cut marks begin to appear. The data from Jericho indicate that both stone and metal cut marks were found in the assemblage in substantial numbers. During the EBA, metal tool marks are present in 41% of the bones of Jericho.

But the frequencies of metal cut marks in other Early Bronze (EB) sites is different from that seen above for Jericho. At sites, such as Afridar near Ashkelon, 89% of the cut marks belong to stone tools and the remainder are metal tool marks. At the nearby EB site of Ashkelon Marina, the similarly low percentages of metal cut marks are found. Only 1 out of the 7 bones with identifiable cut marks had a metal cut mark on it (14.28%). At Be' erotayüm, all of the bones were butchered with stone tools. The situation is less clear at the EB sites of Dalit and Tel Kinrot. While the data are evenly split, the frequencies of cut marks are so small that they have no statistical reliability and should not be given any weight in the analysis. They are presented here merely to demonstrate that metal appears across a wide range of sites during the Early Bronze Age.

Only one site with a Middle Bronze Age (MBA) sample has been analyzed so far (Jericho). The frequency of metal tool marks rises dramatically in the MBA at Jericho to 94% of the total (85.19% in the tell deposits and to 95.19% in the tomb deposits). This indicates the nature of the dramatic change between the two periods. The pattern for the MBA continues in later periods. Metal tools made almost all of the cut marks.

Raw Material by Geographical Region

Some spatial interpretations of the data can be made, but the data are very incomplete. There is evidence for early use of metal for butchering during the MBA from a variety of sites, ranging from the southern (Afridar and Ashkelon) and central coastal regions (Dalit), through the northern Negev (Arad) to the Jordan Valley (Jericho) see

Metallurgy in the Near East. Table 1 Distribution of cut marks by period and site

Period	Subperiod	Site	Stone no.	%	Metal no.	%
Protoneolithic		Jericho	4	100.00	0	0.00
PrePottery Neolithic	PPNA	Jericho	17	100.00	0	0.00
PrePottery Neolithic	PPNB	Jericho	15	88.24	2	11.76
PrePottery Neolithic	PPNC	Atlit yam	117	100.00	0	0.00
PrePottery Neolithic	PPNB	Yiftahel	4	100.00	0	0.00
Pottery Neolithic		Jericho	1	100.00	0	0.00
Pottery Neolithic		Lod	23	100.00	0	0.00
Pottery Neolithic		Neve Yam	10	100.00	0	0.00
Pottery Neolithic		Tel Dan	10	100.00	0	0.00
Pottery Neolithic		Tel Hereiz	12	100.00	0	0.00
Chalcolithic		Gilat	34	100.00	0	0.00
Early Bronze Age/EB I		Afridar (1963)	10	100.00	0	0.00
Early Bronze Age		Arad	86	91.49	8	8.51
Early Bronze Age		Jericho	10	58.82	7	41.18
Early Bronze Age		Dalit 2	1	100.00	0	0.00
Early Bronze Age		Dalit 78	0	0.00	1	100.00
Early Bronze Age		Tel Kinrot	1	100.00	0	0.00
Early Bronze Age	EB I	Ashkelon Marina	6	85.71	1	14.29
Early Bronze Age	EB I	Afridar	8	88.89	1	11.11
Early Bronze Age	EB I/EB IV	Rujm Be'erotayim	6	100.00	0	0.00
Middle Bronze Age total	Tell and Tomb	Jericho	13	6.07	201	93.93
Early Iron Age	Eleventh century BCE	Ashkelon tell	0	0.00	6	100.00

below. Other regions of the Country, such as the Central Negev, do not show any use of metal. It is difficult, at present, to discuss spatial trends within any single site since the data are not yet processed from this perspective.

Raw Material by Taxon

While there is no perceived pattern of which taxa were butchered with the various types of raw material, the EB metal cut marks are concentrated on domestic and wild cattle remains. This is visible in the data from Jericho, with its large frequencies (Table 2). In the periods with metallurgy (EBA and MBA), both domestic and wild taxa are butchered with both metal and stone tools. This pattern can also be seen in the data from EB Afridar (Table 3).

Comparison with Other Sources of Data

In Israel and the PA areas, the origins of metallurgy have also been investigated through the analysis of lithics. Steve Rosen (1997) demonstrated that the first stage in the adoption of metallurgy did not involve the wholesale replacement of flint tools (as is commonly assumed). Functional chipped stone tool types gradually disappear between the end of the Chalcolithic and Iron Age. Some types disappear because of changes in subsistence (arrowheads), while others are replaced with metal types that had a corresponding function (axes). Some stone tool types disappear quickly (at or prior to the beginning of the Bronze Age – arrowheads), others disappear gradually through the Bronze Age (axes), and some continue to be used into the Iron Age (sickles). To explain the continued use of stone (in the face of increasingly available metal tools) into later periods, Rosen has suggested that until a clear improvement in efficiency emerges, the economy would perpetuate the use of the traditional material.

While the data from the region is admittedly very small, geographically unrepresented, and was collected for the most part haphazardly archaeologists in the field, they still represent the only available data. Even so, they can be used to represent changes in the region over time. Eventually, more information will be added to the database and process across space may be investigated.

Problems that plague the analysis are that it is hard to obtain a statistically significant pattern from small sample sizes and it is always possible that some material from multiperiod sites (e.g. Jericho) that is found in one or another stratum is either residual or intrusive, especially when the objects are small (such as animal bones). As a result, it is always possible that when you have a very small database, the effect of possible intrusions becomes statistically greater. It will only be from relatively large samples that we can have enough reliable data to draw definitive conclusions. Nonetheless, the data allows us to draw some tentative conclusions.

The evidence indicates the evolution of a butchering technology that changes over time. It was exclusively

Metallurgy in the Near East. Table 2 Distribution of cut marks by taxon and period (NISP) – Jericho

Period (revised)	Domestication	Taxon	Metal	Stone	Grand total
Protoneolithic	Wild	Gazella sp.	0	4	4
PPNA	Wild	Gazella sp.	0	14	14
		Sus scrofafer.	0	1	1
		Vulpes vulpes	0	1	1
		Bos primigenius	0	1	1
PPNB	Domestic	Bos taurus	1	1	2
	Wild	Gazella sp.	0	9	9
		Sus scrofafer.	0	1	1
		Bos primigenius	1	4	5
Pottery Neolithic	Domestic	Ovis	0	1	1
Early middle BA	Wild	Gazella sp.	0	1	1
EBA	Domestic	Bos taurus	3	4	7
		Ovis	2	3	5
		Ovis/Capra	2	2	4
	Wild	Ovis orientalis	0	1	1
MBA	Domestic	Equus caballus	2	1	3
		Ovis	0	1	1
		Ovis/Capra	17	2	19
		Sus scrofa dom	1	0	1
		Sus scrofafer.	2	0	2
	Wild	Dama mesopotamica	1	0	1
MBA tomb	Domestic	Bos taurus	3	1	4
		Capra	14	0	14
		Capra hircus	9	0	9
		Equus asinus	4	0	4
		Ovis	105	6	111
		Ovis aries	19	1	20
		Ovis aries ?	2	0	2
		Ovis/Capra	22	1	23
Grand total			210	61	271

Metallurgy in the Near East. Table 3 Distribution of cut mark by taxon (NISP) based on light optical microscope – Afridar

Domestication	Taxon	Metal no.	%	Stone no.	%	Grand total no.
Domestic	Bos taurus	1	12.50	7	87.50	8
	Bos taurus ?	0	0.00	1	100.00	1
	Capra hircus	0	0.00	2	100.00	2
	Ovis aries	0	0.00	4	100.00	4
	Sus scrofa dom.	0	0.00	1	100.00	1
	Ovis/Capra	0	0.00	4	100.00	4
Wild	Alcelaphus buselaphus	0	0.00	1	100.00	1
	Bos primigenius	1	100.00	0	0.00	1
?	Large mammal	1	50.00	1	50.00	2
	Medium mammal	1	100.00	0	0.00	1
Grand total		4	16.00	21	84.00	25

reliant upon stone tools from the Pre-Neolithic levels (represented at Jericho), through the various sites represented by PrePottery and Pottery Neolithic, and into the Chalcolithic periods. Most tools were probably unmodified flakes, haphazardly made, or blades. In contrast, the data from the EBA and MBA indicate a gradual, followed by a substantial shift in butchering technology from stone to metal. Stone butching

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technology continues to play an important role in the EBA, but it is barely present in the MBA. This is not surprising given the differences in the nature of metallurgy between these two periods. Only copper or occasionally natural arsenical alloys (i.e., arsenical bronze) are in use until the very end of EB III, when tin makes its appearance. The evidence from the cut marks provides independent supports such a shift in metal technology. A functional butchering bronze metallurgy is entirely or almost nonexistent in the EB and this is evident by the lower use of metal tools in the butchering process.

It is apparent that there are some spatial differences in the availability of metal. While most sites have little or no metal cut marks during the EBA, major centers such as Jericho have substantial quantities. This may reflect the beginning of differential access to valued resources over time.

The data presented above are important for increasing our understanding of the spread and rate of adoption of a functional metallurgical butchering technology. It would appear to be adopted in spurts, similar to the process described for the abandonment of stone tools (Rosen 1997). These patterns appear to be more common than previously thought. Comparable data from other regions show striking similarities (as in the central Balkans and in southern Turkey; see Greenfield 1999, 2000a,b, 2002b).

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Metallurgy in Northern South American Indigenous Societies: Pre-Columbian Goldwork and Social Change

Carl Henrik Langebaek

Goldwork played an important role in the development of northern South American chiefdoms, particularly in Columbia. Thus, the history of goldwork is also the history of social change among indigenous societies. Although relations between social organization and goldwork are little known, new research has provided valuable information especially during the last years. It is now known that just the presence of goldwork is no indication of social complexity. How spectacular and well crafted goldwork is does not help to measure social complexity either. In all northern South American regions, first evidence of social differentiation (*not* political centralization) is reported early in the sequence, sometimes in the absence of evidence of goldwork. In most cases, goldwork was introduced at a relatively late date, long after social differences developed. But there are chronological differences, both in the introduction of goldwork and the development of complex societies. In the San Agustín Region, goldwork is dated around 0 AD in the Upper Magdalena Region. It is somewhat earlier in the Calima region and much later in the Sierra Nevada de Santa Marta and the Eastern Highlands. The range is from around 400 to 1000 AD in the Sierra Nevada de Santa Marta and from 1000 to 1200 AD in the Eastern Highlands. Evidence of social differences, on the other hand, is much earlier in all regions. Nonetheless, despite differences in chronology, and the contrast in some of the most conspicuous evidence of monumentality, early chiefdoms with political centralization are associated in many regions with an important investment of energy in mortuary practices and spectacular goldwork. Late indigenous society's goldwork was much less impressive.

There is evidence regarding the highly individualistic nature of the early elites. Objects that are found in their burials are frequently unlike anything else excavated in the same region. Early burial goods from Sierra Nevada de Santa Marta, Calima and the Upper Magdalena are not only different from materials found in domestic contexts but also from those found at other elite burials. Frequently, elite objects are inspired in foreign iconography. The San Agustín statuary incorporated lowland representations; in Calima, goldwork was similar to Upper Magdalena statuary. Neguanje offerings have been compared to Lower Central American and Quimbaya goods. Early Muisca goldwork was similar to the Quimbaya goldwork. Nonetheless, long distance trade of luxury items during the periods of chiefly development seems to be limited. The Calima goldwork imitated the statuary of San Agustín, but elite objects from San Agustín are yet to be found in the Calima region. Likewise, the La Badea burial in Dosquebradas includes gold ornaments similar to those found in the Calima region during the Yotoco Period, but they are not identical. The Neguanje burial includes goldwork similar to what has been called Classic Quimbaya, as well as pottery that has been compared to that of la Guajira and stone adornments comparable to those of Lower Central America. But these goods are not identical to anything else found in other burials and they seem to have been locally crafted. In the Muisca territory early evidence of goldwork was probably inspired in the so-called Classic Quimbaya style. However, we are not talking about imports, but instead of locally produced goods. This is not to argue against the fact that during the early period of chiefly emergence some objects were traded, sometimes over long distances, for this was certainly the case. It just means that copy and imitation were practiced more often than trade. Whether this means common cultural identity or not is not known. What is clear is that local conditions seem of importance to explain when and how goldwork was adopted and consumed.

The role that imitating crafts from abroad played in early chiefdoms was probably related to the role of leaders as intermediaries with the outsiders. Helms

(1981) has proposed this on numerous occasions. If Reichel-Dolmatoff (1988) is right about the iconography of many Columbian gold objects, it seems reasonable to argue that shamanistic icons played an important role as the basis of leader's legitimacy. The fact that most of the early goldwork in all four regions was locally crafted contradicts the idea that emerging elites concentrated on long distance trade. Instead goldwork would have functioned in highly competitive systems, within the context of basically local changes in demography, settlement patterns and economic conditions. As most elite objects were locally crafted, and undoubtedly are of extraordinary elaborate craftsmanship, it seems reasonable to argue that the production of elite objects was of importance for early chiefs, whether they or attached craftsmen were in charge of such production. Thus far, the direct evidence of such craftsmanship is scant. Besides isolated objects, like an Ilama metallurgy tool kit and the fact that an early workshop for goldworking was found in San Agustín associated to a mound and elite burial, no other workshops have been found. At any rate, production of gold adornments seems to have been very limited precisely because these were elite objects, limited to few individuals. The only way in which such early craftsmen had a "market" was because of the fact that prominent leaders passed away and elite goods went with them.

The contrast with late chiefdoms is evident in all four regions. What were previously materials associated with the elites (i.e., gold or luxurious stones) were later extensively used by the populace. Most frequently, gold adornments did not find their way to burials because they were inherited and accumulated by the living. In the case of the Muisca, the use of gold was not limited to the elite and neither was it among the Tairona. The fact that nose rings are so frequently represented in Sonso pottery suggests that this might have been the case in the Calima region too. This information is consistent with the idea of increasing craft specialization. Despite the fact that certain objects were consumed only by the elite, a characteristic of late chiefdoms in the Sierra Nevada de Santa Marta, Eastern Highlands, Calima, and the Upper Magdalena was that production became specialized and oriented toward the supply of a larger number of consumers. Late Muisca, Tairona, and Calima pottery becomes so standardized that the existence of centers dedicated to their production is suggested. In the Muisca territory, sites dedicated to the production of large quantities of pots, gold offerings, and spindle-whorls have been reported. In the Valle de la Plata region, it is only during the last pre-Columbian period that a distribution network from a single producing center of pottery prevailed. And this was probably not just the case with ceramics. In the Sierra Nevada de Santa Marta ethnohistorical information documents the existence of villages specializing in the production of stone adornments and goldwork.

Another common trait in late chiefdoms is that most of the labor force was not used for the construction of monuments, but rather for the construction of earthworks dedicated to the production of food. Terraces for agriculture, irrigation, and drainage systems become usual traits in the Sierra Nevada. In Calima, the landscape is transformed as never before by agricultural practices. In the Eastern Highlands, mounds and terraces are also related to agriculture for the times prior to the arrival of the Spaniards. Archaeological surveys in the Upper Magdalena and the Muisca territory suggest settlement was not oriented toward the exploitation of the best soils during the period of early chiefdom emergence. Conversely, in the case of the Muisca, it seems that the sixteenth century large villages and seats of chiefly power were located on some of the best soils in the region.

There are few documents where the production of ornaments is described in detail for northern South America. According to one source from the Magdalena Valley the leaders themselves were goldworkers (Martínez 1989). Nonetheless, in the Muisca territory production was in the hands of specialists attached to their service. In this territory it even seems that the position of goldsmith was inherited (Langebaek 1996: 130). In all regions, the production of gold objects in late periods was directed toward supplying a large portion of the population, whether it was a matter of producing adornments, as was the case among the Tairona, or offerings, as it is reported among the Muisca. In all cases, it seems that a larger demand relates to processes of population growth. Available research does not allow comparisons between the production of late chiefdom metal ornaments and that of earlier chiefdoms. The often small, mostly *tumbaga* (an alloy of gold and copper) ornaments that seem to constitute a large proportion of production in late chiefdoms are certainly not very attractive to museums, and they are often disregarded. But given that access to such goods was in most cases open to the populace, there is every reason to believe production was considerable.

Another feature of late Columbian chiefdoms was the increase in external relations that were at least partially controlled by the elites. The traditional view is that early elites depended on long distance exchange networks and that somehow they collapsed before the Spanish conquest. However, early goldwork was not only locally produced in all areas but in many cases it was highly individualistic, and probably made for specific individuals. Thus it is difficult to speculate about extensive trade networks and even less about their demise. In contrast, sixteenth century sources depict active trade routes (Langebaek 1987, 1996; Kurella 1994). Such trade involved the long distance exchange of luxuries (Szaszdi 1983; Boomert 1987; Whitehead 1990), as well as the exchange of raw materials and crafts. In the case of long distance trade, goods such as seashells, stone beads, and even some gold ornaments from the coast found their way to the Eastern Highlands. Crafts such as pottery circulated across ethnic frontiers, but this usually involved short distances within ethnic boundaries.

Goldwork played an important role in the development of northern South American chiefdoms. Gold objects are ideal means of communication. Therefore, its use depends upon a social context that determines the way in which it was used, its value, and, undoubtedly, its meaning too. As archaeologists learn more about pre-Columbian goldwork they have become aware of the complex ways in which ideological and economic factors came into play among goldworking indigenous societies.

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Metallurgy in Pre-Columbian South America

Gray Graffam

Numerous pre-Hispanic artifacts of gold and silver craftsmanship testify to the exquisite skill of ancient Andean peoples in their production of metallic art. Prior to European arrival, ancient metallurgists prevailed in working gold, in winning silver and copper metal from a variety of rich ores, and in creating various sophisticated alloys. Ancient artisans triumphed in working these materials in ingenious ways to improve their performance and appearance, and in joining them to form complex composite pieces. A tremendous wealth of exquisitely crafted metal ornaments and metallic art was created through native talent. Today, the skill of pre-Hispanic Andean peoples in winning and working metals is revealed by early historical sources, archeological research, and the remaining portion of metal objects that avoided the Conquistador's torch. Some of the finest examples come from the Moche and Chimu regions of northern Peru; they include funerary masks, breastplates, diadems, and crowns, some of which are inlaid with decorative stones of turquoise and chrysocolla.

Early historical sources are clear in their portrayal of native Andean peoples as skilled metallurgists. Among the first chroniclers, Cieza de Leon described the successful native process of smelting silver, using wind-blown furnaces (*huayras*). Historical records for Potosi are also clear in stating that it was through the work of native metallurgists that the silver wealth was first tapped. For nearly three decades, from 1545 to 1572, all silver production was the result of skilled Andean natives, who used thousands of wind-blown *huayra* furnaces to smelt the rich silver–lead ores. Such furnaces were still employed by Andean natives in the seventeenth century, at which time they were recorded by people familiar with Old World metallurgy, and similar devices have been employed well into the twentieth century.

Archeological research today includes the discovery and study of metallurgical sites. Work at the site of Batan Grande in northern Peru reveals a centuries-long sequence of copper–bronze production, ending with Inca-period efforts just prior to the Spanish Conquest. Detailed research by such scholars as Izumi Shimada and John Merkel reveals the sophisticated nature of the smelting procedure, and reconstructs the various steps used in the metallurgical process. In addition, recent related efforts by Heather Lechtman focus on the source of the ores used in the production of the copper–arsenic alloys, arguing for a highland-coastal exchange. With regard to detailed archeological investigations of sites where metal was crafted, rather than smelted, the research on metal craftsmanship at Chan Chan is an important contribution, which examines the activities carried out by metal smiths within a particular district of that pre-Incaic city. Also of note are investigations into the pre-Hispanic smelting facilities and processes in the South Andes. To date, the earliest metallurgical (copper) slags in this latter region come from the Wankarani site in highland Bolivia; they date between 250 and 1200 BCE. Of particular note, research at the Ramaditas site in northern Chile reveals a highly skilled, natural draft technology operating in the Atacama region by 100–50 BCE, where pre-Hispanic metallurgists were capable of achieving a good separation of copper metal from slag during production. These studies lend weight to the idea of a highly effective metal smelting technology in place in the South Andes during the first millennium BCE.

In general, it is thought that gold working preceded copper smelting, gold being found in a natural metallic state in association with certain minerals. The earliest known gold-working kit and beaten gold work in the Andes date to approximately 1500 BCE from Waywaka, Peru. The first working of native copper would also be theoretically of a similarly early date.

The most extensive body of research on ancient Andean metallurgy deals with analyses of the metal artifacts themselves. Included here are laboratory studies on gilding, joining of metals, alloying, and the other techniques of artistry and design. When the Spanish began melting metal objects shortly after the Conquest, they noted with dismay that not all "golden" objects were in fact pure gold. Many specimens appeared to be gold on the surface, but were actually copper alloy in the core, which meant that they had little of their anticipated content of precious metal. Modern laboratory studies have succeeded in replicating the ancient techniques employed in gilding, as well as the casting, welding, and forming of exceptionally well-crafted objects (Lechtman et al. 1982; Tushingham et al. 1979). Andean craftsmen were adept in altering the appearance of an alloy, sometimes within the same piece, as in the case of Vicus nose ornaments. In some cases, their illusions seemed to accomplish the impossible, where different metals appeared to be welded together. These ancient metal smiths exercised superb control over their artistic medium, in which the color of the metal was as important a factor as the iconography that the piece intended to convey.

As one shifts from the North Andes to the South Andes, there is a shift in the metallic art from complex and fully modeled pieces to artifacts of decorated sheet metal. In Bolivia, northern Chile, and northwestern Argentina, metallic art most often takes the form of objects made from flat metal. Discs, diadems, bracelets, rings, and pendants are common forms, all executed from hammered sheet. Casting is also known, but seems to be used primarily in the manufacture of axes and mace heads, i.e., nondecorative objects that required more substantial weight. The tradition of working sheet metal has a long antiquity, extending back three millennia.

Today, Andean natives remain active in working metal and crafting pieces of native art. Like their counterparts in the American Southwest, they melt coins for metal, rather than smelt ores as formerly done. The end product is most often geared toward tourist consumption, which means that it is generally of a form that is readily marketable. Still, there is a folk practice that persists among the native Andean peoples, one which has an extremely long history.

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Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy

Mark T. Lycett, Noah Thomas

Despite the long pre-Columbian tradition of metallurgical technology in West Mexico, there is no evidence for the development of metallurgy in the US Southwest prior to Spanish colonization. Metal bearing minerals are widespread in the region and were used as pigments and ornamentation prior to Spanish contact (see Extra). Discussions of the largely untapped potential of mineral wealth are ubiquitous in Spanish colonial descriptions of New Mexico from the sixteenth through the nineteenth centuries. Documentary sources suggest that iron, copper, and other metals of every day necessity were relatively scarce in this colony. Small amounts of manufactured metals appear in assemblages from Franciscan missions and other Pueblo settlements occupied during this period. Despite the importance and widespread use of these metals, there is little evidence of mining or processing of local ores, and it has generally been assumed that all metal in colonial period New Mexico was imported from New Spain. While this supposition may be true for much of the material recovered in colonial period assemblages, strong evidence of metal production has been found in a few Hispanic contexts and from the missions of San Pedro and San Marcos. While some of these processes were spectacularly unsuccessful, copper metallurgy appears to have been the predominant focus of this technology. Archaeological and metallurgical analyses suggest a number of important patterns in the organization and development of these processes. Spatial segregation of technological processes and activities is coupled with a diversity of ore bodies, metals, and products, and shifts in the use of facilities and processes. These create a complex mosaic of emergent experimentation in novel and hybrid technologies shaped by the requirements of colonial tribute demands, locally available resources, indigenous knowledge and practices, and frontier exchange relationships.

The colony of New Mexico was established in 1598, at the height of Spanish silver production in the New World. The mines in New Spain had produced unprecedented wealth for the Spanish crown and had begun to influence European economic systems through the easy availability of silver currency allowing for the development of early capitalism. The profitability of the mines in New Spain was in a large part due to the availability of cheap labor, primarily composed of both coerced and paid Native American workers. In addition to mining activities, Native West Mexican smiths were sought after for their traditional metalworking skills. The incorporation of indigenous individuals within the industry also allowed for the development of technologies better suited to the dry, wood scarce environment of northern New Spain than European water powered and charcoal fueled smelting practices, through the incorporation of indigenous traditional materials and technologies. To facilitate production along these lines, Spanish administrators often uprooted whole indigenous communities through forced relocations in order to obtain closer proximities of labor, ore and fuel sources.

In contrast to Western Mexico, the organization of early colonial metallurgy is very poorly documented in New Mexico, with strong evidence of metal production from a very few contexts. Recent excavations on the early to mid-seventeenth century industrial terrace at the Mission of San Pedro, known alternately as Paa-ko Pueblo, have recovered extensive evidence suggesting that the Pueblo occupants of this village experimented with a range of metallurgy technologies including the reduction of copper oxide and lead sulfide ores to produce copper and lead metals, the refining of silver through cupellation,[1] the manufacture of sheet and cast copper artifacts, and the forging of iron artifacts.

Located at the head of the San Pedro Valley, one of three major drainage systems on the eastern slope of the Sandia Mountains, this site lay outside of any of the major settlement clusters or "provinces" identified by Spanish colonists. It was a small scale, intermittently occupied, and partially incorporated community. Although the village was part of the mission system, it never had a resident friar or a permanent Spanish presence. The situation of a metallurgical facility within this remote community may have allowed some colonists to engage in a valued form of production outside of the scrutiny of colonial administration while

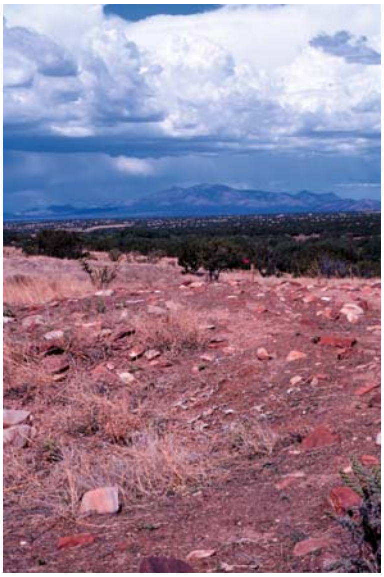
[1] Cupellation is the recovery of precious metals in a cupel by exposure to a blast of hot air that oxidizes the unwanted base metals, such as lead, which are partly absorbed. A cupel is a small container in which precious metals are refined, especially in which gold and silver are separated from base metals during assaying.

still maintaining access to mineral sources, fuel, and a subject labor force (Fig. 1). Nevertheless, the evidence at Paa-ko points toward a strong Pueblo involvement in the design as well as the implementation of these technologies.

At this site, a terraced hill slope covering more than 200 m^2 was repeatedly used for metal production with numerous superimposed and interdigitated facilities produced through periodic episodes of use, maintenance, and reconstruction over a number of years (Fig. 2). The specific functions of these facilities may have included copper smelting, copper ore roasting, charcoal preparation, and iron forging. Both Spanish and Puebloan construction techniques were incorporated in the structure of the facilities. Traditional Puebloan adobe and masonry construction techniques are integrated with introduced construction technologies such as mold-made adobe and core and veneer masonry techniques. In addition, ventilation shafts and deflector shields typical of pre-Columbian subterranean structures in the region are incorporated into several different furnace designs (Fig. 3). Such syncretism suggests a process by which Puebloan knowledge as well as labor were incorporated within the introduced technology.

Slag and metal recovered from Mission San Pedro suggests wide variation in the technology producing materials reflecting temperature and atmospheric conditions of the smelt. Though copper appears to be the primary metal produced, in some high temperature smelts, large amounts of iron were cosmelted from the gossan[2] ores producing a copper–iron alloy (Figs. 4, 5a, b, and 6). Lower temperature smelts were conducted as well, producing a copper metal with copper sulfide inclusions (Fig. 7). Both alloys have been found in association with finished copper artifacts and copper sheet scrap suggesting the inclusion of both alloys within the overall production process of the facility (Fig. 8).

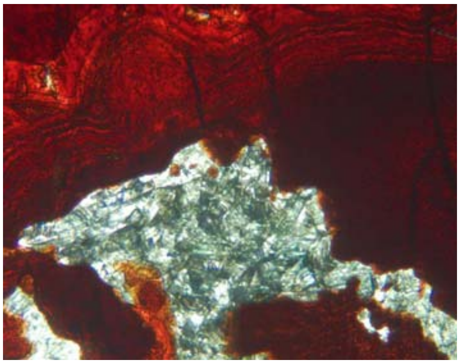
The variation in smelting regimes may represent the experimental and improvisational nature of the technology employed at the facility suggesting a process by which practitioners developed techniques appropriate for local materials. The development of extractive metallurgy at Paa-ko employed both the knowledge of



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 1 View from Mission San Pedro looking east towards local ore deposits in the Cerrillos Hills and the Ortiz Mtns. Photo by Noah Thomas.

Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 2 Excavated metallurgical terrace, Mission San Pedro. Photo by Mark Lycett.

Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 3 Furnace feature exhibiting integration of Puebloan and Spanish construction techniques. Photo by Mark Lycett.

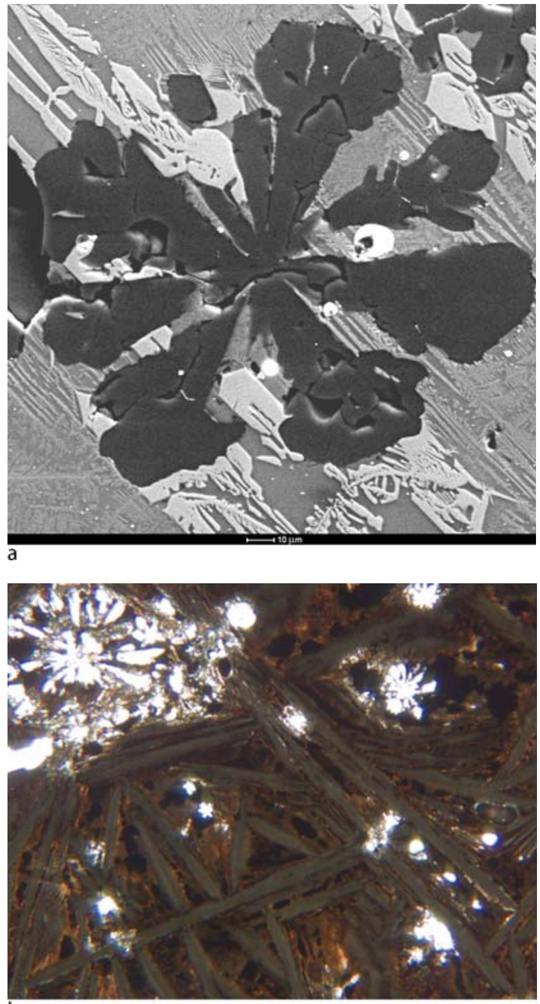


Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 4 Petrographic section in plain polarized light of gossan containing malachite, cuprite, and banded iron hydroxides. This is the main ore type found at the facility. Magnification 100×. Photo by Noah Thomas.

high temperature and high reducing metallurgy technologies, such as those applied to iron smelting, as well as knowledge of lower temperature processes more appropriate for copper extraction.

The focus on copper production apparent from the volume of copper slag and predominance of copper artifacts and scrap recovered from the facility is unusual given that the focus of Spanish colonial metallurgy in the New World was on silver extraction. Copper production as an industry in New Spain was relatively small and was focused in West Mexico, under the technological control of indigenous Tarascan smiths up until the turn of the seventeenth century. Yet, copper played a significant role in the global exchange of metals. The growth of the copper industry in Europe can be directly tied to the development of colonial exchange at the frontier of colonial expansion. Central Europe became a center for production in this system during the fifteenth and early sixteenth centuries, using copper left over from the *Saigerprozess*, the extraction of silver from copper metal with the addition of lead, to produce items for trade such as copper and brass kettles, knives, and ornaments.

A possibility that may explain the predominance of copper metallurgy at Paa-ko may be the adaptation of this global model to local silver ores and colonial exchange relationships in the New Mexico colony. The materials recovered from the facility such as lead slag, galena, and litharge fragments containing copper and lead prills,[3] suggest that one of the technologies present at the facility included a process of silver refining utilizing cupellation, involving both lead and copper metal (Fig. 9).



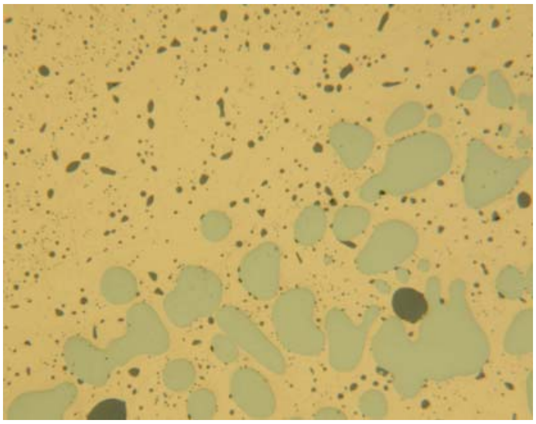
a

b

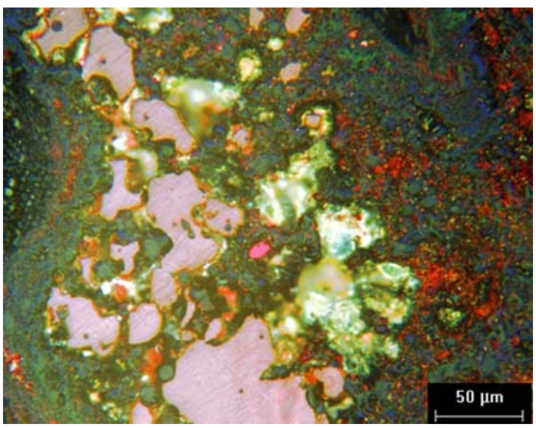
Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 5 (a, b) SEM-BSE compositional image and petrographic section in plain polarized light of slag from the facility exhibiting high temperature quartz and iron silicate minerals associated with temperatures in the range of 1,200–1,400°C. Photo by Noah Thomas.

The evidence from Mission San Pedro may represent a participation within two colonial systems of value: one centered on the production of silver and the generation of wealth within models of European commerce, and one centered on the colonial trade and exchange relationships of frontier communities. The most common form of manufactured copper in these samples is sheet copper, occurring as both manufacturing debris and finished artifacts (Fig. 10). Sheet copper commonly occurs in other mission assemblages, although there is no evidence of copper production or its by-products from most of these sites. Copper, as distinct from silver, was a metal of relatively little value in the exchange networks of colonial New Spain, but copper ornaments were a novelty in colonial New Mexico, circulating in

3 A prill is the button of metal from an assay.

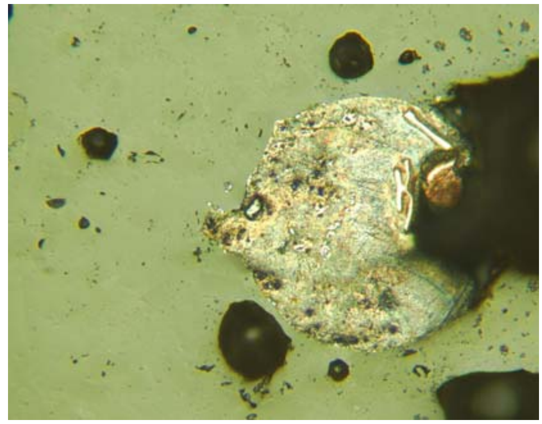


Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 6 Metallographic section of copper–iron alloy produced at the facility. Magnification 200×. Photo by Noah Thomas.



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 7 Metallographic section of the low temperature product of relatively pure copper in association with cuprite and charcoal. Magnification 50×. Photo by Noah Thomas.

Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 8 Copper–iron alloy ingots from high temperature smelt. Photo by Noah Thomas.



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 9 Polished section in plain polarized light of litharge recovered from the facility at Mission San Pedro containing copper and lead metal. Magnification 100×. Photo by Noah Thomas.

Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 10 Cache of copper sheet scrap and finished artifacts recovered from the facility at Mission San Pedro. Photo by Noah Thomas.

partially overlapping systems of value defined by both colonizer and colonized. Metallurgical practices may have been simultaneously understood as forms of commercial production, disciplinary instruments of Spanish church and state, and an idiom of Christian and indigenous identity formation through personal adornment.

Metal has been recovered from the seventeenth century missions at the sites of Abo Mission and Quarai, in the Salinas district, from San Marcos, San Lazaro, and San Cristobal in the Galisteo Basins, and from the Zuni site of Hawikuh and the Hopi site of Awatovi. Much of the metal recovered from these sites is poorly documented or is so sparse that it is impossible to develop an overall sense of how metals were used by the Pueblo population. The excavations at Pecos Pueblo are an exception. Over 344 metal objects were recovered from this excavation, providing for an adequate data set in which to compare the information gleaned from the historical documents.

The metal assemblage from Pecos is dominated by copper sheet scrap both as sheet fragments and as rolls. As Kidder notes, "more than half of the collection consists of small, irregularly shaped scraps of thin sheet metal, varying from the size of a fingernail to that of the palm of one's hand. Their edges are sometimes cut as with a sharp instrument, sometimes roughly torn" (Kidder 1932: 308). The high frequency of this material suggests that copper metal was being worked by the Pueblo inhabitants of this Mission. Kidder suggests that the scrap represented the reduction of copper kettles much like that which occurred in Northeastern Native American historic sites. This may in fact be the case, as the historical documents suggest that a large volume of copper material was coming into the colony as copper alloy vessels (see Note) (Fig. 11).

The frequencies of artifact types listed historically and recovered archaeologically suggest a pattern of Puebloan use of metal artifacts in the seventeenth century that stresses clothing and adornment (Fig. 12). In addition to this, the predominance of copper sheet scrap suggests that European copper goods were eventually highly modified to produce other artifacts that perhaps were perceived to have a higher value. At least eight of the 16 crosses recovered from Pecos were made from sheet copper suggesting a relationship between the working of copper sheet through the reduction of domestic artifacts, and the production of objects of adornment.

The emergence of novel forms of production in colonial settings is an historical process marked by experimentation, adaptation, and variation. Evidence of this process at sites like Paa-ko (San Pedro) and Pecos indicates involvement with European metallurgical technologies included production of a variety of metals through a variety of techniques, recycling of existing materials, and the working or finishing of metals from both sources. The participation of Puebloan communities in Spanish metallurgy suggests that indigenous knowledge, indigenous materials, and indigenous exchange networks may be at least as important as indigenous labor in the implementation of new technologies.

Extra 1: Pre-Colonial Metal Use in the Southwest

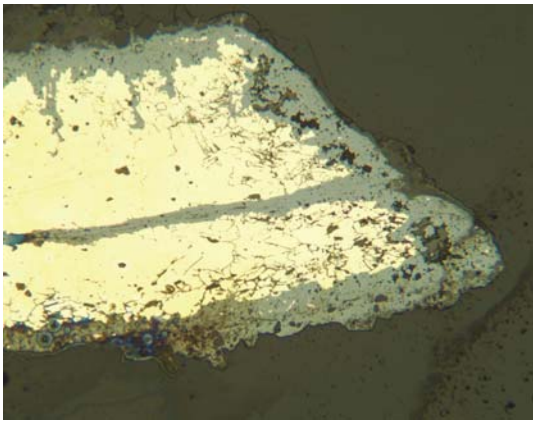
Despite the presence and time depth of metallurgical technology in West Mexico, little evidence exists for the transference of techniques of metallurgy to the US Southwest prior to Spanish colonization. Trade in metal objects of West Mexican origin existed by the tenth century, and possibly earlier, based on the presence of copper bells in sites from Chaco Canyon, the Hohokam region of southern Arizona, and the Mogollon mountain region. Trade in bells to the US Southwest follows the chronological patterning of technological style of West Mexican bell types. Based on this chronology, two phases have been recognized by Vargas. Phase I consists of trade in non alloyed copper bells 800–1250 AD, and Phase II consists of trade in stylistic forms associated with alloyed copper bells from 1250–1520 AD. As Vargas (1995) notes, this trade appears to have been highly restricted and/or infrequent. In both phases distribution is centered on the Hohokam region of southern Arizona. As of yet, no solid evidence exists for the smelting of copper or the production of copper objects within the region during the precolonial period.

Despite the fact that metallurgy appears not to have been practiced, metal bearing minerals are prevalent within the region and were extensively used prior to Spanish contact. Both copper and lead bearing minerals were used as pigments, as objects of adornment, and as components in the indigenous pyrotechnology of lead glazed ceramics. The development of lead glaze in the Puebloan world began in the fourteenth century and continued to be practiced through the early colonial period up until the Pueblo revolt of 1680.

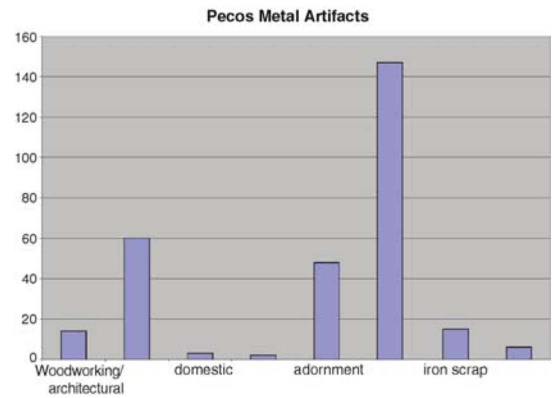
Extra 2: Historical Data on the Introduction of Metals and Metallurgy

The historical record suggests that a wide variety of metals came into New Mexico with the initial colonization of the late sixteenth and early seventeenth centuries. Iron, lead, and mercury were brought in as raw materials for the mining industry and the production of tools and lead shot. Other metals and alloys entered the colony as finished

M



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 11 Polished section of a reworked brass sheet fragment recovered from the facility at Mission San Pedro. Magnification 50×. Photo by Noah Thomas.

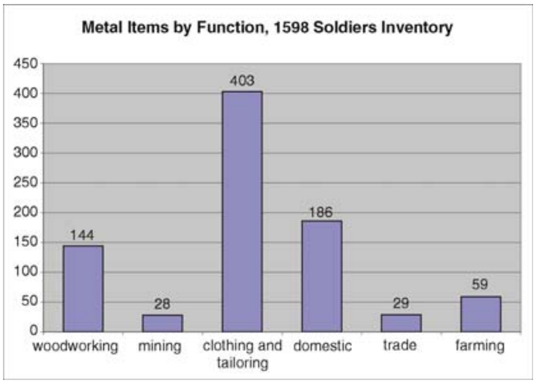


Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 12 Metal artifacts recovered from the excavations at Pecos Pueblo. Artifacts listed by function.

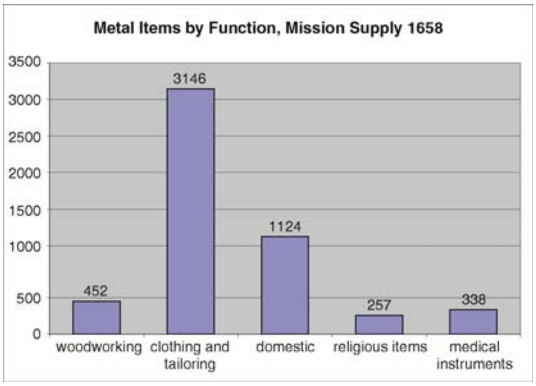
tools, religious articles and ornaments. Though iron was probably the most predominant of metals imported, copper and copper alloys appeared in large quantities primarily in the form of domestic items. Tin, pewter, silver, and gilded items are mentioned both within the inventory of items brought in the initial colonization of 1598 and in the requested items of the mission supply caravan as well.

Excluding iron goods needed for horseshoeing, when comparing the lists of items brought in the initial colonization with the mission supply lists of the 1650s, the most prevalent metal items are tools related to clothing and tailoring activities (Figs. 13 and 14). These include items such as needles, thimbles, awls, pins and scissors. These items were also the predominant trade good brought in the initial colonization. Their high frequencies may be due to their ease of transport, the low cost per quantity as an item of trade, and/or their general perceived utility across ethnic boundaries.

The second most prevalent item by function is domestic implements. This category most likely represents the largest category outside of horseshoeing equipment in terms of volume and weight and is dominated by copper alloy items. Copper kettles, boilers, *ollas* (a pot or jar having a wide mouth), and *comals* (large flat griddles on which tortillas are cooked) are mentioned specifically. In the mission supply list of 1658, 37 and 20 pound bronze *ollas* and 25 pound copper kettles are requested. These probably refer to both European and Mexican manufactured items. Brass and bronze alloys were most likely produced in Europe, while copper vessels may have been produced in traditional copper working communities in West Mexico. Much of the copper produced in New Spain in the sixteenth century was done so within these communities.



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 13 Metal items listed in the Salazar inspection of the Oñate colonizing force of 1597. Items grouped by function.



Metallurgy: Pueblo Indian Adaptations of Spanish Metallurgy. Fig. 14 Metal items listed in the mission supply list of 1,658. Items grouped by function.

In the colony of New Mexico, as a remote and isolated enclave, access to European and West Mexican goods and smithing expertise was limited, yet maintenance of metal goods must have been a concern and required individuals with requisite experience. The inventory of tools for the forging and smelting of metals brought in the initial colonization suggests that this knowledge and expertise resided primarily with individuals in the mining industry. Though mission centers were established as institutions for the socialization of Native American individuals, mission supply lists do not carry requests for metallurgical tool kits. Therefore it is more probable that the transference of the technology, at least in the initial colonization of the seventeenth century, occurred through the mining industry among coerced Native American laborers.

See also: ►Indigenous American Knowledge Systems

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Metallurgy in Southern South America

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The Andes represent the largest source of mineral wealth in the Americas and the birthplace of New World metallurgy. Metallurgical exploitation of these resources occurred for millennia prior to colonial contact, as testified by numerous artifacts of gold, silver, and bronze. Prior to the arrival of Spanish conquistadors in 1532 AD, indigenous South Americans smelted silver ores, hammered gold sheets, and annealed copper alloy sheets, independently of technologies that, by then, were highly developed in the Old World. Despite this extensive history, we know astonishingly little about the development of metallurgical techniques through time.

Today we learn about ancient metallurgy primarily through three sources of information. The first is the collection and analysis of artifacts recovered from archaeological excavations. However, looting of archaeological sites is pervasive and as a result the archaeological record is incomplete (Jones and King 2002). This means that the archaeologist often works with either a small fraction of the original material, or with artifacts that have been removed from their original context. Moreover, looters frequently "restored" looted artifacts, severely limiting what information can be drawn from their appearance (Shimada and Griffin 2005). The second source of information comes from historical and ethnographical data collected at the time of conquest. For recordkeeping purposes, Spanish conquistadors documented the looting of Inca palaces and exploitation of Inca mines (Lechtman 1976). Useful as these archives are, they tell us little about those peoples who preceded the Inca. Moreover, the Spanish were primarily concerned with the acquisition of gold and to a lesser extent silver. They make little mention of copper and copper alloys, even though these represent the foundation of Andean metallurgy. The third method is that of archaeometry. Archaeometry is the application of scientific methods to archaeological sites or artifacts. In the Andes, the most common archaeometric analysis employed is a compositional chemical analysis (Lechtman 1999, 2002). Recently, scientists have also utilized geochemical analysis of lake sediments to track atmospheric pollution from smelting. This method was used to establish the onset of smelting at the town of Potosí in the highlands of southern Bolivia (Abbott and Wolfe 2003). This method provides an independent record of the timing and intensity of smelting for the region. However, as with the previous approaches, it has its limitations. It cannot answer which group specifically was smelting or how it was used or valued by ancient South Americans, and is restricted to regions, which contain continuous sedimentary environments suitable for analysis (i.e., lakes, swamps, bogs, etc.). Despite the limitations of each of these methods, by studying them in concert, it has become apparent that indigenous South Americans possessed extensive knowledge in acquiring metals from various ores and also in combining and working metals into elaborate artifacts. Here, we review the major findings related to the procurement and smelting of nonferrous ore bodies in the southern Andes and the manufacture and use of various alloys as tools and objects of adornment within indigenous South American culture.

Smelting

Nonferrous metal ores have been smelted in South America for approximately 2,500 years. The earliest evidence to date for smelting activity in southern South America comes in the form of copper slag from the Wankarani site in the highlands of Bolivia dating between 900 and 700 BCE (Ponce 1970). Slag, also known in the Andes as *scoria*, is the waste or by-product of smelting. Often this is all that remains for the archaeologist to find as an indication of metallurgical activity (Van Buren 2005). Very little research has been conducted on the metallurgy at Wankarani and to date little is known about what type of metal artifacts were being produced and how the control of metal resources was governed.

To the southwest, additional evidence for early smelting comes from recent research at the Ramaditas site in the Guatacondo Valley of northern Chile (Graffam 1994, 1996). Here, excavations have revealed evidence that copper smelting and sheet metal working (*repoussé*) began near the first century BCE. This finding confirmed that not only does metallurgy date back in excess of 2,000 years in northern Chile, but that this activity was often carried out independent of the presence of a large formalized state or Empire (Graffam 1994, 1996). Northern Chile contains abundant ores of copper and the exceptionally arid environment allows excellent preservation of artifacts. This makes Chile an ideal locality to conduct future metallurgical research.

On the *altiplano* of southern Bolivia, a silver deposit known as Cerro Rico de Potosí was once the world's richest silver mine. Legend attributes the discovery of silver at Potosí to the penultimate Inca ruler, Huayna Capac, in the mid-fifteenth Century AD. However, this date was recently challenged by the discovery of much earlier metal pollution in a nearby lake that can only be explained by local smelting activity (Abbott and Wolfe 2003). During smelting, trace metals are released into the atmosphere and are subsequently deposited into the lake environment through precipitation and dry atmospheric deposition. As soils, algae, and sediments accumulate at the bottom of the lake, they preserve these atmospherically derived metals. Natural archives, i.e., lake sediments, are sensitive enough to pick up even preindustrial emissions (see Renberg et al. 1994). Lake sediment cores (tubes of sediment recovered vertically from the bottom of a lake) were collected from a high alpine lake downwind of Cerro Rico de Potosí. Geochemical analysis of the sediments revealed a long history of smelting activity beginning shortly after 1000 AD, 400 years prior to the supposed discovery of silver! The use of this method to track metallurgical activity has only just begun and research is currently underway to understand the chronology of smelting throughout the Andes.

The final source of information on indigenous smelting at Potosí comes from a combination of historical archives and ethnoarchaeological research. Given its richness, Potosí was the central focus of colonial mining for years after conquest. As a result of this attention, a written chronicle of smelting techniques in use at Potosí exists. For example, between 1545 and 1572 AD, Inca silversmiths under colonial rule using indigenous furnaces conducted all silver production. Three different types of furnaces were recorded by the Spanish during this time as they worked Potosí and the nearby mine of Porco. The first type of furnace was simply a pit dug into the ground that reduced ores rich in silver. The second type was a small, and sometimes portable, reduction furnace called a *huayara*. These charcoal-fired, wind-drafted furnaces were lined with clay and were often placed on mountaintops to take advantage of strong winds. As such, they were prone to destruction by any number of natural forces (e.g. landslides, earthquakes) and to date none have been recognized in the archaeological record. Recently, however, a huayara has been found still in use today in Bolivia (Van Buren 2005). This is an important discovery, which promises to contribute a great deal toward the understanding of ancient smelting techniques and their remains in the archaeological record. The third type of furnace was a *tocochimpu*, which was normally used to refine silver in combination with argentiferous galena or *soroche* (lead sulphide). Cieza de León was one of the first Spanish chroniclers to describe the use of soroche at Potosí and documented its use as a flux to enable extraction of silver from even low-grade ores. Future research combining historical archives, archaeological and ethnoarchaeological research is sure to illuminate lingering questions regarding the spatial and temporal homogeneity of smelting technology in the southern Andes.

Despite these advances in the smelting of ores, direct analysis of the metal artifacts themselves is the most common analytical approach. The most frequent analysis performed is that of a compositional analysis which determines the relative proportions of the metals which make up an artifact. This has shown that the vast majority of Andean artifacts are composed of alloys. Alloys, rather than pure metals, are pervasive in both Old and New World metallurgy for three reasons. First, occurrences of pure copper, silver, and gold do not commonly occur in any large quantity. Second, alloys have the benefit of often being harder than objects made of native metal, as is the case with silver and gold (Lechtman 1996). Third, by combining one or more metals, the melting temperature of those metals is lowered, which facilitates the smelting of ores. This is important as all pre-Columbian metallurgy was done without the use of bellows and had to rely on natural drafts to aerate furnaces.

The most common alloys found in southern South America have been those of arsenic–copper (arsenic bronze), tin–copper (tin bronze) and ternary alloys of copper, arsenic and nickel. There is also evidence that the Inca alloyed bismuth in bronzes recovered from the site of Machu Picchu (Gordon and Rutledge 1984). Alloys composed of copper–gold (a binary alloy sometimes referred to as tumbaga) and copper–silver–gold (a ternary alloy) have also been found, though not in the same quantity as copper alloys (King 2000). The precious metal artifacts that are found normally occur as items of personal adornment (e.g., discs, bracelets, rings, and pendants) associated with individuals of high social status, and as religious or ceremonial items (Olsen Bruhns 1994). Because of the extensive looting which has taken place in Peru, both recently and during colonial times, few precious metals remain and our understanding of them remains comparatively sparse. Here we focus our discussion on the appearance and distribution of copper alloys as they represent the backbone of Andean metallurgy. We then highlight two examples in which indigenous South Americans altered the appearance of copper-gold and copper-silver alloys to give them the appearance of precious metal.

Bronze Alloys

Arsenic bronze was the earliest alloy to be utilized in both northwest Argentina and southern Peru. In northwest Argentina, arsenic bronze was in use by 400 AD and its use continued until colonial conquest. This bronze alloy was used both for tools (axes, chisels, and wedges) and finer domestic items (awls, needles, bracelets, and tweezers) (González 1979; Fester 1962). In southern Peru the earliest evidence for arsenic bronze metallurgy occurs at the site of Pikillacta in the Lucre Valley circa 600 AD (Lechtman 1997). This occurs during the influence of the pre-Inca Empire known as the Wari, which controlled the area from approximately 600 to 1000 AD (McEwan 2005). These arsenic bronze artifacts are normally represented by domestic items or tools (Lechtman 1997). Naturally occurring alloys of copper and arsenic are readily available in the high Andes of central/southern Peru and would have been accessible to native South Americans. Therefore, arsenic bronze metallurgy characterized the time period between 400 and 1000 AD in southern Peru and northwest Argentina.

In contrast, in Bolivia there is a paucity of both natural alloys and artifacts made of arsenic bronze. Rather, tin bronze and copper–arsenic–nickel alloys seem to have been the metals utilized. The earliest occurrence of this alloy in Bolivia is found on the Bolivian *altiplano* around 600 AD (Lechtman 2002). Tin bronze was favored for ornamental rings, while copper–arsenic–nickel appears to have been preferred for needles, nails, and chisels (Lechtman 2002). The tin for tin bronze appears to have been obtained from the rich "tin belt" of the *altiplano*, where it primarily occurs in the mineral cassiterite (tin oxide). No source has yet been found for the copper–arsenic–nickel alloys. Therefore, tin-based bronze metallurgy in northern Bolivia appears to have begun around 600 AD. This is broadly contemporaneous with the widespread use of arsenic bronze metallurgy in nearby southern Peru and northwest Argentina. Future research is needed to understand what, if any, interaction was occurring between Bolivia and southern Peru at this time of florescence of the copper industry.

Traveling north and forward 200 years to 800 AD, the site of Batán Grande represents early arsenic bronze metallurgy along the north coast of Peru. Previously undocumented in the New World, Batán Grande is a prehistoric metallurgical center situated in the La Leche Valley (Shimada et al. 1982, 1983). Smelting here began circa 800 AD and continued until just prior to the Spanish conquest. Though small quantities of copper ore are locally available, arsenic bearing minerals are not. However, the highlands of northern Peru are rich in arsenic bearing minerals; this fact has led Lechtman (1991) to argue that highland miners might have provided coastal smelters with the necessary arsenic.

The mechanism for this highland-coastal exchange, be it social, economic, or otherwise, has yet to be adequately explained.

Batán Grande was also the site of a large-scale cosmelting operation heretofore undocumented (Lechtman 1999). During cosmelting, a mix of both the sulfides (the primary ore minerals) and oxides (the secondary or the weathered alteration product of sulfides) were charged into the furnace. This mixing need not be deliberate and yielded clean, coherent copper–arsenic alloy ingots (Lechtman and Klein 1999). Cosmelting represents a dramatic improvement in smelting operations while eliminating noxious arsenic fumes that might otherwise have been generated.

Moving forward to the mid-fifteenth century AD, the Inca Empire implemented the use of tin bronze for domestic and household metal items throughout Peru, Bolivia, northwest Argentina, and northern Chile. This widespread occurrence of tin bronze associated with the Inca Empire has been dubbed the so-called "Tin Horizon" (Costin 1989; Lechtman 1996; Lechtman and Klein 1999; Owen 1986). The tin would have been prepared as sheet stock and then could be dissipated through the Empire where it was added to local alloys of arsenic bronze or simply added to local copper to form tin bronze (Cositn 1989; Lechtman 1976). Adding tin to existing bronze technology improves the workability of the metal and increases the hardness of the finished product (Costin et al. 1989). The Inca represent the culmination of metallurgical development in native South American history until the conquest of the Spanish in 1532.

In summary, two loci of bronze based metallurgy can be distinguished for the southern Andes. This appears to be a direct result of differences in local resources (arsenic-copper deposits in southern Peru and northwest Argentina versus tin–copper deposits in northern Bolivia). The situation changes with the establishment of the Inca Empire, after which tin bronze becomes the domestic metal of choice throughout the Andes.

Precious Metals

Although artifacts made of bronze alloys are the most commonly found during archaeological excavation, gold and silver remained the most prized metals during Inca and pre-Inca times as well (Costin et al. 1989). For the Inca, gold was endowed with spiritual and symbolic meaning and was believed to be the rain of the sun, while silver was the rain of the moon (Jones and King 2002). However, artifacts composed purely of silver or gold are extremely rare. Considerably more common are alloys containing a mixture of copper and gold or silver. After the Spanish conquistadors took control of Peru, they began to melt down what they believed to be golden objects. To their surprise, they discovered that these "golden objects" were in fact composed of copper alloys and had only very thin surfaces of gold. This was because locally available resources, combined with sophisticated alloying techniques were used to produce golden surfaces on alloys containing small percentages of precious metals (Lechtman et al. 1982).

Experimental archaeology has been especially important here in determining how Andean cultures manipulated alloys to accentuate desired qualities. Two of the best examples of native abilities were the processes of electrochemical replacement plating and depletion gilding. In electrochemical replacement a copper alloy is given an extremely thin and even surface coating of sliver or gold. To accomplish this, silver and gold were dissolved in an acidic or corrosive solution (Lechtman et al. 1982). A copper artifact was dipped into this solution, and a chemical reaction would occur that resulted in a very thin and even "plate" or surface coating of silver or gold. In addition, the specific color of the object could be altered simply by varying the relative amount of silver or gold in solution (Lechtman et al. 1982). Depletion gilding was used on alloys of copper-silver-gold. Here, naturally-occurring chemicals are used to separate the gold from the silver, leaving a surface of the desired precious metal. These are just two of the techniques in which native South Americans manipulated the appearance of metal artifacts in order to achieve a surface of silver or gold. These technologies appear to have been developed by the Moche (100 to 800 AD) on the north coast of Peru and remained a northern phenomenon until the rise of the Inca Empire in the mid-fifteenth century. At this time the Inca Empire relocated the northern metallurgists to Cuzco to serve at the Inca capital. Further research is needed to document fully the full range of both Inca and pre-Inca alloying techniques.

In short, a wide variety of metallurgical techniques were used by Andean cultures, and considerable skill was demonstrated in the manipulation of nonferrous ores. By integrating the fields of archaeology, ethnohistory, and geology a great deal can still be learned about these cultures' use of metals.

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Meteorology in China

Li Di

Chinese meteorology, here referring to the traditional meteorology which was used in China, has many unique characteristics. Although China began to adopt Western meteorological knowledge as it was introduced in the seventeenth century, Chinese traditional meteorology lasted 250 years. Chinese meteorology can be described from four aspects.

Knowledge About Meteorological Phenomena

The Chinese recognized some meteorological phenomena 3,000 years ago. In the inscriptions on borns or tortoise shells of the Shang Dynasty (ca. sixteenth to eleventh century BCE), there were some words meaning rain, frost, snow, thunder, lightning, rainbow, etc. The Chinese identified the relationship between the rain and rainbow;

they knew if there was a rainbow in the western sky in the morning, it would rain soon. The Book of Songs declared, “White dew is frost.” In this case, frost must have been frozen dew. Two thousand years ago, the Chinese also recognized the six segments of a snowflake.

Wang Chong (AD 27–97) was one of the first to record meteorological phenomena. He said that the rain came from the ground, not from the sky, meaning that the rain came from the vapor rising from the ground. He also said that clouds and fog are omens of rain, there is dew in the summer but frost in the winter, and rain when it is hot but snow when cold. He understood that rain, dew, frost, and snow were formed of vapor from the ground at different temperatures.

The ancient Chinese had exact knowledge about rainbows, too. Kong Yingda (AD 574–648) who lived in the early time of the Tang Dynasty, pointed out that the rainbow was created by the sun’s shining on the waterdrops. Sun Wanxian and Shen Guo (AD 1030–1094), who lived in the Northern Song Dynasty, studied the rainbow too, and agreed with Kong Yingda. Sun Yanxian said that the rainbow was the reflection of the sun in the rain, created when the sun shines on the rain.

They also had a good deal of knowledge about the wind and the clouds. In the fourth century, it was recognized that the trade wind had 24 fans. Li Chunfeng (seventh century) recorded the wind as having 10 grades according to its strength and 24 types according to its direction. Shen Guo once recorded a land tornado in his book. “There is a tornado coming from the south-east in Enzhou and Wucheng. It looked like a huge sheep horn, and carried all the big trees. Quickly it disappeared in the sky.” Sima Qian (b. 145 BCE) divided clouds into three types according to their height from the ground. Eighteen pictures of clouds were drawn in the fourteenth century according to weather conditions. Later the number reached 32.

Weather Forecasting

Many methods of weather forecasting were used in ancient China. The first is forecasting according to the air humidity. In the second century, the Chinese recognized the relationship between the sound of a musical instrument and the weather. Later, Wang Chong pointed out that it would rain as the strings of a *zheng* (an instrument in some ways similar to the zither) became slack. No later than the eighth century the Chinese recognized that many waterdrops appearing on a solid body with good heat-conductivity, or high temperature and great humidity, were all omens of the rain.

The second method is forecasting the weather according to optical phenomena such as rainbows, rosy clouds, and halos. Some records written in the nineteenth century proved that the natives of Fuzhou could predict a heavy rain and a great wind, even a typhoon on the sea, according to the position and height of the rainbow. In the eleventh century, Kong Pingzhong pointed out that the morning glow is the omen of a rain, while the evening glow is the omen of a sunny day. Lou Yuanli, who lived in the Yuan Dynasty, stated that the solar halo was the omen of a rain, and the lunar halo of a wind. He also pointed out that the direction of a wind was the direction of the gap of the lunar halo.

The third method is forecasting according to the movement and patterns of clouds and fog. Clouds and fog are the bases of some weather phenomena such as rain and snow, so their height, patterns, and direction can be used to forecast the weather. Since the Tang Dynasty, there have been many such forecasts. Huang Zifa, who lived in the Tang Dynasty, once forecasted, “if there is some cloud moving against the wind, it will rain.”

The fourth method is the forecast according to sounds and lightning. There were many weather-related proverbs in ancient China. “If there is lightning in the southern sky, it will rain; if in the northern sky, it will not.” (Lou Yuanli). “If the lightning is irregular, it will rain hard.” “No rain, but thunder, go by boat, come by feet,” meaning it would not rain for some days.

The fifth method is according to the activities of animals. Some animals are sensitive to weather changes. The ancient Chinese could forecast the weather according to their activities. Wang Chong said, “If it is going to rain, ants migrate, earthworms come from their holes.” There was a proverb in the Tang Dynasty that said that if ants blocked up their holes, it would rain. Also ancient Chinese recognized that if birds’ wings moved hard as they fly, it would rain.

Meteorological Survey and Instruments

The ancient Chinese conducted many meteorological surveys and invented many surveying instruments.

Wind and Surveying Instruments

Two thousand years ago, the Chinese used a surveying flag and Xiangfeng bird to judge the direction of the wind. A Xiangfeng bird was made of copper slices fixed on the top of a high pole. It could be revolved by the wind, and its head was always along the direction of the wind. At first, Xiangfeng birds were used in meteorological observatories; later they were used in the government and private houses. Even now, some Xiangfeng birds can be found on the tops of some towers. Li Chunfeng recorded the method to measure the direction and speed of the wind using a chicken feather, i.e., to measure according to the moving direction and dip angle of the feather. In 1716, the Qing Government set up a meteorological network to survey the direction of the wind using surveying flags, which was the primary form of the modern meteorological network. However, the Chinese also began to use western wind surveying instruments at that time.

Precipitation and the Chinese Precipitation Gauge

Because precipitation was very important to agriculture and people's lives, in the Eastern Han Dynasty (AD 25–220) the court ordered that every noble government should report precipitation in the period from the beginning of the spring to the beginning of the autumn. Qin Jiushao recorded a kind of precipitation gauge – Tianchi Basin, which was widely used in 1247. The Western precipitation gauge and distiller were recorded in Chinese books of the eighteenth century.

Humidity and the Surveying Method

In the Western Han Dynasty, the Chinese invented a method to measure the air humidity by hanging a lump of earth and a bar of charcoal (or a feather). When the air was dry, the bar of charcoal (or the feather) was light; when the air was humid, it was heavy, but the earth had little change in its weight. By hanging a lump of earth and a bar of charcoal (or a feather) on the two ends of a staff separately and fixing a lifting string on the middle point, making the staff horizontal in the dry air, a humidometer was made. When the air became humid, the end which had the charcoal fell down. Huang Lüzhuang (AD 1626–?) invented a humidometer to indicate the air humidity by a moving needle. Later, Ferdinand Verbist (AD 1623–1688), a Belgian missionary, invented another one.

Atmospheric Temperature and Pressure

The Chinese paid much attention to atmospheric temperature. Wang Chong once pointed out that the atmospheric temperature changed during a day and affected rain and snow directly. Until recent centuries, the Chinese had not invented a thermograph. In the nineteenth century, Zou Boqi (AD 1819–1869) recorded a barometer for the first time.

Achievements in Phenology

Phenology is the process of discovering meteorological laws by the regular activities of some animals and the regular changes of some plants. The Chinese began their study in phenology a long time ago; some records of phenological phenomena written 3,000 years ago have been found. In Xiaxiaozheng (Lesser Annuary of the Xia Dynasty), there were some records of the turn of the months. The knowledge of the 24 divisions of the solar year in the traditional Chinese calendar was gained in the Spring and Autumn Period (770–476 BCE) and the Warring States Period (475–221 BCE). Every day marking the 24 divisions has relationships with agricultural activities. The Chinese usually arranged their agricultural work and other activities according to the 24 divisions of the solar year.

There are many records of phenological phenomena written during the period of the Western Han Dynasty to the Song and Yuan Dynasties (ca. second century BCE to fourteenth century AD). Lu Zuqian (AD 1137–1181), who lived in Northern Song Dynasty, observed the phenological phenomena in Jinhua, Zhejiang province for 19 months and made many records, including the blossoming of 24 kinds of flowers such as winter sweet, peach, plum, lotus, and chrysanthemum, and the first appearance of the spring warblers and the autumn insects.

No later than the Spring and Autumn Period the Chinese recognized that migrants' activities changed with the seasons. Shen Guo recorded in his book that the natives of Hebei called the frost "information frost," because they knew there would be a frost when the wild white geese came.

There are many Chinese records of meteorological phenomena, and they are still used today.

See also: ►Shen Guo, ►Li Chunfeng, ►Qin Jiushao, ►Wang Chong, ►Surveying

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Meteorology in India

A. S. Ramanathan

From the beginning, people tried to understand their surroundings and make use of their beneficial aspects. Their first action in this direction was to produce food, making use of the available water in the rivers and rainfall in the region. Though initially extreme phenomena like heavy rains, winds, cold and hot spells, droughts, and floods appeared incomprehensible and hostile, early humans gradually sorted out their seasonal character and planned their agricultural operations accordingly. Thus began in a crude way the development of weather science all over the world.

In India, the development of this science commenced in the early Ṛgvedic period. That the heat of the sun lifts the water to the atmosphere which after some time comes down as rain was recognized by the Vedic seers at a very early stage. In order to explain the occurrence of rain during a restricted period of about 2 months in their region in extreme northwest India, they imagined that water was absorbed by the sun's rays in the vast ocean areas in the south during the winter season and the humid air carried northward by the sun's rays. When the sun attains its extreme northward position and starts retracing its path, the humid air gets deflected near the foot of the Himalayas and brings rain from the east to their region. These moist easterlies replace the westerlies that were present in the region before the arrival of the monsoon rains. Whenever there was drought, they performed rituals to invoke the rain god. They believed that in nature there is a feed of a substance called *soma* from above into the atmosphere, which aids the occurrence of rainfall. Therefore they fed into the ritual fire some substances like wild dates and some special types of grass which produced smoke and were believed to be effective in aiding rainfall.

The post-Vedic scholars developed the subject further, mainly working on the pregnancy concept of rainfall. They looked for symptoms in the winter season for the commencement of pregnancy and identified the characteristics of winter disturbances in their region as indicating the same. Working along these lines, they were able to observe weather very carefully during the premonsoon months and were able to define the course of events which go toward the nourishment of rain embryos and the delivery of good summer rainfall at the right time after 195 days. Any departure from the defined meteorological conditions during the growth period, such as too much rainfall or snowfall, unfavorable winds, and temperature, was said to affect the quantity of rainfall delivered during the rainfall period. They also believed that hail would occur if the rain fetuses stayed too long in the atmosphere. The moon's position with respect to the sun and the stars was believed to influence the formation of rain embryos. The moon was conceived as a replica of soma in the heavens, and soma was capable of fertilizing the atmosphere.

Based on such concepts and extensive observations, the post-Vedic scholars developed several rules of long range rainfall forecasting. If they were successful, it was certainly due to their capacity to observe day-to-day weather and individual weather elements, like clouds, temperature conditions, wind, rain, lightning, and thunder. They were extremely clever in mentally working out correlations based on observed data. For short- and medium-range forecasting they framed many rules of thumb based on winds, clouds, temperature, lightning, thunder, moisture in the atmosphere, behavior of people, animals, birds, snakes, worms, insects, trees, and plants, as well as visual impressions of the sun, moon, stars, and sky. They were so thorough with local weather that their capacity to forecast in the short- and medium-range was as high as that of any modern forecaster who does the same with sophisticated equipment and maps.

Measurement of rainfall in India dates back to the fourth century BCE. A standard rain gauge was constructed around the third century BCE, and this system of measurement was prevalent in North India for a very long time (third century BCE to sixth century AD).

Well before the birth of Christ, the Arab dhows sailed across the Indian Ocean for trade purposes. Hippalus, a Greek pilot of the first century, sailed across the Arabian Sea for the first time. A handbook for merchants called *Periplus* was written by a Greek around AD 50. Subsequently, Arab geographers wrote many books giving details of Indian Ocean voyages. Sidi Ali's *Mohit*, written around AD 1554, not only gives a map of the Indian Ocean area, but also mentions the occurrence of monsoons at 50 distinct places.

With the arrival of more voyagers from the west in the Indian Ocean, a steady effort for systematically observing the wind, weather, and weather systems of the Indian Ocean commenced. In his first voyage from Melinda to Calicut in 1499, Vasco da Gama made use of the monsoon winds and reached his destination in just 3 weeks. William Dampier published many observations of Indian Ocean weather and weather systems in his travel accounts. He was a sixteenth-century buccaneer who lived and worked with some of the rowdiest pirates in history. But he was also an astute observer of nature in general and weather in particular. In his *Discourse on Winds and Breezes*, *Storms and Currents*, he deals with general wind systems throughout the world and their seasonal changes, which include the Southeast trades of the South Indian Ocean and Northeast and Southwest monsoons of the North Indian Ocean. During the seventeenth and eighteenth centuries, the military and trade activities of the European powers in the Indian Ocean waters increased.

Matthew Maury in his *Physical Geography of the Seas* (1874) explained the formation of monsoon winds as resulting from the heat of the plains and deserts of the Asian region. The following ideas about the mechanism of the Southwest monsoon and its rainfall were generally agreed upon by the meteorologists of the nineteenth century.

The plains of North India get very hot during the summer, and the air over that region ascends and becomes light. As a result, air over the sea areas, where the pressure is high both in the neighborhood of the equator and south of it, moves toward the region of low pressure of the land. The Southeast tradewinds, while moving northward and crossing the equator, become

Southwest winds, owing to the rotation of the earth. Again, these Southwest winds do not blow directly into the region of low pressure, but go around it in an anticlockwise direction. If one stands with one's back to the wind, the pressure to the left is lower than to the right in the northern hemisphere. In the southern hemisphere, the relation is reversed. The copious precipitation of the west coast is due to the high mountains which run along the coast. The higher the mountains, the heavier the precipitation. The monsoon is sustained by the latent heat released during the precipitation, which adds more heat to the atmosphere, and therefore further rarefaction takes place. Strong winds blow into the region of heavy rainfall, since air from the neighboring regions rushes to occupy the space created by ascending air.

Meanwhile, more knowledge was added to the science of cyclones in the Indian Ocean. Henry Piddington made a monumental contribution to the science of storms. He was the first to coin the term "cyclone", which gained world usage later. In a series of papers he gave detailed accounts of many Indian Ocean cyclones. His bestseller at that time was the *Horn Book of Storms for the India and China Seas*, which was followed by another book called *Horn Book for the Law of Storms*, in which he explained the use of transparent horn cards provided in his book for finding out the center of cyclones.

Many Indian meteorologists, led by Desai, Rao, Koteswaram, and Majumdar, worked on various aspects of the formation of cyclones. They investigated the role of the upper tropospheric flow patterns in the intensification, movement, and dissipation of tropical disturbances in the Indian Ocean. The availability of aircraft winds and satellite pictures enabled the meteorologists, such as Raman and Srinivasan, to study the low-level convergence and associated winds around the calm eye region of the cyclone, upper-level divergence, and the relation of the direction of movement to the upper-level winds. They also studied the influence of sea surface temperature on the formation of the cyclone.

As regards the Southwest monsoon, the upper air observations of wind and temperature and also the newly formulated dynamical concepts enabled the meteorologists to understand many synoptic aspects of the monsoon. Many meteorologists studied the role of the easterly jet stream and the Tibetan high, the northward shift of the westerly jet stream, the advance of the intertropical convergence zone to northern India, and the extension of equatorial westerlies. Koteswaram and Flohn (1960) made important contributions in this field.

Today meteorology in India is a highly developed subject, both from the research and service point of view.

See also: ►Navigation

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Meteorology in the Islamic World

William J. Mcpeak

Medieval Islamic conceptions of nature and physical phenomena were partially based upon a translated accumulation of Greek thought. Among the Greek philosophers who had conjectured upon the phenomena of the atmosphere, the most famous was Aristotle (384–322 BCE), whose geoscience treatise in four books called *Meteorologica* dealt not only with atmospheric phenomena but also with the general terrestrial aspect (including geological, hydrological, and oceanographical ideas) of his systematic cosmology.

Some of the questions pondered were meteorological: whether the Milky Way and comets were of terrestrial or celestial origin, hail forming theories, the origin of wind, the relation of thunder and lightning, and optical theories of the rainbow and the halo.

With the ninth century came a stabilization of the long political turmoil after the Islamic conquests. Also, with the rise of the Abbasid Caliphate at Persian Baghdad, that civilization and India significantly influenced the seminal culture of the new Islamic empire. With the founding of a translation center within Caliph al-Maʾmūn's (813–833) *Bayt al-Ḥikma* (House of Wisdom) at Baghdad, the next three quarters of a century would be very important for Islamic thought.

The *Meteorologica* would have been included among the Aristotelian translations. Evidently the first translation of the work into Arabic from the original Greek or Syriac of about 820 was that by the Jewish Arabic scholar Yaḥyā ibn-al-Biṭrīq (fl. ca. 820). Abū Naṣr al-Fārābī (ca. 870–950) had, following the Persian mathematician al-Kindī (ca. 801–ca. 866), adopted the Aristotelian classification of knowledge with study of nature under physics. In addition, the general scheme of Islamic knowledge defined philosophical science with seven subdisciplines of natural sciences, with meteorology as one of those. Though virtually lost, al-Fārābī's many large commentaries on Plato and Aristotle included the *Meteorologica* in his *Kitāb Iḥṣāʾ al-ʿulūm*. But he only discussed the traditional conception of the four elements of matter – earth, air, fire, and water – in noting the contents of the work.

Four particularly outstanding Islamic thinkers accentuate the tenth through the twelfth centuries. The great Afghani polymathic scholar Abū Rayḥān al-Bīrūnī (973–1048) wrote copiously, though again many works are known only by name. A rare linguist, who knew not only Arabic and Persian but also Turkish, Sanskrit, Hebrew, and Syriac, he steered clear of formal Aristotelian commentary, showing an observationally rich interest in the geosciences. His *Taḥdīd Nihāyāt al-amākin li-taṣḥīḥ masāfāt al-masākin* (Determination of the Coordinates of Cities) discussed fossils, physical geology, geography, and the ancient geodetic problem of finding the circumference of the earth. His *Kitāb al-tafhīm li-awāʾil ṣināʿat al-tanjīm* (The Book of Instruction in the Art of Astrology) also contained much on the sublunar world, including weather and climate over the known globe. Of the more conventional meteorological fare, he accepted basic ancient atmospheric ideas, including a variant view of the Milky Way as atmospheric smoky vapors screening the stars. The three most recognizable Islamic contributors to meteorology were: the Alexandrian mathematician/astronomer Ibn al-Haytham (Alhazen 965–1039), the Arab-speaking Persian physician Ibn Sīnā (Avicenna 980–1037), and the Spanish Moorish physician/jurist Ibn Rushd (Averröes 1126–1198).

The commentaries of these great philosophers reflected the high end of Arabic evolution toward the dictates of observation based on the logic of both critical deductive and inductive reasoning. Ibn al-Haytham, particularly noted for his seminal experimentally based inductive reasoning, was the first outstanding medieval Arabic theorist of physical optics with important applications to meteorological phenomena. His prolific output included some 20 science treatises, including his great optical treatise *Kitāb al-manāẓir* (Book of Optics).

Among the optical discussions, the treatise contained his extensive experiments and findings on reflection and refraction, and his experiments on the rainbow mechanism, a phenomenon all the vogue as a physical problem in the Middle Ages. His rainbow findings were also reported in his *Qaws quzaḥ wa'l-ḥāla* (On the Rainbow and the Halo), a work not in the *Optics* nor available other than as a manuscript. Ibn al-Haytham's innovative experimental method entailed a laboratory to study the phenomena of the earth, such as chemical compounds, as well as his optical studies. Aristotle had considered the rainbow a reflection phenomenon from clouds of uniform drops acting as a continuum surface like a convex mirror. Ibn al-Haytham, researching reflection of light from plane and curved mirrors, reasoned that the phenomenon was a case of reflection similar to a spherical concave mirror. He simulated the rainbow colors by transmitting sunlight through glass spheres of water, spherical concave mirrors representative of clouds, with the cloud still acting as a continuum. Unfortunately, he also decided that refraction had nothing to do with the phenomenon, considering the same mechanism for the lunar halo and solar corona. He also employed his ideas of reflection in dealing with a terrestrial Milky Way in one of his treatises, *al-Majarra* (On the Milky Way).

Ibn al-Haytham has been considered the first thinker to realize the refractive, i.e., light bending properties, of the atmosphere. The phenomenon had been continually hinted at since ancient times in the discrepancies found in observing celestial objects because of near horizon distortion of position and size. He wrote a short treatise, *Mas'ala fī Ikhtilāf al-naẓar* (A Question Relating to Parallax). And, in his *Fī maʿrifat irtifāʿ al-ashkhāṣ al-qāʾima wa-aʿ midat al-jibāl wa irtifāʿ' al-ghuyūm* (Determination of the Height of Erect Objects and the Altitudes of Mountains and of the Height of Clouds), he was evidently the first medieval thinker to use knowledge of refraction in theorizing by a convoluted geometry that the atmosphere was much lower than the ancients had estimated. His near contemporary Cordoban Ibn Muʿādh (ca. 989–1079) should also be mentioned in regard to atmospheric height for his singular hypothesis in his treatise – mistakenly attributed to Ibn al-Haytham – "On the Dawn" (evidently known only by the Latin translation by Gerard of Cremona *Liber de crepusculis*), also called "On Twilight and the Rising of Clouds." Sunlight before sunrise and after sunset are also phenomena of refraction, and Ibn Muʿādh estimated the angle of depression or the sun at dawn and evening twilights, arriving at the fairly accurate value of 18° by which the height of atmospheric moisture (believed responsible for twilights) and thus atmospheric height could be determined.

Ibn Sīnā a and Ibn Rushd represented concerted Arabic commentary as it moved from the eleventh to the twelfth century. Though more noted for his varied contributions to medicine, Ibn Sīnā contributed to physical science in 20 volumes of general thought, *Kitāb al-ḥāṣil*. He also wrote on the seasons and climate in the *Kitāb al-Anwā*ᵓ (Book of Meteorological Qualities). Ibn Sīnā's meteorological significance centers on the rainbow mechanism and the medieval fascination with the origin of the Milky Way. Departing from Aristotle's cloud continuum and Ibn al-Haytham's spherical mirror analogy, he reasoned that the rainbow was the result of reflection from the total amalgamation of water drops – this being the key discovered later – supposedly released by clouds as they dissolved into rain. His observational prowess is seen in his explanation. The idea came to him by watching the diffraction of sunlight by water drops created by the watering of a garden in a bathhouse. He thought the Milky Way celestial in origin, voicing yet one more assent to a physical concept important to both meteorology and astronomy as an eventual point of redefinition of the ancient boundaries of celestial and terrestrial phenomena. Yet, as with thinkers to follow and into the late eighteenth century, the fact that the Milky Way was an expanse of stars and not a by-product of those stars, escaped him as well. Ibn Rushd also held a celestial opinion of the Milky Way, one more both analytical and worthy of further discussion.

Contrary to a later conception of Ibn Rushd as slavishly Aristotelian, we can say that his jurist's logic followed the exact Aristotelian order of nature as a model of systematic formulation. Ibn Rushd wrote both short introductions and extended larger commentaries, such as *Al-aṭār al-ᶜalwiyya,* which included textual discussion, arguments about the opinions of other commentators, and his own analysis.

The Milky Way was a more bothersome challenge. Ibn Rushd decided that Aristotle's theory was untenable since it depended on the reality of hot and dry exhalations which had not been proved. He also reasoned by the phenomenon of parallax (the apparent change in position of relatively close objects with change in position or view of an observer) that if the Milky Way were terrestrial (below the sphere of the moon) and thus relatively close, it would have a backdrop of different stars depending on where it was observed. In proving this, Ibn Rushd spent time observing and recording the positions of the Milky Way with respect to the stars in the constellation of Aquila from different locations. He found no change. He also noted that because the Milky Way was a constant phenomenon, whereas the exhalation was an ever changing one, the Milky Way appeared to be in the celestial sphere. But ultimately he kept the phenomenon terrestrial, calling it an atmospheric refracted image of light from a conglomerate of small stars seen from the perspective of earth.

Among later commentators was Abū'l-Faraj (Aboulfarag d. 1286), the Nestorian bishop, who wrote a theory in 1279 of the Milky Way phenomenon in relation to fixed stars and constellations. He leaned toward considering the Milky Way as wholly consisting of stars and having nothing to do with terrestrial nature.

Islam's commentary also turned to its first generation of philosophers. Optical interests seemed to die with Ibn al-Haytham, until Quṭb al-Dīn al-Shīrāzī (1236–1311) and his student Kamāl al-Dīn (d. 1320) pursued a more critical look at his optics in *Tanqīḥ al-manāẓir* (Revision of Optics), which also delved into rainbow and halo theory. In analyzing Ibn al-Haytham, Kamāl al-Dīn initially looked to Ibn Sīnā's rainbow as a water drop reflection phenomenon, leading him to consider the water drops as analogous to transparent spheres of water. This was the breakthrough conclusion, allowing him to reason that two refractions took place, one on and one in a cloud drop in the rainbow optics. Kamāl al-Dīn used a better conceptual physics and geometry to explain the rainbow than Ibn al-Haytham had used.

The cultural devastation of the Mongol invasion of the thirteenth century punctuated the end of the Islamic golden age. Nonetheless, it left its intellectual legacy in North Africa and passed to Spain, where cosmopolitan Toledo served as a clearinghouse of translation for both Christian and Islamic scholars.

See also: ►Ibn Sīnā, ►Ibn Rushd, ►al-Maᶜmūn, ►al-Kindī, ►al-Bīrūnī, ►Ibn al-Haytham, ►Astronomy in Islam, ►Optics in Islam, ►al-Shirāzī -Kamāl al-Dīn

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Military Technology

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The term military technology is broad, and, as a subject restricted to non-Western cultures, potentially laden with analytical complexity. In fact, the constraints of a survey make it necessary to view the more technical innovations of the larger cultures rather than the myriad of variations on pointed weapons fashioned by essentially all peoples. Stimulated by environment and nature, the gamut of world cultures have used artistic and functional inventiveness in weaponry. Non-Western ancient military technology provided significant origins for Western military technology as well.

The first most significant line in the military technology progression was metallurgy of copper in the transitional period between the Neolithic and true Bronze Ages, approximately between 4500 BCE (perhaps 5000 BCE) and 3500 BCE in the Near East arc from Mesopotamia to Egypt. Copper's cold malleability enabled the earliest metalworkers to beat, rather than fire it from the ore as with harder metals. In doing so, they could fashion a metal version of basic wood, bone, and stone pointed weapons: arrow tips, spears, and particularly, swords. This was followed by smelting (melting metal to separate out impurities) and founding (melting the purer metal for casting and molding). By about 3000 BCE the general use of copper and experiment with its alloys (bronze with tin and brass with zinc) ushered in the Bronze Age to southwestern Asia over five centuries before general use. This was an essentially Near Eastern phenomenon, probably disseminated to India, Anatolia, and surrounding areas after this.

As far as we know today, the first great civilization of humanity was that of Sumer in southern Lower Mesopotamia after 4000 BCE. Among so many accomplishments handed down to subsequent Mesopotamian civilizations and the west, one especially important one was worked copper alloys and probably bronze swords. Mesopotamian cast copper mace heads, the first technical use of metal, date from 2500 BCE. About the same time Sumerian smiths were casting socketed axe heads. In the north, Semitic peoples to be called Akkadians, from which the Assyrian and Babylonian cultures developed, assimilated Sumerian technology. Before 2000 BCE non-Semitic, Indo-European invaders from central Asia began various waves of infiltration from Asia through Asia Minor into Mesopotamia and on to India. All would leave their military mark. Among these were the Hittites from the northwest and later the Hurrians from the northeast and the Caucasus – the one moving into Lower, the latter into Upper Mesopotamia.

The Hittites overran most of Asia Minor (Anatolia) after 2000 BCE and about 1500 BCE invaded Babylonia long enough to raze Babylon. Anatolia, a high plateau fringed by mountain ranges, was rich in mineral resources, among these gold and silver, but most importantly iron. The Hittites probably ushered in the early Iron Age by their use of this much harder metal in their weapons. In the general extent of southwestern Asia the Iron Age did not arrive until about 1000 BCE, although a few Mesopotamian objects of perhaps smelted iron have been dated before 2200 BCE, and some Egyptian work has been conjectured as even older. Iron was much superior to bronze in edged and projectile weapons and required higher temperature metallurgical processes of smelting iron ore and founding the crude metal. Although it was thought in some quarters of the last century that Egypt was the cradle of iron work, development of its metallurgy may have been contemporary with that of Asia Minor, considering abundant Egyptian iron resources. The use of iron also brought more effective defensive hardware, i.e., in armor and in horse trappings and the chariot.

The horse and the two-wheeled chariot were Hittite innovations to western Asian warfare. The horse brought mobility to tactical maneuvering on the battlefield for the specialized soldiers called cavalry. The chariot was introduced during the eighteenth century BCE and likely by the Indo-European Aryans (Indo-Iranian, also metalworkers – perhaps early iron weapon users) who invaded Iran from the northeast at that time and influenced the Hittites and evidently held sway over the Hurrians. The chariot provided a further tactical edge, allowing a soldier or two soldiers to act in concert in inflicting multiple casualties at one time. As specialized warriors, the charioteers introduced military class rule to Near Eastern civilizations. With the added innovations of scythe-like blades on its wheels, the chariot also added the mass fear psychological factor to warfare. The Hittites took northern Syria in their clash with Egypt about 1400 BCE, the latter having adopted the horse and chariot after their temporary defeat by the chariot tactics of the Hyksos, Amorite peoples who invaded Palestine about 1700 BCE. These latter also contributed large fortification technology to the general mud wall military architecture pool of the Near East which started with the high curtain walls of ancient

Jericho (8000 BCE), the first example of specialist military architecture.

By the middle of the fourteenth century BCE the Assyrians were able to take the military ascendancy in Upper Mesopotamia and eventually all of Mesopotamia by the late eleventh century BCE, to become a great empire. By the eighth century BCE the Assyrian army had reached an apex of coherency, a blueprint for the Persian army. Made up of both professional and militia soldiers, the Assyrian army equipped all troops with finely tempered iron weapons. They employed cavalry and chariots, archers (using the composite recurved or reinforced bow, found in the Middle East to 3000 BCE), and slingers, who used the simplest, oldest missile weapon. Adding to their siege tactics, sappers (essentially meaning diggers at that time) were used in approaches to mud-walled defenses, as were battering rams and wheeled platforms, equipped with shielding defenses against arrows, for rolling against such walls. By the sixth century BCE the Persians had become heir to the Assyrian Empire and to the diverse military technology of the Near East. It remained dominant for 200 years until the informal transition of east to west finally came face to face with the challenge of Greece under Alexander the Great in the middle of the fourth century BCE.

In the Far East, Chinese civilization as far back at 2000 BCE was characterized by a value placed on functional technology. The integration of the wall into Chinese cultural architecture was given a profound military expression in the Great Wall, which was started in 214 BCE by the first emperor Shi Huangdi as a linking of earlier rampart walls. It was meant to keep out the north/northwestern invaders who would plague China for centuries. The crenellated, brick-faced wall still stands, stretching some 4,000 miles and 30 ft (9 m) high, with regular spaced square watchtowers 40 ft (12 m) high with a 9–12 foot (3–4 m) passageway through them. Along with their own cultural variations on basic weapons, the Chinese designed light hunting crossbows by the fifth century BCE and were using them in combat by the second century BCE.

The use of iron metallurgy continued to be the prime advance in military technology. Iron ore is plentiful all over the world. Variations of alloying iron with carbon in smelting processes, which included the introduction of air blasting to fan the fire (the forge) to high temperatures, meant that steel (iron with a small proportion of carbon) and its hardening were probably fairly contemporaneous with iron working (from 1000 BCE). Although dating is indeterminate, the great deposits of iron in Central Africa and the proximity of the Egyptian influence point to limited iron and steel forging. Indian weapons of iron were prevalent by 500 BCE. In fact, tempered steel was produced fairly early in India. Bars, rods, and plates of raw steel were exported throughout the Near and Middle East. Indian steel was used in the founding of blades of "watered steel" (the process of folding malleable steel over and over then beating it out). These light, high tensile strength curved (Damascus) blades enabled the effective long sweeping offensive draw cut, used by both the infantry and cavalry of western and central Asia down through the last century.

The development of the relatively simple smelting methods of steel and steel weaponry was disseminated eastward to southeast Asia via Indian colonization. Iron weaponry and working began independently in China about 500 BCE and smelting of crude steel was fairly contemporaneous (about 400 BCE). By the Middle Ages the effectiveness of the Mongolian steel saber, influenced by Middle Eastern contacts, was supplanting the straight Chinese sword. Japanese iron weaponry, with Chinese influence, began about 200 BCE, although the earliest relics date between the second and eighth centuries BCE. The best of the distinctive long, slightly curved samurai steel blades date from the twelfth century and progress to the fine temper-lined watered blades of later centuries. All these areas applied iron and steel technology to military accoutrements and armor. The work of the Near and Middle East, China, and Japan was particularly artistic as the Middle Ages progressed.

Although the steel sword would remain the principal weapon of the great non-Western cultures, the destructive potential of gunpowder technology into the High Middle Ages was to affect the larger non-Western cultures as it did the West. The use of incendiaries was already ancient, most noticeably in China. The so-called "Greek fire," the generic term for a variety of mixtures based on naphtha (a petroleum distillate) added to sulfur, pitch, turpentine, tars, and oils (in modern interpretation, probably a suspension of metallic sodium, lithium, or potassium in a petroleum base), was perhaps in crude use by the fifth century BCE. It is noted as being used by the Boeotian Greeks at the siege of Delium in 424 BCE during the Peloponnesian War.

The historiographic origin of gunpowder, that is black powder, is still controversial. The gunpowder recipe itself is of uncertain origin, but its basic constituents are now generally first attributed to ninth century Chinese alchemists. It might also be the independent product of Islamic lands, most like Moorish Spain by the mid-twelfth century. From there it perhaps moved to India where there may have been independent knowledge and use of the chemical ingredients from the late eleventh century. It was known in northern Europe by the early thirteenth century. The argument for an intermediary disseminator, the Eurasian Steppe lands, the European/Asain crossroad, to Islam and Europe, particularly by the thirteenth century Mongols is also plausible.

Explosive application of gunpowder in a weapon has also been controversial. Some theorists of Chinese primacy (Chinese toy rocket experiments for fireworks evolved early) date bamboo-tube hand guns or cannons and rockets for arrows and spears from AD 900–950. Various types of incendiary arrows, slings, and javelins, as well as incendiary and exploding bombs, grenades, and fire-balls are also attributed to the Chinese by the eleventh century. The historical point of military effectiveness of such devices remains uncertain. Widespread military use in China did not appear until the Song-Jin dynastic wars of the twelfth and thirteenth centuries. By the thirteenth century bomb technology with iron casings and large size was used by Chinese and Mongolian antagonists in land siege warfare. There is also evidence of time delay fusing using flintstone abraded against steel wheels to set off multiple mines in fourteenth century China. Rockets were introduced to Europeans during the Mongol western invasions at the Battle of Legnica in 1241. There is also evidence of rockets in India in the 18th century.

Gunpowder weapons applications appeared about the middle of the thirteenth century in Muslim North Africa and Moorish Spain as crude iron and iron-reinforced wooden bucket mortars for flinging stones in fortifications warfare. Also, Moors were using effective rockets on Spanish soil by 1249. Thereafter some evidence shows that the evolution of mortars, cannons, and finally handheld firearms progressed with most tactical efficiency in Europe, although some historians date Chinese cannons of significant size and metal composition from as early as the tenth century. Non-Western applications were innovative in their own right. By the middle of the fourteenth century, cannons mounted on walls or on mobile carriages and cradles had replaced most of the traditional engines of war in both Europe and the Near East. And Eastern projectiles ranged from stone balls to huge arrows with sheet-metal fins.

The growing threat to Eastern Europe, the Adriatic, and the Aegean by the ascendancy of the Ottoman Turks through the fourteenth century was furthered by their pursuing the use of artillery to challenge the weakening Byzantium Empire. A parallel was the thirteenth century Mongol challenge and conquest of China, with cavalry, siege tactics, and gunpowder technology. By the fifteenth century the Turks were casting – sometimes with the guidance of European renegades – huge bronze mortars and cannons, such as those used in the final siege and fall of Constantinople in 1453.

The Turks also turned to the Western matchlock arquebus, the first gunpowder longarm, which was the single most important transitional pivot from medieval to modern warfare. The Ottoman domination over the Arab world influenced firearm dissemination to Arabia and North Africa where, unlike the more angular stock of Turkish and Persian guns, styles reflected Arab and Kabyle preferences.

The influence of the West on the Asian Pacific was initially felt in trade and subsequently in acquaintance with western gunpowder technology. Perhaps the most interesting case involved the Japanese, who quickly adapted the matchlock arquebus which the ubiquitous Portuguese traders, already established in China, brought in 1542. The Japanese matchlock was an austere but highly stylish weapon, smaller in size and caliber than western matchlocks with a spring design firing mechanism, which soon joined the traditional feudal weapon array and went on to change the tactical maneuvering of the civil warfare of the sixteenth century.

The Korean civilization provides an interesting development in Asian and world naval warfare at this point in military technological history. Located on a strategic peninsula, the Korean people endured centuries of piratical incursions from the Japanese islands on one hand and politically complex dynastic invasions' from the Chinese mainland on the other. A sophisticated native culture, including science and technology (particularly, shipbuilding), was able to grow from the tenth century. Until 1592 peace and cultural advances continued. Then the Japanese general Toyotomi Hideyoshi unified Japan, calling for the invasion of China through Korea, which refused his passage. Although they had cannon, the Koreans did not have the matchlock longarms of the 200,000 Japanese invaders. The ensuing incursion was successful until 1593 when the Korean admiral Yisunsin invented what must be the first ironclad ship, evidently thin iron plating over a high, flattened oval-shaped ship of 16 oars with circumference cannon ports. Burn and board-proof, a fleet of these "tortoise boats" was sent against and defeated a Japanese armada in Chinhai Bay. This triumph provided the impetus to drive the Japanese out.

The Chinese perpetuated their own hand cannon, large wall artillery technology, and shipboard cannon well into the nineteenth century. They adapted to the Portuguese style of longarm lock but designed their own pistol grip-like stock. Both features influenced the far away Malaysian peninsula gun style which itself influenced the intermediate region of the Gulf of Tonkin. On the under side of Asia, Indian matchlocks showed significant regional variations from both the Portuguese and Arabic initial introduction. Three basic subcontinent Indian matchlocks were joined by very stylized weapons from Ceylon (Sri Lanka). By the early seventeenth century the Ceylonese exceeded the Portuguese in the manufacture of musket size matchlocks, one type with a unique bifurcated scroll butt. The Burmese side of the Malaysian peninsula essentially used Indian matchlocks with local decorations.

Although more isolated non-Western peoples continued to use the matchlock (indeed, the Japanese did until the early nineteenth century), most succumbed to trade and import and adapted to the progression of firearms manufacturing and, just as significantly, ordinance technology in keeping with the single-minded exigencies of superiority in warfare. These latter factors inevitably and irrevocably set the new course of non-Western military technology as a dependent reflection of the West, a reflection all the more thought provoking in the modem shadows of nuclear and chemical weaponry.

See also: ►Gunpowder

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Military Technology in Ancient Egypt

MICHAEL BERGER

Weapons and warfare were a part of ancient Egyptian life from the Prehistoric periods through Dynastic times. While examples of actual weapons, chariots, fortifications, and ships are relatively rare, Ancient Egyptian art and archaeology provide us with many depictions and descriptions of these objects. This information helps us to identify and reconstruct some of the technologies of the Late Prehistoric and Pharaonic periods (3500–332 BCE).

Weapons

The Ancient Egyptians used a large a variety of weapons in the Predynastic and Dynastic periods. Many of the early types continued to be used throughout the Pharaonic period. Generally, weapon innovation in Egypt tended to lag behind neighboring states and groups in Southwest Asia due to social, technological, geographical, and political factors (Spalinger 2005: 15). Whereas individual craftsmen produced weapons until the Late Neolithic period, by the Early Dynastic period specialized royal workshops were producing larger volumes of weapons (Gilbert 2004: 71–72; Gnirs 2001: 405). At the beginning of the New Kingdom, new weapons were introduced into Egypt from Western Asia, and a period of innovative design started, during which Egyptian craftsmen perfected designs for the chariot and composite bow (Shaw 1991: 59, 68–69; Spalinger 2005: 1).

Most scholars categorize Egyptian weapons by their range: short-, medium-, and long-range (Schulman 1995: 290). Weapons can also be grouped according to their function: e.g., specialized weapons, tool-weapons, etc. (Gilbert 2004: 33). Both methods are useful, and they provide different perspectives on the way weapons were used in Egypt.

Short-range or close-combat weapons were the mace, club, ax, stabbing spear/lance, dagger, sword; medium-range weapons were throwing stones, throw-stick/boomerang, throwing spear/javelin. Long-range weapons were the sling and bow and arrow. Specialized weapons were the mace and sword; weapon-tools were the spear, ax, club, boomerang, sling, and bow and arrow. Tool-weapons were knives, hammers, etc. (Gilbert 2004: 33).

The primary materials for the production of weapons were stone, copper or copper alloy, wood, and leather, but bone and ivory were also used (Hoffmeier 2001: 406). Use of chert/flint in tools and weapons dates to the Paleolithic period and continues through the Dynastic period, for specific weapons, like spear and arrow heads, because it was abundant in Egypt and fairly easy to work (Hoffmeier 2001: 406; Gilbert 2004: 33, 71–72; Nicholson and Shaw 2000: 28–29). Copper was used for weapons by the end of the Neolithic period, and continued to be used after bronze became more widely used in the Middle Kingdom. (More copper objects were found in Tutankhamun's tomb than bronze ones; Nicholson and Shaw 2000: 153–154.)

Natural, unworked stones were probably one of the earliest weapons (along with sticks). Stones could be thrown or used as hand-held weapons (Newberry 1893: Pl. 14). Slings were an inexpensive and easily made weapon, and could propel a stone to a greater speed and attain a superior range than a thrown stone (Hoffmeier 2001: 410). While there is no evidence in early Egypt for slings, they are used in later periods (Gilbert 2004: 70).

Military Technology in Ancient Egypt. Table 1 Ancient Egyptian chronology

Late Predynastic period (3200–3032 BCE): Dynasty 0
Dynastic or Pharaonic period (3032–332 BCE): Dynasties 1 to 30
Early Dynastic period (3032–2707 BCE): Dynasties 1 and 2
Old Kingdom (2707–2216 BCE): Dynasties 3 to 8
First Intermediate period (2216–2046 BCE): Dynasties 9 to early 11
Middle Kingdom (2046–1794 BCE): Dynasties late 11 to 14
Second Intermediate period (1794–1550 BCE): Dynasties 15 to 17
New Kingdom (1550–1070 BCE): Dynasties 18 to 20
Third Intermediate period (1070–664 BCE): Dynasties 21 to 25
Late period (664–332 BCE): Dynasties 26 to 30
Greco-Roman period (332 BCE–395 AD)
Ptolemaic period (332–30 BCE)
Roman period (30 BCE–395 AD)

Maces were made from a shaped stone with a hole drilled through its middle for the handle. Many examples of disc-, oval-, and pear-shaped maces have been found in mortuary or temple contexts. Hard stone mace-heads in early Egypt were a status symbol. Maces are represented in the art of all periods, but their numbers decline after the early Dynastic period (Shaw 1991: 31; Gilbert 2004: 35–41; Shaw 1991: 31–32; *MH* 2, Pl. 102).

Although primarily used as hunting weapons in the Predynastic and Dynastic periods, sticks were also used by warriors and soldiers (Capart 1904: Pl. 1; Gilbert 2004: 69–70). Staffs and clubs were probably among the earliest weapons, and they are used throughout the Pharaonic period (Capart 1904: Pl. 1).

Axes were some of the oldest and most common weapons in ancient Egypt (Shaw 1991: 34–37). Stone axes (probably all hand-held) date to the Paleolithic period (Hoffmeier 2001: 407). Flint axes were produced in the Neolithic period, but the earliest evidence of an ax with a handle is perhaps the one on the Hunter's Palette, which dates to the end of the Late Predynastic period (3500–3300 BCE; Gilbert 2004: 63). Starting in the Mid-Predynastic period copper axes appear in Lower Egypt and subsequently appear throughout the country. Early axes are of plain form, some with holes and others with lugs for attaching to a handle, and most examples seem to be from the Early Dynastic period (3032–2707 BCE; Gilbert 2004: 63–68). In the Old and Middle Kingdoms semi-circular and rounded ax blades are shown used by Egyptian troops in siege scenes (Arnold and Settgast 1965: Fig. 2). These ax heads would have been attached to the haft with leather bindings (Shaw 1991: 34–37). A "scalloped" or three-"tanged" ax head was also used in the Middle Kingdom (2046–1794 BCE; Blackman 1914: Pl. 3). At about the same time, in Syria and Palestine axes with "duck-billed" blades and socketed heads were used and show up as copies or imports in Egypt (Hoffmeier 2001: 407; Spalinger 2005: 15; Gnirs 2001: 405). Later, in Western Asia and New Kingdom Egypt, longer, narrower ax blades that were more suitable for piercing shields or helmets appear and were possibly developed as a response to the introduction of armor (Shaw 1991: 34–37) (Table 1).

Examples of large-chipped stone spearheads dating to the Paleolithic period have been found in Egypt (Hoffmeier 2001: 407). One of the earliest representations of a spearman is on the Hunter's Palette (Gilbert 2004: 58). Flint spearheads continued to be used in the Old and Middle Kingdoms, even though copper spearheads appear in the Late Predynastic period (Gilbert 2004: 59). Bronze, socketed spearheads appear in the New Kingdom (Shaw 1991: 37). Spears could be used as an offensive or defensive weapon, but the javelin was primarily an offensive weapon. The lance or long spear was used as a thrusting weapon and was used in the Predynastic and Dynastic periods (Gilbert 2004: 60–61; Hoffmeier 2001: 407).

Bifacially flaked flint daggers and knifes were used in the Neolithic period and Predynastic periods. Copper daggers appear in the Middle Predynastic period and continue in use throughout the Dynastic period. Daggers were provided with wood, bone, or ivory handles (Gilbert 2004: 42; Shaw 1991: 37). As the use of bronze expanded in the New Kingdom, a longer dagger or short-stabbing sword was developed (Hoffmeier 2001: 407). By the Ramesside period (1292–1070 BCE), mercenaries in the Egyptian army employed longer, double-edged, pointed swords. The sickle-sword or *Khepesh* first appeared in Mesopotamia, and the Egyptian varieties that appeared in the New Kingdom were modeled on the West Asian types and may have been used more like an ax than a sword (Spalinger 2005: 15; Hoffmeier 2001: 408).

The bow and arrow were used in all periods, starting as early as the Late Paleolithic period (Gilbert 2004: 44–45). Until the New Kingdom most bows were made from a single piece of indigenous wood, which could be used to construct both the simple and double-curved/convex types of "self"-bows (Western and McLeod 1995: 77–79). These early bows did not have a nock for the bowstring, but instead the string would have been wound around the ends several times (Hoffmeier 2001: 408–409). Self-bows continued to be used in the New Kingdom, and 14 examples were discovered in the tomb of Tutankhamun (McLeod 1982: 1–2).

Influences from Western Asia led to the adoption of the composite bow in Egypt. Because of its construction – a laminated sandwich of wood between horn and sinew – the composite bow was more elastic and therefore had greater range and penetrating power than self-bows (Shaw 1991: 37, 66). There were recurved and triangular types of composite bows (Shaw 1991: 42, 66).

Arrows were composed of three elements: the point or arrowhead, the shaft, and the fletching. Arrow points were made from stone, ivory, bone, and wood in all periods and copper and copper alloys in later periods (Gilbert 2004: 46; Hoffmeier 2001: 409). Arrowheads were made in a variety of shapes, depending on use (Gnirs 2001: 405). Arrows with copper alloy points did not become common until mid- to late Dynasty 12 (ca. 1875–1794 BCE; Spalinger 2005: 15), and it was afterwards that the use of flint points declined (Gilbert 2004: 48–54). However, 20 arrows with flint transverse points were discovered in Tutankhamun's tomb (Gilbert 2004: 48–54). Reeds and wood were used for arrow shafts. The nocks could be cut in the reed or in a nock-piece made from wood, bone, or ivory fitted into posterior end of the shaft (McLeod 1982: 4–5). Fore shafts were attached to the anterior part of the shaft and could be made from the same materials as the nock-piece; the fore shaft was often sharpened to serve as the point. If arrowheads were used they could be attached to the shaft with mastic (Gilbert 2004: 49). Two, or more commonly, three, or four vanes of feathers were added to provide stability to the arrow in flight (Western and McLeod 1995: 77–79). Depictions of quivers were rare until the Middle Kingdom, and prior to that time archers usually carried arrows in their hands (Capart 1904: Pl. 1; Blackman 1915: Pl. 8 – both methods depicted here). (It is possible that the quiver was introduced into Egypt from Western Asia, since the Egyptian word for quiver is derived from a Semitic word; Spalinger 2005: 15.) In the New Kingdom quivers were still carried but were designed to attach to the sides of chariots as well (Shaw 1991: 66–67).

Shields are the only type of defensive equipment depicted in early Egyptian art (except perhaps the parry stick; Gilbert 2004: 43–44). In the New Kingdom new types of shields, helmets, and body armor appear, possibly as a reaction to the introduction of new powerful offensive weapons, like the composite bow and sword, and the increasing use of copper alloy for missile and hand weapons (Davies 1930: Pls. 16, 22, 23, and 24; Gnirs 2001: 405). The shields found in Tutankhamun's tomb were made from wood, leather, and other animal hides. In the New Kingdom copper or copper alloy shields or shield parts may have been used. Leather scale armor was used, as were leather tunics with attached copper alloy scales (Hoffmeier 2001: 410).

Chariots

Whether the Hyksos introduced the chariot into Egypt or if it came from Southwest Asia by some other means, its first mention in an Egyptian context does not occur until the beginning of the New Kingdom (1550 BCE; Spalinger 2005: 8–14, 18–23). The adoption of the chariot was rather rapid, since many of the technologies and conditions required for its construction and use already existed in Egypt in the late third and early second millennium BCE. For example, horses and the wheel are attested prior to Dynasty 18 (Gnirs 2001: 402; Shaw 1991: 65). However, the first steps in the development of the chariot occur elsewhere in the Middle East (Schulman 1980: 117–118; Hoffmeier 2001: 410; Littauer and Crouwel 2000). While the Hyksos may have employed chariots, there is no mention of their using them, nor has any evidence of chariots been discovered at Tell ed-Dab'a (Hoffmeier 2001: 410). There may be a reference to a chariot or chariot team on the Kamose stela, but the first clear text reference is found in the autobiography of Ahmose Son of Ibana, a career sailor who fought under the early kings of Dynasty 18: Ahmose, Amenhotep I, and Thutmose I (Lichtheim 1976: 12–14). Fragmentary battle scenes depicting teams of chariot horses and chariots were discovered in the ruins of King Ahmose's funerary structure at Abydos (Harvey 2001: 52–55).

The expense of chariot building and maintenance meant that its use was limited to the royalty and nobility (Schulman 1995: 295–297; Gnirs 2001: 403), so from the very start, the chariot was a status symbol, which besides being used in a military context was also employed in domestic activities like hunting and inspecting estates (Davies and Gardiner 1936: Pls. 50, 68; Davies 1903: Pl. 17; Davies 1905: Pl. 13).

There are few surviving examples of chariots or parts of chariots, but fortunately the Egyptians often portrayed them in paintings or relief sculptures on tomb or temple walls. Actual vehicles or vehicle fragments include the chariot from Yuya and Tuya's tomb, the Florence chariot, the six examples from Tutankhamun's tomb, the body of a chariot of Thutmose IV, and the Amenhotep III hub fragment (Davis 1907: Pl. 32; Carter and Mace 1927: 54, 60; Carter and Newberry 1904: 24–38; Hansen 1994: 52).

In art, chariots are shown in domestic contexts (e.g., Ahkenaten and Nefertiti visiting a temple), being constructed (e.g., in the tomb of Puimre), or in military contexts (e.g., Ramses II fighting the Hittites at Kadesh). In battle scenes, there is often a two-man crew represented, a driver, who also often holds a shield, and an archer.

The chariot was a mobile platform for archers, usually operating at a distance from the enemy. It also performed some of the duties that were later assigned to cavalry, such as screening infantry and out-flanking and pursuing the enemy. Use was limited by terrain: rivers could be difficult to ford and rough ground presented obstacles. Therefore chariot use was restricted to relatively flat ground, and because they were light and unarmored they could be easily damaged (Davies and Davies 1933: Pl. 7 – bearers easily carry parts of a chariot). Egyptian accounts of the battle of Kadesh relate that the Hittites deployed 2,300 chariots, but Schulman believes this is an exaggeration (Schulman 1980: 132). Nonetheless, the *Annals* of Thutmose III record that 924 chariots were captured at Megiddo (Gnirs 2001: 402).

Chariots were primarily composed of parts made from a variety of woods and leather, although other materials like metal fittings, textiles, glue, bone, and ivory were also used (Shaw 1991: 64). Chariot workshop scenes became a popular subject for New Kingdom tombs; they show workers making wheels, bodies and other components of chariots (Davies and Davies 1933: Pls. 7, 10, 11, and 12). Local and imported woods were used for many parts, some of which, like rails, drive poles, and yokes, required steam bending, a technique the Egyptians possessed prior to the New Kingdom (Nicholson and Shaw 2000: 357; Shaw 2001: 63–64). Leather was also used liberally in chariot construction, for floors, harnesses, and tires (Nicholson and Shaw 2000: 309; Scheel 1989: 47; Hoffmeier 2001: 410; Carter and Mace 1927: 56; Shaw 1991: 63), and for binding and protecting the more vulnerable components of the chariot (Davies and Davies 1933: 12).

The first Egyptian chariots had wheels with four spokes (Davies 1923: Pl. 23, bottom). A larger, stronger wheel was probably required as the chariot became bigger in order to accommodate a two-man crew (driver and warrior). Therefore, an eight-spoke wheel was briefly used, but this was abandoned in favor of the six-spoke wheel, which was found sufficiently strong to bear the weight of the crew (Carter and Newberry 1904: Pls. 10–11; Carter and Mace 1927: 57, 58). The hub or nave was the most complex component of the wheel and was composed of morticed halves, together with the six V-shaped spoke segments, and tenoned wheel flanges (used to extend the hub along the axle to prevent wobbling; Hansen 1994: 52; Carter and Mace 1927: 57).

Fashioned from a single piece of wood, Egyptian chariot axles were long (2–2.3 m) to provide great stability and maneuverability. There were no bearings, but the axle could be fitted with greased leather sleeves to minimize friction and wear from the wheel (Hansen 1994: 54). The placement of the axle at the rear of the vehicle helped to distribute the crew's weight between horses and wheels, and absorb some of the shock of the ride (Carter and Mace 1927: 56) (Fig. 1).

The body of an Egyptian chariot was small and light, being composed of a bent wood support frame and rails, with side panels of linen and leather. Most chariot bodies were open in the back. Portions of the body were attached or stabilized by leather lashings to the floor, pole, and axle (Hansen 1994: 59).

Bow cases, arrow quivers, and javelin cases would have been attached to the sides of the chariot, but only paintings or relief carvings of these survive (Fig. 2).

Chariot warriors are occasionally shown wearing helmets and leather (?) armor, but most commonly, the crew and horses were nearly unprotected. Perhaps its mobility and speed were effective in keeping the chariot crew and team safe. Representations of chariot teams on tomb or temple walls provide much of our information about leather harnesses and bridles. Though metal bits were used, none have been found with surviving chariots (Carter and Mace 1927: 59), but

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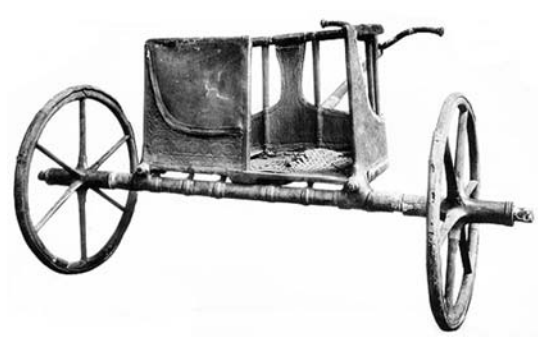
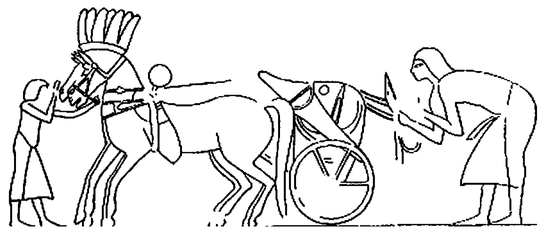


Military Technology in Ancient Egypt. Fig. 1 The Chariot found in the Tomb of Yuya and Tuya (Newberry 1893: Pl. 32).



Military Technology in Ancient Egypt. Fig. 2 A bow case mounted on the side of a chariot (Newberry 1894: Pl. 12).

examples from excavations indicate metal bits were standard equipment (Spalinger 2005: 19).

Horses became an important commodity in Egypt at the same time the chariot was introduced. Most of Egypt's horses were captured in battle, imported, or obtained as tribute (Spalinger 2005: 19; Shaw 1991: 65; Schulman 1995: 295–297).

Fortifications/Siege

Evidence for fortifications, assaults on fortified places, and sieges first appeared in Ancient Egypt during the Predynastic period. Some of the large, decorated cosmetic palettes, or fragments of palettes that were found at Hierakonpolis and elsewhere, are decorated with scenes that occasionally include fortifications. For example, on a fragment of the "Bull Palette" is a relief carving of a fortified enclosure, represented in plan by a wall with buttresses. Similar scenes are found on the Narmer Palette and the so-called "Libyan Palette." From this time forward, depictions and descriptions of defensive architecture and assaults on fortified places became popular subjects in Egyptian art and literature. Monumental mud-brick structures were constructed during the early Dynastic period at Hierakonpolis (Kasekhemwy "Fort") and Abydos (Shunet el-Zebib), and while these buildings had a funerary purpose, they are our earliest archaeological evidence that the Egyptians were capable of building large-scale fortifications at this time (Figs. 3–7).

Scaling ladders and towers start to be represented in some of the tomb decorations of the Old Kingdom, as seen in the Dynasty 5 (2504–2347 BCE) rock cut tomb of Inti at Deshasheh (Petrie 1898: Pl. 4) (Fig. 8).

Beneath the scaling ladder two Egyptian soldiers and their commander are prying blocks or bricks from the wall. In the Dynasty 6 (2347–2216 BCE) tomb of Kaemheset at Saqqara a large ladder with two wheels at the bottom is shown propped against the wall of a city during an Egyptian assault (Quibell and Hayter 1927: Frontispiece). Egyptian soldiers armed with axes and

Military Technology in Ancient Egypt. Fig. 4 Bull Palette detail (Capart 1904: 235, Fig. 166).

Military Technology in Ancient Egypt. Fig. 3 "Bull Palette" fragment (Capart 1904: 235, Fig. 166).

Military Technology in Ancient Egypt. Fig. 5 Narmer Palette and detail of bottom (Capart 1904: 237, Fig. 168).

Military Technology in Ancient Egypt. Fig. 6 Narmer Palette, detail of bottom (Capart 1904: 237, Fig. 168).

Military Technology in Ancient Egypt. Fig. 7 "Libyan Palette" (Capart 1904: 229, Fig. 160).

pickaxes are shown, attempting to create a breach or undermine the fortifications.

A number of fragments of a siege survive from the mortuary temple of the Dynasty 11 King Mentuhotep II (2046–1995 BCE) at Deir el Bahri and from the Theban tomb of Intef (TT#386), who commanded the army under Mentuhotep (Arnold and Settgast 1965: 50–51 and Fig. 2). A mobile siege tower is shown in the battle scenes from Intef's tomb, and like the ladder portrayed in Kaemheset's tomb it also has wheels.

From Dynasties 11 and 12 are depictions of assaults on fortifications from the tombs of high officials at Beni Hasan (Newberry 1893: 85, Pl. 14 – tombs of Khnumhotep I (#14) and Amenemhat (#2); Newberry 1893: Pls. 5, 15 – tombs of Baket III (#15) and Khety (#17)) (Fig. 9).

Either the fortified structures depicted in these tombs were constructed on mounds, or the lower portions of their walls were protected by a glacis (a cleared bank sloping down from a castle's walls. It makes a clear line of fire in which attackers have nowhere to hide). The glacis would have reinforced the walls, made it difficult for sappers to undermine them, and prevented siege towers from approaching. The tops of the walls were crenelated and had towers that protruded outward. From the protection of a shelter the attackers used a kind of lance-like weapon to create a breach in the upper parts of the walls or to clear the parapet of defenders.

As Egyptian influence grew in Palestine and Nubia during the Middle Kingdom, Egyptian kings constructed forts along these frontiers to protect trade and communication routes (Shaw 1991: 16–23). In the region of the Second Cataract several forts and fortified

Military Technology in Ancient Egypt. Fig. 8 Siege scene from the tomb chapel of Inti at Deshasheh, Dyn. 6 (Petrie 1898: Pl. 4).

Military Technology in Ancient Egypt. Fig. 9 Assault on a fort from the tomb of Amenemhat (#2) at Beni Hasan (Davies 1903: Pl. 14).

towns were constructed or expanded; the most elaborate ones were at Mirgissa, Buhen, and Aniba. The forts had elaborate defenses, including massive brick walls, buttresses, towers, counterscarps, glacis, and ditches. Their plans were similar to one another, with regularly laid out streets, lined with buildings for government officials and garrison troops (Emery et al. 1979: Pls. 2–4).

The kings of the New Kingdom maintained many of the older frontier forts and built new ones in the region south of the Second Cataract.

Depictions of battles and assaults on fortified towns are displayed on the walls of later New Kingdom temples. Textual references to sieges include the account of Ahmose Son of Ibana about the fall of Avaris, the Hyksos capital in Egypt's eastern Delta, and Sharuhen, a Hyksos stronghold near present-day Gaza City. These cities only fell to the Egyptians after several campaigns and sieges (Lichtheim 1976: 12–14), leading Redford to suggest that Egyptian siegecraft was not very sophisticated at this time (Redford 1992: 138–139). However, it is possible that the Egyptians revisited these cities several times, during several campaigning seasons, rather than conducting a single lengthy siege (Redford 1992: 129).

Thutmose III spent several campaign seasons in Palestine, Syria, and Mitanni. For the first time in Egyptian accounts the *Annals* of Thutmose III describe a siege wall at Megiddo, presumably constructed to prevent any of the populace from escaping and to protect the Egyptians from sorties and from an enemy relief force (Redford 2000: 31–33).

There are several temple relief scenes from the reign of Ramses III that depict assaults on fortified towns in great detail but show no real advances in either fortification or siege technologies (*MH* II, PL.90; *MH* II, PL.87; *MH* II, PL.94 and 95 (photo); *MH* II, PL.88 and 89 (photo)). The fortified "Eastern High Gate" of Ramses III's mortuary temple at Medinet Habu resembles some of the Syrian fortifications that are depicted in some of the relief scenes of sieges from Dynasties 19 and 20 (*MH* VIII, PL.591; *MH* II, PL.87).

Following the New Kingdom, Egyptian control of Nubia and Syria–Palestine began to wane as did royal authority inside Egypt. The unsettled conditions of the Third Intermediate period (1069–664 BCE) were witness to the construction of additional fortified towns and cities throughout Egypt. The Kushite King Piye (r. ca. 746–715 BCE) recorded the events of his campaigns in Egypt on the Gebel Barkal Stele, including descriptions of fortified sites in Middle Egypt and the Delta, some of which were besieged and assaulted by his forces (Lichtheim 1980: 66–84). At the siege of Memphis, one of his commanders suggested building a ramp or causeway across inundated land to bring Piye's troops before the walls of the city. Though there is no previous record of ramps being used in sieges, there are examples that survive in architectural contexts (as on the inside face of the first pylon at Karnak). In addition, in Papyrus Anastasi I, which dates to the late New Kingdom, a military officer is given the task of estimating the volume of materials (brick, reeds, and beams) needed to construct a ramp of specific dimensions (Gardiner 1911: 16–17, 31–33). Rather than construct a causeway or build siege towers, Piye used ships to ferry his troops right up to the walls of the city where they successfully overwhelmed its defenses (Lichtheim 1980: 75–76). Piye's forces also may have used siege engines called "hurler" and "wooden servant" at Hermopolis, but their exact functions remain unknown (Lichtheim 1980: 71–73; Schulman 1995: 298–299). A generation later the Assyrians assaulted Memphis and captured it using siege techniques similar to those used earlier by the Egyptians.

Navy

Although boats have been depicted in Egyptian art since Predynastic times (Berger 1992: 107–120), it is difficult to ascertain their specific military uses until later periods. The earliest boats were reed craft, but local and imported woods were used in boat construction from at least the Old Kingdom (2707–2216 BCE). In a military context it seems that boats were primarily used to transport troops and materials (Lichtheim 1976: 12–14). The earliest surviving representation of a conflict on water is carved into the ivory handle of the Gebel el-Arak knife, which dates to the Naqada II period (ca. 3500–3300 BCE; Shaw 1991: 59–63). Examples of large-wooden boats were discovered in 1991 in 14 boat graves near the Shunet el-Zebib at Abydos (University of Pennsylvania; Pierce and Kosty 2000: ►http://www.upennmuseum.com/pressreleases/forum.pl?msg=43).

Scenes of boat building are often included on the walls of Old Kingdom tombs, such as the Dynasty 6 tomb of Mereruka at Saqqara (Sakkarah Expedition 1938: Pl. 152). Two large, wooden boats dating to Dynasty 4 (2639–2504 BCE) and belonging to the funerary equipment of King Khufu were discovered beside the Great Pyramid at Giza, and the Palermo stone describes a 52-m boat that was built during the reign of Khufu's father Sneferu (r. ca. 2639–2604 BCE; Wilkinson 2000: 141–144). One of the Khufu boats has been restored at Giza. Instead of a keel it has a central shelf and two side shelves that provide stability. The planks of the sides are joined to one another by pegs, ropes that run through a system of holes on the inside of the planks, and by hook scarves (Landström 1970: 28).

Six boats were discovered near the pyramid of Sesostris III at Dashur. One of the boats has planks that are joined only by pegs and by dovetailed fasteners (Landström 1970: 90). Hogging-trusses were also used in lieu of a keel to strengthen river craft and sea going ships alike (Landström 1970: 64, 12–23).

Ships are often shown in the funerary art of the Middle Kingdom, including model wooden boats, and it is in a scene from the early Middle Kingdom tomb of Inyotef at Thebes that archers are depicted firing from boats or barges. Prior to the emergence of the chariotry, it seems that the elite mobile arm was the navy (Spalinger 2005: 5). At the end of Dynasty 17 and the beginning of Dynasty 18 Egyptian naval activities against the Hyksos are described on the Kamose stele, and in Ahmose Son of Ibana's tomb biography (Goedicke 1995: 103–104; Lichtheim 1976: 12–14).

The Sea Peoples attacked Egypt during the reigns of Rameses II (r. ca. 1279–1213 BCE), Merneptah (r. ca. 1213–1203 BCE), and Rameses III (r. ca. 1183–1152 BCE). The sea and land battles that Ramses III fought against these invaders are described and depicted on the walls of his mortuary temple at Medinet Habu. They provide the first glimpse of a pitched sea battle in Egyptian art. Ships seemed to be specifically constructed for warfare; the Egyptian examples have fighting platforms at prow and stern, and lion-headed protrusions at the prow, which have been described as both battering rams and figureheads. Sailors and marines fought ship-to-ship, using swords, slings (?) and bows and arrows, during the melee phase of the battle (*MH* I, PL.40).

As previously described, at the beginning of Dynasty 25 the forces of King Piye used ships as assault craft to overwhelm the defenses of Memphis (Lichtheim 1980: 75–76).

As Egyptian maritime contacts widened during the mid-first millennium BCE Egyptian naval technology was influenced by other powers in the Eastern Mediterranean, and in order to compete, Dynasty 26 kings built Phonecian/Greek type war galleys (Shaw 1991: 59–63).

See also: ►Leather, ►Wood

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Mining: Copper Mining in the Great Lakes (USA)

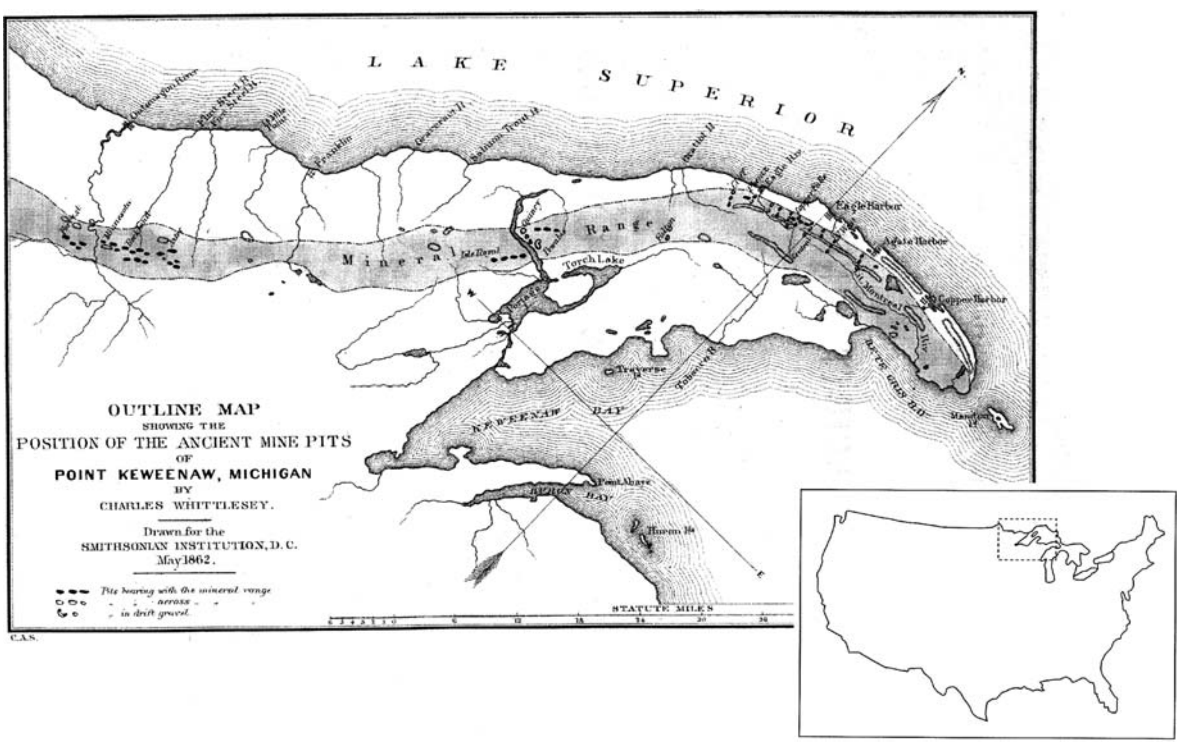
SUSAN R. MARTIN

The roots of indigenous metal mining are ancient in eastern North America. Evidence for early metal mining in North America comes from the copper-bearing regions of the western Lake Superior Basin in the central part of the continent. Here are to be found veins of elemental copper dispersed within sandstone and basalt bedrock, lying relatively close to the surface. In addition, pieces of loose elemental copper lie scattered in the glacial drift that is to be found in many streambeds and riverbanks. These pieces of useable copper and their parent veins were discovered and exploited by Native American people as early as 7,000 years ago. Though the first metalworking technologies of North America derived from the same technologies that people worldwide universally applied to reducing and using stone for tools, this long tradition of using copper for tools and ornaments is the product of native North American ingenuity. Moreover, the traces of this industry of copper mining and working (spoil piles, pits, discarded hammers, and other tools) were visible to the first capitalist American mining entrepreneurs of the Lake Superior basin who established their own mines on the same old ground that had proved itself first via native mining efforts (Foster and Whitney 1850). Archaeological research in the Lake Superior Basin and other copper-bearing areas documents the long-standing importance of copper technologies in the lifeways and practices of the indigenous people of the continent (Fig. 1).

The bedrock geological history of the Lake Superior region is fairly well understood (LaBerge 1994); its basement of pre-Cambrian bedrock, part of the Canadian Shield, is very ancient. The deposition took place around 1,100 million years ago (MYA), initiated by a period of roughly 25 million years during which a series of enormous movements of magma broke through a cross-continental rift and laid down some 200 extensive lava flows. This activity was intermittent, and followed by long periods of erosion and sedimentary deposition. The resulting strata are deformed by faulting and subsidence to a broad syncline that underlies Lake Superior and its drainage basin.

Gases trapped in the cooling lava, especially at the tops of flows, created porous structures in which later precipitation of minerals took place. Fissures in the lava and interspersed sedimentary rocks provided places where deposition of elemental copper occurred. The copper itself "was likely leached from volcanic rocks deep within the rift by hydrothermal solutions and was then deposited in these same rocks at relatively shallow levels closer to the surface. The timing of the widespread deposition of copper postdated the formation of the bedrock strata by about 20–30 million years and occurred from about 1,067 to about 1,047 MYA" (Martin 1999: 27–28). The result of this activity comprises the largest body of elemental copper known on earth, and its relatively shallow and accessible position allowed people to recover it. The copper-bearing strata outcrop in a narrow band about 3–6 km wide lying in a southwest to northeast direction along the Keweenaw Peninsula and Isle Royale on the western shores of Lake Superior; the beds also outcrop at the northern and eastern shores of the lake, and extend, deeply buried, further to the west into Minnesota. In other areas, native (elemental) copper is a common though irregular constituent of copper ore deposits in Tennessee, Georgia, New Jersey, Nova Scotia, and elsewhere (Levine 1999).

The Lake Superior deposits are quite variable in actual copper content and in form. In sedimentary bedrock deposits, the copper is finely dispersed; in the basalt bedrock the copper is more likely to be found in



Mining: Copper Mining in the Great Lakes (USA). Fig. 1 Map of the keweenaw Peninsula, Lake Superior, USA, indicating locations of prehistoric copper mining pits. Source: Whittlesey 1863.

fissures, veins or nodules of varying sizes. Masses of copper weighing several thousand kilograms were occasionally encountered. The most useful deposits for prehistoric people were of two kinds: thin veins that yielded sheets of copper, or fist-sized nodules of copper. Reducing very large pieces to useable sizes was somewhat beyond the reach of native technologies, but smaller pieces of both kinds could be rendered into tools and useful objects relatively easily. Useful nodules were sometimes found as constituents of the local late Pleistocene glacial drift or in redeposited gravel banks along streams and rivers. This copper-bearing drift is also widely dispersed across the central portions of the North American continent, where glacial ice flows carried copper and other detritus far from their points of geological origin.

The simplest and least-effort way to acquire copper in elemental form was to search and dig through the many beds of glacial drift in the rivers and streams surrounding the Lake Superior and adjacent regions. Based upon the many pitted areas observed and mapped by Whittlesey during the mid-nineteenth century (Whittlesey 1863), these beds of glacial drift were systematically explored for copper nodules. The glacial drift with copper as a constituent was/is widespread across the central part of North America (Salisbury 1885), and occurred south and west of Lake Superior as far as Iowa and the Dakotas.

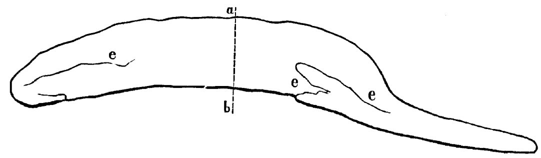
In addition to such areas, the bedrock veins were also systematically visited and mined over many thousands of years. Finding the buried veins was a simple matter of being observant. In the western Lake Superior basin, the veins of metal are visible in some surface basalt bedrock outcrops, particularly those that were scoured by glacial action. In other areas, erosion and water action revealed buried veins and nodules. In still others, companion minerals marked the probable occurrence of copper veins. Mining pits on Isle Royale investigated by the University of Michigan in the early 1960s dated to ca. 2470 BCE ± 150 radiocarbon years (Fitting 1975: 238). The early geologists Foster and Whitney described the pattern of such mining pits on the south shore of Lake Superior; observing that along "a distance of nearly 30 miles, there is almost a continuous line of ancient pits along the middle range of the trap (sic), though they are not exclusively confined to it" (Foster and Whitney 1850: 161). The typical pit was rather shallow and followed the course of a vein of copper in a small-scale simple excavation. Alvinus Wood described one that he observed during his excavations on the Keweenaw Peninsula in the late nineteenth century. "It was shown to be 14 ft. deep, having been filled up by the sliding-in of material composed largely of broken rock, taken out in sinking the ancient shaft, and left near its mouth" (Wood 1907: 288). According to Wood, the pit measured about 7 ft. in diameter. In scale, these pits were most comparable to quarrying a face of exposed rock, similar to the mining of flint that had been done for millennia, as opposed to the burrowing or tunneling more typical of recent hard rock mining.

The ancient mining was done with stone hammers that people used to crush the bedrock surrounding a copper-bearing vein. The hammers were, for the most part, unaltered impromptu tools found in the local glacial gravel. Mining pits are sometimes most readily identified by the appearance of many of these expended (shattered) hammers. The hammers were of various sizes and materials; most were of basalt or gabbro and weighed about 2–4 kg, although larger ones were also used, especially early in the mining sequence. Some of the hammers had minor surface modifications, such as a partial or full groove pecked into the circumference to allow a withe or handle to be attached. Pry bars of wood or copper were probably also used to loosen the copper within the vein, and there is some suggestion, especially borrowed from other primitive mining locations around the world, that fire might have been used to weaken the trap rock so that freeing the copper took less mechanical effort. Experimental work on Lake Superior prehistoric mining methods demonstrated, however, that such methods did not measurably improve the efficiency of removing copper (Bastian 1963). Additional artifacts, including copper tools, wooden bowls, wooden ladders, paddles, and other accoutrements of mining were reported to be found in the mining pits investigated by Whittlesey (1863). The size of the mining pits and their conformation suggests that one or two persons could work comfortably within a pit, and experiments showed that ca. a cubic foot of trap rock per hour could be removed from a pit face simply by stone hammering (Bastian 1963: 24).

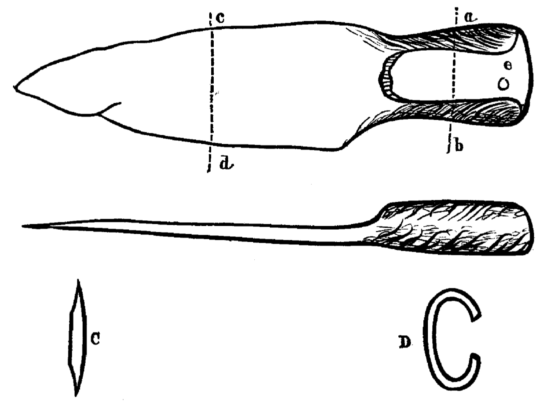
The native people of central North America fashioned myriad forms of elemental copper artifacts, using simple techniques of repeated cold-hammering and annealing. Despite a search that has already lasted for more than 150 years, there is no unequivocal evidence for intentional melting, smelting or casting of metal artifacts in the Lake Superior region or elsewhere in the eastern United States. All known artifacts were produced in much the same way: careful repeated hammering and heating to recrystallization temperatures. The finished copper objects ranged from weighty woodworking tools to finely crafted ornaments and decorative objects. It is probable that the basic knowledge of elemental metal-working was more or less common across North America, because many elemental metal deposits were known and exploited: at multiple localities in the eastern United States, in Mexico, in the southwestern US, and along the western rivers of Canada. The region around the Lake Superior basin with its large numbers of copper artifacts from local sites allows the researcher a fairly comprehensive look at how specific artifacts were designed and manufactured. Modern researchers established, via experimental replication as well as microscopic studies, the basic outline of prehistoric metalworking techniques (Clark and Purdy 1982; Leader 1988; Vernon 1990). Using the methods of cold or hot-hammering and annealing, the artifacts were carefully fashioned by repeated cycles of heating, hammering, and cooling, with carefully directed blows from a stone hammer creating the final form. Annealing, or reheating to recrystallization temperatures (in excess of ca. 250–300°C), restores malleability and was an essential part of the process; otherwise the hammered copper quickly became brittle and cracked under additional stress. Metallographic inspection of hammered copper revealed "the hammering technique, although primitive in itself, was carried out with assurance and skill; the sheet metal is often of fairly uniform thickness even though laminations are sometimes present" (Wayman et al. 1992: 133–34). Larger artifacts, such as wood-working tools, were hammered and annealed to render a nodule of copper to a desired form. Or, copper sheets were hammered to an even thickness, rolled and then rehammered to consolidate the copper into a thicker artifact form. Final annealing was frequently done, and annealing temperatures may have exceeded 600°C for some artifacts. Ornaments (such as beads) and sheets of copper were sometimes hammered around wooden forms, or mandrels, to produce a final artifact shape. Other artifacts, such as Hopewellian earrings and decorative ornaments of some Mississippian cultures, were composite artifacts of wooden cores clad with a thin cover of fine sheet copper (Fig. 2 and 3).

Finishing touches sometimes included additional limited cold-hammering to harden work edges of tools such as knives and projectile points. Grinding or beveling of work edges was also fairly common, and some artifacts such as harpoons or projectiles were perforated to enable the securing of a wooden shaft or handle via a copper rivet. Hopewellian and Mississippian cultures used elaborate finishing techniques on their ornaments. Decorative items were embossed, cut out, and perforated in a wide variety of forms depending upon the particular cultural traditions of the artisans producing the artifacts. Some were finished with a high gloss or polish produced by systematic rubbing with ashes and abrasives such as sand. There is some experimental evidence that prehistoric metal workers were able to draw thin strands of copper wire (Cushing 1894).

There is ample evidence derived from the study of the physical distribution of worked and unworked copper to claim that prehistoric people surrounding the Great Lakes communicated with one another, in part, through the exchange of raw and finished copper materials. In addition, overall close similarities in finished copper artifact forms that occur among and



Mining: Copper Mining in the Great Lakes (USA). Fig. 2 Sketch of copper implement, Keweenaw Peninsula, Lake Superior, USA. Source: Whittlesey 1863.



Mining: Copper Mining in the Great Lakes (USA). Fig. 3 Sketch of socketed implement with rivet hold 'e' and cross sections 'C' and 'D'. Source: Whittlesey 1863.

within regions close to bedded sources suggest active contact between people of different areas, and at least the copying of each other's artifact forms, if not direct/indirect exchange of finished materials. This pattern is well documented for areas east and south of the Lake Superior basin (Brose 1994; Goad 1979; Walthall et al. 1982). It is also apparent from research conducted in the northern Plains, where Lake Superior copper may have been exchanged for locally derived lithics such as obsidian and catlinite (Vehik and Baugh 1994). Other raw materials reported from the western Great Lakes region that may have been involved in regional and interregional trade *vis a vis* copper include hornstone (Pleger 1996), Hixton orthoquartzite (Clark 1991), galena (Ritzenthaler 1957), Burlington chert (Pleger 1996), Knife River flint (Salzer 1986), and marine shell (Hruska 1967). Many authors agree that copper was likely widely distributed via trade over vast distances (Brose 1994; Goad 1979; Winters 1968). Other authors add that trade in perishable items, invisible for the most part in the archaeological record, was certainly part of the picture; meat, skins, shells, reed mats and tobacco are suggested as important commodities, especially in the seventeenth century (Smith 1996). Other less tangible commodities and/or motivators to trading activities may have been related to social status, ethnic differentiation, information exchange, and ritual knowledge (Martin 1999). There is, at least by the seventeenth century AD, a solid body of first-hand reporting that documents the connection between native ideologies and copper materials, which were sought after because they were believed to hold the ritual power to bring good fortune, health, wealth and hunting success (Kellogg 1917: 105).

The use of copper was widespread in prehistory and was an important part of the cultural adaptations of the native peoples of eastern North America, beginning by the seventh millennium BP and extending until the advent of European-influenced cultures. The earliest and strongest evidence for the importance of copper mining in native American technologies and lifeways comes from the region adjacent to the bedded copper deposits of the Keweenaw Peninsula, the southwestern shore of Lake Superior, and Isle Royale, Michigan. Here there is material evidence of systematic collecting for copper within surface glacial deposits as well as extensive evidence of the activities of hard rock mining and quarrying by native Americans. The technologies of mining and cold-hammering elemental copper have become well understood through the efforts of experimental (replicative) research and metallurgical studies. Copper was an integral part of the technological, social and ideological experiences of the region's first people, and was equally significant as a material from which to fashion a tool, a social interaction or a ritual transaction. Copper's significance included social reckoning as expressed in burial and in decorative contexts among peoples of many regions and cultures, as well as social interactions as expressed through trade contexts, and finally within religious representation as expressed in elaborate beliefs about its ritual power.

See also: ►Pueblo Indian Adaptations of Spanish Metallurgy

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Mining in Ancient Egypt and Nubia

Dietrich Klemm, Rosemarie Klemm

After an early period around 4,000 BCE, during which gold nuggets were collected in some Pleistocene wadi (a valley, ravine or channel that is dry except in the rainy season) grounds and perhaps some native copper was also collected in superficial altered copper sulphide-containing quartz veins, real metal mining started in Egypt from around 3,000 BCE. Until that time tools and weapons in early Egyptian culture were generally based on stone tools such as flint knives, arrow- and spearheads, scrapers and axes and hammers of hard stone. The few predynastic copper artefacts, like small tools and fishing hooks, may have been made from such copper sheets in altered copper sulphide-containing quartz veins but also from scanty imports.

It is not clear whether copper or gold mining started first in Egypt; most probably both started contemporaneously.

Copper Mining in Ancient Egypt

Fig. 1 shows the positions of the various copper production sites mentioned in the text. Pre- to early-dynastic (ca. 3,200–2,600 BCE) gold mining has been reported from only a few sites in the Egyptian Eastern Desert, such as Wadi El-Urf near Ras Gharib, Abu Mureiwat near Safaga, Bokari and Higalig in the Central Eastern Desert (Klemm and Klemm 1994). But only in Higalig do remains of early waste dumps with malachite-stained granitic rocks give some hint to copper mining during those early times.

Convincing arguments for Old Kingdom copper mining were found in Buhen south of Wadi Halfa at the western bank of the river Nile, where copper furnaces of the fourth and fifth dynasty were excavated (Emery 1963). But the nearest copper mine in that region is Um Fahm some 80 km south and 30 km inside the eastern Desert (Figs. 2 and 3). In Quban, at the mouth of Wadi Allaqi, copper slags from the Middle Kingdom were discovered (Emery and Kirwan 1936). The next copper mine is Abu Seyal, again about 80 km away in a tributary of Wadi Allaqi. Unfortunately this site is archaeologically very poorly known, but it seems that copper mining here dates back at least until Middle Kingdom times. Also very poorly archaeologically studied is the copper mine of Umm Semiuky in the Southern Eastern Desert of Egypt. The site was covered up during careless early twentieth century copper mining with modern shafts, which also destroyed possible underground operations. Thus, no clear information concerning ancient exploitation of this site is available.

In the Central Eastern Desert of Egypt, in Umm Soleimat (Fig. 4), Old Kingdom to Middle Kingdom copper mining has been detected (Klemm and Klemm 1994). Middle Kingdom copper mining settlement with small furnaces in Wadi Dara (Northern Eastern Desert of Egypt) was confirmed (Castel and Mathieu 1992).

Mining techniques did not vary significantly during the various ancient periods. They started with open cast trenches, following the direction of the copper-containing quartz veins within which the primary copper ores were chalcopyrite ($CuFeS_2$) occasionally digenite (Cu_2S) and a few others. These copper minerals were leached by water and, whether directly in the quartz vein itself or in the joint systems of the host, rocks re-precipitated as copper carbonates, mainly as malachite ($Cu_2[(OH)_2/CO_3]$) or, very rarely, as azurite $Cu_3[OH/CO_3]_2$. Only these carbonates were usable for the ancient metallurgists.

Mining tools for metal mining were until the New Kingdom exclusively of stone. After that bronze

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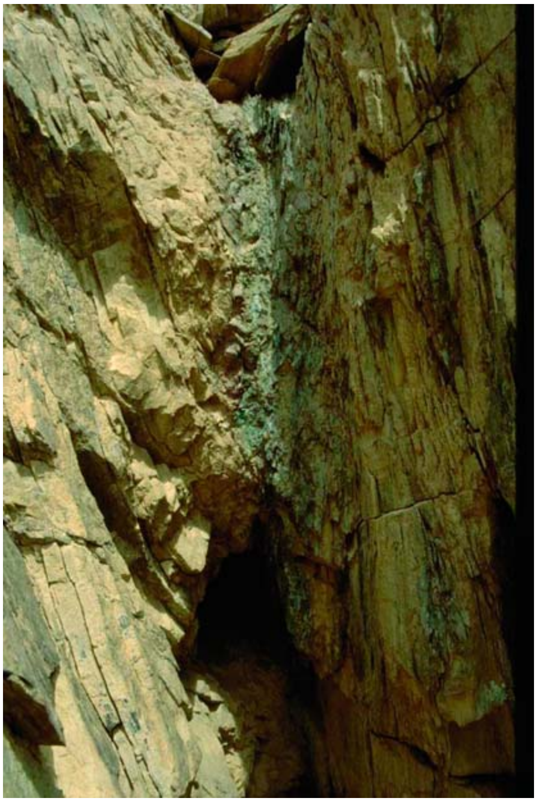
Mining in Ancient Egypt and Nubia. Fig. 1 Topographic map of Egypt and border countries with position of copper mines worked during ancient times (black stars).

chisels, and from Ptolemaic times on, iron and steel were used in metal mining. They mined not only the copper carbonate containing quartz ore, but also the malachite filled joint systems in close vicinity to the veins within the host rocks.

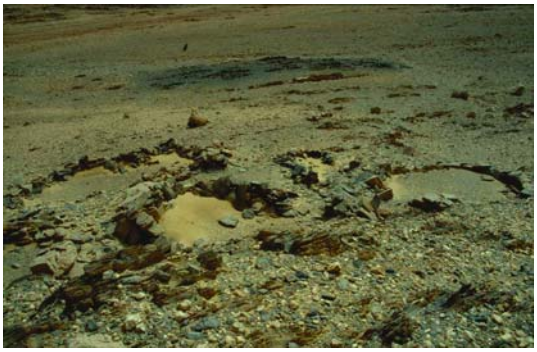
Because of the necessary superficial alteration of the primary copper sulphide minerals, the depth of the trenches reached a maximum about 20–25 m, but they could be deepened when it turned out that the vein might be even richer, e.g., gold bearing.

Apart from imports from Cyprus, mainly during the New Kingdom, the main sources of copper in ancient Egypt from at least the Old Kingdom but probably also from pre-dynastic times on, was the Sinai (Lucas and Harris 1962). In Magharah (southwest of the Sinai Peninsula about 16 km from the turquoise mining site of Serabit el-Khadim) copper mining dates back at least until the third dynasty. In the nearby Wadi Nasb, various inscriptions give evidence of copper mining from the twelfth until the twentieth dynasties. Predynastic copper production was reported (El Gayar and Rothenberg 1995) from Wadi Ahmar, west of Bir Nasb with slags and remains of ancient smelters. Quite a number of other sites was reported (Lucas and Harris 1962) with heaps of copper slag also close to Serabit el-Khadim. The most important copper mining site is Timna, which today is in Israel, not far north of Eilat. The work of Rothenberg et. al. (1988, 1990) gave intensive insight not only to the special mining techniques of this site but also to smelting procedures. According to Rothenberg (1988), copper



Mining in Ancient Egypt and Nubia. Fig. 2 Copper bearing shear zone of Um Fahm in northern Sudan. Note the green coloured remains of malachite in the ancient mine.

Mining in Ancient Egypt and Nubia. Fig. 4 Copper-gold mining site of Umm Soleimat in the Central eastern Desert of Egypt. Note the *green remains of malachite in the host rock*.



Mining in Ancient Egypt and Nubia. Fig. 3 Remains of an ancient workers' settlement in Um Fahm (northern Sudan). The two house types indicate cooperation of Nubian (round huts) and Egyptian (rectangular huts) miners at this site.

workings at this site probably started during the second part of the fourth millennium BCE. In contrast to the Eastern Desert of Egypt, where the copper mineralizations are from hydrothermal quartz vein systems, the Timna ore occurs exclusively as malachite impregnation pockets in sandstone.

Gold Mining in Ancient Egypt

In addition to copper mining, more than 250 gold production sites in the Eastern Desert of Egypt and the Nubian Desert of Northeast Sudan were located (Klemm and Klemm 1994; Klemm et al. 2001).

Gold Production in Predynastic and Earlydynastic Times

Discoveries of gold artefacts, dating back as far as predynastic times (about 3500 BCE) demonstrate that gold production must have taken place in Ancient Egypt (Kroeper and Wildung 1994). Statistical analysis of the geological environments around pre- and early dynastic mining sites indicate unambiguously that the earliest prospectors concentrated their mining activities on well-selected geological targets of gold-enriched quartz veins, mainly in granodioritic rims of Neoproterozoic granitic intrusions, belonging to the so-called older and younger granites of the Eastern Desert. Furthermore, discoveries of the oldest mining tools are connected to mining sites associated with superficially altered quartz vein systems, which originally contained a variable

Mining in Ancient Egypt and Nubia. Fig. 5 Predynastic gold mine of Hagalig in the southern Central Eastern Desert of Egypt. Note the smooth host rock walls of the extracted gold containing quartz vein due to the use of the calabash type two-handed stone hammers (Fig. 6).

Mining in Ancient Egypt and Nubia. Fig. 6 Calabash type andesitic stone hammers from Hagalig, Eastern Desert of Egypt, of 6–10 kg weight with which the gold bearing quartz veins and vein near host rocks were smashed down to powder size.

Mining in Ancient Egypt and Nubia. Fig. 7 Andesitic stone axes with grooved notches for a forked wooden stick from Bokari mining area in the Central Eastern Desert of Egypt used mainly in Old Kingdom gold mining sites.

copper-sulphide mineralization that is almost completely leached out and which has been re-deposited as typical green malachite within the host rock's joint system. This green staining guided early prospectors not only to copper but also to the auriferous quartz veins.

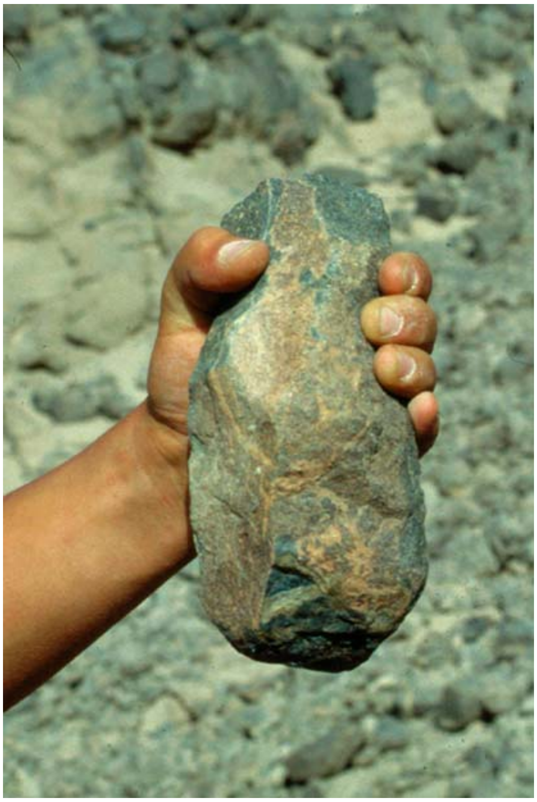
Gold mining in Ancient Egypt started in pre- and earlydynastic times with open pits and moderate underground activities (Fig. 5). During this early period, the gold-bearing quartz veins were crushed *in situ* to a fine powder fraction by huge calabash-shaped stone hammers of 6–10 kg weight, which must have been held with both hands (Fig. 6). In this way the gold slivers within the quartz were liberated for later processing. This mining method formed conspicuous smooth surfaces, both at the walls and the stopes (a step-like part of the mine where minerals are being extracted) of the underground operations.

Gold Production in Old and Middle Kingdom Times

During the Old (2700–2160 BCE) and Middle Kingdom (2119–1794 BCE) the previously described prospecting method of searching for malachite staining in the host rocks continued, but in addition hematite-enriched quartz veins (in places with barite) became important for exploration and, in the case of gold discovery, for subsequent mining targets.

Old Kingdom gold mining techniques continued with *in situ* crushing of the gold-bearing quartz vein systems, but two new basic types of stone hammers were developed: an oval stone axe of 2–5 kg weight (Fig. 7) with a chiselled notch for a forked wooden stick and a more or less cylindrical one-handed stone hammer with a ergonomically formed handle (Fig. 8). With these new mining implements, a more effective exploitation of the auriferous quartz veins was established.

During the Middle Kingdom this tool inventory continued, but additional stone mortars were introduced, allowing for the lumpy quartz ore to be crushed first to about pea-sized grains and then to a powder fraction. Again, no archaeological evidence for further gold recovery treatments during this period has been



Mining in Ancient Egypt and Nubia. Fig. 8 One-handed stone hammer from El Sid mine/Central Eastern Desert with a chiselled, ergonomically formed handle used in Old and Middle Kingdom gold mining sites.

discovered, but the remark of the nomarch (provincial ruler) Ameni, who is quoted in his Beni Hassan tomb as having said "I forced their (Nubian) chiefs to wash the gold" (Newberry 1893) gives a clear hint that hydro-metallurgical concentration processes were well established during these periods.

In Fig. 9, a few gold mining sites for both pre- and earlydynastic times and Old and Middle Kingdom periods are shown. However, quite a few of the early mining sites might have been so intensively overlaid by later operations that today no older surface remains are still visible.

Gold Production in New Kingdom Times

From the New Kingdom (1550–1070 BCE) onwards, gold mining operations concentrated more in the central Eastern Desert, predominantly south of the Qena-Safaga road, and were also spread over the eastern portion of the Red Sea hills (Fig. 10). Because of the conquest of Nubia, exploitation of the Wadi Allaqi area and sites deep into Northeast Sudan (Fig. 11) also became possible. Moreover, gold prospecting targets were significantly enlarged. Quartz vein systems free of hematite and green copper aureoles were also successfully prospected. More detailed studies of the quartz vein systems exploited during the New Kingdom indicate the profound knowledge of the ancient prospectors. They were clearly aware of the general structural control of gold-bearing veins. Furthermore, because of the systematic exploration of remote desert regions during the New Kingdom, granitic–granodioritic areas in the southern and eastern parts of the Eastern Desert became new and important prospecting and mining targets. These were extended to the Wadi Allaqi and even to Northeast Sudan.

Intensive gold prospecting and processing were extended to include wadi-working operations, where gold-bearing quartz samples were systematically picked from the coarse grained fractions of the wadi sediments. At these sites, the employment of hundreds of workers was possible, in contrast to the limited number of miners in underground workings. This led to an enormous increase in gold production, documented by an increase of known gold artefacts.

A radically new milling technique also had a strong impact on gold production at the onset of the New Kingdom. Millstones up to 80 cm long and 30–50 cm wide, with a flat and oval-shaped grinding plane, and differently sized sets of millstones used with one or both hands (Fig. 12) were introduced. These stone mills are similar to the flour mills commonly used in the Nile valley since very early times (Roubet 1989). The introduction of these flour milling techniques into the gold ore processing industry indicate that only from the New Kingdom onwards were the majority of miners Egyptians from the Nile valley. This assumption is also confirmed by the predominant occurrence of typical New Kingdom pottery remains within mining sites in the Egyptian Eastern Desert, and also in Nubia.

Before milling, the initial lumpy ore was crushed down to about bean-sized particles with a double-sided stone anvil of about 30 × 30 cm and a rounded stone pestle of 0.5–2 kg weight. The separation of barren and gold-bearing quartz fragments exclusively by eye was perfected by the workers, as small and uncommon remaining mine dump heaps in the wadi grounds today contain only milky white and translucent barren quartz gravels (Fig. 13).

Separation of gold from the fine-milled quartz powder fraction was managed by washing as attested by preserved tailing dumps. At first view these tailings appear as mostly pink to reddish heaps of quartz sand, analogous to normal desert sand. Investigation with a simple hand lens, however, reveals both sharp-edged quartz grains which are artificial products as well as remaining gold concentrations of about 3–5 g/t. This rather high residual gold content unfortunately caused the destruction of many ancient gold production sites at the beginning of the twentieth century, when modern

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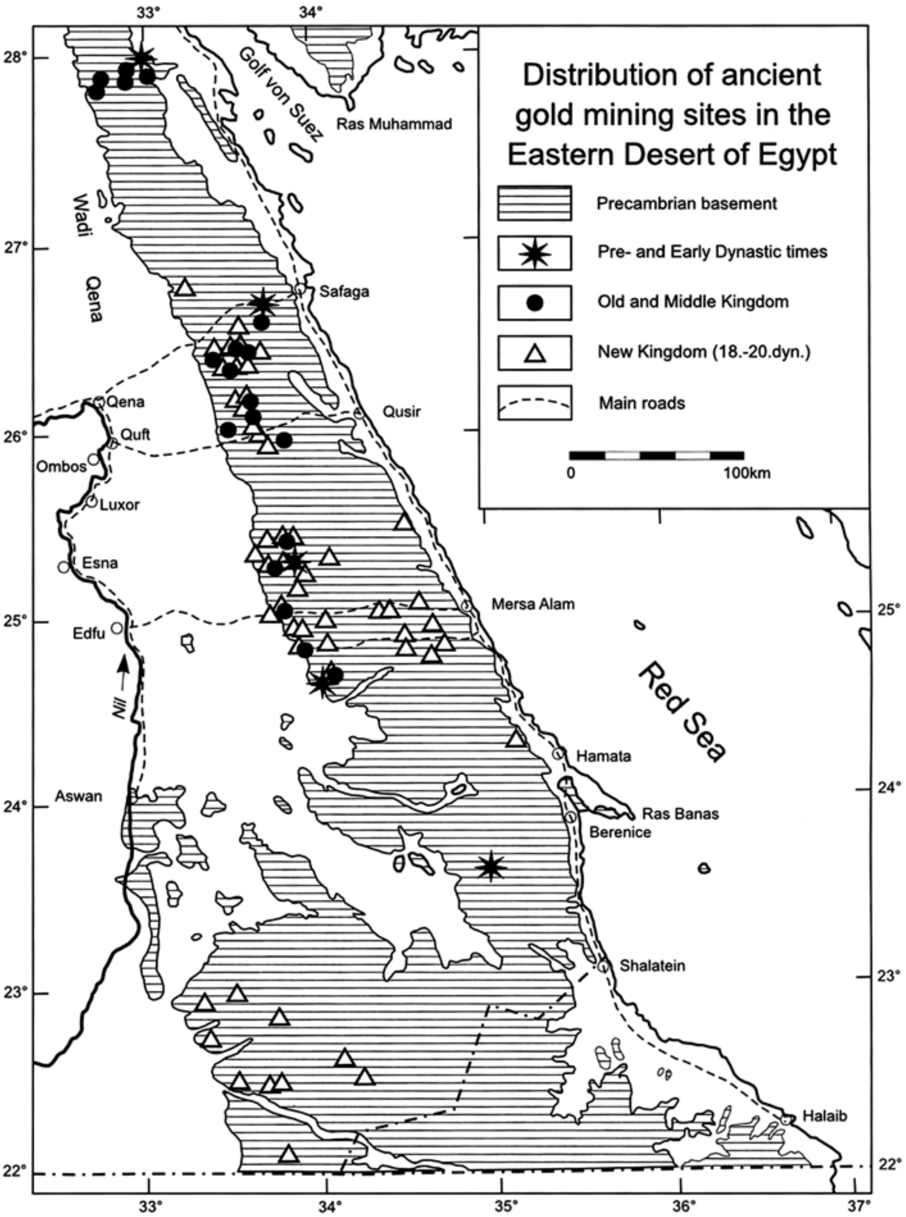
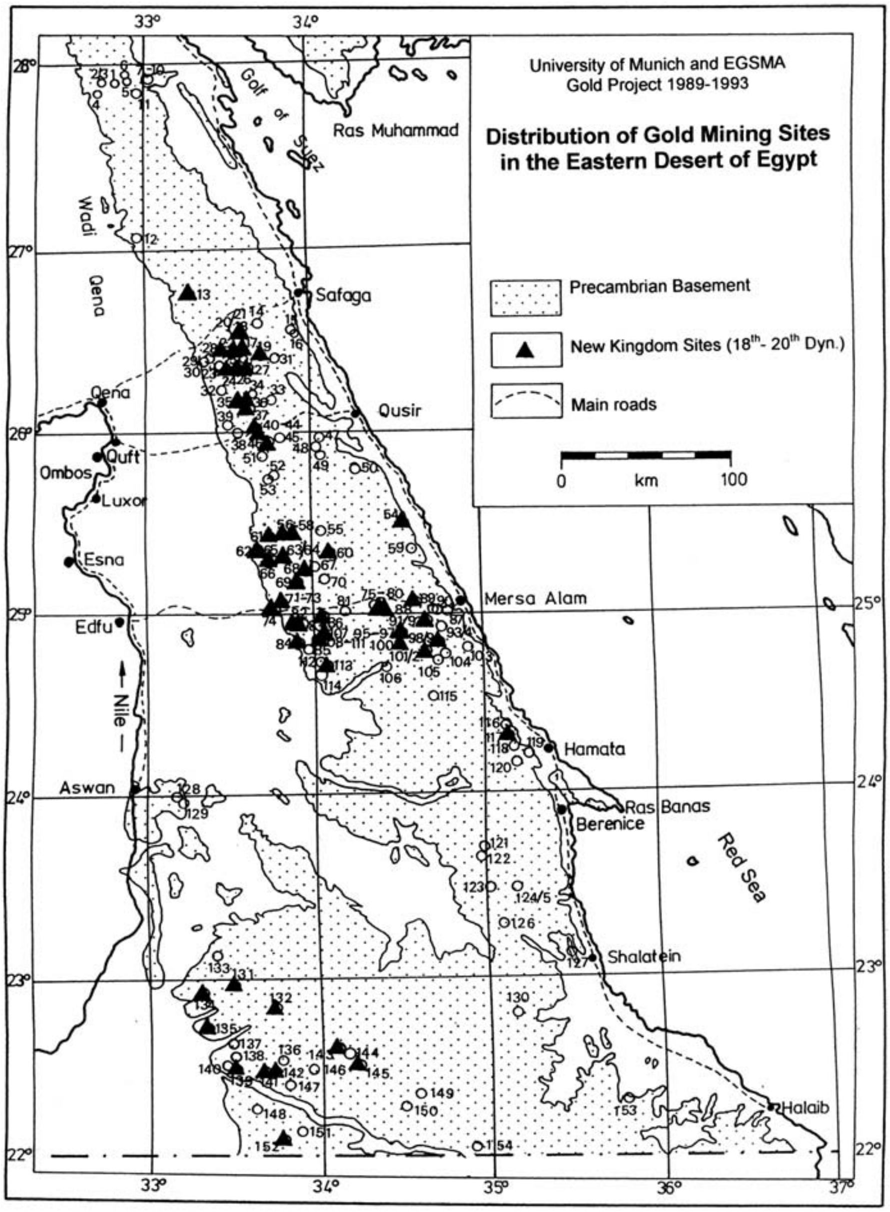


Mining in Ancient Egypt and Nubia. Fig. 9 Map of the gold mining sites in the Eastern Desert with the positions of both Pre- and Early dynastic times and Old and Middle Kingdom periods (after Klemm, et al. 2001).

gold production started with cyanide leaching of the old tailings, thus destroying most of the preserved and untouched original archaeological sites (Schweinfurth 1904).

At quite a few of the New Kingdom gold production sites, inclined gold washing tables constructed of stone fragments, consolidated by primitive clay/sand mortar and with a surface covered by a layer of the same material, can be observed. The lengths of these washing tables varies between 2.2 and 4 m, and they are 40–60 cm wide and 80–100 cm high, corresponding with an inclination angle of 15–20° (like Fig. 14, but in general much more ruined).

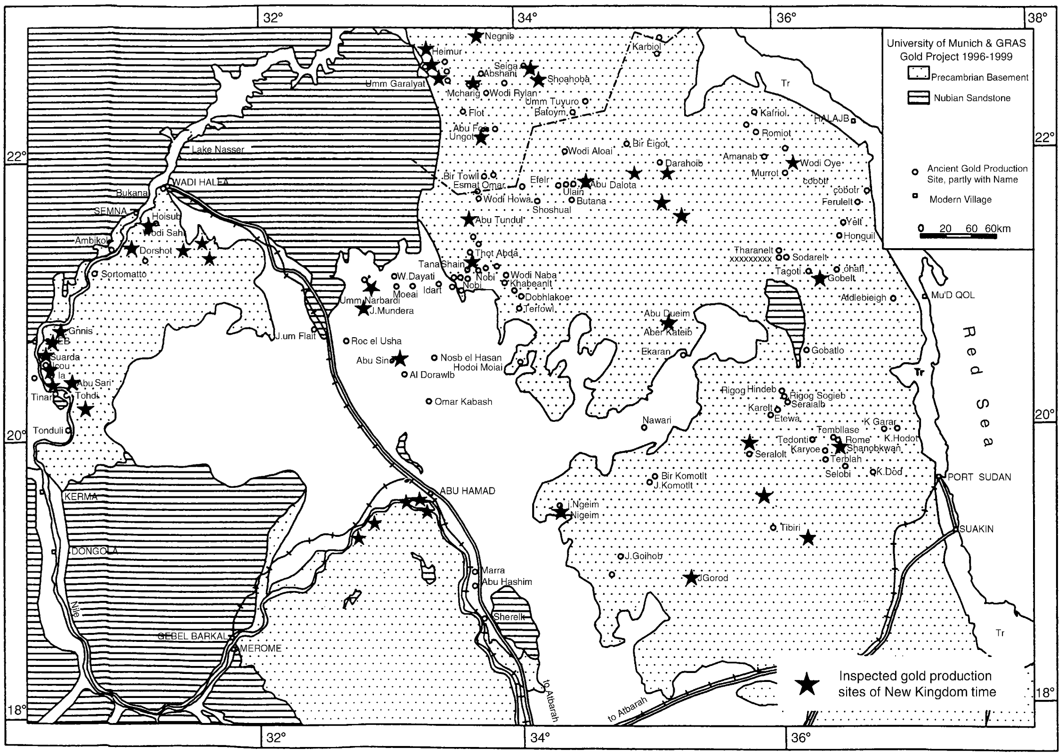
The question remains, however, as to how the planar surface of the inclined table was prepared, to separate the fine-grained gold particles liberated by the grinding process from the quartz ore. No direct archaeological evidence exists for this important step in ancient gold recovery. Because of the lack of any archaeological relics it might be assumed that the covers of these inclined tables were of organic materials. Two possibilities are likely – either a wooden grid or simply



Mining in Ancient Egypt and Nubia. Fig. 10 Distribution of the New Kingdom gold production sites in the Egyptian Eastern Desert. Note the wide activities all over the Desert regions especially within the very southernmost parts around Wadi Allaqi.

sheepskins, as both were commonly used in the more recent past for separation of gold slivers and quartz sand fractions. The sheepskin hypothesis is supported by the supposition that sheep were available at the mining sites as food, and further, both the lanolin grease and the washed fibres of the sheepskins would have trapped the sharp-edged gold particles whereas the barren quartz particles were carried off with the water suspension. The legend of the Golden Fleece, therefore, may have been of Egyptian origin and of far greater antiquity than the voyage of the Argonauts. Finally, burning the pelts containing the gold particles yields a raw gold product, but obviously no witness to this last possible step of the gold recovery procedure remains.

In the early New Kingdom, approximately between the reigns of Thutmosis I (1504–1492 BCE) and Amenophis IV (1351–1334 BCE), Nubia was conquered and incorporated into the Egyptian New Kingdom Empire. Most probably the name Nubia is taken from “nub”, the ancient Egyptian word for gold. Along the river Nile in Nubia, panning techniques most



Mining in Ancient Egypt and Nubia. Fig. 11 Distribution of the New Kingdom gold production sites in Northeast Sudan. Note the concentration of the sites along the river Nile, but also the widely scattered localities all over the vast distances of the Nubian Desert.

Mining in Ancient Egypt and Nubia. Fig. 12 New Kingdom millstones with a flat and oval-shaped grinding plane and differently sized sets of millstones used with one or both hands. These stone mills are similar to the flour mills commonly used in the Nile valley since very early times.

Mining in Ancient Egypt and Nubia. Fig. 13 Remaining New Kingdom waste dump heaps from wadi workings at Umm Garaiyat, Wadi Allaqi, southern Eastern Desert, Egypt. Note that parts of the wadi ground became flooded later, destroying most of the ancient works.

probably increased gold production in the New Kingdom (Vercoutter, 1959). As mentioned above, the Middle Kingdom nomarch Ameni forced the chiefs of the Nubians to perform gold washing. As alluvial river gold is still panned today in parts of Nubia, especially in the area around Shamkhiya, some 30 km west of Abu Hamed, this or a similar technique may have been known during Pharaonic times. Inscriptions on dedication lists at New Kingdom Egyptian temples like Medinet Habu, where "gold of the water" is registered (Hölscher 1957), support gold extraction from alluvial (wadi and river sediments) sources (Fig. 15).

The well-organized housing areas of the various gold-working sites of the New Kingdom are constructed mainly of 3–4 roomed houses, with dry stone walls about 30 cm wide and up to 1.5 m high and, in many

Mining in Ancient Egypt and Nubia. Fig. 14 Two inclined Arab period washing tables perpendicular to each other with a rim of light tailing from Heimur/Wadi Allaqi. This type of washing table has been archaeologically assigned to be in use from the New Kingdom on, but they might have been in use even earlier.

Mining in Ancient Egypt and Nubia. Fig. 15 Nubians bringing gold in pockets and ring ingots. Wall painting remains in the tomb of Huy, viceroy of Kush (Nubia) under Tutankhamun, end of 18th Dynasty, New Kingdom.

cases, with a front terrace (Fig. 16). The lack of any protective enclosing walls indicates that during this period the Eastern Desert of Egypt was peaceful and under the direct control of Pharaonic Egypt. In Nubia, starting from Wadi Allaqi, this peaceful situation became changed at places. At Umm Garaiyat the New Kingdom settlement is protected by a large enclosure wall, and at other sites the New Kingdom settlements are hidden in side wadis, such as at Duweishat and Abu Sari. Other New Kingdom gold production sites further to the south, like Sai Island, Shamkhiya, Tanta and Mograt Island seem to have been operated only within strongly fortified settlements.

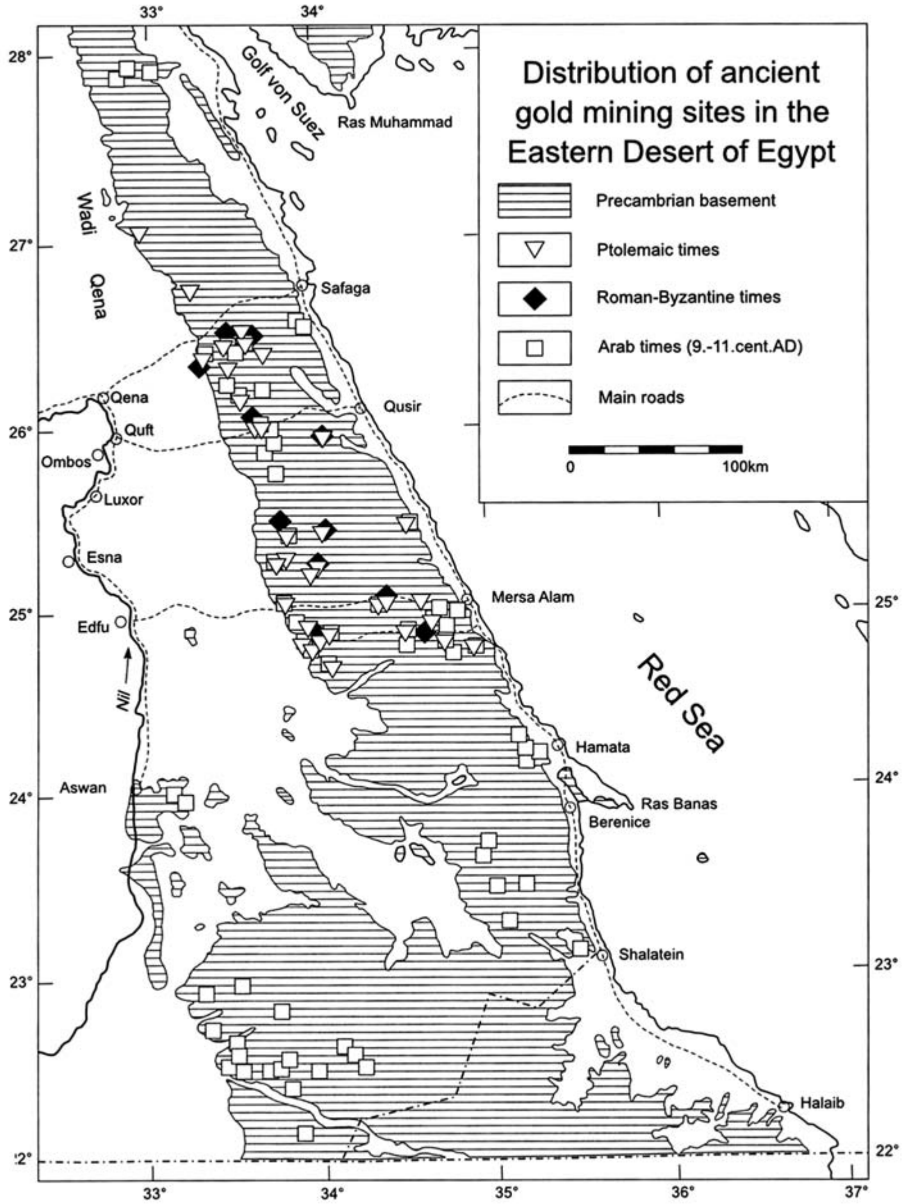
This latter assumption is based on the observation that almost all of the more southerly New Kingdom gold production sites today are only indirectly recognizable, as the typical New Kingdom stone mills and crusher stones are mainly incorporated into the walls of far later

Mining in Ancient Egypt and Nubia. Fig. 16 Remains of a many-roomed stone house from the New Kingdom settlement of Abu Sari gold mining site, Sudan.

medieval fortifications of the Christian kingdom of Makuria. The most probable interpretation is that these fortifications are nothing less than rebuilt earlier defensive installations from New Kingdom times. This assumption is supported by a site called Ras el-Gazira at the westernmost part of Mograt Island (near Abu Hamed in Sudan), where a relatively untouched New Kingdom gold production site is directly protected by an impressive stone fortification with an extended field of rock palisades towards the open eastern plain of the island. Here, as at the other sites, mostly only scanty ceramic remains are detectable as surface inventory, but a detailed archaeological excavation is urgently required.

Mining technique improved significantly in New Kingdom times, mainly with the introduction of bronze chisels, which allowed a much more selective separation of the gold-bearing quartz generations of a multiphase quartz vein from the barren parts of the host rocks. The miners selectively followed the most promising ore shoots, which resulted locally in a somewhat chaotic pattern of underground operations. Fortunately, in most mines supporting pillars ensured the safety of the ancient miners. During the New Kingdom no sophisticated ventilation of the underground operations was developed, limiting the maximum depth of operations to about 30 m, the maximum depth for maintaining a sufficient oxygen level by normal circulation for men and burning oil lamps.

In Figs. 10 and 11 the distribution of the many New Kingdom gold production sites in Egypt and NE Sudan shows the very extensive gold production operations carried out during these times. It should be emphasised that in Nubia these activities were restricted only to the rather limited period between the reign of Thutmosis III and Amenophis III. From the government of Amenophis IV onwards, throughout the Ramesside (about 1300–1100 BCE) period, no archaeological evidence for Pharaonic gold mining within the Nubian



Mining in Ancient Egypt and Nubia. Fig. 17 Distribution of Ptolemaic, Roman–Byzantine gold production sites in the Eastern Desert of Egypt. Note that only in the central parts of the Eastern Desert during Ptolemaic times did gold production activities take place. Note further the sparse Roman–Byzantine sites (after Klemm, et al. 2001).

Desert, south of Wadi Allaqi has been detected. In the Egyptian Eastern Desert, primary New Kingdom gold production started early in the 18th Dynasty and collapsed completely by the end of the Ramesside period; it seems to have been suspended throughout the entire Late Period, until early Ptolemaic times.

Gold Production in Ptolemaic (Greek) Times

It is very likely that in Ptolemaic and also in Roman times essentially no new prospecting strategies were developed and that only the ancient New Kingdom Pharaonic mining sites were reorganized and partly mined out. The mining was again limited by underground shaft termination at a final ventilation depth, approximately 30 m below surface. Only those mines which were located close to the desert roads (Murray 1925) were further exploited or re-established in Ptolemaic and Roman times (Fig. 17). Based on Agatharchides, reported by Diodor III, 12, gold mining took place in the southern part of Egypt, close to the “border of Ethiopia”. In spite of justified doubts about the authenticity of Agatharchides’ description (Woelk 1966) it is generally accepted that gold mining took place in the Wadi Allaqi district during Ptolemaic times, although the exact area is not mentioned literally. Recent investigations (Klemm, Klemm, and Murr 2001) within the Wadi Allaqi area, contrasting Castiglioni et al. (1995), did not confirm any Ptolemaic mining site, and it is most doubtful whether during that period any gold mining activity was feasible in this area, because of the aggressive desert tribes dominating the entire southern Eastern Desert and reaching deep into what is now Northeast Sudan (Updegraff 1982).

A dramatic improvement in milling technique and ore processing was introduced by the Ptolemaists. They used concave-shaped millstones of 70–80 cm length and 30– 40 cm width, with parallel incised, about 1 mm deep grooves on the milling plane. Semi-circular two-lugged millstones of 5–10 kg weight were moved by hand over the grinding plane, milling the pea-sized crushed quartz into a powder fraction and setting free the fine gold slivers (Fig. 18). With this swinging milling method the whole process was about five times more effective than earlier methods. For crushing, the old anvil and pestle system remained, but with an enlarged size of the crusher stone.

Most probably this new design of a concave-shaped milling stone is not an original Greek invention. It may have been derived from the Minoan island of Crete, where this mill type has been excavated in the Minoan cities of Gournia and Festos. Based on the Greek mining experience, Ptolemaic underground mining in Egyptian gold mines became significantly improved. Thus, in gently dipping gold quartz vein workings, dome-shaped mine ceilings allowed the reduction of supporting pillars to distances of 4–6 m, which increased the minable output.

Another important improvement was the adaptation of circular concentration washing plants from the Laurion mining district in Attica, as described in detail by Conophagos (1980). It became possible to process primary gold-bearing sulphidic ores with pyrite, chalcopyrite, galena, sphalerite and arsenopyrite, hitherto not extractable. Remains of such concentration plants (Fig. 19) are well preserved at Daghbag, Bokari and, in spite of recent destruction, also at Barramiya.

The reasons for the reduced Ptolemaic gold mining activities in only the Central Eastern Desert of Egypt are not reported in historical documents, but we know from Roman sources that large parts of the Eastern

Mining in Ancient Egypt and Nubia. Fig. 18 Concave-shaped Ptolemaic gold mill with a two-handled milling stone, together producing a swinging milling technique and thereby increasing the fineness of the quartz ore powder fraction. Gidami gold mining site, Eastern Desert, Egypt.

Mining in Ancient Egypt and Nubia. Fig. 19 Remains of a circular heavy mineral concentrator from Daghbag gold mine, Eastern Desert, Egypt, introduced during Ptolemaic times into Egyptian gold ore processing, but originally designed in the Laurion district, Attica, Greece.

Mining in Ancient Egypt and Nubia. Fig. 20 Cylindrical stone mills for gold milling (quern) from Hashai, Sudan. A Celtic invention, they were imported by the Romans into Egypt and were still used as gold mills in early Arab times.

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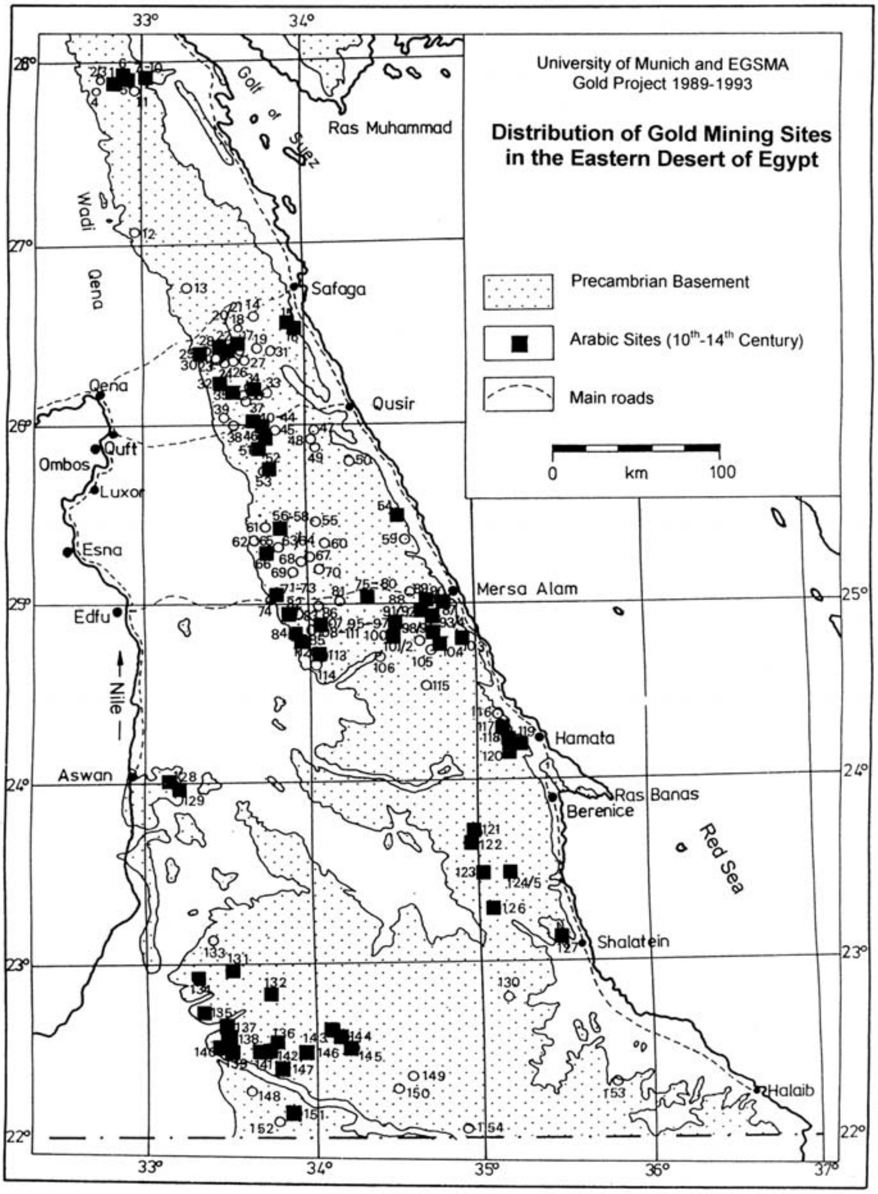


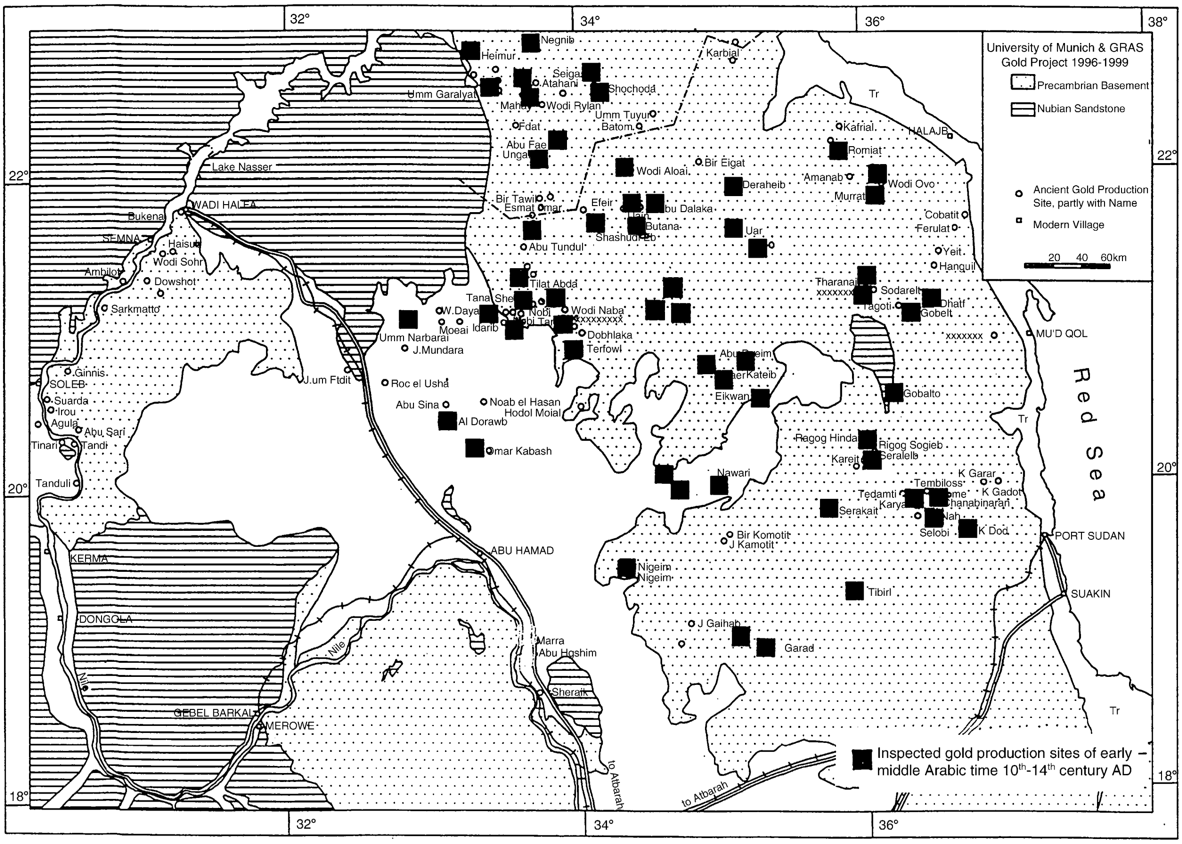
Mining in Ancient Egypt and Nubia. Fig. 21 Distribution of the gold production sites in the Egyptian Eastern Desert during early Arab times. Note the extension to the very south of the desert region.

Desert and Nubia were difficult to subdue because of the aggressive attitudes of the local nomadic tribes (Sidebotham 1991), who the Romans called Blemmyes. The Bisharin tribes inhabiting this region today are regarded as their descendants, and still habitually carry dangerous swords and daggers.

Gold Production during Kushitic Times in Nubia

In Nubia quite a few New Kingdom gold mining sites became reworked later, reusing the older tools, especially the stone mills. At these sites one can observe that the typical, rather flat New Kingdom oval, trough-shaped stone mills bear a distinct deeper secondary concavity, indicating a different and later type of handling of the milling technique.

The most probable age for renewed mining of these sites was during the strong Kushitic Kingdom (about 800–400 BCE). Unfortunately, at these sites only local Nubian ceramics, hard to assign to a distinct period, have been found and more detailed excavations are needed to yield a better chronology. The relatively few sites where this reworked millstone variety, dating to the Kushitic period, was identified, might not have



Mining in Ancient Egypt and Nubia. Fig. 22 Distribution of the gold production sites in the northeastern Sudan (Nubian Desert) during early Arab times. Note that the Arab gold workings never reached the river Nile regions.

been the only gold source of this time, because washing of gold took place in Nubia at least since Middle Kingdom times.

Gold Production in Roman and Byzantine Times

During Roman and Byzantine times, gold production decreased dramatically because of continuous attacks by the desert tribes of the Blemmyes. The Roman presence in the Eastern Desert was restricted exclusively to well-protected desert roads, with fortifications spaced at about a day's walk. It became economically ineffective to protect the many gold mining sites scattered all over the desert. Only a few highly productive sites close to protected roads remained operable during Roman times. In spite of the highly evolved Roman prospecting experience, the gold mining activities in the Eastern Desert dropped nearly to zero in contrast to other regions of the Roman Empire.

The final improvement in the effectiveness of gold processing was the import of the Roman quern technology (Childe 1943), originally a Celtic invention (Cauuet 1991). This type of a round mill, of 30–45 cm in diameter, consists of a basal stone with a disc-shaped hollow in which a round convex upper turning stone was fitted that had a central axial hole and a lateral one for the handle stick (Fig. 20). The quern produced an even finer powder fraction with an improved gold recovery in about a third of the time required by the earlier method. The crushing stones are of characteristic small size (about 15 × 15 cm) and were used as both hammers and anvils. The same tools remained in use until Arab times and querns are still used today within rural areas as flourmills.

For Byzantine times, only very poor archaeological evidence for gold mining exists. Even for the settlement at Bir Umm el–Fawakhir which was inhabited during Byzantine times, and despite the assumption of Meyer and Heidorn (1998), we could find no unequivocal proof for gold ore dressing during an extended survey.

The Bedouin tribes, dominating the entire Eastern Desert of Egypt and the Nubian Desert, traditionally were not interested in mining. This is the same today (Fadl Hasan 1967), as they refuse any digging in the ground, including even simple agriculture in sufficiently watered wadi grounds.

Gold Production in Arab Times

For the early Arab times no field evidence for primary underground gold prospecting has been detected and only existing ancient mining sites became reactivated all over the entire Eastern Desert. In contrast, in Northeast Sudan away from areas close to the River Nile, extensive wadi working operations in secondary gold deposits were started at many new sites. It seems that the mining activities during this period became more concentrated in the southern parts of the Egyptian Eastern Desert including the Wadi Allaqi and especially in the Northeast Sudan. The abundant wadi works in secondary gold deposits formed part of huge fortified settlements, and inclined washing tables surrounded by tailings can be found. According to Floyer (1893), the peak of the early Arab mining activities took place from the 10th to 11th centuries AD, beginning under A. Ibn Tulun (about 990 AD) until the Fatimitic time in Egypt (Fig. 21), and until about 1350 AD in Northeast Sudan (Fig. 22). The rich and highly specialized ceramic finds at these sites indicate different ethnic populations.

We do not know why the Arab gold operations became paralyzed around 1350 AD. Most probably, the productive wadi grounds were worked out and the few underground mines reached their lowest ventilation levels. Around this time also the Christian Kingdoms in Nubia collapsed and their population converted to Islam. Whether this religio-political step has any connection to the cessation of gold production in the Nubian Desert must be left for further investigations.

Nevertheless, it might be taken into consideration that the conversion to Islam opened to the Arabs the possibility of immigration by systematic intermarriage with the local Nubian population. Their concomitant access to the fertile lands around the Nile valley offered a much better livelihood than the increasingly exhausted gold production sites of the unfavourable Nubian Desert.

See also: ►Fishing in Egypt

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Mirrors: Metal Mirrors from India

Sharada Srinivasan

Metal mirrors have a long antiquity in various parts of the Old World and Asia. Mirrors have had considerable magico-religious and aesthetic significance in parts of Asia, for example in China and India. The English word 'speculation' comes from the Roman words meaning magic for telling the future by looking in a mirror (speculum), and mirror divination is still taught in the Tibetan Buddhist tradition. The motif of the celestial maiden, deity or dancer admiring herself in a mirror is an enduring one in Indian sculpture, as exemplified by a Kushan sculpture of a Yakshi or tree nymph from Sanghol (first and second century CE).

Fine bronze mirrors with figurines on the 'tang' or the shank that fit onto their handles are found from ancient Egypt. Early flat, circular or tanged mirrors come from Harappan contexts in the northwest of the Indian subcontinent at Quetta and Harappa in Pakistan (ca. 2000 BCE) and Dholavira in Gujarat, India. These would have been made of bronze with a low-tin content (i.e. less than 10%).

Subsequently bronze mirrors of a higher tin content came into vogue in various parts of the ancient world. Low-tin bronze consists of the coppery-toned solid solution of tin in copper, known as the alpha phase, which enhances its strength. However, it has limited reflectivity, whereas cast bronze with higher amounts of tin has increasingly higher reflectivity. This is due to the formation upon cooling of higher tin bronze of an alpha plus delta eutectoid phase; i.e. a fine mixture of two solid components, the alpha phase and the delta phase which a silvery white intermetallic compound of copper and tin. However, since this delta phase component is also highly embrittling, as-cast higher tin bronze mirrors were usually leaded. Such examples of cast bronze mirrors with 20–25% tin and 5–10% lead are widely found from Han China and the Roman world from the Christian era (Meeks 1993). Bronze mirrors have been one of the most prolific and exotic of Chinese *objets d'art*. The addition of lead improves castability, but lead is an opaque material that is not soluble in copper and may have compromised the reflectivity.

At the village of Aranmula in Kerala in southern India, a unique mirror making tradition survives. Here, a cast high-tin bronze mirror of 33% tin of highly specular or reflective properties is made which is comparable to, if not better than, modern mercury glass coated mirrors (Fig. 1). This is done by optimising the presence of the brittle silvery-white delta phase of bronze while eschewing the use of lead. In an anthropological study, Mukherjee (1978) briefly mentioned the craft of making metal mirrors at Aranmula, while studies were also made by Thomas 1991, Srinivasan and Pillai et al. (1992). The author documented the making of metal mirrors from Aranmula in 1991, followed by detailed technical and micro-structural studies on equipment purchased in early 1992 by Dr. Ian Glover from mirror makers hailing from Malakkara, also in Kerala (Srinivasan and Glover 1995, 1997, 1998). These comprehensive metallurgical investigations on fragments of the mirror alloys established that uniquely, these were made of a binary alloy of copper with 33% tin. This may be described as a high-tin delta bronze due to its close match with the composition of the pure delta phase of bronze, an intermetallic compound ($Cu_{31}Sn_8$) of 32.6% tin and the rest copper. It is this composition, approximating to a pure delta phase, which yields properties ideally suited for a mirror, since it is a hard, stable and silvery compound, which can be polished with great reflectance. The entire mirror manufacturing process seems geared to optimising the presence of this delta phase, which the copper-tin phase diagram indicates forms only within a narrow composition range of bronze of 32–34% tin at non-equilibrium room temperatures (Scott 1991: 95). While this silvery metallic alloy shatters quite easily like glass, this brittleness is offset not by adding lead but by casting a very thin blank, no more than 3-mm thick, which would thus cool quickly with fewer heterogeneities. Then the

Mirrors: Metal Mirrors from India. Fig. 1 Traditional metal mirror of cast high-tin delta bronze (33% tin) made at Aranmula, Kerala.

Mirrors: Metal Mirrors from India. Fig. 2 Cast oval mirror blank of silvery delta bronze mounted on wooden polishing board.

Mirrors: Metal Mirrors from India. Fig. 3 Heating of crucible-cum-mould in a hearth fuelled by coconut husks.

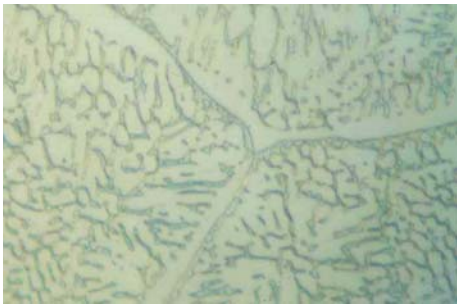
blank is reinforced by mounting it with resin on a wooden mount for the polishing process (Fig. 2). A finished mirror from Aranmula consisted of 32.5% tin, approximating the composition of the pure delta compound of 32.6% tin. Thus, it is remarkable that merely by using traditional 'low-tech' methods and materials a rather sophisticated 'high-tech' metallurgical end product is achieved.

At the workshop of Janardhan Achari of Aranmula, a cleverly made jug-shaped crucible-cum-mould of clay is used for the casting process. The lower portion consists of a two-piece clay mould which is connected to the neck, consisting of a hollow cup wherein the metal pieces to be cast are placed and sealed with clay. Then this closed clay crucible-cum-mould is heated neck down on a hearth (Figs. 3 and 4), whereby the metal melts in the neck, and then the jug-shaped crucible-cum-mould is tipped over so that the molten metal flows into the narrow gap between the oval two-piece mould so that it solidifies into a thin 3 mm oval metal blank. The cast blank, which is retrieved by breaking the mould, is mounted onto a wooden handle and polished over several days with hessian and velvet

Mirrors: Metal Mirrors from India. Fig. 4 Heated inverted crucible-cum-mould being removed from hearth with the lower part containing the metal to be cast. When the jug-shaped crucible-cum-mould is tipped over the molten metal flows into a narrow hollow space for the blank created by two flat disc moulds.

Mirrors: Metal Mirrors from India. Fig. 5 Polishing of cast blank on hessian cloth using the powdered brittle mirror alloy itself for polishing.

cloth to get a mirror finish (Fig. 5). The hardness of the delta bronze alloy was found to be between 500–540 VPN, which is harder than normal steel, and thus the thin mirror blank could be polished almost entirely free of distortion. Ingeniously, the hard mirror alloy is itself used to give the mirror a final polish since it can be easily powdered, as it is highly brittle. This would usefully serve to smooth out and fill in any defects in the cast blank with the same alloy to give the best



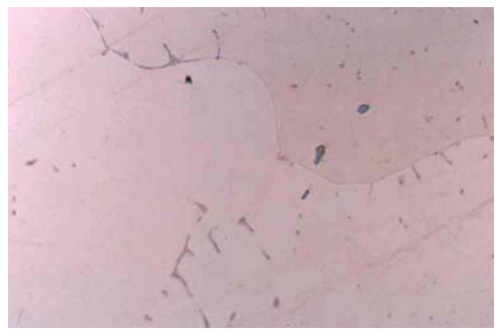
Mirrors: Metal Mirrors from India. Fig. 6 Micro-structure of as-cast 33.4% tin-bronze mirror fragment from Malakkara showing a matrix of silvery-white delta phase with a fine network of bluish alpha plus delta eutectoid (1000X).

Mirrors: Metal Mirrors from India. Fig. 7 Old metal mirror from Kerala showing insignia of the Royal family (seventeenth and eighteenth centuries).

possible mirror finish. The microstructure of an as-cast mirror fragment recently made at Malakkara with 33.4% tin showed a structure consisting predominantly of a matrix of whitish delta phase interspersed with a bluish network of the alpha plus delta eutectoid (Fig. 6).

Such mirrors yield a precise point image, as they do not suffer from blurring due to refraction through glass encountered in standard glass mirrors. The colours seem to be reflected even more brilliantly. For many high-tech applications, the type of refraction that occurs through glass mirrors is unacceptable and 'front-facing mirrors' are used, such as those, which consist of a layer of softer reflective aluminium under a thin protective quartz material. However, as pointed out by T. Poston, the hard Aranmula mirror alloy has comparable reflectivity to these front-facing mirrors and does not scratch easily; unlike a layered surface, it can be repolished. Although the mirrors made these days have a blank which is no more than 7–10 cm along its oval length, in 1998 the elderly Janardhan Achari, perhaps one of the last of the meticulously traditional practitioners, showed a metal mirror with a 30-cm long blank made in his heyday. (Large modern front-facing mirrors are a major challenge to make by the deposition technology).

Fig. 7 shows an old metal mirror from Kerala with the insignia of the Travancore Royal family of Kerala, which may date to the seventeenth and eighteenth century. Metallurgical investigations on tiny fragments of the mirror undertaken by the author at the Department of Conservation and Scientific Research, Freer Gallery of Art, Smithsonian Institution in 1998 indicated that the mirror consisted of almost pure crystals of silvery white delta phase (32.6% tin bronze) (Fig. 8) with practically no eutectoid [as agreed by T. Chase, personal communication]. The absence of the eutectoid suggests that the blank may have been rapidly cooled. This indicates the high level of technological accomplishment in isolating the reflective intermetallic delta compound. This is no small feat even in modern metallurgical terms. The structure of the delta phase is that of gamma brass and contains



Mirrors: Metal Mirrors from India. Fig. 8 Microstructure of fragment of above old mirror showing that it consists almost of pure delta phase crystals with very little inter-granular bluish eutectoid phase (940 X).

icosahedral clusters; the icosahedron being the most symmetric of all objects (Srinivasan and Ranganathan in press). Metaphorically speaking, it is as if the inner beauty of the intermetallic compound mirror stares back at the onlooker gazing into it (Fig. 9). The shadowy whitish patterns in that image (Fig. 9) are in fact the crystals of the predominant delta phase.

This waning handicraft tradition of Aranmula has not only technological significance but also considerable sacred meaning. The Aranmula mirror (*valkannadi* in Tamil and Malayalam), was one of the eight auspicious articles or *ashtamangalyam* set that traditionally made up a bride's wedding trousseau from the Nair and Namburthri communities (Thurston and Rangachari 1909). A Kushan period Jain votive tablet (first and second century CE) (illustrated in Czuma 1985) depicts a mirror as part of the *ashtamangalyam* set. Fig. 10 shows a celebrated sculptural bracket figure of a *madanika* or temple dancer holding a mirror in the steatite temple of Belur, Karnataka of the Hoysala period (twelfth century), and such depictions are also found in the eleventh and twelfth centuries sandstone temples of Khajuraho. [Such mirrors uncannily resemble the thick

Mirrors: Metal Mirrors from India. Fig. 9 Srinivasan demonstrating image reflected in Aranmula mirror with whitish crystals of predominant delta phase being seen in the background.

Mirrors: Metal Mirrors from India. Fig. 10 Sculptural bracket figure from Belur, Karnataka showing *madanika* or dancer with mirror which resembles the Aranmula wooden mount for polishing mirror blanks.

wooden polishing board with a rear handle from Aranmula onto which the mirror blank is fixed with resin for polishing. Indeed, one might speculate that this could have itself been used as a finished mirror as an alternative to the current traditional practice of mounting the mirror blank into a tanged brass frame]. Metal mirrors are also worshipped in Kerala, where they are known as *kannadi bimba.* In a subsidiary shrine at a temple complex dedicated to the Goddess Bhagavati in Ernakulam, Kerala, an old large metal mirror is worshipped as a form of the goddess.

The manufacture of the Aranmula kannadi has been a zealously guarded secret of all but a handful of surviving master craftsmen known as *acharis.* Discussions with them indicate that they believe the craft has an indigenous origin. Local legends link the history of the Aranmula mirror to the Parthasarathy temple to Krishna at Aranmula, one of Kerala's five most sacred shrines. One lively story of the origins of the Aranmula metal mirror was reported in 1992 to Glover by mirror maker Janardhanan Achari (Srinivasan and Glover 1995). Some bronze craftsmen are said to have originally migrated from Tamil Nadu to make artefacts for the Parthasarathy temple. The Raja of Aranmula had threatened to evict, since they had grown fat and lazy. A widow, Parvati Ammal, came to their rescue as she dreamt that Lord Parthasarathy or Krishna had revealed the secret of making an unusual reflecting metal. In an interesting twist, not only was the king placated by the crown made of this material but he also exhorted the artisans to make mirrors for the auspicious *ashtamangalyam* wedding sets of brides-to-be from this alloy dreamt up by the widow.

As indicated before, the unleaded delta bronze mirrors of Aranmula are technologically distinct from mirrors elsewhere, such as the leaded specular bronze mirrors which were common in China. Rather, the Aranmula high-tin delta metal mirror seems to draw from longstanding Indian familiarity with making artefacts of unleaded binary high-tin bronze which had previously been little recognised. Metallurgical investigations were made by the author on vessels from Iron Age burials and megaliths such as from the Nilgiris and Adichanallur in Tamil Nadu, datable to the early to mid first millennium BCE (Srinivasan 1994; Srinivasan and Glover 1995, 1997) and one from Adichanallur by Paramasivan (1941). These were to be wrought and quenched high-tin beta bronze with around 23% tin, ranking amongst the earliest and most finely wrought and elegant examples known in the world, with some having rim thicknesses of no more than 0.2 mm and with a range of decorations from fluted or carinated (shaped like the keel or prow of a ship) shapes, or ringed and floral motifs. Due to the formation at high temperatures of a plastic beta intermetallic compound phase of a composition of 22.8% tin (and the rest copper), these specialised alloys can be hot forged considerably between 600–700°C. Thereafter, quenching in water results in the retention of the high-temperature beta phase in a rapid martensitic transformation, akin to that found in steel, which is characteristic by needle-like structures in the metallic microstructure as seen the quenched structure of an Iron age bowl from Adichanallur. This yields improved properties of golden lustre, musicality, toughness and corrosion resistance. Also, quenching prevents the formation of the low-temperature alpha plus delta eutectoid phase which due to its embrittling effect was undesirable in this case.

Vessels and cymbals of wrought and quenched high-tin beta bronze are still made in Kerala, bearing similarities in design to the megalithic vessels documented by the author in 1991 and with Glover in 1998. Mirrors were amongst the collections from the Nilgiri cairns (of about 40 vessels each in the British Museum and the Government Museum, Chennai) and Adichanallur burials from Tamil Nadu of the early to mid first millennium BCE. One such sample of unleaded 30% tin bronze was reported from the Nilgiri cairns by Breeks (1873: 63, 156). From Sonepur in eastern India an early historic period metallic specimen of 32.4% tin-bronze was reported (Biswas 1996: 187). Minor occurrences of tin have been reported in parts of India such as Hazaribagh in east-central India and in Karnataka in southern India, while the author reported old slags from co-smelting copper and tin ores from the Karnataka region (Srinivasan 1997) which might suggest that minor local tin reserves could have been exploited in southern antiquity. Indeed, Maloney (1975: 26) suggests that tin was one of the items of export from the Karnataka coast by Solomon's army along with peacocks, iron, ivory, apes, gold and silver. Two unleaded bronze samples of 22% and 26% tin were reported from the Indus Valley site of Mohenjodaro (ca. 2500 BCE) (Mackay 1938: 480–81), although without a metallographic study it is not possible to conclude if these were intentionally quenched beta bronzes. From the Bhir mound in Taxila in Pakistan, a binary high-tin bronze mirror of 25% tin was uncovered (Marshall 1951: 567–9). A vessel examined by the author from the Vidarbha megaliths of Maharashtra, carbon dated to about the eighth century BCE, was a quenched high-tin bronze with 21% tin, as was another with 24% tin from the Gandharan Grave Culture of Pakistan of the early first millennium BCE. Rich finds of high-tin beta bronze vessels and bracelets have been found from Ban Don Ta Thailand, fourth century BCE (Rajpitak and Seeley 1979; Bennett and Glover 1992). These show similarities with the Nilgiri and Adichanallur vessels in the ringed and knob-based decorations, although metallurgical comparisons indicate that the south Indian bowls were much more extensively hot forged prior to quenching. While trace element comparisons do not suggest common metal sources, it is possible that Indianised stylistic influences were common to southeast Asia together with other cultural influences such as Buddhism in the latter first millennium BCE. In the medieval Tamil text, *Arrichantira Puranam*, *kanjanam* is used to describe a shining mirror whilst this word is also used to describe cymbals (Tamil Lexicon), conveying the metallic lustre of high-tin bronzes. Thus, it is probable that the Aranmula mirror making process evolved out of longstanding metallurgical traditions prevalent in the Indian subcontinent for the use of bronzes of a high tin content. Significantly, in recent years this skilled and quaint mirror craft from Aranmula has been awarded a Geographical Indicator (GI) patent in India.

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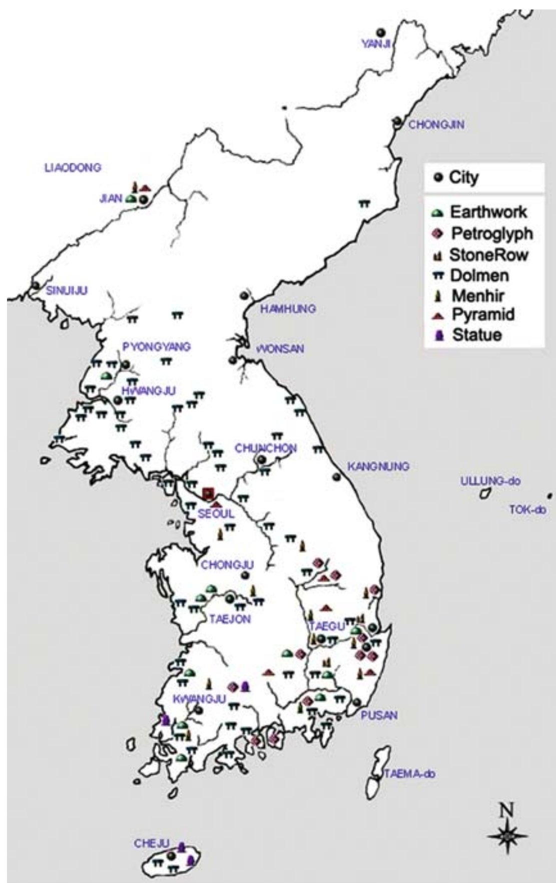
Monuments in Korea

SARAH MILLEDGE NELSON

Megaliths in Korea are either single standing stone slabs (menhirs) or arrangements of standing stones with a large capstone on top (dolmens). Korea has not only the largest number of dolmens in Asia, but the most imposing ones as well. They range in time from about 1500 BCE to the early centuries AD. Dolmens are found throughout the Korean peninsula, but are far more common in areas where rice agriculture was practiced (Fig. 1). Calling these large constructions dolmens is terminology borrowed from Europe, where similar megalithic monuments are found, especially in Western Europe. In Korea they are called *koindol*.

Dolmens are characterized by several standing stones propping up a capstone that covers and extends beyond the vertical stones. A single stone standing alone, without touching another stone, is called a menhir. Various typologies of Korean dolmens have been proposed, sometimes dividing dolmens into as many as seven different types. The simplest division, and the most obvious, is between the table type, which stands above the ground usually on four upright stone slabs with a larger capstone balanced upon them, and



Monuments in Korea. Fig. 1 This map of Korea is showing the ancient remains and the contemporary capital, main cities, rivers, islands around the korean peninsula. Ions of earthwork in the map mean mainly the enormous turf mounds (ancient king's tombs before A.D. 935).

the capstone-on-the-ground type, which covers a burial. The table type is more like the dolmens of Europe after which they are named, but it is clear that those that have only a large stone visible are a close relation. The table type is found mostly in the northern part of the Korean peninsula as well as in Liaoning Province in China, and the other capstone on the ground type is found more in the southern part of the peninsula, although there is no clear demarcation line between the two.

The stone slabs holding up the capstone of the northern type can be as much as two meters high, and the capstone usually weighs several tons. Most were probably burial chambers, although little has been left of their contents. Occasional sherds of red pottery, very rare polished stone daggers, and tubular beads, would place them in the Bronze Age. They appear to be related to cultures from the northeastern part of China that buried their dead in stone slab tombs. If so, then these are highly exaggerated slab graves. They tend to have been erected singly, on heights or in the middle of plains where they could be seen from afar. This meant that they were not difficult to locate, and very few of them escaped looting, in antiquity or later.

Southern style dolmens have a variety of types of graves underground beneath the capstone. They are hard to distinguish from erratic boulders, and therefore have not been plundered at the same rate as the northern ones. Stone cists are the most common form of grave under the ground-level megalithic stone. Some of these burial were untouched, and have yielded small red jars, polished stone daggers, and tubular bead necklaces, sometimes with a curved jade as a pendant. These curved jades are often known in the west by their Japanese named *magatama*, but in Korea they are called *gogok*. Other graves found under dolmens include large jar burials, simple pit burials, and burials topped by a "paving" of small stones. They may have similar grave goods.

In the south, dolmens tend to be found in groups, often in lines. One may be larger or higher than the others, or they may seem to be equal in size. They may be spread along a stream when related to medium sized habitation groups, but as part of larger villages or towns they are often found in one or more rows.

Some dolmens have round pits in them that are known as cup-marks. These could be formed naturally by pebbles being scoured round and round in the rain, but some of them appear to have a pattern and may be deliberately made by a human agency. They have been related in Korea to various myths which associate the birth of important people with eggs.

Menhirs are usually found singly or in pairs. They have been likened to the wooden *changsun* that used to be carved in pairs, one male and one female, leading into Korean villages until the 1970s. Menhirs are less common that dolmens. It is said that there are several fields with seven dolmens arranged in the shape of Ursa Major, or the Big Dipper. The *Chilsong*, the Seven Stars, are sacred to *mudang*, the women shamans of Korea.

Evidence that the southern style lasted into the Iron Age includes one with a cache of Chinese style daggers from the third century BCE. However, most dolmens seem to be associated with Bronze Age pottery and stone tools. It has been argued that rice agriculture brought social changes to Korea that are exemplified by the presence of dolmens. These large constructions would have required considerable labor, which would have had to be coordinated. Furthermore, they suggest permanent leaders, perhaps even chiefs, who had the ability to mobilize the labor of many people. Large villages and towns do not appear in Korea when the main crop consisted of millets; rather, they appear along with rice agriculture and larger settlements. The semi-lunar stone knife, sometimes found in dolmens and always associated with Mumun pottery and Red Burnished pottery, is argued to be a tool for harvesting rice. Nelson (1999) argues that rice agriculture appeared in Korea before dolmens, and that dolmens are related to the increasingly complex social structure that became possible with the cultivation of rice.

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Moses Maimonides

Y. Tzvi Langermann

Moses Maimonides (1135–1204) is without a doubt the single most luminous figure in Jewish intellectual history since Talmudic times. He possessed professional expertise in most of the sciences of his day, most notably astronomy, mathematics, and medicine. Maimonides' early education in Spain, the country of his birth, seems to have stressed the exact sciences in particular. He refers in his writings to his studies with some students of Ibn Bājja. Furthermore, he edited and taught scientific texts written by two Andalusians, Jābir ibn Aflaḥ and al-Muʾtamir ibn Hūd.

In matters astronomical Maimonides' chief contributions concern problems of cosmology and the first visibility of the lunar crescent. As to the former, Maimonides devotes an entire chapter (II, 24) of his philosophical *chef d'oeuvre*, *The Guide of the Perplexed* (Arabic *Dalālat al-Ḥāʾirīn*; Hebrew *Moreh ha-Nevukhim*), to a discussion of the various ways in which the then-accepted models for planets violate certain basic principles of Aristotelian natural philosophy, namely that all heavenly motions be uniform, circular, and about a stationary center. (This problem, by the way, seems to have vexed Andalusian thinkers in particular.) Maimonides surveys the proposed solutions of Ibn Bājja and Thābit ibn Qurra, but he finds no way out of the quandary. It remains a matter of debate among scholars whether Maimonides considered the problem insoluble, since the true workings of the heavens are a matter for metaphysics and hence beyond full understanding, or whether he felt the problem had a solution, indeed, one which would yield a system not very unlike the Ptolemaic models which he criticizes.

In the closing chapters of the section of his law code (*Mishneh Torah*) devoted to the sanctification of the new moon, Maimonides develops a full, sophisticated method for computing whether or not the crescent will be visible on the eve of the thirtieth day of the lunar month. One calculates the "arc of vision," which is the sum of the difference in right ascension between the true positions of the two luminaries, and two-thirds the latitude of the moon. If this arc is greater than 14°, or the sum of the arc and the elongation (the difference in ecliptic longitude between the two luminaries) is greater than or equal to 22°, the moon will be visible. As Maimonides himself avers, the method draws upon written sources, but some of the procedures have been simplified without doing damage to their accuracy.

Maimonides forcefully repudiated astrology. Like nearly all of his contemporaries, he acknowledged a gross physical effect which the motions and luminescence of the heavenly bodies exercise upon terrestrial processes. However, he rejected the notion, central to the astrology of his day, that the stars emanate any noncorporeal force, and he passionately urged that neither individuals nor nations allow themselves to be guided by astrological forecasts.

Maimonides was both a practicing physician and a medical author. According to his account, he traveled daily to treat the sick at court, and upon his return he found his waiting-room full of patients. His medical writings include condensations of the important works of Galen, and a number of original books and monographs. The final section of his own *Aphorisms* (*Fuṣūl Mūsā*, *Pirqei Moshe*) consists of a scathing critique of Galen's views on medicine and philosophy. Maimonides' medical writings display erudition, clear and concise formulations, and insight; however, his place in the history of medicine, particularly against the background of his contemporaries, remains to be determined.

Maimonides held definite opinions concerning the history and philosophy of science. Scientific teachings must be founded upon solid logical demonstrations. True, observations are vital, but purely empirical claims – those whose authenticity rests solely upon repeated observations, but cannot be placed within any logical framework – are not scientific. This point is made forcefully in his treatise on asthma, and it is one of the underpinnings of his rejection of astrology. Moreover, Maimonides held the view that science progresses in a cumulative fashion, through the refinement of existing data and the absorption of new information; there are no revolutionary leaps. Thus he was able to have it both ways with regard to unsolved issues, e.g., the question of the structure of the heavens. He took tactical advantage of the problem, using the cosmological quandary to attack the doctrine of the eternity of the universe (which rested on astronomical arguments), yet at the same time he felt confident enough in his basic understanding of the workings of the heavens to make use of that knowledge as a steppingstone in the path to knowledge of the Creator.

The most lasting influence of Maimonides, at least as far as his Jewish readership is concerned, was not in the specific scientific knowledge that he disseminated. Rather, his momentous contribution was to elevate the study of the sciences within the context of the religious life. According to Maimonides, the ritual performances and ethical demands of the Jewish tradition have as their goal the preparation of the individual for knowledge of God (to the extent that this is humanly possible), and mastery of the sciences is an indispensable step in this process of religious fulfillment. The observant Jew who follows the lead of Maimonides will regard the study of the sciences as a primary religious obligation.

See also: ►Jābir ibn Aflaḥ, ►Thābit ibn Qurra

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Mound Builders

Connie H. Rickenbaker

The subject of mound builders is a vast topic involving numerous groups throughout the Eastern United States. Earthen mounds, one of the visible traits of these cultures, are located from the Gulf of Mexico to the Great Lakes with concentrations in the Midwest along the Ohio and Mississippi River drainages. Numerous mound-building cultures were present across this area and through time, and the mounds served a variety of functions.

In some places conical mounds were built to inter the dead while flat-topped pyramidal mounds served as the foundations for important buildings, such as temples or chiefs' residences. Some of the better known mound sites are Cahokia, near St Louis, Missouri (cultural phases and occupation between AD 800–1200) of the Mississippian tradition (*Cahokia Mounds*), Moundville, Alabama (a dominant center from AD 1250–1500) (*Moundville*), and those associated with the Hopewell Culture (ca. 200 BCE–AD 400), centered in the Ohio Valley (*Hopewell*).

One of the most acrimonious debates of nineteenth century American archaeology concerned the origins of the mound builders of North America. The Europeans first noted the mounds in the late eighteenth century and quickly began arguments as to whether or not the Indians had constructed the structures. These continued until Cyrus Thomas' *Report of the Mound Explorations of the Bureau of Ethnology* (1894) demonstrated that Native Americans had built the mounds.

Styles and raw materials used by individuals varied between cultures based on location and time, but all of the people expressed their creativity and ingenuity through manufactured material artifacts. Indian technology included the actual mound construction, tool manufacture, pottery, and archaeoastronomy. A brief discussion of each technology follows.

Mound Construction

The types of soil and amount of material necessary for mound construction vary with each site whether they were built in prehistoric or historic time periods. The tons of material moved from the point of origin to a mound attest to the division of labor and orderliness of each culture. Individual basket loads denoting the means of transporting the raw material arc often visible at excavations. The number of mounds at a single site varies greatly from one or two to over 100 as evidenced at Cahokia. The number of mounds does not correspond with any particular time period. Watson Brake, the oldest known earthen works in North America, is composed of

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11 mounds all connected by a human-made embankment (*Watson Brake*). One example of mound construction is the serpent mound from the Hopewellian culture which is nearly one-quarter of a mile long (*Serpent Mound*).

The people outlined the structure with small stones and lumps of clay and then dug up tons of yellow clay and then buried their markers. This mound was not a place of burial, but a deliberate religious effigy with the result of a "flawlessly modeled serpent, wriggling northward, mouth agape, trying to swallow a massive egg" (Ballantine 1993).

Tool Manufacture

People of the mound cultures made projectile points for hunting through the process known today as flintknapping. The knapper of a point used an antler hammer or stream cobble to remove flakes from the larger stone core. Smaller flakes were carefully removed as the work progressed on a single point flake. The final forms evident from some mound sites illustrate the meticulous work of highly skilled flintknappers across time and cultures. Changes in projectile point size probably reflect environmental changes that resulted in variations in prey species and probably also in hunting techniques.

For thousands of years prehistoric hunters used a spear or javelin with a point attached to kill their prey. Forms of points aid archaeologists in dating sites where some designs are similar across time, while others differentiate particular cultures. Eventually the *atlatl* or spear thrower was introduced, which increased the casting distance and power of the throws. The hunter held the *atlatl* which was shaped like a large crochet needle. The hooked end was inserted into a shallow socket in the end of the spear opposite the point and hurled with a smooth gliding motion. The *atlatl* was made from available wood while the *atlatl* point was bone or stone.

The technology of preparing meat after the kill also required specialized tools including knives, scrapers, and cutters. Although similarities in design exist across time, individual types are indicative of different cultures. The parent material tells much about a mound site and whether or not the people were involved in trading. Some prehistoric mound sites were cultural trading centers such as Poverty Point (1500 BCE) in northeastern Louisiana where numerous raw materials were used by the people for grafting material artifacts. Trade routes were known to have spanned multiple state areas as the material artifacts were made from copper, quartz, jasper, chert, and flint which were imported into the area (*Poverty Point*).

In addition to the technology for meat preparation, the people of the mound cultures prepared the animal skins for clothing and other utilitarian purposes. Construction of these items required technology for removing, preparing, and sewing the skins. A list of the tools used by people from the different mound cultures includes hammerstones, polishers, and whetstones. These tools required little if any modification of natural materials by the individual. However, once used, the alterations in shape and signs of wear indicate their uses. Other tools such as axes, drills, gouges, celts, and adzes had to be carefully shaped. Drills and gouges were used to make perforations in the skins, while celts and adzes were used for cutting.

Prehistoric technology also included the use of bone to manufacture different tools for the work around a community. The bone tools were made by breaking and grooving animal bones and then grinding the bone to shape the needed object. Fleshers, used to scrape the inside of fresh animal hides, were usually the lower leg bone of a large animal. Awls were used for perforating and sewing along with small hammers, and fish hooks were made from antlers or bone.

Pottery

The need to transport water and store food necessitated the use of containers for these purposes. Pottery making was an integral part of many of the later mound cultures. The earliest designs were simple and fewer vessels were made, but as time passed the designs and technology for pottery making resulted in works of great beauty and complexity. As with projectile points and other tools, the designs, shapes, and materials of the pottery crafted reveal specific information indicative of particular mound cultures.

In addition to everyday use, pottery was also part of ceremonial practices including burial. Whether a vessel or only a potsherd, the pottery yields valuable information about the technology of the cultures. Various tempering materials, including shell, bone, and sand, were mixed with the raw materials to strengthen it. In most mound cultures both decorated and undecorated pieces were crafted and the use of coloring slip was also part of the technology for some.

Decoration on the pottery, whether bowls, jars, or effigy pieces, was usually applied before the vessel was dried. A variety of methods were used which are significant because the individual expressions reflect change over time and culture. Decorations were often made by using the fingertip or a pointed stick or bone. Potters also used the cordwrapped technique which required wrapping a paddle or stick with a cord or woven material and then pressing it into the wet surface to create a pattern. Check-stamped decorating made use of carved bone or wood which was pressed or stamped into the object. As with the technologies of all the mound cultures, some individuals crafted pieces which are exquisite works of art illustrating the creativity and ingenuity of intelligent people from different mound cultures through centuries of time.

Archaeoastronomy

Native Americans are known for their close association with nature and the heavens. The lives of the people from the mound cultures were also intertwined with the cycle of celestial bodies as they observed eclipses and the solstices, devised calendars for ceremonies, and established planting times. They left messages of their science and wisdom in their artifacts and the earthen works which are the visible legacy of their makers.

Archaeologists have studied two research questions related to Mississippian cultures. They concern measurement and units of measurements used by the mound builders/community planners, and archaeoastronomy. Studies have been conducted at Cahokia near St Louis (list of websites provided) and in Arkansas at the Toltec Mound State Park (*Toltec Mound*) to investigate the utilization of both orientation to celestial bodies and preconstruction engineering by the mound builders.

Results from a preliminary study by Sherrod and Rollingson (1987) show that within the Arkansas community there is a predetermined spacing of mounds. The unit is termed the Toltec Module and is measured in increments divisible by 47.5 m. Alignments of the solstice, equinox, and stellar positions are evidence that the mound builders placed importance on the observation and knowledge of celestial phenomena and the mounds were positioned to mark these alignments permanently (*Alignments*).

Reconstruction planning of the community features including mound construction is evidenced by both standardized distance spacing and celestial alignment. "Interaction among many communities of the Mississippi River Valley may well have been widespread with the use of the Toltec Module a reflection of this interaction" (p. 81).

Questions go unanswered and debates continue concerning the mound builders. What do the mounds mean and why were they built? What were the mechanisms which powered the large exchange and trading systems within cultures such as Poverty Point? Also debated is the issue of size of actual populations at the large ceremonial sites. The study of archaeoastronomy and standardized measurements are still in early research stages and thus the extent of Indian technology and meaning are still open for further investigation (*Archeoastronomy*).

Recent research by Saunders et al. (1994) of four mound complexes in Louisiana which predate Poverty Point raises the question as to whether mound construction technology diffused from a single area or independently developed within several cultures. In relation to actual construction of the mounds anywhere, did their makers build one at a time or were multiple mounds under construction at the same time? See below for websites on Watson Brake.

A growing area of research which includes the mound builders is the archaeology of gender (Gero and Conkey 1991; Walde and Willows 1991). Interpretation of archaeological sites has been dominated by views in which women and children were underrepresented if present at all in much research. As the mound builders are studied from more equitable views, questions emerge on women's roles as tool makers and hunters. One theme which unifies the research is the theoretical outlook which views gender relationships as the fundamental structural component to social organization.

Peoples in other parts of the world also built mounds and earthen structures. They frequently consist of only one structure. Several examples are found in Ireland referenced as megalithic tombs and include Newgrange and Knowth (*Knowth*). Lennart S. Madsen discussed earthworks in Scandinavia in his presentation, "The Role of Earthworks in Establishing the Danish Kingdom – second to thirteenth Century AD." At the same Society for American Archaeology 2001 Conference, Maximilian O. Baldia presented "Monuments at the Crossroads: Comparative Archaeology of North American and European Monuments." Their abstracts can be accessed via the internet (*SAA Conference 2001*).

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Moxibustion

Shigehisa Kuriyama

Moxibustion, also spelled moxabustion, is a traditional East Asian therapeutic technique involving the burning of tinder made from the artemisia plant. The technique has three major variants. In one, small cones of the artemisia are burned directly on the skin; in a second, some intermediary substance – commonly a thin slice of garlic or ginger, or a layer of soybean paste – separates the tinder cone from the skin; and in a third, smoldering sticks of artemisia, about a half inch in diameter, are held about an inch to three inches away from the skin. The last two methods fall under the rubric of "warming" or "traceless" moxibustion: both heat the treated sites, but unlike the first technique, they leave no scars. There is, in addition, a hybrid combination of acupuncture and moxibustion in which a clump of artemisia is burned at the protruding end of an implanted needle.

The word *moxa* comes from the Japanese term for the artemisia tinder, *mogusa*. Though the term may have made its way into Portuguese as early as the sixteenth century, printed Western language accounts of the technique began to appear only in the 1670s. For a brief while, it enjoyed a minor vogue in Europe, particularly as a treatment for the gout, but ultimately it did not take root. Still, occasional theses on moxibustion continued to be presented at European medical faculties into the nineteenth century.

The details of moxibustion's origins in China are uncertain. In the most ambitious review of the subject to date, Yamada shows that the therapy originally had magical implications: the aim of cauterization was to drive out alien, noxious spirits. He argues that by the early Han dynasty (206 BCE–AD 220), however, moxibustion had begun to assume a new, quite different identity. Gradually shedding its ties to demonic expulsion, it came to be conceived, instead, as a form of stimulus therapy. The purpose of burning now was to clear blockages in the flow of the body's own essences and rectify imbalances in the distribution of blood and vital breath (*qi*). Yamada's analysis of this change builds upon three theses (1) that the key to the transformation of moxibustion was the "discovery," in the third century BCE, of a series of *mo* – vessels thought to carry blood and vital breath throughout the body; (2) that the theory of the *mo* first arose in the context of moxibustion; and (3) that the practice of acupuncture followed, and was made possible by, the discovery of the *mo* in moxibustion.

Yamada's account may not cover the full story; some evidence suggests that the experience of bloodletting also contributed to the rise of acupuncture. But two points are indisputable. The first is that the earliest descriptions of the *mo* – those in the Mawangdui manuscripts (third century BCE) – concentrate exclusively on moxibustion, and do not mention needling. The second is that from the Han dynasty onward the histories of moxibustion and acupuncture were intimately intertwined. More often than not, acupuncture treatises were, at the same time, treatises on moxibustion. The titles of major traditional texts – from Huangfu Mi's *Zhenjiu jiayijing* (AD 282), through Wang Zhizhong's *Zhenjiu zisheng jing* (1220), to Gao Wu's *Zhenjiu jieyao* (1536) and Yang Jizhou's *Zhenjiu dacheng* (1601) – all evoke needling (*zhen*) and moxibustion (*jiu*) together in the same breath, as a compound, *zhenjiu*. The reason is clear: healing with moxa entailed burning artemisia along the same *mo*, and indeed on the same sites, needled in acupuncture.

Physicians did distinguish between the two therapies. For Yang Jizhow, in fact, the ability to discriminate between when and where to burn and not needle, and conversely, when and where to needle but not burn, marked the superior physician. Gao Wu's *Zhenjiu juying* (1537), for instance, names 45 "forbidden points" for moxibustion (sites where treatment was to be avoided or at least pursued with special caution), but for acupuncture names only 22. The two lists, moreover, have no points in common.

Between the seventh and thirteenth centuries, physicians also composed several treatises devoted to moxibustion alone. Cui Zhiti's *Guzhengbing jiufang* (640) discussed how to treat tubercular diseases with moxa and Wenren Qinian's *Beiji Jiufa* (1226) explained how to deploy moxibustion in emergencies; Zbuang Zhuo's *Gaohuang jiufa* (1128) detailed the special benefits of burning moxa on the so-called *gaohuang* points, whereas the *Mingtang jiujing* (seventh century) reviewed treatment sites more generally, identifying for each site the various ailments treatable by moxibustion.

By slight modifications in technique, moxibustion could be used either to tonify deficiencies in vital energy, or to disperse pathological excess. For example, to tonify, one simply allowed the moxa cone to burn down naturally; to disperse, the therapist blew gently upon the burning cone to make the heat more intense. Traditionally, however, the tendency was to deploy moxibustion primarily as a tonifying technique, and to favor it for treating chronic disorders.

People also turned to moxibustion to prevent illness. In his *Yaofang* (seventh century), Sun Simiao (Sun Simo) notes that officials going to the regions of Wu and Shu made sure always to keep several unhealed moxa spots on their bodies. This, they believed, protected them from a variety of epidemic diseases. More generally, it became proverbial wisdom that burning moxa regularly on special sites like the *sanli* points of the legs warded off sickness of all kinds, and promoted longevity.

Moxibustion's popularity as a prophylactic measure and as a treatment for chronic complaints drew theoretical support from the belief in its tonifying influence. But it also reflected a more basic fact: unlike needling, burning moxa did not require sophisticated technical skill. Once patients learned where to burn – whether guided by illustrated books, tradition, or doctors, then they could treat themselves, or be treated by family members. Thus, while acupuncture and moxibustion shared common historical origins and a common understanding of the body, the sociology of their practice diverged. Whereas acupuncture remained largely the preserve of specialists, moxibustion tended to become part of popular self-treatment. Professional acupuncturists in East Asia today still make use of moxibustion, but so do many patients who have never been needled.

See also: ►Huangfu Mi, ►Sun Simo, ►Acupuncture, ►Medicine in China, ►Medicine in Japan, ►Medical Texts in China

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Mummies in Egypt

Jehane Ragai, Gregg de Young

Mummification was practiced in ancient Egypt to ensure the continued existence of the deceased. At death, several spirits were believed to be released, the most important of which were the Ka, the Ba, and the Akh. A person's fate in the afterlife, in the form of these three spirits, was believed to be directly tied to the continued existence of the physical body.

The Ka, appearing at birth, resembled the human physical body in all aspects. After death, it remained in the tomb with the mummified body, acting as a protective spirit, and fed on the daily offerings presented at the tomb.

The Ba embodied the personality and individual characteristics of the person. It also appeared at birth, but after death was believed to fly off to heaven, returning regularly to visit the Ka and the body. It sometimes seems to serve as "spiritual link" between the two.

The Akh, after a silent or dormant existence during the person's life, separated from the body at death and embarked on a journey through the land of the dead, never to return. All three spiritual elements were essential for the continued existence of the individual and their continued survival depended on the existence of the human body.

Egyptians in the predynastic era, prior to 3100 BCE, buried their dead in shallow graves under the hot desert sands. This left the body prey to wild animals and desert thieves. From the first dynasty (ca. 3100–2900 BCE) on, the Egyptians built mud brick burial chambers, but these, too, proved unsatisfactory because the bodies gradually deteriorated under the action of moisture in these chambers.

By the end of the Old Kingdom (ca. 2600–2180 BCE), the Egyptians had begun to embalm their dead through desiccation by means of dry natron (a mixture of sodium carbonate and bicarbonate). The technique was later termed "mummification" from the Persian word *mummiya*, meaning bitumen or pitch. Corpses embalmed by the Egyptians took on a blackened color, and this effect was mistakenly attributed to bitumen.

By the Middle Kingdom (ca. 2150–1780 BCE), the process was perfect. After death, the body was taken to the "place of purification," where it was stripped and washed in a dilute natron solution. It was then moved to a special "embalming house" where it was placed on a large wooden board. The brain was broken into small pieces by a hooked utensil which was introduced through the nostrils and penetrated the cranial cavity by breaking through the ethmoid bone. The brain was then removed by a long delicate spoon and disposed of. The empty skull was filled with sawdust, resin, or resin-soaked linen.

An incision was then made on the left side of the abdomen and the liver, stomach and intestines removed. A puncture in the diaphragm also allowed for the removal of the lungs. The heart was left in situ as the center in which the good and evil deeds of the individual accumulated. (A light-weighted heart during the day of reckoning would ensure resurrection and an afterlife for the individual.)

The removed organs were washed with a natron solution, dried, and sealed in Canopic jars (often with a solution of natron). These jars were eventually placed in the tomb with the deceased. The empty cavities were washed with palm wine and packed with sand, straw, or sawdust mixed with resin or bags of natron. The body was then placed on a slanting board and covered with dry natron for 40 days to ensure total desiccation by osmosis (the skin acting as a semipermeable membrane).

Following the dehydration of the body came a ceremonial washing and an anointing with oil. The cranial and body cavities were repacked with linen soaked in resin, the abdominal incision was closed, linen balls were placed in the eye-sockets, and the cheeks were padded with linen. The body was then coated with molten resin and subsequently wrapped, beginning from the toes, in strips of linen arranged in intricate patterns. In some cases, the body would be adorned with jewelry, and amulets conferring special protection on the mummy would be enclosed in the linen wrappings.

The entire embalming process took 70 days, after which the ceremony of the "Opening of the Mouth" took place. A priest would symbolically open the mouth of the deceased. This would be followed by an elaborate succession of actions and prayers.

The practice of mummification, with some variations in the process of preparation and wrapping, continued in Egypt until the fourth century AD, when Christianity had become the principal religion. The practice then steadily declined.

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Mummies in South America

Bernardo Arriaza, Vicki Cassman

The Atacama desert, along the west coast of Chile and Peru, is an area of extreme aridity which has provided for unique preservation of human remains and cultural materials from thousands of years ago. The incredible preservation, especially of human mummies, has furnished us with a glimpse at mortuary traditions and rites associated with the first settlers beginning at least 9,000 years ago, through to the arrival of the Spanish Conquistadors.

The Chinchorros fishermen, who lived from 7000 to about 1500 BCE, are of special interest because from 5000 to 1700 BCE, they practiced artificial mummification of their dead. The Chinchorro people lived in the Atacama from Ilo in Southern Peru to Antofagasta in Northern Chile, and occupied about 900 km of the Pacific coast of South America. The area surrounding the modern city of Arica, in northern Chile, was where Chinchorro artificial mortuary practices originated. From this area artificial mummification customs (or intentional interventionary preservation) spread north and south. The bodies were prepared for the journey to the afterlife in remarkable ways. For example, some bodies were completely disarticulated and then wholly reassembled and sculpted. Various styles were practiced through time, such as Black, Red, and Mud-Coated styles. All these styles have two things in common: human intervention in the preservation of the cadaver, and an extended body position for interment.

The Black Mummies were the oldest and most complex, beginning about 5000 BCE and lasting for about two millennia. To make the Black Mummies, the morticians completely cleaned and separated the deceased's bones and soft tissue. Subsequently, the skeletons were reconstructed, and the bodies rebuilt into statue-like rigid forms, using long sticks for internal reinforcement along the extremities and spine. Reed cords bound the bones and sticks together, and a light gray ash paste was applied to stuff and model the individual. The skin was often replaced, and sometimes pieces of sea lion skin were added when the person's own skin did not suffice after drying. Facial features and sexual organs were insinuated. A short wig of human hair was added to the head and secured with cords. Then the morticians painted the entire body with a black manganese paste, which was polished to a high sheen, hence the name Black Mummies.

In contrast, the Red Mummies often were made without disarticulation of the body. Instead incisions were made to remove organs. Long sharpened sticks were pushed under the skin of arms, legs, and the spine to add rigidity, and body cavities were stuffed. After suturing the incisions, the body was painted with red ocher, but the facial mask was often painted black. In a few cases the skin was replaced bandage style. A wig made of long black human hair was added to the head and secured with what looks like a red clay motorcycle helmet. This Red style appeared about 2000 BCE and lasted about 500 years (Fig. 1).

After the Red style, artificial mummification techniques were simplified. The bodies were not eviscerated; they were simply encased in a thick cement-like coating that prevented decomposition. This Mud-coated style lasted only a couple of centuries. After this period,

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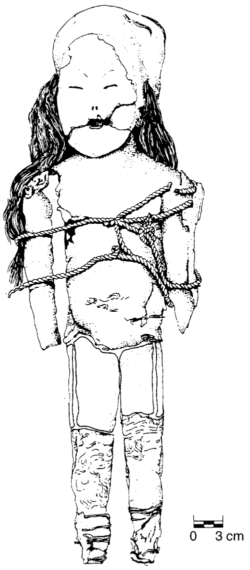

Mummies in South America. Fig. 1 Chinchorro child in the Red Mummy Style (drawing by Raul Rocha, used with permission of the author).

ca. 1700 BCE, the Chinchorro bodies were still buried in an extended position, but were preserved only through the desiccating forces of the environment; they were no longer artificially mummified.

Often the Chinchorro mummies were enshrouded in twined reed mats and buried in shallow pit graves in groups of about six bodies of various ages and both sexes. The cemeteries were located in the sandy coastal dunes beyond the reach of the tides. The few grave goods accompanying the dead were fishing lines, shellfish and cactus fishing hooks, harpoons, bone and stone tools, stone mortars, and gill nets. No individual had a substantially larger number of grave goods that would set him apart as socially above the others. The Chinchorros also received similar mummification and burial treatments regardless of age and sex. Even fetuses were mummified. Apparently everyone was treated equally, with the same mortuary treatment, as would be expected in an early egalitarian society.

Although Chinchorros were simple fisherfolk without knowledge of ceramics, agriculture, or loom weaving, their spiritual and religious life must have been highly sophisticated, as the mummies have demonstrated. The sophistication of the mortuary treatment, the repair of the mummies, and the millennial duration of their practices, all indicate that mummification was central to the social lives of Chinchorro people. It appeared they venerated the mummified bodies of their ancestors by placing them on display for an extended period before burial. Perhaps they petitioned the mummies for blessings during their daily lives. Later South American cultures like the Incas revered their desiccated ancestor mummies (natural mummification). For the Inca the dried bodies of their ancestors were considered *Huacas* or deities that had the power to provide fertility, good crops, and happiness. The Inca brought food and drink to the dead and included the mummies in their religious celebrations. For the Incas and the Chinchorros, the mummies linked the real world with the spiritual world.

The Chinchorros did not vanish after their artificial mummification disappeared about 1700 BCE. On the contrary, their descendants continued to thrive along the Pacific coast, with increased social and political complexity. However, for most areas, after 1500 BCE, the dead were buried in a flexed or seated position, and became natural mummies by the desiccating action of the desert. Post-Chinchorro cultures developed and took advantage of new technologies such as agriculture, weaving, ceramics, and metallurgy, and now the dead were furnished with paraphernalia related to these achievements. Thus, from the numerous grave goods accompanying the dead, it can be seen that post-Chinchorro people also had powerful spiritual concerns about death and the afterlife.

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Munīśvara

K. V. Sarma

Munīśvara (b. 1603), son of Raṅganātha, was born into a family of reputed astronomers of several generations, who had migrated from their original home on the banks of river Godāvarī in the south to Varanasi in the north of India. Munīśvara's paternal uncle, Kṛṣṇa Daivajña, was patronized by the Mughal emperor Jehangir, who ruled from Delhi (1605–1628). Elevating references by Munīśvara to Shahjehan, who succeeded Jehangir as emperor in 1628, and casting the horoscope of the time of Shahjehan's coronation are pointers to the continued royal patronage enjoyed by Munīśvara's family. In his commentary on the *Līlāvatī,* Munīśvara states that another name of his was Viśveśvara.

Munīśvara was a prolific writer, on both mathematics and astronomy, and wrote both original works and commentaries. The *Siddhāntasārvabhauma*, written in 1646, is his major work on astronomy. In 12 chapters, of which nine chapters constituted Part I, the work dealt with the subjects of a normal textbook. In Part II, the work dealt with the armillary sphere, astronomical instruments, and astronomical queries. He also composed a commentary on the work called *Āśayaprakāśinī,* which is dated 1650. On mathematics, Munīśvara has two works: *Pāṭīsāra* and *Gaṇitaprakāśa*. He was an admirer of Bhāskara II. His commentaries on Bhāskara's *Siddhāntaśiromaṇi,* entitled *Marīcī*, and on *Līlāvatī*, entitled *Nisṛṣṭārthadūtī*, are justly famous for their exhaustiveness, lucidity, and citations from earlier authors. He also commented on the *Pratodayantra* or *Cābukayantra*, a short work on an astronomical instrument used for the ascertainment of the time of the day, by Gaṇeśa Daivajña.

Munīśvara had professional detractors whose views differed from his. One was Raṅganātha, author of the manual *Siddhāntacūḍamaṅi* (AD 1640), who, in a short work called *Bhaṅgīvibhaṅgī*, criticized Munīśvara's *Bhaṇgī* (Winding) method of computing true planets. This work was refuted by Munīśvara in his *Bhaṅgīvibhaṅ ī -khaṇḍana*. Another was Ekanātha, an astronomer of Maharashtra origin, settled in Varanasi, who seems to have passed strictures on Munīśvara's exposition of three verses on declension (*krānti*) in Bhāskara's *Siddhāntaśiromaṅi*. Munīśvara refuted Ekanātha's criticism and established his views in a short work entitled *Ekanātha-mukhabhañjana* (A Slap in the Face of Ekanātha).

Though Munīśvara accepted Islamic trigonometry as an aid to studies in astronomy, he severely contradicted the theory of precession advocated by Kamalākara, against which Raṅganātha wrote a work entitled *Loha-gola-khaṇḍana,* which Munīśvara's cousin Gadādhara refuted in his *Loha-golasamarthana* (Refutation of the Loha-gola).

Characteristics that cannot be missed in Munīśvara's writings are the lucidity, chaste language, and the elegant style in which they are couched.

See also: ►Mathematics in India, ►Astronomy in India, ►Precession of the Equinoxes, ►Kamalākara, ►Bhāskara II

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Namoratunga

L. H. Robbins

Archaeoastronomy is the study of archaeological evidence documenting that ancient peoples made systematic observations of astronomical phenomena such as solstices and equinoxes (Robbins 2003, ch. 6). Most typically, archaeoastronomical evidence is reflected in the positioning and alignments of buildings, earthworks and megaliths, such as at Stonehenge in England (Robbins 2000). There, the sun rises over the heel stone on the summer solstice, or first day of summer. In most cases, archaeoastronomical sites are thought to reflect religious beliefs in which the seasons of the year were being monitored for ceremonial purposes as well as for agricultural planning. For example, at the Egyptian desert site of Nabta Playa (Malville et al. 1998: 488) have found megalithic alignments dated to before 4,800 years ago, suggesting "a symbolic geometry that integrated death, water and the sun." This Saharan site is reasoned to have been even older than Stonehenge and other European megaliths. Among other alignments, the stone circle at Nabta Playa known as E-92-9, appears to have been a place that monitored the initial rising of the summer solstice sun.

In Africa south of the Sahara, much less is known about the archaeological record relative to many other areas because of the comparative lack of intensive research. Therefore, the announcement of the discovery of the first archaeoastronomical site in 1978 was of considerable interest (Lynch and Robbins 1978). The site of Namoratunga II, overlooking the barren western shore of Lake Turkana in Kenya has been compared to a miniature Stonehenge. Namoratunga II consists of a series of 19 basalt pillars that have been placed in the ground at angles (Figs. 1 and 2).

The basalt used at Namoratunga II is locally available in the Losidok range. A stone circle surrounds the alignment of pillars, and there is at least one nearby grave marked by upright slabs. This grave is similar to graves at the Namoratunga I site (although Namoratunga I lacks stone pillars) located far to the south adjacent to the Kerio river valley (Fig. 3).

Faint rock engravings which are thought to represent brand symbols used on domesticated animals occur on some of the pillars at Namoratunga I (Fig. 4). The Namoratunga sites are believed to date to approximately 300 BCE.

Mark Lynch, who was working on his Ph.D. in Anthropology at Michigan State University, initially proposed that Namoratunga II was an archaeoastronomical site. Lynch believed that the site was most likely reflective of a calendar system similar to the traditional calendar used by eastern Cushitic speaking peoples of southern Ethiopia. Peoples such as the Borana have a 12-month, 354-day calendar that is based on the rising of Triangulum, Pleiades, Bellatrix, Aldebaran, Central Orion, Saiph, and Sirius. In the Borana calendar, the rising of the above stars and constellations is related to phases of the moon. Lynch found that there were positive correlations between the rising of the seven stars or constellations used in the Cushitic calendar and the alignments of the stone pillars at Namoratunga II.

Like many other archaeoastronomical sites including Stonehenge, the interpretation of Namoratunga II has been controversial. Soper (1982) remeasured the site and argued that the original compass measurements were in error because of magnetite in the stone pillars. For this reason, the view of the site as a calendar similar to the one used by the Borana people has been questioned. Follow up work by Laurence Doyle of the NASA Ames Research Center and Wilcox has confirmed the measurement error detected by Soper. However, when using the tops of the pillars for testing the alignments, Doyle and Wilcox (1986: 129) concluded, "the pillars were used for the specific purpose of aligning with the 300 BCE positions of the Borana calendar stars." (Doyle and Wilcox 1986: 129). They "found 25 two-pillar alignments with the 300 BCE horizon rising positions of the seven Borana calendar stars…" and an equal number of setting positions for the appropriate Borana stars (Doyle and Wilcox 1986: 127). Their statistical tests show that there is a very small chance that these correlations could be random. In a more recent paper Doyle and Frank (1997: 98) have advocated a cautious conclusion by stating that "the Namoratunga II pillars may have been the site of an ancient calendrical observatory, but much yet remains to be done for this to be convincingly concluded."

Namoratunga. Fig. 1 View of Namoratunga II stone pillars near Kalakol (Photo by Robbins).

Namoratunga. Fig. 2 Another view of Namoratunga II stone pillars (Photo by Robbins).

Namoratunga. Fig. 3 Namoratunga I cemetery site showing upright slabs marking graves. Pickup truck for scale (Photo by Robbins).

Interestingly, another stone pillar site has been reported for the eastern side of Lake Turkana at Jarigole, near Alia Bay (Nelson 1995, also see Nelson's paper on Jarigole at ►http://www.arkeologi.uu.se/afr/projects/BOOK/nelson.pdf). The Jarigole site contains

Namoratunga. Fig. 4 Namoratunga cemetery rock art on hill (Photo by Robbins).

at least 28 basalt pillars as well as a thin oval shaped platform and a mound that is about a meter in thickness. Like Namoratunga II, some of the pillars are decorated. However, the decorations appear to be freshly pecked into the surface in comparison to Namoratunga II and, therefore, may well have been added after the site was abandoned. Nelson (1995) believes that the site dates to early in the Pastoral Neolithic based on the discovery of numerous Nderit potsherds, a highly distinctive ceramic tradition centering in the Lake Turkana basin. At the east Turkana site of Dongodien such pottery dates to approximately 4,000 years ago, implying that Jarigole may be about the same age, assuming that the pillars were erected at the same time that the Nderit pottery was deposited at the site. If the age estimate for the pillars is correct than the Jarigole pillars are substantially older than those at Namoratunga II, (ca. 2050 BCE versus 300 BCE) unless the age of the latter site is much too recent.

Nelson (1995: 52) writes that many of the pillars at Jarigole "are badly tilted and are probably shifted from their original position. Therefore, it will not be possible to determine if there are significant astronomical alignments among the pillars." However, Lynch (1978) has noted that pillars are intentionally set in the ground at angles by some Eastern Cushitic peoples in nearby southern Ethiopia. Based on the discovery of human remains and other information, Nelson (1995) has concluded that Jarigole was primarily a mortuary or burial site. Could this stone pillar site be related to Namoratunga II?

Clearly, it would be important to establish accurately the age when the pillars were erected at both Namoratunga II and Jarigole. The age of Namoratunga II is currently based on similarities to Namoratunga I which has yielded a radiocarbon dated human bone sample of ca. 300 BCE (and the good fit between this date and the Borana star alignments at that time), while the age of Jarigole is based on the presence of Nderit pottery. Unfortunately, it is not possible to date when the pillars at either site were erected by the radiocarbon method. However, I have suggested elsewhere (Robbins 2006) that it may be possible to obtain optically stimulated luminescence (OSL) dates from the sediments that lie directly beneath the base of the upright pillars at both sites. OSL dating is now widely used in African archaeology to date the last time that sediments were exposed to sunlight before they were buried. We have used it successfully to date sediments at archaeological sites in the Kalahari Desert of Botswana. In the case of the erection of the Lake Turkana pillars the last time the sediments were exposed to sunlight would have been when the holes were excavated immediately before the pillars were placed in them. The OSL sediment samples could be readily obtained by using a sand auger to dig at an angle directly underneath of the pillars. The resulting ages would for the first time allow for a close comparison of when the pillars at both of these sites were erected, and the OSL method could also be applied to the dating of other stone pillar sites located to the north of Lake Turkana in Ethiopia.

Is the Namoratunga II stone pillar site an archaeoastronomical site? Megalithic sites such as Stonehenge, Namoratunga and Jarigole provide a powerful testimony to the work efforts, symbolism, and beliefs of ancient peoples. Whereas archaeologists have learned much about these sites it is quite likely that they had multiple meanings to the people that created them. It is also clear that such sites can have different meanings to other people through time, such as the use of Stonehenge by hippies, modern druids, and others (Chippindale 1986).

In the local Turkana language Namoratunga means "people of stone," referring to a legend that the pillars (as well as upright grave slabs) were once people who were turned to stone while they were dancing because they mocked a spirit that had appeared to them. It is useful to conclude with the first two lines of a Turkana song that expresses their view about Namoratunga (see Lynch 1978 for the remaining verses).

> "Who knows how the standing stones were forged?
> "Who knows how to make the fire of Namoratunga?"

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N

Nanjing

Richard Bertschinger

The *Nanjing* (Canon on Medical Difficulties) appeared probably in the first or second century AD. However, the Chinese believe it was written in the first or second century BCE. Its authorship is unknown, although tradition has ascribed it to Qin Yueren, the usual sobriquet for Bian Qiao, the eminent Zhou Dynasty physician who is said to have lived in the sixth century BCE. Attribution to an ancient legendary doctor is common in Chinese medical works. The most valued commentary is the *Nanjing Benyi* (The Genuine Significance of the *Nanjing*), compiled by Hua Shou in 1366. The book further develops the ideas of the *Huangdi Neijing* in question and answer format, revealing an increasing tendency for medical books to concentrate on acupuncture.

The following are outlined in the *Nanjing*:

- The criteria for pathology and health
- The existence of *xu* (weak, deficient) or *shi* (full, excessive, toxic) conditions
- The passage of disease through the various organs

- Pathology, especially that concerned with dissipation and cold-induced fevers
- The attributes of a skilled or "divine" physician
- The structure of the organs, including their weights and measurements
- Needling technique

Methods of tonification and sedation are particularly focused upon. Acupuncture points appear for the first time in various groupings, with a concentration on the *shu* (passage) points on the lower parts of the four limbs. One of its most influential ideas is the use of the points for particular categories of disease. Pathologies of the channels, and pulse diagnosis, are also touched upon.

The *Nanjing* contains 81 chapters. The *jingluo* (channels) appear in Chapters 23–29, the *shu* points (passage points) on the limbs in Chapters 62–68, whilst Chapters 69–81 concentrate on needling. These sections show the development of extreme precision in needling, and a focused rationale during practice.

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Nārāyaṇa Paṇḍita

Takanori Kusuba

Nārāyaṇa was one of the major authorities on Indian mathematics after Bhāskara II. We do not know when or where he was born. All we know about his life is that he is the son of Nṛsiṃha (or Narasiṃha). Nārāyaṇa wrote two Sanskrit mathematical texts: the *Gaṇitakaumudī* on *pāṭī* (arithmetic) in 1356 (which is confirmed by the final verses of the book) and the *Bījagaṇitāvataṃsa* on *bīja* (algebra). The two books consist of rules (*sūtras*), examples (*udāharaṇas*) and commentary (*vāsanā*) thereon. A reference to the *Bījagaṇitāvataṃsa* is found in the *vāsanā* on the *Gaṇitakaumudī* but not in the *mūla.*

The *Gaṇitakaumudī* consists of *paribhāṣā* (metrology units), *parikarman* (basic operations) and 14 *vyavahāras*: the traditional eight *vyavahāras kuṭṭaka* (a linear indeterminant equation such that $y = ax+c/b$), *vargaprakṛti* (a quadratic indeterminant equation such that $Px^2 + t = y^2$), calculations for fractions, rules for fractionizing, the net of digits (combinatorics), and magic squares. The 12 *vyavahāra* includes rules to express the number one as the sum of a number of unit fractions, which are similar to those given by Mahāvīra. The rules in chapter 13 are modeled on those of the *Līlāvatī* but are further advanced and can be compared to the rules for combinatorics in metrics and music. The *Gaṇitakaumudī* is the first Sanskrit mathematical text so far available that deals with magic squares.

The *Gaṇitakaumudī* was published by Padmākara Dvivedī in two volumes based on a single manuscript which had belonged to his late father. The numberings are not accurate. A critical edition of the last two *vyavahāras* with an English translation and his own commentary was published by Kusuba in 1993. The entire work was translated from Dvivedī's edition into English by Paramanad Singh in 1998–2002.

There are five cases of enumerations of digits discussed in the 13 *vyavahāra*. Pattern 1: digits unequal to each other are arranged in a fixed number of places. For example, there are four digits, 1, 2, 3, 6, in four places.

Pattern 1

1	1236	7	1263	13	1362	19	2361
2	2136	8	2163	14	3162	20	3261
3	1326	9	1623	15	1632	21	2631
4	3126	10	6123	16	6132	22	6231
5	2316	11	2613	17	3612	23	3621
6	3216	12	6213	18	6312	24	6321

Pattern 2: digits, some of which are the same, are arranged in a fixed number of places. For example, there are four digits, 1, 1, 2, 4, two of which are the same in four places.

Pattern 2

1	1124	4	1142	7	1241	10	4121
2	1214	5	1412	8	2141	11	2411
3	2114	6	4112	9	1421	12	4211

In the following three patterns the digits are variable. Nārāyaṇa calls the highest possible digit the final digit. In pattern 3, the number of places and the final digit are fixed, but the sum of the digits in each extension is variable. For example, the final digit is 3 and the number of places is three.

Pattern 3

1	333	10	332	19	331
2	233	11	232	20	231
3	133	12	132	21	131
4	323	13	322	22	321
5	223	14	222	23	221
6	123	15	122	24	121
7	313	16	312	25	311
8	213	17	212	26	211
9	113	18	112	27	111

Pattern 4: the final digit and the sum of digits are given but the number of places is variable. For example, the sum of digits is seven and the final digit is three.

Pattern 4

1	133	12	2122	23	2131	34	3211
2	223	13	11122	24	11131	35	12211
3	1123	14	1312	25	1321	36	21211
4	313	15	2212	26	2221	37	111211
5	1213	16	11212	27	11221	38	13111
6	2113	17	3112	28	3121	39	22111
7	11113	18	12112	29	12121	40	112111
8	232	19	21112	30	21121	41	31111
9	1132	20	111112	31	111121	42	121111
10	322	21	331	32	2311	43	211111
11	1222	22	1231	33	11311	44	1111111

Pattern 5: the number of places and the final digit are fixed but the sum of the digits is variable. This is an example where the final digit is eight and the number of places is three. The digits are arranged in ascending order.

For each pattern the order of the extension is determined in one and only one way. The numbering is put into each table. The method to restore an arrangement which is unknown though the number of extensions is given and the method to find a serial number when an arrangement is indicated are given. The calculation of the number of variations available and the rule for counting the times of each digit are also given. The arrangement of digits is treated as a number; the sum of all the numbers enumerated is to be calculated.

The *Bījagaṇitāvataṃsa*, which seems to be modeled on the *Bījagaṇita* of Bhāskara II, is divided into two parts. Part I deals with six operations (addition, subtraction, multiplication, division, squaring, and extracting the square root) for positive and negative numbers, zero, unknown quantities and surds as well as *kuṭṭaka* and *vargaprakṛti* mentioned above. The rules for indeterminant equations in the extant portion are similar to those in the *Gaṇitakaumudī* as well as those of Bhāskara II. Part II deals with four subjects: (1) linear equations in one unknown, (2) linear equations in more than one unknown, (3) quadratic equations in one unknown, (4) equations involving the product of different unknowns.

Only Part I and the opening lines of Part II were published based on a single and incomplete manuscript at Benares. The part of Sect. 1 of Part II was published by Hayashi with English translation and his commentary.

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Naṣīr al-Dīn al-Ṭūsī

F. Jamil Ragep

Abū Jaʿfar Muḥammad ibn Muḥammad ibn al-Ḥasan Naṣīr al-Dīn al-Ṭūsī was born on 17 February AD 1201 in Ṭūs in the northeastern Persian province of Khurāsān and died in Baghdad on 25 June 1274. He was a preeminent figure in medieval Islamic history, being a major participant in both political and intellectual life during a century that witnessed monumental changes in the Islamic world. Politically, he was active at the courts in Iran of both the Ismāʿ'īlīs, a Shīʿite sect, and the Mongols who brought to an end both the formidable political power of the Ismāʿīlīs as well as the 500-year old ʿAbbāsid Caliphate. Intellectually, he played an even more important role, forging an intellectual synthesis that can be compared to that of

Pattern 5

1	678	9	368	17	248	25	267	33	147	41	346	49	145
2	578	10	268	18	148	26	167	34	237	42	246	50	235
3	478	11	168	19	238	27	457	35	137	43	146	51	135
4	378	12	458	20	138	28	357	36	127	44	236	52	125
5	278	13	358	21	128	29	257	37	456	45	136	53	234
6	178	14	258	22	567	30	157	38	356	46	126	54	134
7	568	15	158	23	467	31	347	39	256	47	345	55	124
8	468	16	348	24	367	32	247	40	156	48	245	56	123

Zhu Xi (d. AD 1200) in China and Thomas Aquinas (d. AD 1274) in the Latin West. Ṭūsī, though, was not simply a synthesizer and rejuvenator of the Hellenistic tradition in Islam; he also made innovative and significant contributions in science and mathematics.

Ṭūsī was born into a scholarly family of Imāmī (Twelver) Shīʿites, one of the two major sectarian divisions of Islam. Although he received religious education at home, Naṣīr al-Dīn tells us in his autobiography, written when he was in his forties, that his father, "a worldly man," encouraged him to explore different sciences and listen to the masters of various sects and opinions. This he did and began studying the diverse branches of ancient science and philosophy, especially mathematics. Not content to remain in his hometown, he traveled while still a teenager to Nīsābūr, a major city in Khurāsān located to the west of Ṭūs, and became the student of a noted physician and a philosopher. It was at this point in his life that he began to study the works of his famous Persian predecessor Ibn Sīnā (Avicenna), whose works were influential in both the Middle East and Europe. He would later travel to Iraq and study both religious and secular subjects with several noted scholars. Though Ṭūsī's education was far from typical, one can gain some valuable lessons for trends that were occurring at the time. The fact that Ṭūsī was a Shīʿite did not prevent him from studying with persons of different sectarian affiliations. Furthermore he was motivated to travel fairly widely to receive an education. Finally, he studied both religious subjects (*al-ʿulūm al-sharʿiyya*; "the Islamic sciences") and the rational sciences that had been appropriated into Islam (*al-ʿulūm al-awāʾil*; "the ancient sciences"). The latter is important because Ṭūsī, especially in his later writings, felt that the ancient sciences – both philosophical and mathematical – could provide the means to transcend the religious disputes that had plagued Islam.

His formal education completed, Naṣīr al-Dīn would spend some 25 years (from the early 1230s until 1256) at the Persian courts of the Ismāʿīlīs, a powerful Shīʿite group that had for a time vied for ascendancy in the Islamic world. (These were the Assassins of Crusader lore.) Whether Ṭūsī himself willingly converted to Ismāʿīlism or simply pretended to do so is a matter of dispute; whatever the true state of affairs, he did find a refuge from the ravages of the Mongol invasions and did produce some of his most important work during this period of his life.

After the fall of the last Ismāʿīlī stronghold at Alamūt in 1256, Naṣīr al-Dīn, by then a famous scholar, was enlisted by the Mongol conquerors of Iran into their entourage, becoming court astrologer as well as minister of religious endowments. He was also charged with building an astronomical observatory in the town of Marāgha in Ādharbayjān in northwest Iran. This was one of the most ambitious scientific institutions that had been established up to that time; because of the resources placed at his disposal (which included the religious endowments), Ṭūsī was able to oversee construction of the observatory and its instruments as well as a large library and school. A substantial number of scientists and students were attracted to Marāgha; indeed there are reports of Chinese astronomers on the staff. In 1274, Naṣīr al-Dīn left Marāgha with a group of his students for Baghdad and died there in that same year.

Works

Ṭūsī was one of the most prolific authors of the Islamic medieval period, and his works, written in both Persian and Arabic, number something over 150. (This does not include his poetry.) He wrote on both religious topics and on nonreligious or secular subjects that had been inherited in the main from ancient Greece. Here we have an example of an important trend that was beginning to take root in the thirteenth century, namely the breaking down of the earlier division between those who wrote exclusively in the "Islamic" or "Arabic" tradition and those who devoted themselves to the Greek tradition. Among Ṭūsī's religious writings are seminal works on Shīʿīte law (*fiqh*), dialectical theology (*kalām*) and Sufism. Works in the tradition of Greek philosophy included the very influential *Nāṣirian Ethics* and his commentary on Ibn Sīnā's *al-Ishārāt wa ʿl-tanbīhāt* (Book of Directions and Remarks), which helped engender a renewed interest in his great Persian predecessor. Ṭūsī very much hoped that philosophy could provide a means toward rising above the many religious disputes that so racked Islam during his lifetime. In writing his commentary to Fakhr al-Dīn al-Rāzī's work on *kalām*, he wished to widen the opening Rāzī had made in allowing Greek philosophical concepts to enter the intellectual space of *kalām* while at the same time defending those concepts (as expounded by Ibn Sīnā) against Rāzī's attacks.

Naṣīr al-Dīn was especially attracted to the exact sciences, which, as Ptolemy had argued, provided a more sure means to truth than the murkier disciplines of physics and metaphysics. He thus devoted a considerable amount of his intellectual efforts to mathematics and astronomy. His recensions of Greek and early Islamic scientific works represent one of his most important contributions to the Islamic scientific tradition, an attempt to give vitality and renewed meaning to the translation movement of ninth century Baghdad. Because of the lack of an ongoing institutional structure for the teaching and perpetuation of science, Ṭūsī's reeditions, which often included insightful and original commentary, provided the means by which generations of students of late medieval Islam could assimilate the Greek scientific tradition, either with or without a teacher. These included Euclid's *Elements*, Ptolemy's *Almagest*, and the "Middle Books" of mathematics and astronomy with treatises by Euclid, Theodosius, Hypsicles, Autolycus, Aristarchus, Archimedes, Menelaus, Thābit ibn Qurra, and the Banū Mūsā.

In addition to this monumental role as textbook writer, Ṭūsī is also know for his original work, some of which occurs within these recensions. In mathematics, this included a highly sophisticated attempt to prove Euclid's parallels postulate, part of a long tradition that would eventually culminate in the nineteenth century with the realization that such "proofs" were not possible and that consistent non-Euclidian geometries using alternative postulates were constructible. In spherical trigonometry, Ṭūsī produced an important synthesis of earlier results of Islamic mathematicians; this marked a significant step in treating trigonometry as a discipline independent of astronomy, comparable in many respects with what was done later in Europe by Regiomontanus (1436–1476).

Ṭūsī, though, was most famous for his work in astronomy. In addition to a number of elementary treatises on practical astronomy, instruments, astrology, and cosmography (*hay'a*), many of which were meant for students, Ṭūsī also composed his *Zīj-i Īlkhānī*, a major astronomical handbook, for his Mongol patrons in Marāgha. Though not very original, and apparently compiled in haste without incorporating the Marāgha observations, it was destined to be widely used.

Ṭūsī's most original achievement was in theoretical astronomy. From a rather early date, Islamic astronomers had been disturbed by a number of inconsistencies in the Ptolemaic system, for example that some models violated the fundamental principle that all motions in the heavens should conform to the dictate of uniform circular motion. Ṭūsī responded to this by devising an astronomical model consisting of two rotating spheres the smaller of which was internally tangent to another twice as large. By having the smaller rotate twice as fast and in the opposite direction as the larger, Naṣīr al-Dīn was able to produce the linear oscillation of a given point, a property he was able to use in lunar and planetary models that could reproduce Ptolemaic accuracy while preserving uniform circular motion. Ṭūsī's new models had a decisive influence during at least another three or four centuries of late medieval Islamic astronomy, where they provided the starting point for numerous attempts to reform the Ptolemaic system. His device, which has been dubbed "the Ṭūsī couple," found its way into Sanskrit and Greek texts, and was influential in the work of several Renaissance astronomers, including Copernicus.

But Ṭūsī's most enduring influence, in fields as diverse as ethics, natural philosophy, mathematics, Sufism, astronomy, *kalām, fiqh*, music, mineralogy, and logic, was in the Eastern Islamic world, and in particular Persia, where his works continued to be studied and commented upon into the modern period.

See also: ►Marāgha, ►Ibn Sīnā, ►Astronomy in China, ►al-Rāzī, ►*Almagest*, ►*Hay'a*, ►Astronomy in the Islamic World, ►Marāgha

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Nāṣir-I Khusraw

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Abū Muʿīn Nāṣir ibn Khusraw al-Kabādhiyānī was a Persian philosopher, poet, and traveler. Born at al-Kabādhiyān in Transoxania (now in Tajikistan) in 1004, he was one of the founders of Ismāʿīlī theosophy and lived at Balkh and Ghazna (now in Afghanistan) at the court of the Ghaznewid sultans Maḥmūd and Masʿūd. After the Seljuqid conquest, he lived at Marw at the court of Seljuqid Chaghri Beg. He traveled from the Maghreb to India. In Egypt he became Ismaʿīlī and was made the Ismaʿīlī missionary in Persia and Transoxania. In this he was persecuted and was forced to take shelter in Yomghan in the Pamir mountains (now in Afghanistan). He wrote in both Persian and Arabic.

His main work is the *Safar-nāmeh* (Book on Travels), the diary of his journeys, containing an account of life in Egypt under the Fatimid Caliph al-Mustanṣir (1035–1094), and various geographic, ethnographic, and archaeological information.

In his philosophical treatise, *Kitāb zād al-musāfirīn* (Book Supply of Travelers), which is a survey of Isma ʿīlī theosophy, there is information on the history of science and fragments of the philosophical treatises of Abū Bakr al-Rāzī (854–935) on space, time, and matter.

His philosophical *Kitāb jāmiʿ al-ḥikmatayan* (Book Joining Two Wisdoms) is devoted to the harmony between Greek philosophy and Ismaʿīlī theosophy. He also wrote a philosophical *Rowshanāʾī-nāmeh* (Book of Light) in six chapters, *Saʿādat-nāmeh* (Book of Happiness), *Kitāb gushāyish wa rahāyish* (Book of Unfettering and Liberation), *Wajh-i dīn* (Face of the Faith), and *Khān al-ikhwān* (Meal of the Brethren).

He also was the author of a nonextant mathematical treatise, *Gharāʾib al-ḥisāb wa ʿajāʾib al-ḥussāb* (Marvels of Arithmetic and Wonders of Calculators), containing two hundred problems with solutions and demonstrations to solve them correctly. In this treatise Nāṣir-i Khusraw complains of the absence of good mathematicians in Khurasan in his time. He died in ca. 1088.

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Navigation in Africa

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The physical geography and environment of the African continent precluded extensive water transportation on the interior waters, although light boats have been in use at least since the Middle Ages for fishing and transit on lakes and stretches of rivers between rapids and where permitted by depth or the tides. Navigation properly speaking was determined by three distinct regional environmental systems in the north, west, and east. Available historical data are uneven over time and area. Participation of native African peoples in naval activities originating in Africa is not always attested by the sources. In the Mediterranean Sea, ancient Egyptian rulers, the kingdom of Israel, and Carthage made use of the sailing and shipbuilding skills of Phoenicians. Pharaonic Egypt, Israel, and ancient Ethiopia (Axum) used the Red Sea as part of a commercial system linking the eastern Mediterranean with the Middle East, East African coast, and India.

Under the Old Kingdom expeditions had been sent to the land of Punt (southwest coast of the Red Sea or the Somali coast facing Arabia) for gold, ivory, ebony, and myrrh. Ships built at the head of the Gulf of Suez traveled south under the Fifth and Sixth Dynasties (ca. 2470–ca. 2280 BCE). A Red Sea shipwreck under the Middle Kingdom (ca. 2000–1800 BCE) is recorded in the Egyptian *Story of the Shipwrecked Sailor.* Under the New Kingdom, expeditions were resumed by Queen Hatshepsut (ca. 1495 BCE). According to Herodotus, the pharaoh Necho II (ca. 610–595 BCE) was first to attempt linking the Nile with the Red Sea by a canal. After calling off the construction he sent a fleet manned by a Phoenician crew to circumnavigate Africa clockwise. They took over 3 years to complete the journey, discovering in the process that Africa was surrounded by water. Some time before 480 BCE, a counter-clockwise circumnavigation was attempted by Carthage. This voyage, described in the Greek document known as the *Periplus of Hanno*, may have discovered both the Canary and Cape Verde islands, subsequently forgotten and rediscovered again centuries later. In the north, Carthage reached out into the Atlantic as far as the British Isles and possibly the Baltic. Access to these routes was strictly controlled and outsiders were attacked to prevent competition. In the Mediterranean, Punic trade interests inevitably ran into conflict first with Greece and then with Rome. With the decline of Carthage, navigation on the Mediterranean effectively became part of the western scientific and technological tradition.

Oceanic navigation in the African Atlantic is poorly documented. There is no evidence of sea-worthy vessels being constructed in sub-Saharan West Africa in premodern times. However, several reports indicate that sailing in the Atlantic was occasionally attempted, usually resulting in failure. Juba II, king of ancient Mauretania and a Roman ally, sent a fleet to the Canaries in about 25 BCE and later had the Atlantic coast of Morocco explored. In the Islamic period, the route to the Canaries seems to have been forgotten, although the Arab geographers inherited knowledge of the islands from Ptolemy. The legend of a statue at Cadiz forbidding travel beyond the Pillars of Hercules was transferred to the Fortunate Isles (*al-Saʿādāt*), or Eternal Isles (*al-Khālidāt*), as the Arabs called them after Ptolemy. A report by the geographer al-Idrīsī (ca. 1154) tells of an attempted expedition to the Canaries under the Almoravid ruler Yūsuf ibn Tashfīn (1061–1106) who controlled parts of western Africa from the Senegal River to Morocco and Algiers. The admiral in charge having died before departure, the voyage never took place. Al-Idrīsī also describes an intriguing adventure originating in Lisbon. Some time before 1147, 80 explorers (*mugharrirūn*) of Lisbon built a large ship, loaded it with enough food and water for several months, and after sailing west and south for a total of 35 days came to an island where they were forced to land by light-skinned men in boats. The king, speaking through an Arabic interpreter, told of an expedition ordered into the sea by his father. After sailing "across" the sea for a month, that group had returned having found nothing. The explorers were then taken to the mainland, reached after sailing with the west wind for "three days and nights." Their final rescue was effected by the Berbers of the Atlantic coast of Morocco.

Arabic accounts of the thirteenth and fourteenth centuries, especially those by Ibn Fātima (related by Ibn Saʿīd al-Maghribī) and Ibn Fadl Allāh al-ʿUmarī) suggest continuing but accidental maritime contacts between Morocco and Spain on the one hand, and black West Africans on the other. The availability of Arabic or Berber interpreters among peoples encountered by Muslims in these voyages undermines the speculation that these expeditions constitute an African discovery of the Americas. Of special interest is one report by al-ʿUmarī which describes an attempt at exploration of the Atlantic by a ruler of Mali, Abū Bakr II, who was the predecessor of the famous Mansā Mūsā (1307 or 1312–1327). An expedition of 200 light boats was sent down the Senegal River with provisions "to last many years." Only one vessel returned, with a story of the others disappearing in a violent current at sea. The persistent ruler equipped 2,000 new boats (1,000 of them filled with stores of food and water) and departed on a second expedition, never to return. Some have suggested that Morocco was the intended destination but the text gives no such indication, citing "the extremes of the ocean" in the king's order. No such further attempts are known.

Early modern European travelers in West Africa noted the existence of large canoes in the estuaries of rivers from Sierra Leone to the Niger Delta. Some of the large dug-out canoes, made of a single tree trunk, could carry small cattle, several horses, or up to 80 men and their sleeping mats. They had cooking hearths and occasionally "a sort of quarter deck, made of strong reeds" or a platform amidships. The canoes were propelled by wooden paddles and bamboo or palm-tree poles and could have sails made of grass mats (later of woven cloth) attached to masts of light cane. Their speed varied from 1 to 3 miles per hour. Larger vessels from planks may have been made from the sixteenth century on. There is no evidence of the use of outriggers or leeboards until the twentieth century. Boat builders and crews were sometimes drawn from servile populations. In West Sudanese empires, especially Songhay, heavy river canoes were used not only for trade and fishing, but also to enhance the cohesion of the state, to move troops and captives (slaves), and to conduct "naval" attacks or blockades. States had court officials in charge of matters relating to the river or state canoes: in Songhay it was the *hari-farma* (chief of the waters), while Lagos had the *aromire* (friend of the waters). From river estuaries the largest canoes reportedly ventured into coastal waters, against prevailing currents and winds, reaching from the Niger Delta as far as Angola.

Premodern naval communications in Eastern Africa were subject to different conditions in the three subregions: the Red Sea, the East African coast with the adjacent islands, and Madagsacar with the Comoros. Numerous port cities on the coasts of Eritrea and northern Somalia are mentioned in the *Periplus of the Erythrean Sea* and in Ptolemy's *Geography* for the first and second centuries AD, respectively. Adulis (ancient Berenice, at Massawa) became the principal port of the Ethiopian empire (Axum). Both Pseudo-Callisthenes (third century) and Cosmas Indicopleustes (sixth century) attest to the presence of Ethiopian merchants in India and Ceylon (Sri Lanka). However, it is not always clear in these or later reports who the sailors and navigators were. *The Periplus of the Erythrean Sea* specifies Arab supremacy on oceanic routes leading from Yemen to Africa and India. Early Islamic history records attacks on Arabian ports and shipping by Ethiopians, repulsed by the Arabs who established their firm control on the Red Sea by the early eighth century. However, Africans from the coasts of Ethiopia, the

Horn and the Dahlak islands continued to be involved in trade and piracy on the Red Sea. They also served as sailors on boats sailing the Indian Ocean owned by Arabs, Persians, Swahili, Indians, and even Portuguese. Massawa boats were described in the eighteenth century as "very slight and unsafe," but capable of carrying a "great weight." They were, as in previous centuries, of the sewn type with mat sails, equipped with a crew of seven or eight men.

Zeila and Barbara were major African counterparts to Aden, receiving fleets from Africa heading north or Indian and Persian Gulf vessels destined for Jedda. From Zeila and Massawa trade routes led inland, providing important access for Ethiopia to major commercial networks even during the centuries of its isolation from the world by a ring of Muslim principalities bordering on the sea. The port of Suakin attracted shipping largely because of Abyssinian gold. So many Ethiopians were engaged in oceanic shipping that an important social class of *Habshis* (i.e., Abyssinians) evolved in India's mixed coastal communities. Ibn Battūta first reports their presence at Calicut and Ceylon in the fourteenth century. Sometimes associated with the East African immigrants called Sidis (who spoke Swahili and often originated as slaves from Mozambique and Mombasa), Habshis acquired special influence in the seventeenth and eighteenth centuries as sailors and soldiers protecting shipping from Gujarat in the northwest to Surat and even Bengal. One Sidi was the admiral of the Bijapur fleet and had under his jurisdiction the coast north and south of Janjira, the port attacked by the Moghuls in 1659. In the Bombay region in 1648 one area was controlled by a Habshi responsible for maintenance of a marina for the purposes of transporting pilgrims to the Red Sea and protecting commerce. The office carried the title of *wazīr* and was attained through merit. Some Habshis were non-Muslims. Habshi crews serving on Portuguese and Arab-owned ships often carried their families aboard. African sailors were apparently also involved in piracy on the West Indian coast.

In the southwestern part of the Indian Ocean, sailing between the African mainland and the island of Madagascar was made difficult by the strong southward currents in the Mozambique channel and the weak reach of monsoons. Swahili legends of origin would put Muslim settlers on the Comoros as early as the eighth century, but the first trustworthy reports speak of Malay (Wāqwāq or Qumr) people reaching African destinations at a time when Mozambique was barely known to the Arabs and no evidence exists for African voyages from the mainland.

The earliest report of a Malay attack against a northern Swahili town (Qanbalū, on Pemba Island) dates back to 945. The Arabic book *Marvels of India* tells of a 1,000 boats attacking the city from the sea and surrounding channel. The assailants had plundered parts of Mozambique and an island six days' distance away. Their home was at the distance of one year's journey. In the thirteenth century Ibn al-Mujāwir speaks of an earlier, vaguely ancient, invasion of Aden by the Malagasy people (al-Qumr) who arrived in great numbers in boats to displace local fishermen. They were later expelled by Kushites from the Somali peninsula (Barābir). These people disappeared, and their skill had been lost, but a boat from al-Qumr arrived at Aden in AH 626/AD 1228–1229. Ibn al-Mujāwir describes it as an outrigger vessel; he admires the sailing skill of these people who managed to sail from Madagascar to Aden in "one monsoon," instead of three stages involving layovers at Kilwa and Mogadishu. Around 1500 Ahmad ibn Mājid includes the Comoros in the scope of Arab navigation. After the arrival of Portuguese, and especially after hostilities developed in the north, Swahili migrations to northwest Madagascar and the Comoros expanded while the Malagasy navigation declined. Comorian sailors became occasional pirates and were involved in slaving raids against the mainland coast until the nineteenth century. Malagasy in turn attacked the Comoros from the eighteenth century, adapting for slaving raids large canoes otherwise used for whaling and capable of carrying 30 men. Some raids even reached across the Channel. Outrigger canoes were called *parabou*. There were also two-bridge galleys *coracores*, one-mast ships (*pajalas*) and *palans*, similar to small galleons.

The coast of East Africa proper, subject to the monsoon regime, is distinguished by the great number of coastal sites used as trading ports and fishing settlements. African participation in trans-oceanic navigation has not been documented for pre-Islamic or even early Islamic times but local inter-island shipping must have evolved sufficiently early to allow offshore island settlement by at least the ninth century. According to al-Idrīsī (mid-twelfth century) the Zanj people did not have seaworthy vessels and ships from Oman and elsewhere exported their goods. By that time a network of sailing routes connected harbors from southern Somalia to northern Mozambique. The Swahili-speaking coastal Africans dominated local shipbuilding and trade but other groups, including the Bajun, provided sailors as well. Navigation on the Swahili coast carried many general characteristics of Indian Ocean navigation, including the sailing calendar, dependence on the monsoon, sidereal rose, some boat types and terminology rich in loan-words from Arabic, Persian, and Indian languages. It also had some distinctive features and deeply affected the social culture of the coast. The best known is the maritime Swahili culture of the island city of Lamu (Kenya).

The sailing calendar was based on monsoons within the solar year. The marine year began in early August, when the gusty southern kusi wind subsided. The New

Year's celebration, called *siku ya mwaka*, marked the resumption of shipping activity after a pause during May–July. The Persian word Niruzi, also used for this festival, gave rise to the false impression that this calendar was Persian in origin. Different subperiods within the monsoon were best suited for plying the routes between Malindi and Madagascar, Kilwa to Sofala and back, Sawāhil (northern Tanzania) to Mogadishu, Aden and thence to Hormuz or Gujarat and the Maldives. Travel north was more difficult due to both the southwest monsoon and the strong contrary currents in channels between the mainland and the islands. The "normal" boundaries of Swahili travel were Cape Delgado in the south and Mogadishu in the north. In the fourteenth century the city of Pate briefly attempted to dominate the coast, but it always had to compete with its neighbor Lamu and the more remote Mogadishu, Malindi, Mombasa, and the powerful Kilwa. Regional and local rivalries involved sailing to foreign lands (Arabia or India) or to the mainland, and attacks and blockades from the sea. In island setting, it was generally faster, easier, and safer to sail from one destination to another than travel overland well into the nineteenth century. Traditional histories reflect everyday awareness of the tides, currents, and coastal breezes. The Portuguese arrival in East Africa did not noticeably change local shipbuilding and sailing practices, although this was not so elsewhere; the Eastern Arabian and Persian Gulf influences both pre- and postdated this European infusion. Local ships still carried traditional trade goods and even revived with the rise in slave trade before its suppression by the British in the late nineteenth century. By that time Zanzibar and Kilwa were the two leading ports of the coast, followed by Mombasa and Lamu.

Navigation proper was not highly developed. Given limited distances, boats mostly coasted. The steady daily and seasonal pattern of the winds made observation of local features such as banks, current speeds and tides more important than instruments. Actual stars rather than compass rhumbs[1] were used for determining latitude. Travel was slow, averaging one knot an hour, if rest days are included. In the fourteenth century Ibn Battūta was told that the area of Sawāhil was two weeks' sail from Mombasa. In the early nineteenth century it still took two weeks to reach Madagascar from Kenya with a fair northerly wind *kaskazi*. Traffic between Lamu and Somalia resumed immediately in August, reached its peak in November and died down in January. Foreign craft from the north began to arrive in November.

[1] A line which crosses successive meridians at a constant angle; called also rhumb line, and loxodromic curve. To sail on a rhumb means to sail continuously on one course, following a rhumb line.

The sailing calendar was paralleled by a ritual calendar. At Lamu, a local ship owner held the hereditary office of *mkuu wa pwani* (master of the strand). This dignitary led the dhow launching, invariably accompanied by both an African *ngoma* festival and a Muslim ceremony. Other elders (*wazee*) gave the blessing and burned incense. The shipwright (*fundi*) was given a ceremonial present and the captain (*nakhoda*) declared by the *mkuu*. Magic was resorted to in order to bring favorable sailing conditions or take wind out of an opponent's sail, break his mast, etc.

Today's dhows (*daus*) are sea-going sailing ships with very large lateen sails, which still may be rowed or poled when necessary. They serve as fishing vessels and may be flat-bottomed or keeled. Newer dhows are made of fiberglass and have motors. The formerly prevalent *mtepe* (*dau la mtepe*), no longer in existence, was a type of sewn boat of up to 30 tons carrying a square sail of matting, double-ended with an upright mast. The local "big ship" is *jahazi*, a fairly recent type of sea-going coaster, single-masted, transom and with upright stem, with a cargo capacity of 25–60 tons. A smaller version of the same type used for intercoastal shipping is called *mashua*. *Buti* was a large (20–60 tons) coastal vessel type, now obsolete, with one mast, and a slightly curved upright stem and square stern. *Baghala* is the most beautiful and largest (100–300 tons) of the dhows, a two-masted vessel with square stern, originally from the Persian Gulf. Bum is a layman's name for lateen-rigged sea-going dhows. The small-keeled *msumari* (*dau la msumari*) also carries a lateen sail. The double-outrigger canoe *ngalawa* rarely occurs north of Mombassa. Lack of timber limits shipbuilding; local wood may suffice for plank-built boats of small dimensions but dugout canoes have to be imported (for example, from Madagascar).

See also: ►al-Idrīsī, ►Ibn Battūta, ►Medicine in Africa

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Navigation in China

Ho Peng Yoke

Did the Chinese visit North America before Columbus? Did Chinese navigators land in Australia before Dampier and Cook? These two puzzles often pass our minds when we turn to the topic of Chinese navigation. In 1761 C.L.J. de Guignes wrote that in the early part of the sixth century a Chinese monk named Huishen had sailed to the west coast of North America. The story did not gain much support, but some interest in the issue was revived in the last two decades by the discovery of two pre-Columbian stone anchors off the Californian coast. One of the anchors is in the shape of an equilateral prism, and the other looks like a large cylinder with a hole bored through the center. Both were suggested to be of Chinese origin. As for Australia, aborigines along the northern coast still remember contacts with their northern neighbors who visited them annually in the past for the purpose of trade. Among them were the Macasarese and the Buginese; the former were preceded by the Baijini. The Baijini were said to be technologically advanced, with much lighter skin color; among the things they bartered for was *trepang*, from which the typical Chinese delicacy sea-slug was prepared. Hence they could be identified with the Chinese, the only people who knew how to prepare sea-slug. While we cannot yet arrive at a definite answer to the two questions it is possible to show that at least the technology and skill were already there in the past for Chinese ships to reach their destinations.

The Chinese must have navigated their rivers and coastal waters since the dawn of history. The character *zhou* for boat written on tortoise shells and buffalo shoulder-blades used for the purpose of divination during the Shang period (traditional dates 1766–1122 BCE) took the form of a boat. Documentary records on navigation in ancient China are, however, rather scanty. Confucius himself once made a remark on venturing upon the open sea in a raft. Then comes the story about the emperor Qin Shihuangdi sponsoring expeditions to the East China Sea to seek the elixir of immortality during the third century BCE. Modern archaeology has provided evidence that Chinese sailors had taken to the high sea at least by the third century BCE. In 1976 the ruins of a large shipbuilding site of that period was discovered at Guangzhou in South China. The site could hold ships weighing between 50 and 60 tonnes and measuring up to 30 m in length and about 8 m in width.

In the year 118, the Han astronomer Zhang Heng (78–139) noted that there were stars not visible to people in China itself, but that were seen by seafaring people. There were already a number of books on this subject then, but unfortunately none of them has survived. Those seafaring people could have steered their boats by the sun and the stars. Star catalogs were already available in China, even before Zhang Heng made observations with the new astronomical instrument he constructed. By about the seventh century maritime trade between China and the Arab countries saw Chinese and Arab sailors traveling between the ports of east and southwest Asia. Arab merchants traveled in Chinese boats. The large number of Tang potsherds of about the mid-eighth century discovered by the Japanese Idemitsu Archaeological Mission in 1966 at Fustat near Cairo and in Aidhab on the Red Sea coast of Egypt bear testimony to this trade. It could be during the mid-ninth century that Chinese navigators first made use of the magnetic compass. This could have taken place later, but not after the mid-eleventh century when Shen Gua (1031–1095) described the mariner's compass. This early form of compass consisted of a magnetic needle suspended by a thread.

With the invention of the mariner compass and increase in maritime trade the shipbuilding industry became highly developed during Song China (960–1279). In 1960 the remains of a Song wooden craft measuring 24 m long and about 4 m wide for navigating in rivers and canals was discovered in Yangzhou, Jiangsu province. Then in 1974 the remains of a *Fuchuan* – Fujian-built ship – was recovered in Quanzhou, Fujian province. Measuring over 34 m and weighing about 374 tonnes, it was composed of 13 water-tight compartments, the bulkheads. The shipbuilding industry continued to flourish during the time of the Mongols (1271–1368). Marco Polo gave an estimate of over 200,000 sailing vessels in China.

The most famous maritime exploration ever made by the Chinese was that of Zheng He (1371–1434). His fleets included some very large vessels. According to the *Mingshi* (Official History of the Ming Dynasty), the largest ones measured 134 m in length and up to 55 m in width. Modern scholars gave different estimates for their displacement, varying from over three thousand to just over eight hundred tonnes. In 1405 Zheng He made his first expedition to Southeast Asia and the Indian Ocean, employing a fleet of 63 ocean going junks. During the next thirty years he made six other expeditions to the Indian Ocean. His explorations preceded the Portuguese by several decades. For example, he visited Calicut in India in 1405, some ninety years before the latter arrived. He brought home strange animals like zebras and giraffes, and rare drugs, minerals, and other curiosities during his visits to Africa. He sailed along the eastern coast of that continent. One unanswered question is whether he had navigated round the Cape of Good Hope and ventured into Atlantic waters.

The late Ming military compendium *Wubeizhi* (Treatise on Armament Technology) compiled by Mao Yuanyi in 1628, contains the original schematic sailing charts tracing the routes followed by Zheng He and navigational diagrams indicating the star positions to be maintained during the voyages. The charts show the courses of the ships across the seas, with legends giving detailed compass-bearings, with distances expressed in number of watches. They also describe more interesting coastal features, showing half-tide rocks and shoals as well as ports and havens. For example in the description of the voyage from Bengal to Malé in the Maldive Islands through Sri Lanka, it gives the polar elevation for every stage of the journey, such as mentioning that a certain mountain in Sri Lanka would be sighted when the polar altitude had sunk by a certain number of degrees. Hence Chinese sailors in the early fifteenth century already knew the method of finding and running down the latitude. For measuring the altitude of a star, Zheng He's crew probably made use of the cross-staff, which was an instrument used by Chinese surveyors as early as 1086. The traditional Chinese clepsydra would not function properly at sea. Needham suggests that they had an alternative, by simply using the incense or joss-stick, which was a popular method used for timekeeping.

The Chinese constructed many types of sailing vessels to suit different needs and environments. Navigating rapid shallow streams, sailing on big rivers and along the coast, transporting food and merchandise along the Grand Canal, and venturing further afield to the Indian Ocean would require different types of ships. Chinese sailing vessels differed from Western sailing ships in their hull structure and in their sails, as well as in their methods of propulsion. The word "junk" was first given to Chinese ships in records of the travels of Odoric of Pordenone and that of Ibn Baṭṭūṭa during the fourteenth century, but the origin of this word is uncertain. Needham suggests that it could have come either from the Chinese word *chuan* or from the cognate Javanese and Malay words *jong* and *ajong*. The term *sampan* is used for smaller Chinese sailing vessels. Undoubtedly it originated from the Chinese term *sanban*, which is written in two forms. One form literally means "three boards", indicating its size. In the nineteenth century the term referred to river gunboats rowed by eight oars on each side.

The oldest form of Chinese ship had a carvel-built hull without the keel, the stempost and the sternpost of European and Arabian ships. Generally, the Chinese junk could be either flat or slightly rounded at the bottom. However, there were also junks with a V-shaped bottom as in the case of the Fujian-built ships. The planking of the Chinese junk did not meet at a point at the stern and the stem, but stopped abruptly and was joined transversely by straight planks.

Also unlike its European counterpart, the Chinese junk had neither frames nor ribs; instead it was composed of solid transverse bulkheads, which gave rise to several water-tight compartments. This valuable shipbuilding technique could have been inspired by the bamboo that the Chinese used for some smaller rafts and for so many other purposes. Many types of bamboo raft still ply the rivers in China today, Some of them are made with the giant bamboo *dendrocalamus giganteus* that grows to a height of some 25 m and has a diameter of about 30 cm. To enable the raft to slide over river rocks, the bow is usually bent upward by heating. If a piece of bamboo is bisected longitudinally the nodal septa would represent the transverse bulkheads and the stem and stern transoms.

The sails used in Chinese ships were also different from those of their European counterparts. Different cultures developed different types of sails to take advantage of winds coming from different directions. For example the ancient Egyptians had the symmetrically hoisted square sail. The Chinese on the other hand had the lug-sail, which consisted of an upper sail support slanting upward away from the mast, called the canted yard, and a horizontal sail support at the bottom called the horizontal boom. The sail was often strengthened by battens of bamboo, the ends of which were fastened to bolt-ropes suspended from the yard to take the weight of the sail. The sail was often made of bamboo matting and was kept flat and taut by using multiple sheets of matting. Several masts were used for larger vessels, the number varying from two to five. These masts would be staggered thwartwise such that one would not becalm another. The rake of a system of masts often radiated like the spine of a fan. The Chinese mat-and-batten sail had several advantages over the canvas sails used in European ships. It could manage with a material which, although not as strong as canvas, was aerodynamically more efficient. It offered more protection against tearing, and could easily be furled, as it would readily fall into pleats thus dispensing with having to send some crew member aloft to take in reefs.

The Chinese propelled their boats by punting with long poles and by rowing using steering oars and stern sweep. However, they also employed an ingenious method of mounting the oar approximately in the line of the main axis of the boat, and moving the oar from side to side about a fixed fulcrum. This was the Chinese *yaolu* that had fascinated many Western observers in the past. Louis Lecomte remarked that they made use of the *yaolu* as the fish did its tail.

The rudder is standard equipment in a sailing craft to control the direction of movement, although the same function may be performed by other means, such as by the oar and the paddle, albeit less efficiently. In the Western tradition the sternpost rudder is hung on pintle and dudgeon. What the Chinese did was to develop an axial rudder that could move up and down in guides. In shallow water it could be raised to its highest position to avoid damages, while in a heavy monsoon in the open sea it could be set in the lowest position for protection from the breaking water and to improve the ship's windward sailing quality. Sometimes the rudders were riddled with holes. These were fenestrated rudders. The holes were supposed to minimize the drag on the ship caused by the turbulence of the water flowing past the rudder, thus improving the hydrodynamics of the rudder. A ship would sometimes carry rudders of different sizes for use in different conditions. Sometimes instead of the rudder, the steering oar was developed into a long stern-sweep in boats that navigated rapid rivers and land-locked waters. The rudder is only effective where there is relative motion between the boat and its surrounding water. When a boat comes down with the same speed as a descending rapid, the rudder does not operate. A long sterns-weep, however, depends on the reaction to water resistance and controls the movement of the boat.

Thus Chinese ships ruled the waves in East Asian waters for a long period of time until the sixteenth century when the Portuguese arrived in East Asia and found no equal to their *calivers* outside the Atlantic. In the meantime from the days of the arrival of the latter until the second half of the twentieth century, the progress of modern science and technology had also left Chinese shipbuilding far behind. Although modern technology has already taken over from the traditional shipbuilding industry in China, we can still see Chinese junks and sampans navigating between ports in coastal waters in the China Sea and traditional rafts of all kinds sailing the rivers and the lakes in China today.

See also: ►Bamboo, ►Stars, ►Zhang Heng, ►Shen Gua

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Navigation in India: Sea and Inland Navigation

R. S. Varshney

Ancient Tradition

The great landmass of India is surrounded by sea on the east, south and west and has a large number of sheltered harbours situated all along its 5,700 km long indented coastline. There are also many large navigable rivers. Careful examination of ancient scriptures and archaeological discoveries has brought to light actual remains of docks, wharfs, jetties and warehouses in ancient times. References to sea journeys, navigation, boats, ships and docks are scattered in various verses of the *Vedas*, *Purāṇas*, *Meghamala*, *Mayurcitraka*, *Vṛhatsaṃhitā*, *Harivamsa* and other texts.

The *Ṛgveda* Aryans knew the slopes of a region by the help of rivers. That Aryans navigated on seas is clear from their worship of Jalnath (The Lord of the Sea). The *Ṛgveda* says, "Do thou convey us in a ship across the sea for our welfare."

Aryans possessed knowledge of boats which were something like submarines. Here is a *shloka* (verse) from the *Ṛgveda*. "O Pushan, you work as a messenger by use of your boats which move under the ocean and also in the air. These boats have instruments with which things inside and outside sea can be seen." The Vedic Aryans understood the construction and operation of sea boats.

In the *Ṛgveda*, the God Varun has knowledge of the routes of the oceans and also of the vessels sailing on them (*Rig*. 1.25.7). The same text further adds that merchants used to send out ships to foreign countries. A hymn in the *Atharva Veda* says that the boats which rode the waves were broad in beam, spacious, comfortable, resplendent with strong rudders and faultless in construction. The *Ramayana* refers to distant lands where the worm grew that yielded the silken thread and to the Lohit sagar, the references being to China and the Red Sea, respectively. *Rāmāyaṇa* also describes the boat journey undertaken by Bhagwan (Lord) Rama. The epic *Mahābhārata* mentions the naval activities of Pandavas. *Vriksha Āyurveda* a botanical treatise written in the sixth century BCE, mentions the types of wood best suited to boat building. *Yuktikalpatru* by Bhoj served as a textbook to later Indian shipbuilders.

The *Ṛgveda* mentions a naval expedition sent out by Rsi-king Turga under the command of his son Bhujyu. The ship was wrecked in a storm, but some of the occupants, including King Turga and his followers, were rescued by Ashvins, the twin brothers, who came in their hundred-oared galley.

Three things emerge from these references: first, ships were sent to foreign countries for trade; second, multi-oared boats were used in expeditions, and third, Vedic Aryans knew sea routes.

Archaeological excavations have revealed that, during the Harappa period (2500 BCE), there was a flourishing maritime trade between Kathiawar and the Persian Gulf countries. Of special significance is the evidence of the existence of a port city, called Lothal, 80 km southwest of Ahmedabad, which had docking facilities comparable to the modern ports of Mumbai and Vishakhapatanam. There were other ports also along the Gujarat Makrau and Konkan Malabar coasts.

The Bible also refers to early maritime commerce from India. In the days of Solomon items such as ivory, spices and peacocks could only have come from India.

In Mauryan times, for an account of navigation, we rely mostly on the *Jataka* stories. Greek writers often corroborate the facts mentioned therein. According to Greek writers like Arrian and Curtius, shipping was a highly developed industry in India in the fourth century BCE, and the same facilitated the passage of Alexander's army of over 100,000 soldiers through the Indus. Mauryan kings not only encouraged sea trade but also streamlined the administration of the navy. The *Arthaśāstra* of Kauṭilya (321–297 BCE) vividly describes the duties of the head of the naval department and the port officers. Important port installations of this period have been found recently at Kaveripattinam and Dharnikota on the east coast. Overseas navigation encouraged by the Mauryan emperors received further impetus under the Andhra-Satavahan kings and the rulers of the Chola–Pandyan kingdoms. The most important source of information concerning seaports of India in those days is the author of *Periplus* who hailed from Alexandria. He mentions a number of ports on both the western and the eastern coasts.

The Shravathi River in Karnataka is navigable from Honavar up to Gersoppa, which is mentioned in ancient texts. The most important port discovered is at Udyavara (called Odara in the Oxyhydrinchus papyrus), a small village 6 km south of Udipi, from which the saint Madhavacharya hailed. The mound known as Baleragudda marks the citadel of this ancient port city.

The early Tamil works of the first century AD describe at length the port establishments of the east coast such as Poomphar, i.e. Kaveripoopattinam, the chief port of the Chola kingdom. Other ports which are significant from the point of view of commerce during the first few centuries of the Christian era are Arikamedu near Pondicherry now identified as Pokduke or Poduca and Kainapara or Konark in Orissa. The Gupta emperors also encouraged inland and overseas navigation for trade. In the fifth century AD, Hamza of Isahan writers mention that Indian ships used to be moored at Hira near Hufa on the Euphrates River, the major role in the sea trade being played by the merchants from Sindh and Gujarat. The merchants of Gujarat colonized Java.

After the decline of trade with Rome, the Chalukyan and Chola kings encouraged sea navigation with the eastern countries especially Burma, Sumatra, Java, Borneo and the Island of Bali. I-tsing, the Chinese traveller who visited India (630–644 AD) says that Indian navigators and traders could be seen at all the busy ports of the east coast from Burma to China and in the Malayan Archipelago.

The four centuries between 200 BCE and 200 AD marked the heyday of Indian shipping. It was during this period that the Indians carried on their colonization of distant lands as far as Sumatra and Java, the latter of which still manifests its ancient Indian connection.

Marco Polo, who visited India in the thirteen century, left a vivid description of Indian ships. He saw ships that carried ten small boats slung on the sides, like present day lifeboats, with falls and tackles to lower them into water and heave them over the sides, along with 60 cabins below the rain deck for passengers. They were mostly foremasts and with as many as 14 watertight compartments.

A notable event of the early eighth century was that under the Arab onslaught on Persia, a good number of Persians, refusing to be converted to Islam, left their motherland by sea and sought asylum in the western ports of India. Their descendants are the Parsis of India.

They contributed greatly to the commercial, shipping, shipbuilding and industrial development of the land of their adoption.

Ibn Baṭṭūṭa, in the account of his travels in India, mentions the large boats that plied in the Indian rivers. He also describes in detail the manufacturing techniques of Indian ships. In the first quarter of the sixteenth century, on the western coast, the Zamorins of Calicut maintained a great naval force. Vasco da Gama also left a graphic description of the fleet of Calicut.

European travellers in India spoke highly of the strength and durability of Indian boats and ships. Nicolo Conti observed, "They build some ships larger than ours with five sails and as many masts."

India's maritime supremacy was maintained with the Mughals. Emperor Akbar gave impetus to shipping and shipbuilding. According to the *Ain-i-Akbari*, 40,000 vessels were engaged in commerce in the river Indus alone. Abul Fazal, the author of *Ain-i-Akbari*, mentioned the elaborate rules for the organization of the navy.

Advent of Europeans

In the last few years of the fifteenth century, events took place which had far reaching effects on navigation and the maritime world. The hostility between the Christians of Europe and the Muslims of Asia acted as a powerful factor in intensifying the efforts towards navigational exploration. In 1487 Bartholomeu Diaz passed the Cape of Good Hope and reached the Indian Ocean. The 'Hope in Good Hope' was the hope of the imminent discovery of the sea route to India. Vasco da Gama sailed from Portugal on 8 July 1497 and landed at Calicut on 27 May 1498. For the first time, a ship from Europe had arrived in India by an all-sea route.

By the middle of the seventeenth century the Dutch had become the masters of the trade of the Eastern Archipelago, ousting the Portuguese from the area. They then turned towards India, drove the Portuguese out of Sri Lanka, and operating with Colombo as their base, unleashed a sustained attack on Portuguese settlements in India. The Cochin establishment soon came under Dutch control; only Goa, Diu and Daman were left to the Portuguese.

It was now the turn of the English to establish direct contact with India. The East India Company was formed to break the Dutch monopoly and got a charter from Queen Elizabeth on the last day of the year 1600 granting it the monopoly of the Eastern trade. By and by Indians lost control of navigation of sea routes and Indian shipping gradually declined.

For nearly a 150 years the East India Company's main activities were confined to commercial aggrandizement. Within 50 years of Auragazeb's death (1707), the country was so confused in its political affairs that it provided an inviting ground for adventurers. The English emerged superior in naval power and they were able to displace the French and others.

In the final burst of glory, preceding extinction as it were, Indian naval power under the Marathas put up a brave fight against the supremacy of the European powers. Shivaji, the builder of Maratha power, had patronized the shipbuilding industry too. With the help of Tukoji Angray, the head of the Koli community of Ali Bagh, he built up a formidable fleet which, from 1694 to 1758, under the command of the Angrays, established complete control of the sea from Malabar to Travancore. The Indian shipbuilders of those times had such a high reputation that the Dutch and the English had some of their ships built by them.

During all this time, the seaborne trade of India had been rapidly increasing. But with the passing of trade in the more important commodities and the control of navigation on the high seas into English hands, Indian merchants and their shipping gradually disappeared from the scene. In a limited way, Indian shipping operated in the coastal waters and there were perhaps a few ships in trade with the Persian Gulf, the Arabian and the East African ports. The pilgrim traffic to Jeddah which had state patronage under the Mughals continued in Indian hands. Despite heavy setbacks, there were still many Indians who ventured into shipping and kept alive the tradition of shipping enterprise. It is on record that even after the rule of the sea had passed to the Europeans, Gurjarat businessman continued to show courage and skill as merchants, seaman and pilots. According to historian Tod (1025 AD), for Biji Singh of Bhavnagar, his port was his grand hobby and shipbuilding his chief interest and pleasure.

Any account of shipbuilding in the eighteenth and nineteenth centuries must include the work of the great Parsi family of Wadias. For nearly a century and a half, from 1736 to 1884, the members of this family were master builders at Bombay dockyard and built over 350 vessels.

However, the encouragement to Indian shipbuilding in the early days of the Company's rule had been vigorously opposed in Britain by many of the Company's Directors themselves. In India itself measures were taken to discourage shipbuilding.

Steamships

In the meantime, a great revolution had taken place in shipping. Steam had begun to be used for propelling ships. Only those countries that were mechanically advanced could rule the high seas. All these advantages were held mostly by England and she made the fullest use of them. In the third and fourth decades of the nineteenth century the steamship began to prevail over the sailing vessel which gradually disappeared from the high seas. In 1825, the steamship “Enterprise”, a small ship comparable with the coasters of today, left England on August 16 and reached Kolkata on December 7. This was the first steamer to perform a transoceanic voyage to India.

The two years, 1819 and 1919, stand out significantly in the history of modern Indian shipping. While 1819 saw the steamboat appear in Indian waters for the first time, 1919 saw the establishment of the first large Indian steamship company.

Decline of Indian Shipping

A number of small shipping companies owned by Indians were registered in the nineteenth century mainly to carry on coastal trade. All of them faced stiff competition and hostility from the British companies, mainly the Peninsular and Oriental (P&O) and the British India Steam Navigation Company (BI); they could not survive long.

But in the wake of the *swadeshi* movement at the turn of the nineteenth century, Chidambaram Pillai, a disciple of Lokmanya Tilak, entered the fray by launching the Swadeshi Shipping Company of Tuticorin in 1906. The flag of Swedeshi Shipping vessels bravely bore the words “Vande Mataram” (Mother, I bow to thee, which is the National song of India) a slogan which then served as a red rag to the bureaucratic bull. The fate of such a defiant patriotic venture can easily be imagined. An offensive was promptly launched against it. Pillai was arrested and sentenced to a long term of imprisonment for taking part in political meetings. The company crashed on the rocks of politics, not on the rocks of business. Similar was the fate of the Bengal Steamship Company, established in 1907 by Jyotindranath Tagore, brother of the famous poet and Nobel laureate Rabindranath Tagore. How disappointing the situation was is clear from the fact that about eighty shipping companies were registered in India between 1836 and 1918. By 1946 only seven still existed, and all of them were very small.

Revival

By now the patriotic fervour of the country had developed a strong economic flavour. Impressed by the generous contribution of the people to the war effort and especially by the bravery of Indian soldiers, the Government of India also was inclined to modify its imperialist policy a little.

The year 1919 provided a suitable setting for the entry of the Scindias on the Indian maritime scene. Scindia’s owe their birth to a stroke of inspection, a moment of illumination, almost to an accident of history. It was a chance meeting between Walchand Hirachand and Watson, a British engineer, during the former’s railway journey from Delhi to Bombay on sixteenth Feb. 1919, that disclosed to him that a passenger ship was for sale in Bombay. It was the S. S. Loyalty owned by the Maharaja Madhavrao Scindia of Gwalior.

Walchand decided to bid for it. After getting down in Bombay he proceeded straight from the Victoria Terminus station to the dock to have a look at the Loyalty. After inspecting the ship, Walchand decided to form a syndicate to buy the Loyalty and establish a limited company to run it. On March 27, 1919, the Scindia Steam Navigation Company was registered with an authorized capital of Rs. 4.5 crores. On April 5, 1919, the S. S. Loyalty sailed from Bombay as an Indian passenger ship bound for Europe and the United Kingdom. It was a historic day in India’s maritime annals, the day on which Indian shipping was reborn. Appropriately, since 1964, April 5 is celebrated annually as India’s National Maritime Day. Although the Gwalior Maharaja retained no interest, financial or otherwise, his name came to be permanently associated with the company.

River and Canal Navigation

Rivers have been used for navigation since the earliest times, and in some cases water transport was the only means of communication between places. Big rivers in the north, like Ganga and Yamuna, have always been used extensively for navigation especially in eastern UP, Bihar and Bengal. Similar is the story of southern rivers like Krishna, Kaveri, Godavari, etc. The central India rivers have also been used as waterways.

Steamers on the Ganga

Various types of Indian boats were used on the Ganga and houseboats were popular among European officers. Boats carrying merchandise from Allahabad to Calcutta, a distance of 1,300 km normally took about 20 days in the dry season. The Journey upstream was difficult and took almost three to four months.

Lord William Bentinck, Governor General of India (1828–1835), showed keen interest in the development of steam traffic on the Ganga. In 1834 a regular passenger service started on the Ganga. The passenger boat, William Bentick, was launched in Calcutta in April 1934. In October, its sister ship, “Thames” was also commissioned for service.

River and Canal Navigation in the South

The Madras Presidency also experienced water transport improvements early in the nineteenth century. A canal linking Madras with the Egmore backwater was completed in 1806, and it was named after Cochrane, who became its proprietor. Lord Dalhousie, Governor General (1846–1856), acknowledging the benefit derived from the Ganga Steamers, was eager to extend such facilities to the Godavari, Indus and other rivers. On the west coast, canals were also built. In Malabar the important canals were from Cochin to Tirur, 125 km from Baypore to Badagara, 69 km and from Balaptom to Canara frontier, 35 km.

Indian Ports, Maritime Transportation and Inland Waterways After Independence

After Independence there was tremendous progress in sea and inland navigation. India has 11 major sea ports: Kandla, Mumbai, Nhava Sheva, Marmagao, New Mangalore and Kochi on the west coast and Kolkata Haldia, Vishakhpatnam, Chennai, and Tuticorin on the east coast. The 11 ports in India are the responsibility of the Ministry of Shipping but are managed by semi-independent port trusts overseen by boards appointed by the Ministry from Government departments, including the navy, port labour and industry, ship owners and shipping companies.

In order of gross weight tonnage conveyed annually, Mumbai, Vishakhapatnam, Chennai and Marmagao are the most important ports in India. In addition there are some 139 minor working ports along with the two coasts and on offshore islands. Total traffic at the 11 major ports increased from 107 million tonnes in 1984 to 179 million tonnes in 1993. In 1993 there were three Indian government owned Shipping Corporations, the most important of which was the Shipping Corporation of India. There were also between 50 and 60 private companies operating a total of 443 vessels amounting to 6.5 million gross registered tonnes, more than 300 of which were 1,000 gross registered tonnes or more. Indian tonnage represented 1.7% of the world's total. Over all, the share of Indian vessels in total Indian trade is around 35%.

Some of the important shipping companies are: Indian National Ship Owners Association, Mumbai; Varun Shipping Co., Mumbai; Great Eastern Shipping Co. Ltd, Mumbai and Essar Shipping, Bangalore. India has four major and three medium sized shipyards, all government run. The Kochi Shipyard in Kochi, Hindustan Shipyard in Vishakhapatnam and Hooghly Dock and Port Engineers in Kolkata are the most important ones in India. Thirty-five smaller shipyards in India are in the private sector. Dry docks at Kochi and Vishakhapatnam accommodate the nation's major ship repair needs.

In addition to its coastal and ocean trade routes, India has more than 16,000 km of Inland waterways. Of that number, more than 3,600 km are navigable by large vessels, although in practice only about 2,000 km are used. Inland waters are regulated by the Inland Waterways Authority of India, which was established in 1986, to develop, maintain and regulate the nation's waterways.

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Navigation in the Indian Ocean and Red Sea

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Navigation in the Indian Ocean has historically used the monsoons. The Chinese knowledge of monsoons was documented first but the Indians and Middle Easterners benefited from them as well. The Greeks learned about sailing with monsoons between the Red Sea and northwest India no later than the expedition of Nearchus (326–325 BCE). A Roman port was established at Adulis on the Red Sea to trade with India under Ptolemy III Euergetes (247–221 BCE). The Greek *Periplus of the Erythrean Sea* (first century AD) attests to the Arab domination of routes between Arabia, East Africa, and India. With the rise of the Persian Sassanid Empire, Yemen, a crossroads of sea trade, became subject to rival interests of Persians, Byzantines, and Ethiopians. Persians seemed to control the navigation in the western part of the ocean until shortly before the rise of Islam. In the mid-sixth century, the Nestorian Christian merchant Cosmas Indicopleustes of Alexandria described travel by sea to Yemen, Axum (Ethiopia), and Taprobane (Sri Lanka), where he observed various ethnic groups participating in the Indian Ocean trade. It is often believed that Indian participation in ocean navigation was discouraged by Hindu restrictions on travel, but South Indian archaeology shows the existence of deep-water harbors accessible to large vessels at least from the second century BCE, and South Indian languages contain extensive vocabularies related to ships, shipbuilding, and navigation, albeit recorded sometimes in sources dating from the tenth century AD or later. Established practices of shipping, travel and contact were behind the faster progress of Islamization in the coastal areas of India, and there was a smooth transition of groups engaged in navigation and trade to participation in the networks following the Islamic religion and using Arabic as one of their languages.

Islamic navigation in the Indian Ocean and the Red Sea and the Persian Gulf is often referred to as Arab navigation largely because the known sailing instructions and literary works describing methods of navigation are in Arabic. Early statements by some European scholars to the effect that the Arabs did not like or know the sea ignore the fact that Islam arose among northern Arabs at the time when south Arabians had accumulated many centuries' worth of sailing experience. The revival and expansion of oceanic trade under the Abbasid caliphate (750–1258) must have involved not only Arabs and Persians but also coastal populations who converted to Islam later, but the sources are not specific on this point. Participation of Gujarati sailors is well documented in medieval and early modern periods. The Sind port of Daibul (Dewal, east of Karachi) gave the name to the East African group WaDabuli, descendants of the Daibul settlers who are mentioned in Swahili chronicles and dynastic oral histories recorded in the sixteenth–twentieth centuries. The first Dabuli migrations probably took place before 893, when an earthquake severely damaged the city, which was later abandoned. In the fourteenth century, participation of Indian Muslims as well as non-Muslims in merchant navigation and piracy is recorded by Ibn Baṭṭūṭa. According to Marco Polo and Conti, the Malabar coast of southwest India was where ships from China met with those arriving from the west.

The Red Sea was the scene of early contacts between Muslims and Africa, especially Egypt and Ethiopia. It continued to play a role of conduit between the Mediterranean and the Indian Ocean and eventually carried heavy annual pilgrim traffic to Jedda and al-Jār (the port of Medina during much of the Middle Ages). Mocha was the main port in the south, Aqaba in the northeast, Qulzum (a major naval base) and Quṣayr were prominent on the Egyptian coast, and 'Aidhāb on the African coast opposite Jedda. Outside the Bab el-Mandeb the ships stopped at Aden on the Arabian side or Zeila on the African side. Pirates found refuge on Dahlak and the smaller islands; once out in the Gulf of Aden, Socotran piracy was a threat.

During the Crusades the Red Sea became a scene of European attacks on Muslim shipping. Rulers of Egypt always tried to gain control of both coasts of the sea as well as Yemen. The Turkish conquest of Egypt and Yemen in the early sixteenth century made the Ottomans masters of the Red Sea and allowed them access to the Indian Ocean, where they tried to take over shipping routes leading to India, the Persian Gulf, and Africa. However, they were forced to yield to superior Portuguese force and later suffered naval intrusions into the Red Sea by both European and Indian (Gujarati) vessels. A major concern for Turkish authorities at Mocha and on the Ethiopian side (*eyelet of Ḥabasha*) was the security and provisioning of the pilgrims to Mecca. Bombay, Goa, and Surat served as major ports for the Red Sea India trade, and Massawa had a colony of Indian merchants (*Banyans*) from the late sixteenth century.

Sailing from the north was relatively easy, although passing the tip of the Sinai Peninsula was feared because the winds from the Gulf of Aqaba and Gulf of Suez met there. Ships carried from the ocean to the Red Sea by the monsoon had to sail against northerly winds once past the strait of Bab el-Mandeb. Jedda was the terminus of oceanic routes; transit further north had to use smaller boats. The only extant sailing instructions for the Red Sea cover the distance from Jedda to Aden (by Ahmad ibn Mājid, ca. 1500). Latitude measurements taken by the stars could use the Polaris *Jāh* because of the northerly location. "Triangular instruments," not described otherwise, and quadrants are mentioned. Finding one's location was not difficult in confined waters but navigation was dangerous because of numerous coral reefs, contrary winds, and currents. The journey from the north to the south end took 30 days (sailing by day only and coasting), but the ships of Saladin's navy could reach the speed of four to five knots. The north wind of the Red Sea *shamāl* reached the southern part only from May to September, coinciding with the short period when the prevailing wind in the Gulf of Aden was westerly, thus propelling ships into the Indian Ocean. The southeasterly wind of the Red Sea *azyab* reached half way up.

Navigation in the Indian Ocean was dominated by the monsoon (from Arabic *mausim* 'season'), a wind system that reverses direction seasonally. Both halves of the Indian ocean are subject to monsoon regime. The southwest monsoon *kaws* begins in March on the East African coast, slowly spreading eastwards. It reaches its maximum strength in June and blows across the ocean until October, bringing the heaviest rains to India in June and July and causing heavy swells which made landing difficult and even closed the ports. The northeast monsoon *azyab* originates from the Indian mainland in early October, reaching Zanzibar by late November. It makes it easy to sail almost directly from Malacca to Jedda as the wind continues into the Gulf of Aden. Between the monsoon periods, voyages were made in other directions, using variable winds and breezes. March to May are such changeover months in the northwest corner of the ocean. In the Gulf of Aden the predominant non-monsoon wind is easterly. Travel from India to Africa had to be begun by early February. From Aden and Yemen one needed to leave in mid-October, and from northeast Arabia by late January, but one could not sail to Socotra during the same season. From Socotra to southeast Arabia one sailed in March–April, while India could be reached also by departing in May and during the August–September season *dūmānī*. Travel down the African coast was recommended from mid-November to April. From Bengal one had to leave westward by January; leaving from Malacca, Java, and Sumatra in February or March one could still reach Ceylon. Travel from Gujarat to Bengal and Indonesia began in April or late summer. October brought cyclones to the Bay of Bengal. The eastbound roundtrip journey from the Persian Gulf across the ocean took 18 months. China-bound ships started from the Gulf in September or October, reached Kalah Bar in January and passed through the Strait of Malacca in time to use the southern monsoon in the Sea of China. Return to Malacca took place with the NE monsoon between October and December, then ships could cross the Bay of Bengal in January and reach Arabia in February or March.

Navigation between the Middle East and China is confirmed by reports of an Arab embassy to China in the seventh century, a Persian settlement in the island of Hainan in 748, and a mixed Arab-Persian colony at Canton in the eighth–ninth centuries. In the seventh century Persian ships took 20–30 days to reach Sumatra from China, and one month from Ceylon to Palenbang. In the ninth century "Chinese ships" or "China ships" (that is, ships sailing to China) are reported in the Persian Gulf. Smaller boats brought goods from Basra and other ports of Siraf where they were reloaded on the large China boats. Ceylon (Sarandīb) was also visited and described by Arabic authors. Sea travel from the Persian Gulf to East African islands is mentioned by Arabic sources in the ninth century and described as routine in the tenth by the historian and traveler al-Mas'ūdī, although the country of Sofala (southern Tanzania and northern Mozambique) was then still poorly known. The Persian Gulf ports of Siraf and Hormuz as well as Oman were dominant on that route at the time; Aden emerged to prominence somewhat later. Some of the tales of Sindbad the Sailor (of Basra) originated in stories of Indian Ocean sailor and merchant adventures collected in the book *The Marvels of India* by Buzurg ibn Shāhriyār (ca. 950). Much of Marco Polo's return journey in the late thirteenth century must have taken place in Muslim boats and followed routes mentioned in this book. In the fourteenth century Ibn Baṭṭūta. traveled by ship across the Red Sea and later to Africa, visiting Mogadishu, Mombasa, and Kilwa. On other occasions he sailed along the west coast of India and possibly to China. In India he encountered merchants from Cairo and Northwest Africa and fell victim to Indian pirates. He reported the presence of Chinese junks at Ceylon and planned to travel on one himself. The famous Chinese voyages led by the Ming court official Zheng He (Jeng Ho) constitute the last known attempt by China to break into the Indian Ocean network. Two of these, in 1417–1419 and 1421–1422, reached Africa, visiting Malindi and the Horn of Africa. Even the arrival of the Portuguese caused only a disruption and reorganization of shipping. Lodovico Varthema (ca. 1510) and the early Portuguese sources note the continuing international presence at western Indian ports: Egyptians and "Moorish" mechants and ships from Hormuz, Arabia, Abyssinia, Kilwa, Malindi, Mombasa, and Mogadishu at Cambay, on the Malabar coast and the islands (Maldives and Laccadives). Early naval battles between the Portuguese and combined Muslim navies (e.g., at Diu in 1512) resulted in capture and destruction of numerous Muslim vessels (In the sixteenth century only the Chinese had ships able to withstand attacks of the Portuguese galleons). However, the Portuguese soon realized that they would be unable to stop native shipping, and turned their efforts to diverting trade to ports which they controlled, carriage in their own ships, and taxation of all others. By the time the Dutch and the English arrived, an accommodation had been reached. However, intra-European competition, added to Christian–Muslim rivalry, contributed to preexisting pirate activity, especially in the Persian Gulf and on the Gujarat and Malabar coasts. The maritime Muslim trade revived somewhat in the seventeenth–eighteenth centuries and declined again in the nineteenth century, at least in part due to increased British control over the routes and ports of the western Indian Ocean. Another factor was the growing dominance of European companies in the long-distance East–West trade and their penetration of local trade.

The sources for traditional Arab navigation date mostly from the late fifteenth through the sixteenth century, while our knowledge of ships and shipbuilding in the region is modern or contemporary. There are vague, scattered references to earlier sailing guides *rāhnāmaj*, devices and ships. Naval law is best known from the Malacca code of Shāh Maḥmūd (1488–1530). A sixteenth century Persian source lists 12 categories of crew members with job descriptions. The best information on navigation proper and sailing routes comes from the works of Aḥmad ibn Mājid of Julfar in Oman (d. ca. 1504) whose recognized expertise made him into a patron saint of Muslim sailors. A learned practitioner, he composed navigation manuals and sailing instructions, largely in verse, to ease memorization. From him we learn the names of several earlier pilots, dating back to the tenth-twelfth centuries. To these Aḥmad ibn Mājid added the names of his own father and grandfather; apparently, the profession of pilot was hereditary but not highly regarded. It has been asserted by some scholars that Aḥmad ibn Mājid was the pilot who guided Vasco da Gama from Malindi to Calicut but this has been contested by others. Although he spent his life on the Indian Ocean, it appears that Aḥmad ibn Mājid was aware of the different methods of navigation in the Mediterranean. Other extant works on Islamic navigation belong to Sulaymān al-Mahrī (ca. 1511), a native of Shihr who wrote several practical and theoretical treatises, and the Ottoman writer Sidi Ali Çelebi who compiled a Turkish summary of the former two authors' work while moored in Gujarat in 1554 after a Portuguese attack on the Turkish Indian Ocean fleet originally commanded by the portolan-maker Piri Reis.

Contemporary Arabic names of ships, *baghala*, *ganja*, *sanbūq*, *jihāzī*, apply to vessels with square, transom, sterns showing European influence. The older type is represented by vessels now called *būm* and *zārūq* – double-edged, coming to a point both at bow and stern. The name *sanbūq* was formerly applied to the small craft of the Red Sea; *jalba* was the sewn boat typical of the Indian Ocean region. First mentioned in the *Periplus of the Erythrean Sea*, sewn boats were carvel built, with planks edge-to-edge, and stitched with ropes of palm fiber. The timber was teak or coconut wood. They were leaky and frail but had advantage over clinker-built boats with overlapping planks when striking a coral reef. A common legend explained that nails were not used because of the dangerous power of a magnetic rock somewhere in the middle of the ocean which could attract the nails. However, iron as well as stone anchors were used. The generic names for "ship" were *markab* and *safīna*. Indian pirates had *bārijas*; smaller boats called *zawraq*, *qārib*, and *dūnij* are also mentioned in medieval texts but no particular shape is indicated. *Dau* is a generic name for lateen-rigged vessels; the Arabs do not use it. The basis of classification was the form of the hull. The ships were usually one-masted, often without decks, with a cargo capacity of up to 200 tons. Erecting the mast and the rigging, and even making the sail was the responsibility of the owner *nakhūda* and the crew rather than the shipwright. The lateen sail associated with Arab ships probably evolved from a square sail on the Indian ocean; its use in the Mediterranean is first noted in the ninth century. African and Indian vessels continued using square sails of coconut matting into the twentieth century. The lateen is a tall, triangular fore-and-aft sail with the fore angle cut off to form a luff [the front edge of a sail]. It allows sailing into the wind by going on the tack, although Arab mariners preferred not to sail closer to the wind than 90°. It is possible that a second sail (topsail) was sometimes used. No reefing was done in strong wind, but the yard could be lowered. Two side rudders were originally used for steering, although by the thirteenth century the stern rudder was known. Sailing speeds averaging 1–3 knots were normal but could reach 6 knots under favorable winds.

The most important person on board ship was the *mu'allim* who served both as captain (*rubbān*) and pilot. He was hired for the voyage and allowed to carry merchandize as part of his pay. The shipmaster (*nakhūda*) was a merchant; ships were often owned by shareholders. We know Persian terms for eleven ranks of crew members; of these, the most important were the bo'sun (*tandīl*), the ship's mate (*sarhang*), the steersman (*sukkān-gīr*), and the look-out (*panjarī*). Sailors were called *khallāsī* or *khārwah*. The captain was responsible not only for navigation but for the safety of passengers and goods as well. Among the necessities he carried were a nautical directory (*rahnāmaj*), measuring instrument (*qiyās*), bussole (a very exact compass) (*huqqa* or *dīra*), lodestone (*ḥajar*), lot (*buld*) and lantern (*fānūs*). The pilot's principal science consisted of knowing the coasts, winds and seasons, and his ship. Before departure, the Muslim prayer, *Fātiḥa,* was recited and an invocation was made to Khidr, the mythical patron saint of mariners.

By the sixteenth century, Arabic sailing manuals list over 30 different routes. Navigational books (*dafātīr*) and charts (*ṣuwar*) carried on board are mentioned in the tenth century; Aḥmad ibn Mājid calls his "chart" *qunbāṣ*, but no charts have come to light. G.R. Tibbets argues that the Arab pilot plotted his course in his head and did not need a chart; besides, proper charts could not be made because the Arabs had no way of correctly determining longitude at sea. The winds and geography of the Indian Ocean allowed the pilot to be guided roughly by the latitude of his destination (determined by the Pole star altitude). Once that was reached, he sailed down the latitude toward his goal. Another way was to keep to a recommended bearing until land was in sight and then make corrections. Extant Arab maps do not allow practical application to navigation. A Chinese chart based on the Zheng. The expedition shows the routes from China to Hormuz, the Red Sea and Africa, but no measurements can be taken from it. Charts from Muslim Indian (Gujarati) nautical manuals (*roz nāmah*) of the seventeenth–eighteenth centuries show some European influence and use stellar compass bearings and Arab units of time-distance. A possibility of Chinese influence has been suggested as well. Considering that Arab information is already found on early sixteenth century Portuguese maps, it is clear that the sharing of information among mariners created a truly international maritime culture drawing on indigenous and regional traditions and innovations.

The Arab system of nautical orientation evolved on the Indian Ocean in the intertropical region, but probably north of the Equator; it may have been representative of all Indian Ocean sailing. It is based on a 32-rhumb (*khan*) sidereal rose (*dīra*) divided into eastern and western halves separated by the Polaris (*Jāh*) in the north and the South Pole (*al-Quṭb*) in the south. The east and west divisions approximate the rising and setting of certain bright stars and constellations (Ursa Minor, Ursa Major, Cassiopeia, Capella, Vega, Arcturus, Pleiades, Altair, Orion, Sirius, Scorpio, Antares, Centaur, Canopus, Achernar). This system may have been in place by the ninth century. The bearings (*majrā*) were set by the actual stars, visible in the clear skies, not by the mathematically correct rhumbs. The compass was not unknown but rarely used or even carried. Star altitude (*qiyās*) was measured in units called *iṣba‘* (finger), supposed to correspond to the arc covered by the little finger of an outstretched hand. Its degree value measured 1/2 of the distance from the Polaris to the true pole, and thus varied with precession. In 1394 one *iṣba‘* equalled 1°56′ but in 1550, 1°33′. The full circle of 360° corresponded alternatively to 210 or 224 *iṣba‘*. *Iṣba‘* also measured 1/24 of a cubit. For longitude estimates, one *iṣba‘* equalled 8 *zām*, each *zām* corresponding to the distance covered in 3 h of sailing. A variety of other measurements, including something approximating triangulation, were calculated in these units. The altitude of the Polaris was supposed to be taken at its inferior elevation.

The instruments used for measurements included the *kamāl*, *lawḥ*, and *bilistī*. The *kamāl* was a rectangle of horn or wood with a string through the middle. It was held against the horizon in an outstretched hand, with the cord held in the teeth by the knot. Knots tied at certain intervals on the cord corresponded to the varying arcs covered by the rectangle. Variations of this instrument included knots tied at intervals corresponding to locations on a set route, a set of boards (*lawḥ*) corresponding to different arc values fixed on the cord, and the cord being held to the nose. The *bilistī* was a later version of the *kamāl*, with a rod replacing the cord, and four sliders of different sizes; most likely it postdates the Portuguese arrival because its function is essentially that of the *balestilha* (a nautical instrument of orientation, similar to the astrolabe). By the nineteenth century, the traditional system and the instruments had been largely driven out of use or forgotten, although the name and expertise of Aḥmad ibn Mājid were still respectfully remembered. Today's fiberglass dhows are equipped with motors and navigated with modern charts and instruments.

See also: ►Ibn Mājid, ►al-Mas‘ūdī, ►Ibn Baṭṭūṭa, ►Navigation in Africa, ►Pirī Reis, ►Geography in the Islamic World, ►Maps in the Islamic World

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Navigation in the Pacific

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Three thousand years ago, Polynesian voyagers had already reached the small Pacific island chains of Tonga and Samoa. A thousand years later, following, as some scholars believe, the refinement of navigational capabilities and canoe design, they reached the far distant Marquesas, Tuamotus, and Society Islands. Geoffrey Irwin maintains on the basis of archaeological evidence and empirical analysis that there probably was no pause in the prehistoric settlement of eastern Polynesia. The rate of voyaging may very well have increased in accordance with the larger ocean gaps between archipelagoes. Voyagers eventually reached the small and very isolated Easter Island, may very well have established voyaging routes between the Society Islands and Hawaii, and may have even reached the coast of South America as is suggested, among other things, by the transmission of the sweet potato.

The questions of when the Pacific was settled are not as variable and questionable as those about how it was settled. The challenge of this issue, at least in terms of distance and the diminishing target areas of land as one moves east, becomes increasingly great as one can see by looking at a map of the Pacific Ocean. Several scholars consider all of these movements to have been the consequence of population demands, warfare, and the basic desire to explore and keep seeking. But the notion of great navigators who controlled their destiny and the destinies of those who put their trust in them, and who could ride the sea at will, prompted many articles and treatises. It also provided the easy and attractive answer to the haunting questions concerning the ancient settlement of Oceania.

Percy Smith, who wrote mostly between 1890 and 1920, promoted a migration of deliberate and controlled dimensions which he believed was most evident on the basis of Polynesian traditions and the inferences that one could make from them. He acknowledged the importance of applying the fields of ethnology, historical linguistics, and especially oral traditions to his theories on the ancient Aryan origins of the Polynesians. These alleged achievements included a voyage from Borneo to Hawaii in about AD 450 (the fact that voyagers continued on to Hawaii even after reaching hospitable islands along the way indicated to Smith that they were following the directions of a previous navigator), the reaching of Antarctic waters by two deliberate voyagers described in traditional histories, and the frequent voyaging between Tahiti and Hawaii (using the Line Islands as resting points) which eventually ceased in the fourteenth century, because the "boldest navigators of the race" had departed

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to New Zealand in the fourteenth century Great Fleet of the Maori people.

Elsdon Best, writing during the same time, also endowed navigators and voyagers in the Pacific with a perceptiveness of the environment and an adherence to the messages of traditions which made well planned, deliberate voyagers of settlement and communication a reality among the far flung islands of Oceania. While numerous early European explorers in the Pacific expressed wonderment in their journals at the existence of complex and populous societies on both low and high islands, which were at one stage thought to be remnants of a sunken continents occupied by survivors, very little was ever recorded on the actual means by which indigenous navigators dealt with practical problems related to the art of oceanic path-finding.

Buck, during the next 30 years, considered more practical questions on canoe capabilities and types, and the evidence that ethnology in Polynesia suggested in relation to early Polynesian migration. He also asserted the probable movements and routes used by Polynesians to reach islands throughout Polynesia and the eastern regions of Micronesia and Melanesia. He recognized the relevance of Polynesian traditions and related genealogies for tracing Polynesian origins and for understanding early voyaging and settlement in the Pacific, with an emphasis on voyages between the Society Islands and New Zealand.

But these speculations and the assignment of great skills to navigators who then sailed the Pacific with complete control, denied, or superficially addressed issues. They thus failed to consider the diverse problems of both natural and human origin which confront a navigator without modern instruments on an open ocean. Were there explicit strategies followed for the initial exploration of islands to the east of the easier "voyaging corridor" from Southeast Asia to Melanesia? If they were deliberate voyages with the intention of settlement, were such initial voyagers and those that were to follow one-way or two-way voyages? If two-way voyages were accomplished, were they done so regularly or perhaps even for the purposes of inter island communication? What might have been the distance limit for such intentional voyages of return? How did changes in climate and stellar positions over a long period of time affect the success rate of such voyages? Why did voyaging in some areas apparently cease before it did in other areas? Then, there is the question which has generated a significant amount of literature on the overall issue of oceanic voyaging and settlement. This involves numerous practical problems of reaching land, including the use of land indicating signs such as the flight of birds, the swell of waves generated from an unseen island or islands, the "loom" of land produced from an island's white sand and a still lagoon reflecting the sun's glare, the ability to determine set and drift en route, the ability to steer and maintain a course from a known sequence of stars, and the ability to maintain or to eventually recover such a course when stars are obscured or the winds change.

Was it possible that early voyagers in the Pacific were capable of using island "blocks" and "screens" that are created by the ability to perceive and interpret these wave patterns emanating from unseen islands, the flight of certain sea birds (or "bird zones"), types of fish, seaweed, water color, and clouds gathering over a distant island? These elements may have offered a 30–40 mile radius around each island which essentially expanded the size of an island target. Such perceived circles ultimately overlap throughout significant areas of the Pacific and could have enabled navigators to sail for an archipelago from even great distances before seeking a specific island within the archipelago.

Voyaging researcher David Lewis in his numerous voyages with present-day indigenous navigators of the Pacific has also recorded the glowing plaques of bioluminescence that can indicate the existence of land 80–100 miles away. But the elements of darkness and overcast skies have often been used by critics to maintain that many components of these blocks were not consistent enough to be dependable.

The academic granting of voyaging prowess to indigenous voyagers of the Pacific by these early writers and the lack of precise information on the practicality and effective means of using these natural elements to find land (not to mention the formidable question of how a course could be maintained over long distances before arriving at these island blocks), was underscored by Andrew Sharp's books and articles between 1956 and 1969 which dismissed the ability of Polynesians to exercise any significant control over their voyages. Sharp maintained that these voyagers were incapable of compensating for set and drift during the course of a voyage, of maintaining a course in accordance with star paths or movements when the night sky was obscured, and of being unable to comprehend their position and the position of their destination once they were driven off course by a gale or storm. According to Sharp, Polynesian traditions with names of distant islands and directions for reaching them were actually derived from European contact. Polynesians knew of distant archipelagoes. The Raiatean navigator Tupa'ia expressed this knowledge to Captain James Cook in 1769 whose assistants in turn created a map (apparently misunderstanding Tupa'ia's directions for north and south) that stretched from Fiji to the Marquesas. This merely demonstrated that Polynesians had traveled these distances but not necessarily as a result of deliberate and return voyages. Sharp also stressed that the apparent random distribution of several important plants and animals is simply reflective of the haphazard nature of Pacific settlement.

While the accidental settlement of Polynesia, according to Sharp, did occur primarily from west to east (a direction which is generally agreed upon by Pacific scholars), winds and currents drove later voyagers in all directions. Although Sharp did allow for the ability of Polynesians (particularly in Tonga and the Tuamotu Archipelago) to undertake voyages of no more than 300 miles without intervening islands with the intention of marking a return voyage home, the severe limitations of a noninstrumental navigational system nevertheless made even these voyages open to chance. The use of this "primitive navigation" by Pacific voyagers made them unable to protect themselves against any lateral displacement and did not enable them to derive much consistent and valuable information from horizon stars or to use stars to establish either latitude or longitude.

Thor Heyerdahl meanwhile challenged the general acceptance of an oceanic settlement pattern from west to east, maintaining that archaeological, botanical, ethnological, biological, geographical, and navigational evidence supported a Peruvian movement from South America into Polynesia using balsa rafts with strategically arranged guara hardwood centerboards. He maintained that Spanish expeditions into Polynesia actually followed sea routes established by the Incas and often referred to traditional accounts of the voyager Yupaanqui Inca Tupacor Tupac Inca. He was said to have departed from Peru in search of legendary Pacific islands, using the traditionally known island of Sala-y-Gómez as the primary landmark for beginning a voyage to the west, and to return 9–12 months later with "dark" people, which suggests that he may have voyaged as far west as Melanesia. In an attempt to prove that such voyages were possible, Heyerdahl and a crew sailed the Kon Tiki balsa raft from Peru to an eventual landfall on the atoll of Raroia in the Tuamotus in 1947. Heyerdahl, however, has been criticized by various scholars for, among other things, selectively neglecting evidence which strongly suggests a Southeast Asian origin of the Polynesians, his contention that "primitive asiatic craft" could not have successfully sailed from Southeast Asia to Polynesia, and for undermining or ignoring the fact that seasonal shifts in the prevailing winds of the Pacific do occur, making well planned voyages from west to east possible.

Sharp's works instilled what researcher Ben Finney characterizes as a "healthy corrective to some extravagant claims." The inferring of the abilities or inabilities of indigenous voyagers to control their destinies at sea on the basis of poor references in the journals of European explorers, simply produced theories which had little practical, at-sea evidence to support them. Ben Finney's and David Lewis' investigations into the navigational abilities of indigenous voyagers in the Pacific have made significant contributions to scholarship in this area.

Finney was and has been involved for a number of years in the building and sailing of the Hawaiian double canoe Hōkūle'a. Beginning with its first, noninstrumental voyage from Hawaii to Tahiti in 1976, it has provided an important component to Hawaiian cultural revival in the immediacy of its connections with the voyaging heritage of the Hawaiian people. It has also offered numerous opportunities for navigators (first the Satawalese navigator Mau Piailug and more recently the Hawaiian navigator Nainoa Thompson) to test and develop their use of various noninstrumental, navigational strategies to deal effectively with the voyaging problems of maintaining an accurate course under various natural conditions. This has also given other scholars the opportunity to apply these voyaging experiences to important questions related to the early settlement of Oceania, particularly the question of the movement from west to east which is normally a movement against prevailing winds. The Hōkūle'a 1985–1987 "Voyage of Rediscovery" in the Pacific engaged in experiments in west to east movements (in this case, from Samoa to Rarotonga via Aitutaki and from Rarotonga to Tahiti) to attempt to understand how voyagers effectively exploited periodic westerlies to cross the crucial gap between the Western Polynesia and Eastern Polynesia cultural provinces via the Samoa–Tahiti expanse. These methods for exploiting changes in the trade winds, often interrupted by low pressure systems, if they were undertaken by skilled navigators, would necessarily have required strategies for perhaps specific legs between western and eastern Polynesian islands.

Some items out of the rather voluminous literature on indigenous noninstrumental navigation and voyaging in the Pacific address the impact that climatic changes between the warming period of the Little Climatic Optimum (up to the twelfth and thirteenth centuries) and the advent of the Little Ice Age (approximately the fifteenth century) could have had on the occurrence of storms and thus the ability of voyagers to engage in long distant trips of exploration and settlement. Some scholars theorize that although voyagers from Eastern Polynesia were able to reach and settle in New Zealand by the early fourteenth century, this climatic change may have ultimately prevented them from going further to reach Australia and Tasmania. Some scholars have also conjectured on the impact that changing star patterns over several millennia may have on present-day investigations into this great achievement of human migration. At least one scholar has investigated how this change may provide a historical link between Arab and current Carolinian navigational star systems (Halpern 1986).

It should be emphasized, however, that all this scholarship on indigenous navigational abilities in relation to the chronology and patterns of human settlement on Pacific islands is incomplete without incorporating the findings and theories of other areas of scholarship, particularly archaeology. While not necessarily being directly concerned with navigational capabilities, they often provide solid physical evidence of the past, from which theories on such migration and voyaging achievements can be made and developed and/or challenged. The part that archaeology plays in attempting to answer many of these questions cannot be understated, although the extensive work that has been done in the field and remains to be done cannot be given adequate summary in this article.

The literature on indigenous voyaging in the Pacific has also covered the use and possible use of several indigenously devised navigational aids – the best known of which are the Marshall Islands stick charts which a German writer, Schück, attempted to describe in 1887, noting European references to the existence of Marshallese maps as early as 1817. Europeans in the late nineteenth century noted the use of these charts which are basically intended, through unique connections of various sticks of wood and shells, to document wave patterns and swells in relation to specific islands in the two archipelagoes of Ratak and Ralik in The Marshall Islands. Several articles refer to the secrecy that was once associated with them, while Hops noted that only the Marshall Islands may have the natural prerequisites which make the existence of stick charts unique to them. Another device that has been explored in the literature has been the sacred calabash filled with water whose holes near its top allegedly enabled a navigator to establish the latitude of Hawaii. This was accomplished by lining up Polaris at a 19° angle during a voyage from the south, and thus allowed a navigator to turn confidently to the west where he would eventually find Hawaii. Although confusion over a large calabash in the Bishop Museum in Hawaii added to the controversy, the use of the sacred calabash has generally been dismissed as being impractical. Others include the existence of nine coral stones on the northwestern end of Arorae atoll in Kiribati, perhaps used at one time by voyagers to set their courses to neighboring islands in Kiribati, a stone canoe in Beru (*kiribati*) for instructional purposes, a coconut wind compass with four directional holes used by Tahitian voyagers, the use of dials with wood hanging from strings with knots to indicate the position of stars, a bow hole and cord used for star course steering, the seeking of divination before a voyage through the tying of knots in palm leaves, and a cane filled with water to determine latitude and perhaps used in the Caroline Islands.

Research on the cognitive systems of indigenous navigators who still undertake voyages in the Pacific, particularly from the atolls of Satawal and Polowat in the central Caroline Islands of Micronesia, is far more extensive than these occasional references (with the exception of Marshallese stick charts) to these unique devises. Gladwin's groundbreaking study on thought processes involved in ixPolowatese navigational knowledge which he related to the academic test performance of economically underprivileged individuals in the United States, has been followed by numerous works concerned with the canoes, navigators, and navigational systems of Polowat and Satawal. There are also ethnographic concerns about cultural and social elements which enable noninstrumental indigenous navigation on these islands to survive in a modern technological world. While Western material influence has contributed to the decline of indigenous voyaging in areas where it was pursued until relatively recently, as has the actual government banning of voyaging, traditional navigation on these two atolls forms an integral part of their identity and society.

One well documented navigation technique found in the literature which discusses these esoteric systems is the technique of *etak*. The system of etak defies Western conceptualizations of movement in that a reference (sometimes imaginary island) to the side is seen as moving toward and past the voyager's canoe while the canoe remains stationary. The navigator is subsequently able to determine his position and progress in relation to stars and the etak segments that they provide. The survival of these systems of course depends upon how successfully they are transmitted to the young. The maintenance of star courses through songs and chants allowed for these courses to be used in recent 600 mile voyages between Satawal/Polowat and Saipan in the Northern Mariana Islands, despite the fact that such voyages had apparently not been undertaken since the early part of the twentieth century.

We now know of this rich voyaging heritage which many Pacific islanders value in the context of their cultures today. And we are aware of the questions that relate to what must be seen as an astonishing achievement in human movement throughout a vast Pacific Ocean at a time when Europeans were still depending (and would continue to depend for a long time) upon the sight of a coast. It is little wonder why the literature on indigenous navigation voyaging in the Pacific has developed as it has since the latter portion of the nineteenth century.

See also: ►Maps and Mapmaking: Marshall Islands Stick Charts

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Navigation in Polynesia

Richard Feinberg

Polynesian dispersal through the Pacific islands is one of the great maritime accomplishments of human history. In wooden boats held together with cord fashioned from coconut husks, and following the stars, sun, waves, and wind, they populated the vast triangle bounded by Hawai'i, Rapanui (Easter Island), and Aotearoa (New Zealand).

The Polynesians' ancestors migrated from Island Southeast Asia to the Bismarck Archipelago in northeastern Papua New Guinea by 2000 BCE, where they left their distinctive Lapita pottery. Around 1500 BCE, they moved out into Fiji, and then to Tonga and Samoa. During the next two millennia they spread throughout the area now known as Polynesia. Later, a series of back-migrations populated the western Polynesian "outliers" scattered through the regions commonly identified as Melanesia and Micronesia.

Some of these voyages were likely purposeful exploratory forays. Others were forced migrations resulting from population pressure or political and military conflict. Some were accidental drift voyages by sailors who had lost their way, or by fishermen swept out to sea. At each stage, return voyages probably were made for purposes of trade, marriage, and exchange of information.

Thinking about Polynesian seafaring abilities has shifted several times since early European contact. The French explorer Bougainville was so impressed by the canoes he witnessed in Samoa in 1768 that he called the archipelago "The Navigators' Islands." Britain's Captain James Cook noted that Polynesian canoes were often as fast and maneuverable as his ships, and he carefully recorded Raiatean Tupaia's impressive geographical knowledge. Even as late as the middle twentieth century, Sir Peter Buck (Te Rangi Hiroa), director of Hawai'i's Bishop Museum, took Polynesian traditions of voyaging, exploration, migration, and settlement quite literally.

The tone of the discussion altered radically with the publication in 1957 of Andrew Sharp's *Ancient Voyagers in the Pacific*. Sharp argued that, in the absence of instruments, human beings lacked the ability to navigate successfully for more than a few hundred miles. In particular, he argued, one could not detect, accurately estimate, and correct for current or leeway drift. Over distances of the many hundreds (sometimes thousands) of miles claimed by Polynesian oral traditions, he argued, errors would have been compounded, making the prospect of intentional landfall almost nil. Therefore, exploration and settlement were almost certainly the result of accidental drift voyages by sailors blown off course or forced, against their will, to put to sea.

This view again shifted with the pioneering ethnographic work of Thomas Gladwin (1970) on the Micronesian atoll of Puluwat and David Lewis' more wide-ranging survey in 1972. They and others have documented voyages of hundreds of miles with accuracy comparable to that achieved with modern instruments, as well as the techniques through which this is

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accomplished. Most of the active voyaging in recent times has been conducted by Micronesians, but the techniques are similar to those employed by Polynesians in the past. This is confirmed by comments from Polynesians recorded by early European explorers, and those few Polynesian communities where traditional wayfinding techniques have been retained in recent times.

A second line of evidence casting doubt on Sharp's drift voyage argument is provided by the direction of settlement. Linguistic and archaeological data make it clear that migration was predominantly west to east, against the prevailing winds. Recorded drift voyages, by contrast, are almost always in the opposite direction. Such voyages have certainly occurred, and more than a few sailors have been lost at sea. This however, cannot account for exploration and settlement of the Pacific.

A third strand of evidence comes from computer simulations. Importantly, in 1973, Levison, Ward, and Webb demonstrated that Oceanic exploration and settlement could not have been a result of accidental drift, but must have resulted primarily from purposeful voyaging by skilled seafarers and navigators. They did this by taking into account prevailing winds and currents, and comparing them with the geographical relationships among the various islands and archipelagoes.

The final line of evidence supporting the proficiency of Oceanic navigators comes from experimental voyages with replicas of traditional voyaging canoes, using traditional navigational techniques. In 1980, a group of Taumako (Duff) Islanders from the eastern Solomon Islands built a traditional voyaging canoe (*te puke*), which they successfully sailed to Guadalcanal, over 400 miles away.

At least equally impressive are the exploits of *Hōkūle'a*, a replica Hawaiian double-hulled voyaging canoe, built with modern materials but to traditional design, which has been sailed successfully through most of Polynesia. Its first major voyage was to Tahiti, following traditionally prescribed star paths, and performed under the guidance of Mau Piailug, a master navigator from Satawal Island in Micronesia. Later, Nainoa Thompson, a Hawaiian trained largely by Piailug, navigated *Hōkūle'a* without instruments through all the major Polynesian archipelagoes. From 1991 to 1994, the Hawaiian Voyaging Society constructed *Hawai'iloa*, a double-hulled canoe built of traditional materials. Since that time, *Hawai'iloa* has been sailed through much of Polynesia. Most prominently, in 1995, she joined a fleet of voyaging canoes from Aotearoa (New Zealand), Cook Islands, and Hawai'i to sail, without instruments, from French Polynesia to Hawai'i (Finney 2003).

Canoe Design

To travel safely on the vast Pacific Ocean requires seaworthy vessels. These had to be sturdy, maneuverable, able to resist leeway drift, and (to some degree) sail into the wind. For lengthy journeys, they had to be large enough to carry a good quantity of food, drink, and sometimes crops and livestock. This was accomplished differently in different parts of Oceania.

Most common were single-outrigger canoes ranging from small vessels paddled by one or two men (or occasionally women) for coastal travel and inshore fishing to the great Fijian *camakau* which might approach 100 ft in length and rival European sailing ships for speed. Resembling the *camakau* were voyaging canoes of several Polynesian outliers: e.g., Takuu (*vaka fai laa*), Nukumanu (*vaka hai laa*), and the Polynesian islands of the Santa Cruz group in the eastern Solomons (*puke*). Outlier Polynesians on Anuta still make single-outrigger sailing canoes which they have been known to sail hundreds of miles – to Vanikoro, northern Vanuatu, and recently to Santa Ana Island off Makira. In the outlier atolls, such as Nukumanu and Takuu, islanders have adapted the Fijian and Micronesian design of interchangeable bow and stern, where the canoe is tacked by moving the sail to the opposite end of the vessel, thereby always keeping the outrigger upwind. On other islands, such as Tikopia and Anuta, the more common Polynesian pattern was adopted. Bow and stern are distinct; the outrigger is always kept to the same side (most often, to port); and the canoe is sometimes sailed with the outrigger to the lee side of the craft.

Most imposing of the Polynesian voyaging canoes undoubtedly were the great double-hulled vessels of the Polynesian heartland. Such canoes have been reported from Rotuma and Tuvalu, south to Tonga and Aotearoa, and north to Hawai'i. More specialized developments included the New Zealand Maori's impressive single-hulled, outriggerless canoes, designed to carry scores of warriors primarily in coastal waters. For an inventory of Pacific Islanders' canoe construction and design, Haddon, and Hornell's encyclopedic treatment remains unparalleled.

Polynesian voyaging canoes could cover well over 100 miles a day with a favorable wind. The outrigger or double-hull design provides resistance to leeway drift without the need for a deep keel, which is a hazard sailing through a sea studded with shallow reefs. It is difficult, however, to beat into a head wind; and even the best outrigger canoes cannot sail at better than a close reach or approximately 75° off the wind.

Navigational Techniques

The most important tool for Oceanic navigation is the stars. Near the equator, stars rise from the east, travel more or less straight overhead, and set toward the west. The expert navigator knows the relationship between the bearings of various islands and the rising and setting points of various stars. Ideally, he identifies a star that he knows rises directly over the target island and points the bow of the canoe toward that star. When the star rises too high to be a reliable guide, the navigator turns his attention to another star following approximately the same trajectory. A sequence of such stars may well continue through the night, and it forms a star path.

In reality, it is unlikely for a sequence of stars to rise or set directly over the target island, so the navigator must set off the bow at an appropriate angle from the stars' actual position. In addition, the navigator must be able to estimate the direction and speed of wind, current, and leeway drift in determining a proper heading.

Wind strength and direction are not overly difficult to estimate as long as one can see the stars, moon, or sun, while leeway drift depends on the contours of the canoe's hull and heading in relation to the wind. It often can be gauged by the angle between the canoe and its wake.

Current is most difficult to estimate, but not impossible. First, a navigator knows the prevailing currents in the region that he plans to sail. These tend to be fairly constant at a particular time of year. The current's velocity is confirmed when the canoe is still near the point of embarkation, or when sailing over shallow reefs. The greatest danger is if currents change direction while one is in deep water, far from land. Such shifts are difficult to detect, but there are sometimes useful clues. Anutans, for example, say that when the current and wind are running in opposite directions, seas tend to be unusually steep and white-capped. Conversely, when wind and current coincide, the seas are exceptionally flat in relation to the strength of the wind. Thus, by feeling wind strength and seeing or feeling the condition of the sea, one often discerns the current's direction even in deep water.

Fixing one's position on the ocean is another major problem. Latitude can be gauged with some accuracy by identifying zenith stars: stars located at a point that is directly above the observer. In addition, the configuration of stars at a given latitude at the same time on any given night is identical regardless of longitude. Therefore, one can estimate latitude by observing the altitude at which specific stars rise and set. Longitude, however, cannot be gauged from observation of the sky and must be estimated by dead reckoning. This means that the navigator fixes the position of his canoe in relation to the islands in his universe by estimating the vessel's speed, direction, and how long it has been at sea.

This is difficult, requiring the navigator to keep a running total of his vessel's progress at all times. One consequence is that he cannot sleep, other than occasional brief naps, even on a lengthy journey. Sharp argued that the element of human error inherent in dead reckoning is cumulative and, over a distance of many hundreds of miles, would be too great to permit accurate landfall. Empirically, it has been demonstrated, however, that the error is random and tends to cancel itself out. Therefore, the longer the voyage, the smaller the probable error.

During the day, when stars are unavailable, Polynesian navigators use the sun. This is practical in early morning and late afternoon, when the sun is low on the horizon. Toward mid-day, however, it loses value as a navigational aid. The sky also loses its navigational value when it is obscured by clouds, whether in the day or night. Under such conditions, auxiliary techniques are needed.

Navigators are aware of the prevailing wind patterns. If the sky is overcast, they assume that winds will remain constant until the stars and sun can once again be seen.

Still more stable and reliable are swells. A regular ground swell is produced by winds from far away, blowing over a vast expanse of ocean. Such swells remain constant despite shifts in local wind direction. An expert navigator can distinguish the regular ground swell from choppier seas produced by local winds. Indeed, some Micronesians have demonstrated the ability to distinguish several swells caused simultaneously by different far-off wind patterns. Polynesian master navigators almost certainly could do the same. By holding a steady course in relation to the swell pattern, then, the navigator maintains his bearings until celestial bodies become visible again.

In addition, sea marks such as deep reefs that can be detected from the color of the water may help indicate one's route. Use of such marks has been reported ethnographically for Micronesia, and at least some Polynesian navigators undoubtedly employed similar techniques.

Sailing strategy, particularly for exploratory voyagers, was clearly to sail counter to prevailing winds. This could be accomplished by waiting for a westerly shift at a time when the prevailing winds were from the east. If landfall was not made in a reasonable amount of time, it was expected that the wind would shift again, making for an easy return home. This accounts for the generally west-to-east direction of Polynesian migration.

Likewise, in historic times, Anutans like to sail at the beginning and end of the trade wind season, when breezes are relatively light and unstable, but the prevailing wind is from the southeast. During this period, they can usually find a period of a few days when wind of moderate strength is blowing in the preferred direction. Should it shift before they reach their destination, they can almost always return to their point of departure.

Geoffrey Irwin further suggests, plausibly although without definitive evidence, that long-distance voyagers employed "latitude sailing." This involves sailing to the latitude of the target island but at a point well to windward, then making landfall by running downwind. Sailors from all parts of the Pacific also minimized their risk by island hopping, thereby breaking lengthy journeys into shorter segments. And they aimed, wherever possible, for groups of islands rather than isolated targets.

Land-Finding

As the navigator approaches land, he uses a variety of techniques for homing in on his objective. These include attempting to make landfall during daylight to minimize the chance of either being swept onto an exposed reef or overrunning the target. Then, before land is visible, it may be located via one of several indicators.

Among the most important of these are the flight patterns of birds that roost on land at night and fly to sea to feed during the day. Reflected waves are shaped differently from waves produced directly by the wind, and they can, at times, be felt at distances of more than 20 miles from land. Refraction patterns are more difficult to decipher but are used by a few peoples. Clouds tend to accumulate around the peaks of high islands, indicating their presence; and a greenish tint to clouds may sometimes indicate the presence of an atoll when it still cannot be seen from a canoe.

Polynesia in Comparison with Other Culture Areas

A few writers have made much of the distinction between Polynesia and other Oceanic culture areas in terms of seafaring acumen. Edward Dodd, for example, has suggested that the comparatively short distances traversed by Melanesians and even Micronesians means their vessels and wayfinding techniques could be less sophisticated than those of Polynesians, who sometimes had to sail thousands of miles, e.g., on journeys from Tahiti to Hawai'i or Aotearoa.

Clearly, the logistics of such lengthy voyages posed problems not faced by Micronesians sailing from the Carolines to Saipan – a distance of about 500 miles. On such journeys, for example, the importance of dead reckoning increases and a smaller proportion of the voyage is guided by land-finding techniques such as reflected waves or flight patterns of birds. However, modern ethnographic evidence from around the Pacific and beyond supports the view that navigational techniques were fundamentally similar throughout Oceania. The transferability of old skills to new locations, and their ability to meet new challenges, is demonstrated by the success of Mau Piailug and Nainoa Thompson, piloting the *Hōkūle'a* through major portions of the Polynesian Triangle.

See also: ►Outliers

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Nazca Lines

David M. Browne

On the desert plains and the fringes of the valleys that form the heartland of the ancient Nasca culture of the south-central coast of Peru is a vast array of ground markings that are known collectively as the "Nazca Lines." The most extensive concentration of these constructions, termed *geoglyphs* by archeologists, is found on the Pampa de Nazca between the Ingenio and Nazca valleys. The pampa is an elevated desert plain 200 km^2, between 400 and 600 m above sea level. It is severely dissected by dry watercourses formed by periodic flash floods. About 3.6 million m^2 of this area are covered by geoglyphs. Concentrations of markings also occur on the slopes of and on the plateaux and pampas between the other valleys of the Nazca drainage, and are particularly dense in the Palpa area. Geoglyphs are also known further north, in the Ica valley, where the other major centers of the Nasca culture are found.

Geoglyphs take many forms, but can be grouped into four main classes: biomorphs, enclosures, lines, and geometric figures.

Biomorphs are stylized representations of various creatures, the commonest being birds, among which are hummingbirds, the condor, pelican, and frigate bird (Figs. 1 and 2). There are also depictions of a monkey, fox, lizard, spider (Fig. 3), killer whale (Fig. 4), and fish, as well as a few drawings of plants or flowers and bizarre combinations of body parts (Fig. 5). Humanlike figures are also found, particularly in the Palpa area. Most forms are outlined by a continuous line usually about 0.6-m wide, which never crosses and ends near where it starts. The greatest concentration of biomorphs occurs in the northwest corner of the Pampa de Nazca, above the south edge of the Ingenio valley and close to a major regional center of the Nasca culture. Some biomorphs appear to be isolated drawings, but others, for example the monkey, seem to have a direct association with other geometric figures. Despite the impressive size of some drawings they are generally insignificant in scale when compared to many of the enclosures.

Enclosures are trapezoidal, triangular, quadrangular, and rectangular clearings defined by stone banks up to 1-m high (Fig. 6). They vary greatly in area and proportion, the largest occupying the space of several football fields. This class of geoglyphs is the most frequently occurring form outside the Pampa de Nazca.

Nazca Lines. Fig. 1 Nazca biomorph: hummingbird (from the author's photo collection).

Nazca Lines. Fig. 3 Nazca biomorph: spider (from the author's photo collection).

Nazca Lines. Fig. 2 Nazca biomorph: stylized bird with long zigzag neck (from the author's photo collection).

Nazca Lines. Fig. 4 Nazca biomorph: stylized killer whale with trophy head (from the author's photo collection).

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Nazca Lines. Fig. 5 Nazca biomorph: "pair of hands"; possibly stylized root crop (from the author's photo collection).

Nazca Lines. Fig. 6 Nazca Lines: trapezoids (from the author's photo collection).

Where they are built on the flat spurs between valleys they follow the long axis of the topography; on hillsides their narrow ends point toward the top of the hill; and where they are constructed in the bottom of a small, dry tributary valley their narrow ends point toward its head. About 300 are found across the Pampa itself, roughly two-thirds of which are orientated to the line of watercourses, with their ends pointing upstream. Enclosures are commonly found in association with other forms of geoglyphs such as line centers, spirals, and zigzags.

Line centers consist of a series of straight lines converging on or radiating from usually a hillock or low mound on the periphery of the Pampa de Nazca. The lines vary in width and length, some running for several kilometers. Over 90% of the geoglyphs found on the Pampa are associated with the 62 line centers identified so far. However, only about a quarter of the centers are interconnected, suggesting that these features cannot be interpreted as a simple coherent system. Line centers are frequently connected to enclosures. Long lines, unconnected to line centers, running dead straight for several kilometers with no regard for topography are another feature of the Pampa and elsewhere, as are pairs of parallel straight lines.

The most prominent of the geometric forms found are spirals created by a single line along which it is possible to enter and exit in an unbroken progress. Other figures include zigzags and "fingers" consisting of a series of concentric semicircles formed by a single line continuously running parallel to itself in a set of arcs.

Contrary to some assertions, constructing the geoglyphs required no great engineering skill and no more complicated surveying equipment than simple stakes and rope. The surface of the pampa is covered by rocks which are subjected constantly to daily extremes of temperature and humidity which lead through bacterial action to the formation of characteristic dark-collared varnish on their upper parts. The underlying soil is lighter in color, and if the surface stones are removed a bright patch of ground is created, contrasting strongly with the darker, undisturbed desert floor. This contrast will persist for centuries, only gradually diminishing as the same weathering agencies act upon the newly created surfaces. In most cases the construction of a Nazca geoglyph involved nothing more than stripping the required width or area of its upper stones and regularly piling the rocks along the edge to form a boundary. Judging from some apparently incomplete examples, an intermediate stage in the construction of an enclosure was to collect the surface stones in a series of small piles on the surface of the intended clearing, probably in baskets rather than by sweeping, before removing them to the edges. It has been estimated that it would take ten people to clear 16,000 m^2 in a week, and in a trial a spiral of 10-m diameter was built in less than 2 h. The construction of the biomorphs probably required a preliminary model such as a figure etched on wood, sand drawing, or textile embroidery. The precise method whereby the final geoglyph depiction was scaled up from this model is unknown, although several geometric systems have been suggested. Attempts to demonstrate the use of a particular standard unit of measurement in their formation have been unconvincing.

The practice of etching or building figures in the unoccupied desert adjacent to settlements seems to have been started by the communities sharing the Paracas material culture in the two centuries before ca. 200 BCE. Evidence is emerging to show that the activity may have started in the Palpa region with the construction of humanlike figures, perhaps inspired by a tradition of inscribing petroglyphs. Roughly contemporaneously, mythical beings related to the so-called "Oculate Being" of Paracas iconography were built on the Pampa de Nazca. There is little doubt, however, that most geoglyphs were built by the peoples of the Nasca culture (ca. 200 BCE–AD 600), although the practice was continued locally on a small scale by some communities until the late fifteenth century. Two radiocarbon dates from wooden posts supposedly associated with lines fall within the later Nasca period. Nasca pottery is found so repetitively on the surface of many enclosures as to indicate their construction and use during its currency. Radiocarbon dating of the organic material sealed under the varnish on rocks lifted by line builders indicates a similar date range. Additional support is given by the clear association of some geoglyphs with Nasca ceremonial architecture at the great pilgrimage center of Cahuachi and the lesser complex at Llipata.

Various explanations have been advanced for the Nazca Lines that they were fields, the sites of textile workshops, a giant sports arena, and even markers and landing places for extraterrestrial spacecraft! The idea that they fulfilled primarily an astronomical function has been championed by the principal fieldworker on the Lines, Maria Reiche. In her view the linear geoglyphs functioned to mark the solstices, the rising and the setting of the moon, and the rise of the Pleiades. The multiplicity of some lines she explained as the attempts of ancient astronomers to compensate for the precession effect, the subtle shifts over time in star rising and setting positions. The biomorphs were regarded as representing constellations, for example the spider for Orion and the monkey for Ursa Major. The whole system was supposedly elaborated for calendric purposes, principally to predict the onset of the rains so essential to agriculture in the extremely arid Nazca environment.

Reiche's claims for significant, repetitive astronomical alignments have not been supported by other studies. A more basic objection to her approach is that it projects on to the evidence a European, Northern Hemisphere perspective which ignores Andean peoples' astronomical perceptions. By using historical and ethnographic analogies it is possible to offer plausible explanations of the geoglyphs' forms and functions which make sense in the context of a general Andean religious tradition.

The location and form of the Lines leaves little doubt that they were built for ritual purposes. Many of the lines connected to line centers bear a general resemblance to Inca roads, and footpaths are still discernible within them, supporting the view that they were processional ways. The use of straight-line paths has been shown to have been in widespread use up to the present day in Andean religious observances. The lines defining biomorphs and geometric figures are also laid out in a fashion which would allow uninterrupted procession through the figure. The core of the line centers, and the enclosures, were probably the foci of the processions where the principal rites and offerings were enacted. Depictions on Nasca pottery suggest that the participants in these rituals would have been specially attired, often wearing masks, and proceeded by rhythmic dancing to the accompaniment of drums and pan pipes (Fig. 7). The evidence of broken pottery and offerings of foodstuffs attests to ritual feasting and sacrifice.

It is highly probable, given general Andean practice, that kinship groups (*ayllus*) in acts of obligatory communal labor would have been responsible for the construction and maintenance of particular lines and figures and for the organization of the relevant rites at a certain time of year, imparting a type of calendric significance to the geoglyphs. Some of the biomorphs, such as those along the edge of the middle Ingenio valley, may have been ancestral emblems of such social groups. The palimpsest of geoglyphs found can be explained in part by a practice of periodical renewal of the sacred site at a slightly different location.

The basic concern of the Nasca people was the fertility of their valleys, which was entirely dependent on the arrival of waters from the Andes to the east. It is not unlikely that peaks in these mountains were deified

Nazca Lines. Fig. 7 Early Nazca figurine: masked shaman (from the author's photo collection).

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and perceived of as the sources of this lifeforce. The shape and orientation of many of the enclosures can be argued to be symbolic of the flow of water from the highlands. Similarly, certain geometric geoglyphs such as spirals and zigzags may have been symbols of a water cult. Offerings of *Spondylus* shells, associated with rain in Andean lore, have been found in connection with mounds, possibly altars, at the ends of some trapezoids. One recent theory (Silverman and Proulx 2002) proposes that the geometrics actually indicate the position of water-bearing faults and that the trapezoids show the line of subterranean watercourses determined by dowsing. In some cases, such as at Cantalloc, south of Nazca, the layout of a trapezoid in relation to a lesser hill seems to be a model of the topographic relationship of a valley with an adjacent mountain.

The Nazca Lines were a product of intense, repetitive ritual activity over several centuries, concerned with guaranteeing the continuing fertility of the valley oases upon which human society is utterly dependent in southern Peru.

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Nīlakaṇṭha Somayāji

K. V. Sarma

Nīlakaṇṭha Somayāji (AD 1444–1545) was one of the eminent astronomers of Kerala in South India. He was a pupil of Parameśvara, the promulgator of the Kerala Dṛggaṇita School of astronomy, and left after him a long line of astronomers. He was also a prolific writer on astronomy.

Nīlakaṇṭha's writings include *Golasāra* (Essence of Spherics), *Siddhāntadarpaṇa* (Mirror of the Laws of Astronomy) with his own commentary, *Candracchāyāgaṇita* (Computation of the Moon's Shadow), *Tantrasaṅgraha* (Resumé of Astronomy) in eight chapters, composed in AD 1501, Commentary on the *Āryabhaṭīya* of Āryabhaṭa, and *Jyotirmīmāṃsā* (Investigations on Astronomical Theories). Two of his works, *Grahaṇanirṇaya* and *Sundararājapraśnottara* are known from references but are yet to be retrieved.

While Nīlakaṇṭha's commentary on the *Āryabhaṭīya* is elaborate and exhaustive, and is infused with novel interpretations and new ideas, his *Jyotirmīmāṃsā* is of particular interest, in that it is wholly devoted to certain fundamental matters relating to Hindu astronomical theories and practices. It throws ample light on Nīlakaṇṭha's practical approach to astronomical studies. He says that there is no place, in a physical science like astronomy, for mythological explanations to astronomical phenomena. Enhanced by examples, the *Jyotirmīmāṃsā* emphasizes that astronomical computations should tally with actual observation. According to Nīlakaṇṭha, continued observation of planetary movements, experimentation, logical deduction, and enunciation of periodical corrections towards correlating computation with observation are the *sine qua non* of practical astronomy. Results obtained by the application of such corrections have to be verified at times of successive eclipses, which are visible celestial phenomena. Small errors that arise on account of observations being made from the surface of the earth, instead of from its center, are to be corrected by reducing the basic angular distances to the *dṛggola* (visible celestial sphere). Conversely, it is stated that in the case of the gnomonic shadow, it is the measure in the *dṛggola* that needs to be reduced to that of the *bhagola* (sphere of the zodiac). The *Jyotirmīmāṃsā* of Nīlakaṇṭha reveals him as an astronomer of extraordinary ingenuity and acumen.

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Nilometer

Zaraza Friedman

The Nile played an important role in the historical and the economic life of Egypt. Throughout history, Egypt was an agricultural nation that became the granary of the Mediterranean Basin. The river Nile is one of the most predictable rivers in the world. The rise and fall of the Nile is regular and quite precise with floods that are rarely destructive. After the beginning of the rainy season in Ethiopia, the Nile starts to rise in early June and gradually swells to its maximum by the end of September, when the lands in Egypt are flooded with the appearance of islands. Diodorus Siculus gives a detailed description of this phenomenon:

> The rise of the Nile is a phenomenon which appears wonderful enough to those who have witnessed it, but to those who have only heard of it, is quite incredible. While all other rivers begin to fall at the summer solstice (beginning of June 21) and grow steadily lower, this one (Nile) begins to rise at that time and increases so greatly in volume day by day that it finally overflows practically all Egypt… And since the land is level plain, while the cities and villages, as well as the farm-houses, lie on artificial mounds, the scene comes to resemble the Cycladic Islands (Diodorus, I.36.7–9).

This period of the inundation is also dedicated to festivals and ceremonies such as the account given by Diodorus:

> The masses of people being relived from their labours during the entire time of the inundation turn to recreation, feasting all the while and enjoying without hindrance every device of pleasure (Diodorus, I.36.10).

The flood remained quite static for about one month, then subsided more and more until December or January, when the Nile returned to its original bed. In early June the river was reduced to its half of the flood breadth (Said 1993: 96).

Metrology and the Inundation

The Nilometer was invented for recording the annual inundations in Egypt and to control the floodwater. As the name suggests, the device originates from the area of the Nile in Egypt. The significance of the Nile's floods is associated with Memphis, which is located at the root of the Delta. Diodorus (first century BCE), wrote that the kings of Egypt constructed a *Niloscope* [Nilometer] at Memphis where administrators were appointed to make accurate measures of how many cubits or fingers the river (Nile) had risen or when it commenced to fall (Diodorus, I.36.11). These inundation levels could predict the grain and corn harvest, since the Egyptians kept accurate records of their observations over a long period of terms (Diodorus, I.36.12).

The surveying records of the Nile's levels are difficult to interpret since various measuring devices throughout historical periods did not use the same zero point and most probable not the same scale. The oldest records come from a stone stele, dated to Dynasty V (2480 BCE), known as the "Palermo Stone", named after the Museum of Palermo, where it is found (Fig. 1). Additional parts of this stone are found in the Cairo Museum. The Palermo Stone is assumed to come from the Memphis area. W. Helck completed a study of the stone in 1966 and also converted these records into the metric system:

1 cubit = 7 hands/palms = 28 fingers = 2 spans = 0.524 m (Said 1993).

Nilometer. Fig. 1 Palermo Stone (From Said 1993: 135, Fig. 2.13).

The gauges to record the Nile flood levels were marked in cubits, a metrological unit comprising 6 or 7 palms, thus indicating two kinds of measures: the small cubit = 6 palms and the royal cubit = 7 palms. The hieroglyph used on cubit rods to indicate metrological fingers appears as 4 (a palm with four stretched finger), 5 (a palm with five stretched finger) and 6 (a clenched fist). The small cubit was considered the length of the forearm from the elbow to the thumb, equaling 45 cm, while the royal cubit was the length of the forearm from the elbow to the tip of the middle finger, equal to 52.5 cm (Robins 1982). Since the cubit was the length of a forearm and Egyptian men were of varied height and arm length, there were different cubit units. The royal cubit was divided into 7 palms or 28 fingers (524 ± 5 mm), while the small cubit into 6 palms or 24 fingers (449 mm). The double remen (740.7 mm) was the length of the diagonal of a square with each side of one royal cubit (Singer et al. 1965: 777). This metrological unit was the base of the Egyptian land measure. The double remen was divided into 40 digits (each digit = 18.5 mm).

One of the most significant Nilometers in history was found at Memphis; in ancient literature it was referred to as the "House of Inundation". The zero point in this Nilometer must have been at the ground level of the Memphis agricultural plains. In the Aswan Nilometer at the Temple of Khnum there were two zero points: the lower level corresponded to the low water level of the Nile; the high level equaled the level at which the fields were watered. Said (1993) suggested that the Memphis Nilometer may have had two zero points; thus the records of the flood levels on the Palermo Stone were probably taken in the same way as at Aswan.

The Elephantine Nilometer was considered the most significant station for measuring the Niles's levels (Herodotus II.32, Diodorus I.36.11, Pliny, *NH* V.x.58, Popper, 1951, Pearl, 1956: 52), due to its location off the First Cataract, where the floodwaters reached their maximum height. Plutarch said that the greatest rise at Elephantine amounted to 28 cubits, at Mendes the smallest was 6 cubits, while at Memphis the intermediate (between the high scale at Elephantine and the smallest at Mendes), when normal, was 14 cubits (Pearl 1956: 52). The inundation heights of 15 or 16 cubits given by Herodotus (II.23.), appeared to be the adequate level for the fifth century BCE. The big difference between 28 cubits at Elephantine and 14 cubits at Mendes shows that the readings from the Elephantine Nilometer were done from a scale and not from high and low waters (Pearl 1956: 57). The high numbers in these scales were probably done when they attempted to establish the same zero point at the Nilometers upstream from the Nile's mouth starting at the Delta, on a theoretical fall line which did not correspond to the gradient of the river (Pearl 1956).

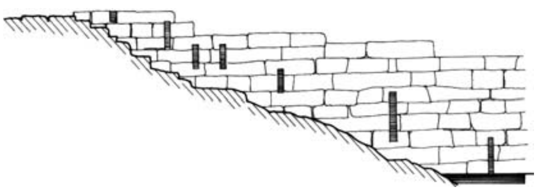
The level of 16 cubits was considered the optimal level for the inundation of fields from the Greco-Roman and early Arabic periods (the measures were taken at the newly built Cairo Nilometer at Roda Island, 715 CE). Pliny (V.x.58) said that when the flood level was 12 cubits (in the province of Memphis), it was a sign of starvation, and even with 13 cubits it still meant hunger. Fourteen cubits brought joyfulness, 15 was freedom, and 16 sheer delight. At Elephantine a good flood meant a rise of 28 cubits, while at Edfu 24 cubits and 3¼ palms were required (Elephantine and Edfu were the main stations off the First Cataract) (Moret 1927: 32). Descending northwards to the Delta, the needed flood level was less than in Upper Egypt; at Mendes and Xoīs, 6 cubits were sufficient (Moret 1927: 32). A record for a "good flood" in the Middle Kingdom during the reign of Senwosret I (1971–1928 BCE) was registered at the level of 21.5 cubits (11.3 m) at the Elephantine Nilometer, 12.5 cubits (6.6 m) in the "House of Inundation" at Old Cairo, and 6.5 cubits (3.4 m) at Diospolis (Tell Balamoun), in the northern Delta.

The Roda Nilometer built at the southern tip of the Island, during the reign of Caliph Abdel ibn-Marawan (715 CE), and later rebuilt by Caliph el-Mutawalik (861 CE), is a covered structure with a well inside. An octagonal marble pillar stands in the middle of the well. On the pillar are inscribed the calibration units in cubits and subdivisions in fingers. Due to both changes of the Roda Nilometer, the scale had different values. The cubits in the oldest scale were divided into 28 fingers from cubit I to XII, and the new scale was divided into 24 digits from cubit XIII to XXI. Since the finger in both scales is the same (1 finger = 1.925 cm), the cubits in the lower part measure 53.9 cm (royal cubit), while those on the upper part equal 46.2 cm (small cubit). The zero point of the scale was fixed at the level of the well's floor; thus the cubit XVI was 8.3 m above the floor of the well (or 16.4 m above sea level). At the time of building the Nilometer, level XVI was considered the effective level of the flood at which the dikes were opened to release the water in the fields at the inundation season.

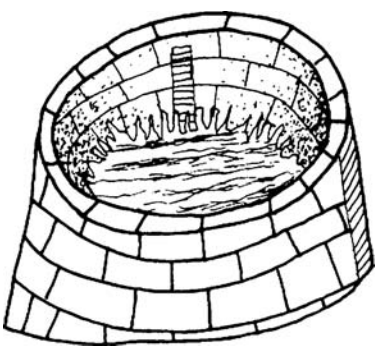
In the Greco-Roman periods the figure XVI and the floodwaters of the Nile became the symbol of life and prosperity not only in the Egypt but also through the Mediterranean World, where the cult of the Nile developed. The Nile Statue at the Vatican Museum in Rome is a relevant example of the personification of the Nile's fertility at the inundation season; sixteen *putti*, each of one royal cubit height, surround the god Nile reclining on his left side, while he holds ears of corn and a cornocopia (Fig. 2). The *putti* symbolize the optimal 16 cubits required for a successful flood.

In ancient Egypt, the god Hapi was the incarnation of inundation and deification of the flood, as attested by

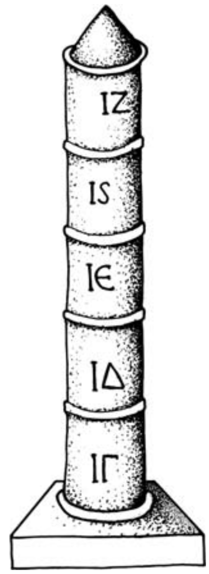
Nilometer. Fig. 2 God Nile with 16 *putti*, each one royal cubit height (From Freeman and Ray 2000: 147).



Nilometer. Fig. 3 Wall or corridor Nilometer (From Said 1993: 153, Fig. 2.25).



Nilometer. Fig. 4 Well Nilometer (Drawing by Z. Friedman).



Nilometer. Fig. 5 Column Nilometer (Drawing by Z. Friedman).

Nilometer. Fig. 6 Composed type of well with column (Drawing by Z. Friedman).

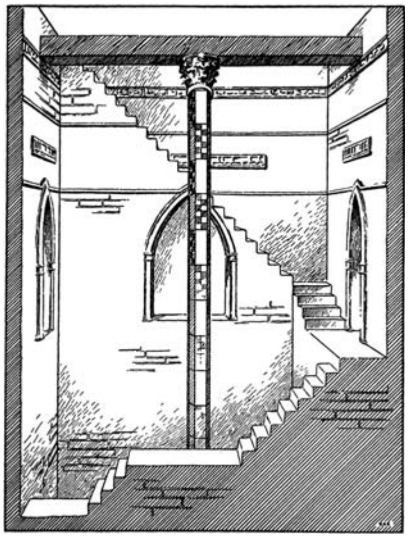
many Egyptian paintings, statues and reliefs. He was the god bringing fertility to the land.

Types of Nilometers

Surveying the remains of ancient Nilometers and their representation in art we may classify them in three main types and some combined types: a wall or corridor with steps (Fig. 3), a well (Fig. 4), and a column (Fig. 5).

The combined types are a well with a projecting column (Fig. 6), or a covered structure with a well in which a column is set in its center, as represented by the Islamic Roda Nilometer (Fig. 7). In all Nilometers the gauge is marked in cubits and subdivided into fingers. Nilometers depicted in art are shown with whole metrological units missing the subdivisions in fingers. The cubits value is indicated by Greek letters. These representations were done for convenience, with the purpose to transfer to the viewer the symbolism of the device and its importance associated with the floodwaters of the Nile. Each type of Nilometer will be described and illustrated with relevant examples.

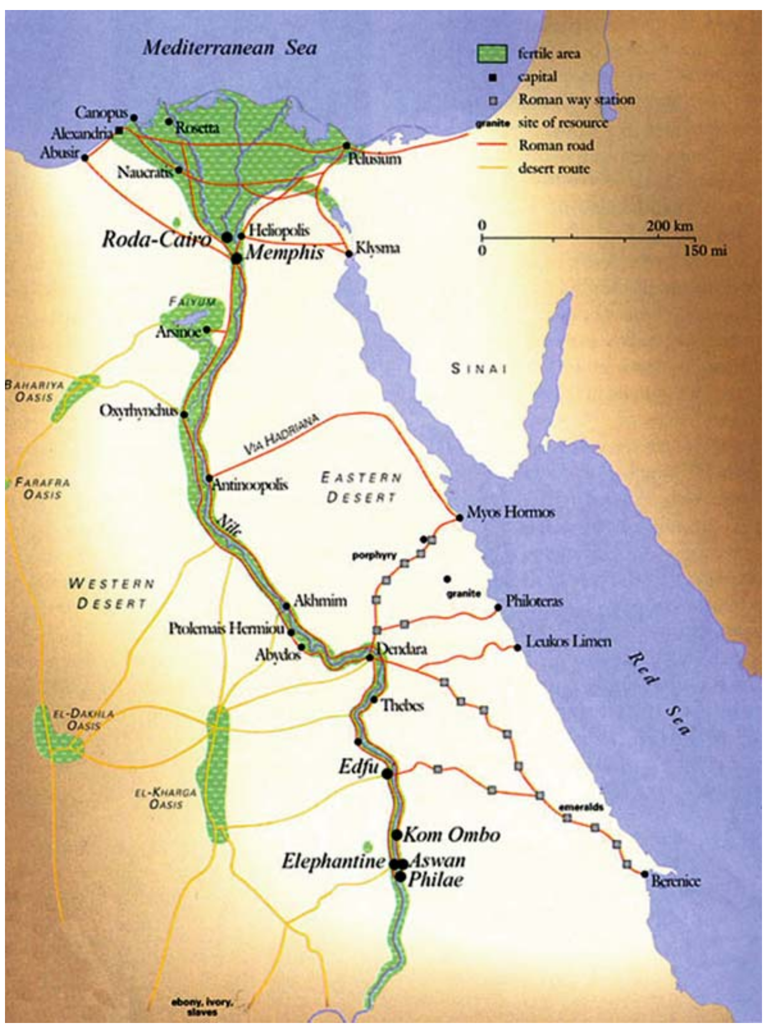
1. Wall or corridor types of Nilometers had their zero point set where the water level was against the steps, thus showing the height of the floodwaters. Such Nilometers were built in temples at Elephantine, Philae, Edfu, Kom Ombo and Dendera (Fig. 8). These devices have the calibration marked on the wall and were built from the Pharaonic periods to the Roman era. The



Nilometer. Fig. 7 Roda Nilometer (From Popper 1951: inner cover).

Nilometer on Elephantine Island (Fig. 9a,b), north of the First Cataract, was one of the most important devices, due to its location where the floods began. This device was located in the Temple of Khnum dedicated to the ram-headed god of Inundation. The Nilometer dated to Dynasty XI, was replaced by a new one built during Dynasty XXX, at the Temple of Satet, one of the Khnum's celestial consorts (Seawright). When Egypt fell to the Roman Empire, the Nilometer at Khnum temple underwent some changes. The new calibrated staircase was roofed with granite slabs.

On the quay of the Karnak Temple gauges were engraved to measure the height of the floodwaters. Many authors have researched them since the late nineteenth century. Legrain (1896), Borchardt (1906), and Beckerath (1966) recorded 45 levels of inscriptions running from the reign of Shosheq I to Psammetik I (Dynasties XXII–XXVII) (Fig. 3). The elevation of the zero point of the Nilometer was fixed at 64 m above sea level. The floods rises recorded at Karnak quay ranged



Nilometer. Fig. 8 Map of the Nile with locations of Nilometers (From Freeman and Ray 2000: 133).

Nilometer. Fig. 9 (a) Staircase Nilometer at Elephantine: ►http://www.lexicorient.com/egypt/aswan04.htm. (b) Close-up of the Elephantine gauge: ►http://www.touregypt.net/featurestories/nile.htm.

from 9.22 to 11.1 m. The years marked "joyful" were those which had an average flood rise of 10.6 m (Said 1993: 152).

2. Well Nilometers seem to be a later type that appeared during the Ptolemaic period. Strabo (first century BCE) gives a detailed account about where such Nilometers were placed at Syene and Elephantine Island:

> The Nilometer is a well on the bank of the Nile constructed with close-fitted stones, in which are marks showing the greatest, least, and mean rises of the Nile; for the water in the well rises and lowers with the river. …Accordingly there are marks on the wall of the well, measures of the complete rises and of the others. So when the watchers inspect these, they give out the word to the rest of the people, so that they may know (Strabo *Geo*. 17.I.48).

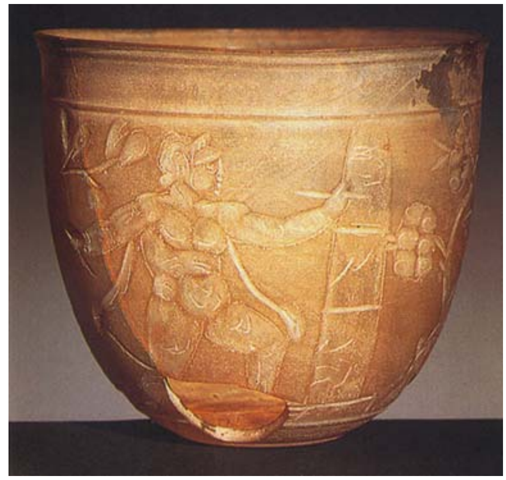
Nilometer. Fig. 10 Well Nilometer in the Nile mosaic from Palestrina (Photo by Z. Friedman).

Pliny informs us that when the inundation season started, it was observed through the well Nilometers, and that it was also advisable not to sail during the high floods:

> The view has been held that it is unlawful for kings or rulers to sail on the Nile when it is rising. Its degrees of increase are detected by means of wells marked with scales. An average rise is one of XVI cubits. The smaller volume of water does not irrigate all locations, and a larger one by retiring too slowly retards the agriculture (*NH*. V.x.57–58).

Both Strabo (*Geo*. 17.I.48) and Pliny (*NH*. II.183), said that the midday sun in the summer solstice did not cast any shadow in the wells and that the light reaching their bottom showed the water level, probably at the crest of the flood (Friedman 2001: 59). The well in the Palestrina Nile mosaics may be considered an illustrative example for a well-type Nilometer (Fig. 10). The rounded well is built with stone blocks. On its right lower edge (at the water level) there are two arched openings that water goes through. The well is placed on the bank in the vicinity of a Hellenistic temple. The splashing water inside the well, viewed from above, may suggest rising floodwaters. A gauge may have been engraved on the walls of the well. Well type Nilometers were modified during the Ptolemaic periods, with stairs in or around them. Such wells were found in temples at Kom Ombo and Edfu. A spiral staircase set in the inner side of the well reached the water level in Kom Ombo Temple (Fig. 11). A gauge

Nilometer. Fig. 11 Well Nilometer at Kom Omb: ►http://hometown.aol.com/_121b_xzkSKIDq8Ea2ZwvSQf8wsKD5Urprh6; p. 2 bottom.



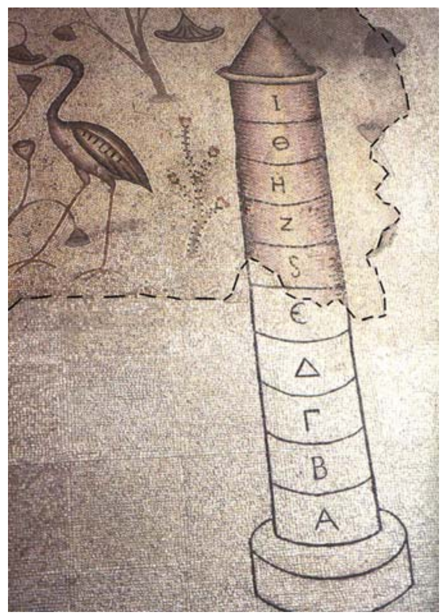
Nilometer. Fig. 12 Column Nilometer on a Roman glass cup (From Harden 1987: 200, Fig. 109 bottom).

may have been engraved on the walls of the well or on the steps as well. A similar type of Nilometer with a rectangular basin with stairs leading to it, dating from early Imperial period, is found in the Temple of Khnum at Elephantine (Meyboom 1995: 244, n. 77).

3. Column Nilometers appeared during the later Imperial period, when the scale was removed from the well to a column. It was much easier to carry such a device and place it at different points to record the flood levels. Tousson (1925:302), mentions that at least during the Greco-Roman periods there was a portable device, which when not in use, was kept in the Temple of Serapis (Moret: 302). In the flood season it was taken out and set up in a well shaft (Bell 1970: 571).

A column Nilometer is quite a common object in art. It is depicted as an individual item or shown with human figures engraving the newly risen flood level. Such an example appears on a Roman glass cup (Fig. 12), probably of Campanian origin, dated 200–300 CE, now at the British Museum (Reg. 1868.5.919; Versluys 2003: 169–170). A single column Nilometer with a conical top appears in the mosaic floor, to the right of the transept, in the Church of Multiplying of the Loaves and Fishes, at Tabgha, on the northwestern shore of the Lake of Galilee (Kinneret), Israel. A considerable part of the mosaic was destroyed and in the past several years it had been reconstructed. The upper part of the Nilometer belongs to the original mosaic, while the lower section is reconstructed (Fig. 13). The mosaic was dated to the fourth to fifth century CE (Schneider 1937). On the shaft are inscribed Greek letters referring to the calibrations from 6 to 10 cubits: S = 6, Z = 7, H = 8, Θ = 9, I = 10 (Friedman 2001: 60).

A column Nilometer associated with Alexandria appears in two mosaics from Israel. The first device is



Nilometer. Fig. 13 Tabgha mosaic (Friedman 2001: 86, Fig. 105).

found in the lower frame with a Nilotic scene, in the mosaic floor from the House of Leontis, at Beit Shean. The mosaic was dated to the fifth to sixth century CE; now it is found at the Israel Museum, Jerusalem. The vertical shaft set on a rectangular pedestal and topped by a rounded tip is placed to the left side of a small temple with a tiled pitched roof (Fig. 14). On the shaft are inscribed the cubits from 10 to 16: I = 10, IA = 11, IB = 12, IΓ = 13, IΔ = 14, IE = 15, IS = 16. The adjacent building may have been the checkpoint where the keepers recorded the flood levels. Above this structure Alexandria is written in Greek letters. The

Nilometer. Fig. 14 House of Leontis, Beit Shean (Photo by Z. Friedman).

Nilometer. Fig. 15 Nile festival mosaic from Sepphoris (Friedman 2001: 86, Fig. 104).

House of Leontis was a synagogue and the room where this mosaic was found probably served as a guestroom. The second Nilometer associated with Alexandria appears in the Nile festival mosaic from Sepphoris (Diocaesarea), in the Lower Galilee (Fig. 15). This mosaic in situ was dated to the fifth to sixth century CE (Netzer and Weiss 1992). The rounded column is set on a structure with an arched opening placed in the water. The cubits on the shaft are inscribed with Greek letters, from 13 to 17: IΓ = 13, IΔ = 14, IE = 15, IS = 16, IZ = 17 (Friedman 2001: 60). Mark 13 is not visible, due to the damage of the mosaic in this section, while the head of the man bent to support on his back the person who engraving the new flood level at 17 hides cubit 14. Alexandria is inscribed above a tall fortified structure; a rounded tower on each side flanks its entrance. The structure is found beneath the lower bank of the river. The number 17 appears twice on the lower bank; the first is found just to the right side of the right-hand tower, and the second is beneath the right arm of the figure placed on a Corinthian column. The newly engraved cubit 17 on the Nilometer and the marking on the lower bank indicate that this level was reached at that particular period of the flood. To the right side of the Nilometer is a large naked figure, with his back turned to the device. He holds a staff in his right hand, probably a ruler of double remen used for measuring the land after the inundation, for tax evaluation. In a mosaic from Sarrīn (Osrhoène), Syria, dating fifth to sixth century CE (Balty 1990: 83), is a Nilotic scene within a wide border. On the left side of a stone-built structure with a pitched tile roof is a two-stored square pillar. The calibration numbers are inscribed with Greek letters on the upper part of the shaft. A large naked figure with a hammer in his right hand and a chisel in the left engraves the number IH = 18 above the existing IZ = 17 (Fig. 16), which seems to show the new flood level at that particular time.

Nilometer. Fig. 16 Nilometer in the Sarrīn mosaic, Syria (From Balty 1990: Pl. XXXIII/1).

Combined types of Nilometers comprise a well with a rounded or square column projecting from it. There are several art depictions dating from the fifth to the seventh centuries CE. A silver plate, which probably was produced at Constantinople at the turn of the fifth or beginning of the sixth century CE, depicts a slim

Nilometer. Fig. 17 Silver Plate from the Hermitage Museum (From Balty 1990: Pl. XXXIV/2).

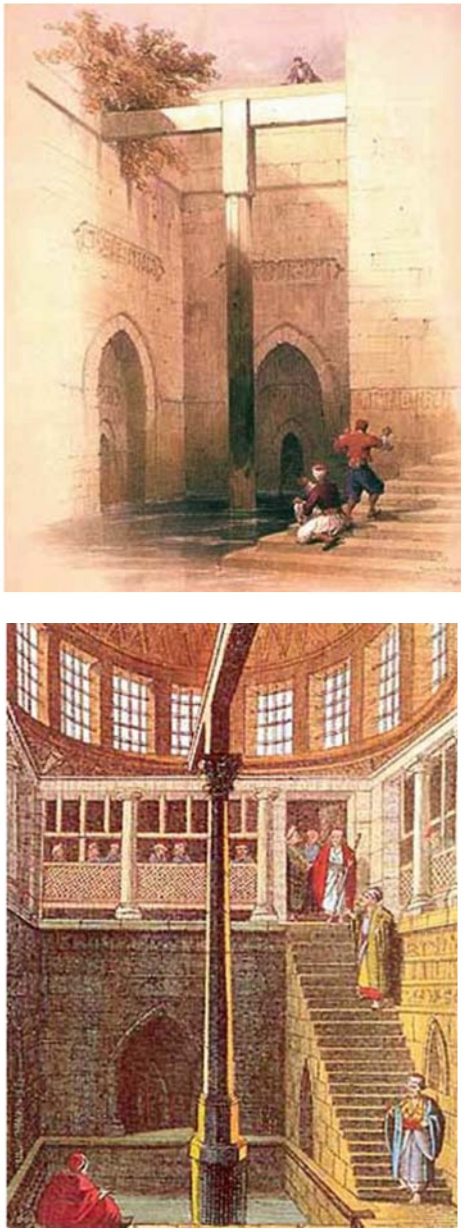
rounded column projecting from a well built with stone blocks (Fig. 17). One man standing on the back of another engraves cubit 5 (Θ = 5), on the upper part of the shaft. This plate is found at the Hermitage Museum at Petersburg, Russia.

Two Coptic rounded textiles dating to the sixth or seventh century CE, at the Louvre Museum, Paris, depict the personification of the Nile together with the Abundance (Euthenia), (Maguire 1990: 218). On the lower part of both textiles is a rounded well, built with stone blocks, with steps ascending to an arched opening at the base of the well (Fig. 18a, b). A large naked figure with a hammer in the right hand and a chisel in the left engraves the number IH = 18 above the existing IZ = 17, on the upper part of the square column. The new number may refer to the new flood level reached at that particular moment.

Nilometer. Fig. 18 (a) Coptic textile (From Maguire 1990: Fig. 14 top). (b) Coptic textile (From Maguire 1990: Fig. 14 bottom).

The Roda Nilometer is a combined type of well with a column set in its center and placed into a covered structure (Fig. 19a,b), roofed by a dome. This first Islamic device was built in 715 CE, at the southern tip of Roda Island, opposite Old Cairo. In Arabic, the Nilometer is known as *miqyas* (Mikyas el-Nil) (Hansen 2003). The Roda Nilometer was built by the Umayyad Caliph Abed Malek el-Marawan, which later was rebuilt by Caliph el-Mutawalik in 816 CE. A flood in 850 CE destroyed this Nilometer. When the new device was built, Abu el-Raddad of Basra was appointed as the guardian of the Nilometer. This tradition was then transferred to his descendents. The priests kept the records of the Nile's levels in ancient times. After Christianity was introduced into Egypt, the office was kept until the Arab conquest, but the Coptic priests still kept the records at Mekyas (Nilometers). The guardian of the Nilometer was Said Mahommed el-Sowafi, a man with no formal education. His records were done by the rule of the thumb, handed down to him by his forefathers who did not pay attention to the original column (gauge) or its gradations (Said 1993: 155).

The Roda Nilometer comprises a covered structure with a well. A marble column was inserted at its center (Fig. 19a,b). This device is connected to the Nile by three tunnels. The southern one is at the level of the well's floor (8.15 m above the sea level), while the other two are at the east, are placed one above the other (Said 1993: 155). The octagonal column inside the well is set on a pedestal (Fig. 19b). Inside the Nilometer structure, leading down to the well, are 45 steps; the height of each is 24 cm (Hansen 2003). The steps also allowed for a quick reading of the water level of the Nile. The scale on the pillar is marked in cubits with a subdivision of fingers. It was mentioned above that the metrology of this column comprises two scales: one subdivided into 28 fingers (royal cubit),



a

b

Nilometer. Fig. 19 (a) Roda Nilometer (David Roberts: ►http://www.touregypt.net/featurestories/nilometerroda.htmp. (b) Inside the Roda Nilometer ►http://www.touregypt.net/featurestories/nilometerroda.htm.

from cubit I to XII, while the other is divided into 24 fingers (small cubit), from cubit XIII to XXI. The zero point was fixed at the level of the well's floor. In different periods, this Nilometer underwent changes. In 1517 (five years after the Turkish conquest of Egypt), a new scale was set up in which the zero point was elevated by 1.62 m above the level of the well and the cubits from IX to XXVII were reduced to 36.1 cm each. In 1861, during the reign of Khadive Ismail, his engineer Mahmoud Saleh el-Falaki repaired the gauge and replaced the older one by a new scale in which the zero point was fixed at 66 cm above the well's floor, and the elevations in meters was changed. Each cubit in the new scale measured 54.1 cm, except for cubits XVI to XXII, which measured 27.1 cm. This change was done to adjust the Cairo readings to those at Aswan. When the level reached 16 cubits at Aswan, the basins in Upper Egypt were inundated, while in Cairo the level was reduced to one half (Said 1993).

In the medieval era, the importance of the Roda Nilometer was celebrated in Fath al-Khalij, the festival of the opening of the canal. The canal was blocked with earth dams and cleaned before the flood. When the Nile reached the level of 16 cubits, the dam was opened to water the agricultural lands. The celebration started at this time and lasted for seven days. During this period, decorated boats crowded the waters. In the hot summer months, the Khalij canal and the ponds were still crowded with boats, and along the shores there were many kinds of entertainment. The grand celebration was not an annual event. When the floodwaters failed to reach the 16 cubits level, the celebrations were canceled and prayers were held instead, to ward off the draught and famine (Abaza 2003). These celebrations ceased in 1899, when the Khalij canal was filled in. The Roda Nilometer was no longer necessary after the building of the High Dam at Aswan in the 1970s, which continues to regulate the Nile's waters.

The purpose of this article was to survey the Nilometer historically and to show how it was depicted in varied art forms. The Nile and its floodwaters were subjects for many historians (ancient and modern), while it symbolized fertility, plenty and prosperity. Through different periods and even in the modern era, measuring the Nile's flood levels was an important factor in the economics of Egypt, which made her the main granary of the ancient world in the Mediterranean Basin. A survey of Nilometers from the early Pharaonic Dynasties revealed that Egyptian society was unified and had an organized system of recording the distribution of the floodwaters, dividing the agricultural lands and assigning tax levels according to the quality of the year's flood.

Pliny (*NH*. V.x.57–58) and Strabo (*Geo*. 17.I.48) attested that the optimal flood level of the Nile was 16 cubits at Memphis. The numbers inscribed in the Sarrīn mosaic and the Coptic textiles (IZ = 17, IH = 18), as well as the lower numbers in the Tabgha mosaic and in the Hermitage plate, do not refer to the desired flood level. They symbolize the importance of the Nilometer and the Nile waters. From historical references we know that a flood level less than 16 cubits brought famine, and if it exceeded that disaster came and the crops were destroyed. This survey of the Nilometers attests that the flood levels were not the same along the

Nilometer. Table 1 Egyptian Chronology

Date	Period	Culture/Dynasties
7000 BCE	Epi-Palaeolithic (7200–6000 BCE)	Qarunian
6000 BCE		
5000 BCE	Neolithic (5200–4000 BCE)	Merimdian, Faiyumian, Badarian, Omarian
4000 BCE	Predynastic (4000–3050 BCE)	Maadian, Naqada I–III
3000 BCE	Early Dynastic (3050–2613 BCE) Old Kingdom (2613–2181 BCE) First Intermediate (2181–2040 BCE)	Dynasties I–III Dynasties IV–VI Dynasties VII–X
2000 BCE	Middle Kingdom (2040–1650 BCE) Second Intermediate (1650–1550 BCE) New Kingdom (1550–1069 BCE)	Dynasties XI–XIII Dynasties XIV–XVII Dynasties XVIII–XX
1000 BCE	Third Intermediate (1069–664 BCE) Late Period (664–332 BCE)	Dynasties XXI–XXV Dynasties XXVI–XXX
500 BCE	Ptolemaic (332–30 BCE) Roman (30 BCE–CE 306)	Ptolemaic Dynasty Roman Emperors
500 CE	Late Antique (CE 306–CE 868) Middle Islamic (CE 869–1250) Mameluk (CE 1250–1517) Ottoman (CE 1517–1798)	AD 641 Islamic Conquest

course of the Nile and also their readings were not based on the same zero point. It appears that there were at least two local zero points, which corresponded to the agricultural plain levels and also to the level where the floodwaters were released into canals to irrigate the fields.

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Number Theory in Africa

PAULUS GERDES

Through the ages the peoples in Africa south of the Sahara invented hundreds of numeration systems, both spoken systems and symbolic ones that use body parts or objects to count or to represent numbers.

Verbal Numeration

The most common way to avoid the invention of completely new number words as one counts bigger quantities has been to compose new number words out of existing ones by relying on the arithmetical relationships between the involved numbers.

For example, in the Makhwa language spoken in northern Mozambique, one says *thanu na moza* (five plus one) to express six. Seven becomes *thanu na pili* (five plus two). To express twenty, one says *miloko mili*, tens two or 10 × 2. Thirty is *miloko miraru* (tens three). *Thanu* (5) and *nloko* (10) are the bases of the Makhwa system of numeration.

The most common bases in Africa are 10, 5, and 20. Some languages like Nyungwe (Mozambique) use only base ten. Others like Balante (Guinea Bissau) use 5 and 20 as bases. Verbal numeration in the Bété language of Côte d'Ivoire uses three bases: 5, 10, and 20. For instance, 56 is expressed as *golosso-ya-kogbo-gbeplo*, that is 20 times two plus ten (and) five (and) one:

	Number word	Structure
1	Blo	
2	Sô	
6	Gbeplo	5 + 1
20	Goloblo	20 × 1
40	Golosso	20 × 2

The Bambara of Mali and Guinea have a ten–twenty system. The word for twenty, *mugan*, means one person; the word for forty, *debé*, means mat, referring to a mat on which husband and wife sleep together, and jointly they have 40 digits.

The Bulanda of West Africa use six as a base: 7 is expressed as 6 + 1, 8 as 6 + 2, etc. The Adele (Togo) count *koro* (6), *koroke* (6 + 1 = 7), *nye* (8) and *nyeki* (8 + 1 = 9).

Among the Huku of Uganda the number words for 13, 14, and 15 may be formed by the addition of 1, 2, or 3 to 12. For instance, 13 is expressed as *bakumba igimo*, meaning 12 + 1. The decimal alternatives 10 + 3, 10 + 4 and 10 + 5 were also known.

A particular case of the use of addition to compose number words occurs in the situation where both numbers are equal, or one of the two is equal to the other plus one. For instance, among the Mbai one counts from 6 to 9 in the following way: *mutu muta* (3 + 3), *sa do muta* (4 + 3), *soso* (4 + 4), and *sa dio mi* (4 + 5). Among the Sango (northern Zaire), 7 is expressed as -*na na-thatu* (4 + 3), 8 as *mnana* (4 + 4) and 9 as -*sano na-na* (5 + 4).

In several African languages, besides the additive and multiplicative principles, subtraction has also been used in forming number words. For example, in the Yoruba language of Nigeria, 16 is expressed as *eerin din logun* meaning four until one arrives at twenty:

	Number word	Structure
16	Eerin din logun	4 until 20
17	Eeta din logun	3 until 20
18	Eegi din logun	2 until 20
19	Ookan din logun	1 until 20
20	Ogun	
21	Ookan le logun	1 + 20
34	Eerin le logban	4 + 30

Another example of the use of the subtractive principle may be found among the Luba-Hemba of Zaire. Seven is expressed as *habulwa mwanda* (lacking one until eight), and nine is *habulwa likumi*, lacking one until ten.

That spoken numeration systems may vary greatly in relatively small geographic regions is shown by the example of Guinea Bissau. The Bijagó have a pure decimal system; the Balante use a five-twenty system; the Manjaco have a decimal system with exceptional composite number words as 6 + 1 for 7 and 8 + 1 for 9; and the Felup use a ten–twenty system in which the duplicative principle is also employed in forms like 7 as 4 + 3 and 8 as 4 + 4.

Sometimes some number words are adjectives, while others are substantives. Where this happens, number word structures may appear that do not correspond directly to an addition, multiplication or subtraction. For instance, in the Tshwa language (central Mozambique) sixty is expressed as *thlanu wa makumi ni ginwe*, five times ten plus one more (ten).

In those contexts where it was necessary to have number words for relatively large numbers, there often appear completely new number words or ones that express a relationship with the base of the numeration system. For instance, among the Bangongo of Zaïre

N

one says *kama* (100), *lobombo* (1,000), *njuku* (10,000), *lukuli* (100,000), and *losenene* (1,000,000). Among the Ziba (Tanzania) one says *tsikumi* for 100, *lukumi* for 1,000, and *kukumi* for 10,000. All three terms are clearly related to *kumi* (10). Only the prefixes change.

Gesture Numeration

Gesture counting was common among many African peoples. The Yao (Malawi, Mozambique) represent 1, 2, 3, and 4 by pointing with the thumb of their right hand at 1, 2, 3, or 4 extended fingers of their left hand. Five is indicated by making a fist with the left hand. Six, seven, eight, and nine are indicated by joining one, two, three, or four extended fingers of the right hand to the left fist. Ten is represented by raising the fingers of both hands and joining the hands. On the contrary, the Makonde, who are also in the North of Mozambique, start counting on their right hand with the help of the index finger of the left hand. Five is indicated by making a fist with the right hand. For six to nine, the representation is symmetrical to that of one to four, that is, right and left hands change roles. Now the index finger of the right hand points at the fingers of the other hand. Ten is represented by joining two fists.

The method of gesture counting adopted by the Shambaa (Tanzania, Kenya) uses the duplicative principle. They indicate six by extending the three outer fingers of each hand, spread out; seven by showing four on the right hand and three on the left, and eight by showing four on each hand.

To express numbers greater than ten the Sotho (Lesotho) employ different men to indicate the hundreds, tens and units. For example, to represent 368, the first person raises three fingers of the left hand to represent three hundreds, the second one raises the thumb of the right hand to express six tens, and the third one raises three fingers of the right hand to express eight units. This is in fact a positional system, as it depends of the position of each man if he indicates units, tens, hundreds, thousands, etc.

Tally Devices

Many types of tally devices were used in Africa south of the Sahara. Two examples of widespread tallies are the following from Mozambique.

Among the Tswa, trees are used to record the age of children. After the birth of a child a cut is made on a trunk of a tree. Each year one adds a new cut until the person is old enough to count for him or herself. Tally sticks are used to control the number of animals in a herd. Each cut corresponds to one animal.

Among the Makonde, knotted strings were used. Suppose a man was going on an 11 day journey. He would tie 11 knots in a string and say to his wife, "This knot" (touching the first) "is today, when I am starting; tomorrow" (touching the second knot) "I shall be on the road, and I shall be walking the whole of second and third day, but here" (seizing the fifth knot) "I shall reach the end of the journey. I shall stay there the sixth day, and start for home on the seventh. Do not forget, wife, to undo a knot every day, and on the tenth you will have to cook food for me; for see, this is the 11th day when I shall come back." Pregnant women used to tie a knot in a string at each full moon, to know when they were about to give birth. In order to register the age of a person, one uses two strings. A knot is tied in the first string at each full moon; once one has completed 12 knots, one ties a knot in a second string to mark the first year, etc.

Other Visual Numeration Systems

There are a variety of numeration systems in Africa that are written in one way or another.

The *koti zigi* game is played by the Gbundi and Mende in Liberia and in the western parts of Côte d'Ivoire. The players form standardized patterns of stones on the ground to represent numbers. One observes that 6 is expressed 3 + 3, 7 as 3 + 1 + 3, 8 as 4 + 4, 9 as 4 + 1 + 4, and 10 as 5 + 5 or 4 + 2 + 4 (see Table 1).

The Fulani or Fulbe, a seminomadic pastoral people of Niger and northern Nigeria, place sticks in front of their houses to indicate the number of cows or goats they possess. One hundred animals are represented by two short sticks placed on the ground in the form of a ∨. Two crossing sticks, ×, symbolize 50 animals. Four sticks in a vertical position, ||||, represent four; two sticks in a horizontal and three in a vertical position, — — |||, indicate 23 animals. For example, the following was found in front of the house of a rich cattle owner:

∨ ∨ ∨ ∨ ∨ ∨ × ||

showing that he had 652 cows.

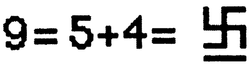
The Akan peoples (Côte d'Ivoire, Ghana, Togo) used money weights. That is to say, they used figurines in stone, metal or simply vegetable seeds as coins. The weight of a figurine was agreed to represent the

Number Theory in Africa. Table 1 The *koti zigi* game

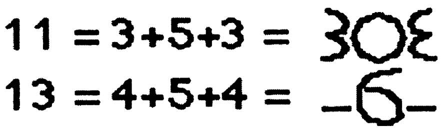
●	●	●	●	●	●●	●	●●	●	●●
	●	●	●	●	●●	●●	●●	●●	●
		●	●	●	●●	●●	●●	●●	●●
			●	●		●●	●●	●●	●●
				●				●●	●
									●●
1	2	3	4	5	6	7	8	9	10

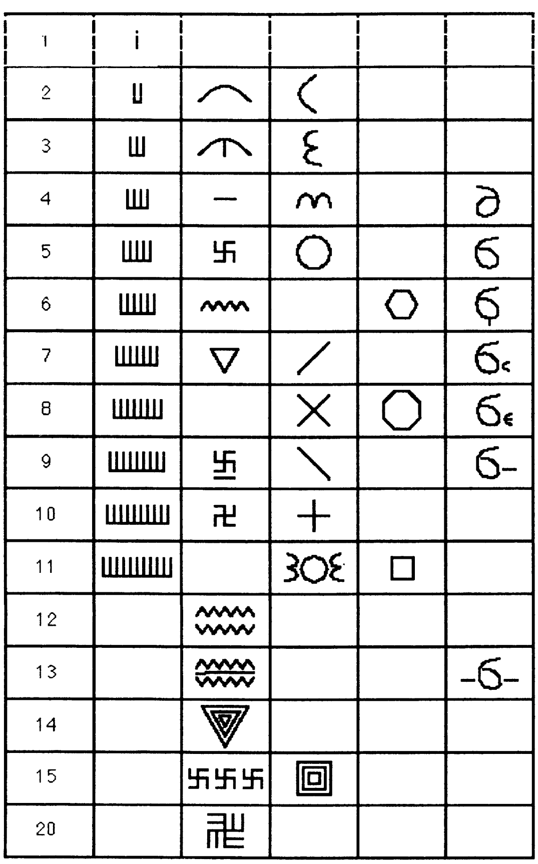
monetary value that corresponded to a certain quantity of gold dust of the same weight. The figurines show animals, knots, stools, sandals, drums, etc. Figurines may also have diverse geometric forms such as step pyramids, stars, or cubes. Many display graphic signs representing numbers. Although in the languages spoken by the Akan peoples, like Anyi, Baoulé, Aboure, Attie, and Ebrie, only base ten is used, base five is also found on the money weights (Fig. 1):

and



The symmetric structure of one of the symbols for 11 and of one for 13 may be observed:

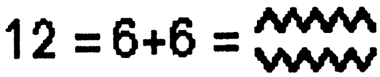




Number theory in Africa. Fig. 1 Examples of numerals on Akan gold weights (see Weights and Measures: Akan Gold Weights).

Duplication may be observed in the transition from

to



See also: ►Weights and Measures: Akan Gold Weights, ►Mathematics

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Number Theory in India

Takao Hayashi

It is difficult to find "number theory" in its proper sense in Indian mathematics. What I am going to describe below is how the Indians have treated kinds of numbers.

In the Vedas (ca. 1200–800 BCE), the oldest Hindu literature, a number of numerical expressions occur. Their favorite numbers were three and seven as well as a hundred and a thousand. The largest number contained in their common list of names for powers of ten is 10^{12} (called *parārdha*). Later (by the fourth century AD), those names came to be employed for denoting decimal places, and became the nucleus of the Hindu list of decimal names (18 in number), while the Buddhists and the Jainas developed longer lists, which contained numbers as large as 10^{53} (*tallakṣaṇa*) or more.

The Jainas even speculated about different kinds of uncountable and infinite numbers (*Aṇuogaddārāiṃ*, between the third and the fifth centuries AD). They divided the whole set of "numbers (*saṃkhyā*) concerning counting (*gaṇanā*)" into three subsets (1) countable (*saṃkhyeya*), (2) uncountable (*asaṃkhyeya*), and (3) infinite (*ananta*) numbers; and further divided the last two sets into three each (Table 1). The entire system of countable–uncountable–infinite depends upon the smallest number (a) of the "restrictively uncountable" set, which in turn is defined by means of white mustard seeds. The text is not very clear on this last point, but its intention was probably the same as what is meant by "the aleph zero" in modern mathematics, the smallest transfinite cardinal number.

Vedic stanzas also contain various series of numbers such as an integer series up to 200, an odd series (1, 3, 5,…) up to 99 (accompanied by 100), an even series (2, 4, 6,…) up to 100, and series made from multiples of 4, 5, 10, and 20, up to 100, etc.

The Vedas tell us that only the gods Indra and Viṣṇu could divide a thousand equally into three, but it is a matter of argument how they did it. Natural fractions (1/2, 1/4, 1/8, and 1/6) also occur in the Vedas.

The *Śulbasūtras* (ca. 600 BCE and later), compendia of geometric knowledge related to the construction of various altars for the Vedic ritual, clearly state the so-called Pythagorean theorem: "The diagonal rope of an oblong produces both [areas] which its side and length produce separately." They explicitly mention several Pythagorean triples also: (3, 4, 5), (5, 12, 13), (8, 15, 17), (7, 24, 25), and (12, 35, 37). Moreover, they give an algorithm for calculating the diagonal d of a square whose side is a:

$$d = a + \frac{a}{3} + \frac{a}{3}\cdot\frac{1}{4} - \frac{a}{3}\cdot\frac{1}{4}\cdot\frac{1}{34}$$

and call this value "one that has a difference" (*saviśeṣa*), which probably means the difference between this approximate value and the true one $(\sqrt{2}a)$. The latter was called "one that makes [a square equivalent to] two [unit squares]" (*dvi-karaṇī*). There is, however, no indication that they recognized the incommensurability of the diagonal and the side. A root approximation formula of the same type is employed in the Bakhshālī Manuscript.

Number Theory in India. Table 1 Classification of numbers according to the Jainas

numbers for counting	countable	....	lowest: 2 middle: 3,4, ..., a–2 highest: a–1
	uncountable	restrictively uncountable	lowest: $a(=\aleph_0\ ?)$ middle: a+1, a+2, ..., b–2 highest: b–1
		properly uncountable	lowest: $b=a^a$ middle: b+1, b+2, ..., c–2 highest: c–1
		uncountably uncountable	lowest: $c=(b^2)^{b^2}$ middle: c+1, c+2, ..., d–2 highest: d–1
	infinite	restrictively infinite	lowest: $d=c^c$ middle: d+1, d+2, ..., e–2 highest: e–1
		properly infinite	lowest: $e=d^d$ middle: e+1, e+2, ..., f–2 highest: f–1
		infinitely infinite	lowest: $f=(e^2)^{e^2}$ middle: f+1, f+2, ... highest: does not exist

Later Indian mathematicians and astronomers, such as Varāhamihira (ca. AD 550) and Brahmagupta (AD 628), used the word *karaṇī* in the two contradictory (but mutually related) senses, the square root of a nonsquare number and the number whose square root should be obtained (or the square of any number), and easily performed the six arithmetical operations involving irrational numbers. Even the irrationality of *karaṇīs* may have been understood by Bhāskara of the seventh century, because he says, in his commentary on the *Āryabhaṭīya* (AD 629), "*Karaṇīs* have a size that cannot be stated exactly," although whether he proved it or not is not known.

Varāhamihira recognized zero (*kha, śūnya*, etc.) as an object of the arithmetical operations. In the *Bṛhatsaṃhitā* he added and subtracted zero in exactly the same way as he did other integers. Brahmagupta in the *Brāhmasphuṭasiddhānta* gave a complete set of rules for the six arithmetical operations involving zero as well as negative and irrational numbers and referred to the quantity called "zero-divisor," $\frac{a}{0}$. Thus by the seventh century AD the Indians acquired a very large domain of numbers including positive and negative integers (they accepted both the positive and the negative roots of a square number), fractions, irrational numbers, and zero, which enabled them to develop *bījagaṇita* ("seed mathematics") or algebra, the theory of equations.

In his *Āryabhaṭīya* (AD 499), Āryabhaṭa provided a solution (called *kuṭṭaka* or the pulverizer) to the linear indeterminate equation: $n = ax + r = by + s$, or $y = (ax + c)/b$. He "pulverized" (i.e., reduced) the coefficients a and b by means of their mutual divisions (the so-called Euclidean algorithm), and found a set of solutions to the reduced form by trial and error. Mahāvīra (ca. AD 850) removed the trial and error by carrying out the mutual divisions until the remainder became 1.

Brahmagupta treated indeterminate equations of the type $Px^2 + t = y^2$.

He showed, among other things, that this equation (called *vargaprakṛti* or the "square nature") can be solved for $t = 1$ if it is solved for $t = \pm 4, \pm 2$, or -1. Jayadeva (the eleventh century or before) gave a rule for arriving at a solution for $t = \pm 4, \pm 2$, or -1 from any solution for any t. Bhāskara of the twelfth century called it the "cyclic" (*cakravāla*) method.

Several rules given by Mahāvīra in his *Gaṇitasārasaṃgraha* indicate that he recognized two roots of a quadratic equation with one unknown, but all of his examples for those rules have two positive roots. (He, however, admits the negative root of a square number when he gives his rules for the six arithmetical operations.) He was interested in the partition of numbers, and gave many rules for partitioning unity into the sum of unit fractions, a fraction into the sum of several fractions, etc. He also treated various mathematical progressions.

Śrīpati, perhaps for the first time in India, gave several rules for factorization in a chapter devoted to algebra in his astronomical work, *Siddhāntaśekhara* (ca. AD 1040). This topic, as well as the partition of numbers, mathematical progressions, combinatorics, and magic squares were highly developed by Nārāyaṇa in his *Gaṇitakaumudī* (AD 1356).

Bhāskara challenged various types of polynomial equations of the second and higher degrees (of special types) with the help of the "pulverizer" and the "square nature" in his work, *Bījagaṇita*, AD 1150. He compared the infinity and the invariability of the "zero-divisor," $\frac{a}{0}$, to those of god and interpreted the negative-ness of a quantity as the contrariness of direction.

Mādhava (fl. AD 1400) and his successors obtained, for the first time in the world, a number of power series for the circumference of a circle, sine, cosine, arctangent, etc. One of the most eminent scholars in his school was Nīlakaṇṭha. A great mathematician and reformer of Indian astronomy, he explicitly stated the incommensurability of the diameter and the circumference of a circle in his commentary on the *Āryabhaṭīya* (ca. AD 1540), although its proof is not found in his extant works.

See also: ►Algebra in India, ►Arithmetic in India, ►*Śulbasūtras*, ►Geometry in India, ►Bakhshālī Manuscript, ►Varāhamihira, ►Brahmagupta, ►Nīlakaṇṭha, ►Mādhava, ►Magic Squares, ►Combinatorics in India, ►Nārāyaṇa, ►Śrīpati, ►Jayadeva, ►Mahāvīra, ►Bhāskara

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Number Theory in Islamic Mathematics

JACQUES SESIANO

Islamic number theory is characterized by two main developments, both of which stemmed from Greek knowledge. One of them is the relation between natural numbers and the sum of their proper divisors, the other the field of quadratic indeterminate equations.

Numbers and Their Sums of Divisors

If N is a natural number, $\sigma(N)$ the sum of its divisors, and $s(N)$ the sum of the divisors without N itself, then $\sigma(N) = s(N) - N \geq 1$. The Greeks called N "abundant" if $s(N) > N$, "defective" if $s(N) < N$, and "perfect" if $s(N) = N$. Euclid had demonstrated that $N = 2^{m-1}(2^m - 1)$ is perfect if $2^m - 1$ is prime; we know today that it gives all even perfect numbers and possibly all perfect numbers. Thābit ibn Qurra (836–901) noticed that 2^{m-1}, p, m given and p prime, is defective or abundant depending on whether $p > 2^m - 1$ or $p < 2^m - 1$. In the same treatise, he provided for the first time a rule for finding a pair of "amicable" numbers, in which each number is equal to the sum of the proper divisors of the other: numbers N_1, N_2 such that $s(N_1) = N_2$ and $s(N_2) = N_1$. The Greeks knew of only one pair (220, 284). His rule, proved in true Euclidean manner, is: if $s = 3 \times 2^m - 1$, $t = 3 \times 2^{m-1} - 1$, $r = 9 \times 2^{2m-1} - 1$ ($m \neq 0, 1$) are prime, then $2^m \times s \times t$ and $2^m \times r$ are amicable numbers. The severe restrictions on N_1 and N_2, however, limit the numerical application considerably.

Evidence of an apparently novel consideration appears in two incidental remarks made by al-Baghdādī (ca. 1000) concerning the solubility of $s(N) = k$, k given natural. It is asserted that $s(N) = k$ has no solution N for $k = 2$ and for $k = 5$. It is indeed true that, among all odd k, only 5 cannot be a sum of (proper) divisors, and a simple rule used by al-Baghdādī for finding numbers N_1, N_2 such that $s(N_1) = s(N_2)$ may be used to verify it (under assumption, though, of the still unproved Goldbach conjecture). If k is even, we know today that, besides 2, there is an infinite number of exceptions.

Quadratic Indeterminate Equations

Two Greek sources inspired Islamic mathematicians. The principal one is Diophantus's *Arithmetica*, of which seven of the original thirteen "books" (i.e., large chapters) were translated into Arabic. The other one is unknown to us today but was the origin of a set of indeterminate equations solved in Abū Kāmil's *Algebra* by Diophantine methods. Abū Kāmil says that such problems were the subject of discussion in his time. A good introduction to Diophantine methods occurs in al-Karajī's *Badīᶜ fī'l-ḥisāb* (Wonderful on Calculation). The theoretical approach to the solution of finding a square which, increased or diminished by a given integer, produces a square in both cases, was treated in the tenth century by al-Khazīn; it later became the central subject of Leonardo Fibonacci's *Liber quadratorum*.

Other Indeterminate Equations

The above-mentioned indeterminate equations always require positive rational solutions. Linear indeterminate equations with positive integral solutions were the subject of a separate treatise by Abū Kāmil, who searched for all such solutions for six typical pairs of linear equations with three to five unknowns. Of note also are attempts to prove the impossibility of $x^3 + y^3 = z^3$ in the tenth century.

See also: ►Abū Kāmil, ►al-Karajī

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Nyāya

Purushottama Bilimoria

Nyāya is one of the six schools of Indian philosophy (ca. 500 BCE to 1500 CE). It represents reasoning or logic, *nyāya,* into the ideals of *adhyātma* (treating of things elusive, such as Being and Self), and *hetu* (reason, treating of things conventional and empirical) (Halbfass 1992: 32). While the former inquiry is reminiscent of the medieval reconfiguration of Aristotelian metaphysics from Aquinas to Dun Scotus, Nyāya metaphysic does not easily fit this frame. Rather, the goal of enquiry is *niḥśreyasa* or the greatest good of wisdom and liberation from ignorance and suffering or *duḥkha*. Thus, this *prāçiṇa* or "ancient" school of Brāhmaṇic thought is enlisted in the service of the erstwhile Vedic orthodoxy (*śruti*) to bolster defense against the "negative ontology" of a threatening Buddhist antirealism. However, the Nyāya is better known for continuing a certain development of the realist thrust of a prior system known as Vaiśeṣika, that is described as "physics," or "rigorous descriptive metaphysic" (Mukhopadhaya 1984 via Mohanty 2001: 209). In time it provided the nascent Brāhmaṇic philosophy with the needed natural-kind category of substance, a theory of universals, and the assumption of a well-structured universe of enduring and individually identifiable entities or particulars described as objectively as possible, albeit, with a parsimonious stringency, foreshadowing the positivist movement in science and ("natural") philosophy closer to our era. This came to imply that we *can* have true knowledge of what there is *as is* (*astitva*). As such Nyāya embodies a metaphysic of thinking and doctrines on what is knowable and the proper means to their knowing – under a theory known widely in the Indian scientific tradition as *pramāṇa*. Both the Vaiśeṣika and the Nyāya begin their disquisition by enumerating the large number of *padārthas* (literally, a "thing denoted by a word") or epistemic categories of that which the correct application of *pramāṇas* will disclose, as expanded *prameyas* or things so known. Unlike Kant's categories of understanding as the analytic conditions for knowledge of things, the Vaiśeṣika–Nyāya categorical schema go much beyond the reductive rational schema and capture substances, properties, universals, and episodic events in the real world.

Enumerating Vaiśeṣika

Let us begin with a discussion of the *padārthas*. The Vaiśeṣika had settled for six (at most seven) positive categories as evidence of the independently existing reals taken to cover the entire knowable sphere, the subjective process of thought included. Although stated as ontological descriptors they really underpin the epistemic fact of what these are expressively known as. These are: substance (*dravya*, e.g., a banana), quality (*guṇa,* yellowness of its skin), motion (*karman,* its ripening, falling), universal (*sāmānya,* its fruity bananeness), particularity (*viśeṣa*, this banana fruit in my hand), and the relation of inherence (*samavāya*, whole to its parts). Each category is further classified into subsets of different natural kinds (a class-defining property within a unique class), again epistemically laden; e.g., there are nine substances (that are marked by their unique respective *jāti* or universals), notably, earth (*pṛthivi*), water (*apa*), heat (*teja*), air (*vāyu*) space (*ākāśa*), time (*kāla*), place (*dik*), self (*ātma*), and mind (*manas*). Qualities (*guṇa*) comprise pain (*duḥkha*), desire (*icchā*), aversion (*dveśa*), and pleasure (*sukha*). Why are there just nine substances? That is because of the commitment to *jātibādhaka*, "a reductive mechanism necessary to avoid excessive realism which posits universals for every general term" (Mukhopadhaya 1984). Besides, all other entities can be subsumed and explained under this category, or rather admitted under newly formed *concepts*, such as of a composite of natural kinds in an artifact that invites apprehension of a general property, e.g., potness (*ghatatva*) in respect of a wheel-turned pot. Motion or *karman* involves a cause–effect process, within strictures. For instance, even though something cannot come out of nothing, the effect is thought not to be preexistent in the originary or prior causal base (e.g., milk), which is radically different from, say, the curd or butter that is produced from it, as the causal process enlists various instrumentations and additional conditions or qualifiers (e.g., enzyme culture, churning, solidifying, and *kāma* or desire of the consumer): a transformation is more than a mere manifestation (Chakrabarti 1995: 318–323). In this descriptive ontology, substance, quality, and motion or effect–cause are coextensive; one and the same being (*sat*) may possess all three; and nothing is possible without these inhering in a substance of one sort or another. So "isness" which accounts for self-identity and individuation, along with the ability to designate (*abhidheyatva*)

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and to know (*jñeyatva*), are the common characteristics of the six categories or classes of reals (Praśastapāda via Sharma 1995: 138–155).

The *Nyāya* Canon

The first systematic exposition of the Nyāya metaphysics occurs in the celebrated work of one Gautama, in his canonical *Nyāya-sūtras*.[1] The true force of "*nyāya*," derived from the exegetical hermeneutic of *reasoning with texts* (via the hermeneut Mīmāṃsā) now bares out in the single-minded pursuit of rooting for an epistemic foundation for knowing with equal concern for good debate and clinching arguments. This exercise of quasi-formal reasoning is aided by other technical discursive moves which came into currency, viz., *saṃśaya, vāda-vivāda, bādha, pakṣa, pūrva-pakṣa*, *vitaṇḍa, jalpa, nigrahasthāna, samayabandha* (or doubt, rules of discussion, criteria of coherence and noncontradiction, proofs, disproofs, basis of agreement and disagreement, cavil, sophistry, time and point of defeat, treatment of the vanquished). Thus "*nyāya*" becomes the formal structure and format of such argumentation, and by refuting the adversaries, or demonstrating the superiority of its own paradigm for understanding and overcoming suffering (*duḥkha*), establishes its own or "*ortho-doxa*" (Daya Krishna 1996: 81).

Now three moves occur in respect of this schemata when Gautama enters the scene. First, the *adhyātma* or theological quest is all but shunned. Second, Gautama shifts the metaphysical emphasis from the Vaiśeṣika framework of substance ontology to a more narrowly conceived epistemic taxonomy. Third, he reconfigures the catalog by expanding it to cover 16 *padārthas*, headed by *pramāṇa*s or methods of knowledge. Only one of these is ontological, *prameya,* restricted object of knowledge, as the second *padārtha* in the constellation. Things that fall under the *prameya* set and its subsets are alone truthfully cognizable (*prameyatva*). Gautama reduces these to 12, namely, self (*ātma*), body (*sarīra*), sense organs (*indriya*), mind (*manas*), cognition (*buddhi*), sensoria (*artha,* like smelling), activity (*pravrtti*), its outcome (*phala*), impurity (*doṣa*), pain (*duḥkha*), transmigration (*pretyabhāva*), and finally, release through *theoria* (*apavarga*) of the self from all these insufferable tropes. Again, for reasons of economy, the ontic-*prameya* class of reals are kept to the minimum. For instance, "darkness" need not be taken to be a separate entity because its presence can be explained in terms simply of the absence of light. Note however that nameability and knowability do not necessarily make the "isness" (*esse*, or "essence") of the object supervenient on the conscious minds, for things exist in their own right independently of being perceived: it is enough that they are perceivable (and nameable). Even after God enters the Nyāya's possible worlds, the Berkeleian imperative of subsuming *esse* to *percipii* is here resisted to the end.

Modern Development

In more recent times, in the hands of a leading Indian philosopher, Bimal Matilal,[2] a somewhat muted form of common sense realism – "direct realism" – both defends and qualifies the thesis of the inexorable independence of things from the perceiving mind. It begins by suggesting that we do indeed see the objects we take ourselves to see, that those objects exist by having parts without being merely the sum of their parts, and that they fall into objective, natural categories. Thus, we see "redness" as a patch (substantial ground) and thence attach qualities of "hot," "ound," "pepperness" to it. Two ingredients in Matilal's defense of this theory have a particular significance: the doctrine that perception is nonpartitive, and an interpretation of the concept of objectivity. Nonpartitive indicates that we can see objects without seeing their parts (e.g., their front-surfaces) or their class-properties (e.g., color and shape). Further, the parts and properties of an object may well feature in the explanation of our coming to see it; but the thesis denies that the parts or properties of the object can enter into the explanation only if they themselves become entities of perceptual awareness. If this is correct, Matilal points out, then the move typically made by the Buddhist phenomenalists that the "support" (*alambana*) for perceptual awareness must be unstructured and immediately given, is blocked. This leads to what Matilal recognizes to be the indefeasible challenge for the Nyāya realist: if phenomenal entities like sense-data have no explanatory role in perception, how do we account for such apparently purely phenomenal illusions as seeing the blue dome of the sky, a rainbow, or a circular disk as elliptical? Matilal's solution introduced a new concept of objectivity. To be objective is to be independent of minds. Being "mind-dependent," however, need not mean being a private, intentional object in the way that sense data and other purely phenomenal entities are. It can mean simply

[1] Gautama's date is given by Vidyābhusan as circa 553 BCE, but this may be way off the mark; Jacobi places the date of *Nyāyāsūtra* between 200 CE and 450 CE, but then there is controversy as to whether this is not the date for the later redaction of the *śāstras* by one Akṣapāda. 7) and See Bijalwan (1977): Daya Krishna (1991: 133).

[2] Matilal (1935-1991) was a rare kind of thinker, a philosopher of sensibility who embodied east and west in balanced proportions and who demonstrated that Indian thought, even in its most metaphysical and soteriological concerns, was rigorously analytical and logical as well as discursive. His work has found broad endorsement and inspired lively debate not only among many contemporary Indian philosophers and Indologists, but also in international philosophical circles.

having a mental event as a causal condition, an event on whose continuing existence the object depends. Although illusory, the blueness of the sky and the ellipticality of the disk are objective at least in the sense that they are not purely private objects of sensation, but are produced and shared by the perception of any observer located in the appropriate position. This is a softer realism than that to which skeptics (and at least some mystics) are committed, according to which objects can exist independently of anyone's capacity to know they exist.

From Absence to the Ultimate

A category Gautama is conspicuously silenton but which becomes increasingly important in Nyāya epistemology is *abhāva*, "absence." It comes in three forms: prior and post-nonexistence (before the food is made and after it has been eaten), unnihilatable nonexistence (once born cannot be rendered *dhvaṃsita* or extinguished, e.g., the absentee gods), and atemporal nonexistence (the blue of the sky).

Notice here another line of controversy that arises between earlier and later-day Nyāya stalwarts. Vaiśeṣika began with a fixed number of *padārthas* (six, or seven), whereas the *navya* (new-) Nyāya school (circa thirteenth century) came to advocate a theory of almost undetermined number of *padārthas*. The economy of distinguishing "limit categories" from limitless concepts is blurred. As Mohanty rightly notes, "[T]here is no doubt something dissatisfying about making a list of categories open. It goes against our love for order, simplicity and system" (Mohanty 2001: 212).[3]

Coming now to the end or goals of this ardent pursuit for knowledge of the reals, actual, possible, and their relative absences, paradoxically, at the end of the journey, even the strictly knowables have their down side – in that they vanish. Nevertheless, these constitute the "ultimates" or necessaries of human knowledge, all else is of contingent value. Everything is determinable in their specific particularity, including the self (*ātma*), which is an object of positive inference (via recognition) based on desire, aversion, motivation (*prayatna*), pleasure, pain, and knowledge: not unlike the instance of the single glance at the dancing girl that evokes several aesthetic and other sorts of responses in the cultured mind (*Vārttika on Nyāya-sutras*. 1.I.10).

Theoria and Nirvāṇa-Soft

Some remarks are apposite at this point. First, that the *whole* is always greater in complexity and composite relations than the *sum* of its parts, such that the Buddhist alternative of partible-aggregation, from simple to general, from *dharmas* to *nirvāṇa,* will just not do. Second, the objects of knowledge are subordinate to and supervene on correct cognition, deliverable by the *pramāṇas* and aided by logical illumination at every stage. However, there is an incremental recourse to *yogaja-pratyakṣa*, or "empirical mysticism," which provides the wherewithal through appropriate yoga-culture, for quantum shifts toward grasping more elusive universals, and universals undergirding generals, composite universals, and such higher-order universals in the hierarchy of omniscience that God might be entertaining on a good day or night. Third, there is the possibility of release from the pleasure and pain in a state of perfection or greatest good – *niḥśreyasa* – which results from reaching a state of *theoria,* which in Nyāya amounts to attaining comprehensive knowledge (*tattvajñana*) of the *padārthas in toto* (or "what all there is to know"). This is not the same transcendental state that is underscored in the more "spiritually" – aligned philosophical systems – such as, in particular, *mokṣa*, or salvific liberation from embodied existence, although *niḥśreya* of the Nyāya will presumably inform the inquirer's ethico-religious practices as well. It is this that is the veritable philosophic end or *theoria* and as such has no necessary connections with life-hereafter, in some remote *loka* (planet-world), or merger with the ultimate Being and so on (Mohanty 1996: 46–50; cf. Potter 1995: 29–59.). It amounts to nothing more nor less than the destruction of all *mithyajñana*, false understandings, as Gautama tells us (*Nyāya-sūtras.* I. i. 22): "Absolute freedom from the aforesaid (pain, wrong knowledge, attachment, etc.)." The commentators dispute the view that in the Final Release the self manifests happiness, being the untenable view of the Vedāntins. For a self that is still enmeshed in *saṃsāra* exudes happiness and so it would make no difference. No pleasures are transported across to the *niḥśreyas* state, not even the positive pleasures of life, desire-driven satisfaction, from luxuries of appetite to Donigerian *kāma-sezama* or other such sensual-sexual pleasures (Halbfass 2003: 156). Thus, like the Buddha's Third Noble Truth and more like the negative utilitarians' liberative ethics, this embeds simply the minimization of pain and suffering, and the eventual elimination of all pains and pleasures, beginning with the exemplary individual (*stoic*) and universalizing this preference–satisfaction for the entire human race. If not that of a semi-somnambulant zombie-like stupor, it is at least a godog's life – a joyless unending free-time verizone – and steeped in *svapnavastha suṣupti*, deep-sleep dreamy state minus the dreams – which in Freudian

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[3] Mukhopadhaya, whose reconstruction of the division between restricted categories (of which he admits only three) and the open-ended concepts that Mohanty is questioning, nevertheless is confident that the controversy is settled by his own conceptual intervention in just this manner, and further that his liberalization of concepts assures progress of knowledge and new epistemes and dimensions of experience. *Explorations* 212.

terms would amount to the sublimative phantasy or working out of unconscious desires, compulsive-obsessive traces, etc. (*Vārtikka* on *N.S.* 4.1.62). There is also a suggestion of the possibility of omniscience without self-consciousness – on a parity apparently with the natural light of divinity. Herein the self reposes in its disinterested or detachedly indifferent beingness, released from both the polarities of pain and pleasure (*Vārtikka* on *N.S.* I.i.22). More than knowledge of the self, it is an all-encompassing knowledge-state. And there is no merging with the Other, no greater or smaller of which could be thought: all such assumptions are tantamount to the transcendental illusion (*viparitabhāvana*) or, worse, transcendental reductionism. The end amounts to "release without transcendence": perhaps "*Nirvāṇa*-lite" is after all merely the desire-cleansed imaginary of *saṃsāra*. And this is the Nyāya's alternative modal possibility of liberation to the Advaita Vedānta and Buddhist contingents.

And so this end-game of all quests is nothing like the unity of all categorical knowledge (as, say, in Kant's "kingdom of ends"), much less the "Thing-in-Itself" or the World-as-Will, nor merely *contemplative theoria* as in Aristotle, nor the nondual self-knowledge as in Śaṅkara's Advaita philosophy.[4] It is as though the diaphanous self reaches a near-death moment, detached from the body and the mind, but not (yet) dying or euthanaized, because that which is external and *nitya* (atemporal) cannot be extinguished. In the end it may be said, the feared antirealist apparition of the Buddha did manage to make a dent in the parsimonious realist ontology of the Vaiśeṣika and its rescue operation in the epistemologically driven antitheological poundings of the Nyāya "analytical" philosophy, despite itself.

[4] Although, Śaṅkara approbatingly cites Gautama from *N.S.* IV.ii.35 where this issue is discussed, under *Brahmasūtra* I.i.iv, because the Advaitin Adiguru also believes that in this state the self has no further contact with the mind, sense-organs, *antaḥkaraṇa*, or inner unifying sense, much less with the world of objects outside. The difference between *apavarga* and *ātmatattva* in Śaṅkara's ideology is that for the latter there is knowledge of the self by the self, in Nyāya there is no knowledge of it as it is not necessary. For other Vedāntins of course, this state of *mokṣa* is full of all kinds of knowledge, including *sarvajñāna* or omniscience (except at its very peak, since Brahman has no name and distinction from the self, Brahman is not an object of knowledge whatever kind of "knowingness" this might involve). Later Nyāya writers introduce *sarvajñāna* via *yogic pratyakṣa* (mystic perception) in one of its two types. On some problems with Śaṅkara's treatment of self, its knowledge and *ānandas*, see two articles on Saṅkara in the Matilal Memorial Volume I (*Bibliography*), Bilimoria 2003 (252-277) and Julius Lipner, "Śaṅkara on *Satyam*, *Jñānam Anantam Brahma*" (301-335).

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Obelisks in Ancient Egypt

Brian A. Curran

Among the characteristic monumental forms employed by the Egyptians – pyramids, sphinxes, etc. – the obelisk seems to have enjoyed the richest and most distinctive "afterlife." Over the two millennia of their original production, Egyptian obelisks varied in size from relatively small funerary stones to the slender, towering monoliths of red Aswan granite that were erected before and within the precincts of the greatest Egyptian temples. Obelisks were dedicated in most cases to the solar gods of Egypt, and their soaring height and tapering shape – capped by a pyramidal (and originally gilded) pinnacle called a *pyramidion*, seemed to reach from the earth into the heavens and touch the rays of the life-giving sun. For centuries to come, these great stones have challenged the imaginations of spectators: Greek and Roman, Christian and Muslim, Renaissance and Modern – who were awed by their soaring height, titanic weight, and paradoxically slender and tapering shape. They were endowed with an aura of sanctity and power through their association with the gods and rulers of a civilization that was already viewed as almost unimaginably ancient by the Greeks and Romans. This aura was embodied for many by the hieroglyphic carvings that covered their four faces, which were believed from Classical times to the age of Napoleon To encode, in veils of allegory and enigma, the most secret doctrines of Egyptian religion and science (Iversen 1961; Curran 1998/1999, 2003).

In the classic formula of the New Kingdom, best represented until the 1830s at the Temple of Amun-Ra in Luxor, a pair of obelisks was erected before the sanctuary's main entrance pylon. These pylons were conceived as sacred "horizons" that marked the passage from the realm of mortals to the kingdom of the gods. In this context, the obelisks literally rose to "pierce" the sky and commune with the deities of the rising and setting sun, just as the ceiling of the temples' colonnaded halls supported ceilings carved with the stars and constellations of the heavens (see Bell 1997: 133–134). But the biggest obelisk ever erected – the 32.15 m (105.5 foot), 455–510 ton obelisk of Thutmose III (1479–1424 BCE) was set up as a single monument at the Great Temple of Amun-Ra in Karnak. This towering monolith of red granite was quarried – like all the major Egyptian obelisks – at Aswan in Upper Egypt. Still incomplete at Thutmose III's death, the obelisk was completed (with additional inscriptions) and erected some 35 years later by the King's grandson, Thutmose IV (1400–1390 BCE). For nearly two millennia the great obelisk stood alone as an object of special veneration at Karnak, until it was torn from its base by order of the emperor Constantine (306–337 BCE) and, after a series of delays, transported to Rome by his successor, Constantius II (337–361 BCE), in 357 BCE. Upon arrival, it was raised on the *spina* or median strip of the Circus Maximus; next to a very large (but smaller) obelisk erected more than three centuries earlier by Augustus (see below). In 1587–1588, the obelisk was located and excavated from the ruins of the Circus by order of Pope Sixtus V, who initiated the second great phase of obelisk installations in Rome. The obelisk was moved to the Piazza of San Giovanni in Laterano and its broken pieces were set in place by a great "obelisk machine" devised by Domenico Fontana (for its present location, see Fig. 1). In 2006, the obelisk was again surrounded by scaffolding, erected to preserve and restore the monument from the ravages of traffic, pollution, and a terrorist bomb (for the full history of the Lateran obelisk; see Iversen 1968–1972, 1:55–64; Habachi 1984: 112–117; D'Onofrio 1992: 243–259).

History

As the story of this largest of all Egyptian obelisks amply illustrates, these monuments attracted the envious and acquisitive eyes of self-styled successors of the Pharaohs from the time of the Ptolemies and Roman emperors to relatively modern times. As a consequence, a large number of them have been yanked from their original locations in Egypt and transported at great expense (and with great fanfare) to provide ornaments for the capital cities of the Roman and later empires. Rome received the bulk of them, to the extent that some 48 of them were visible in the city by the middle of the fourth century BCE. Thirteen of these can be seen in

Obelisks in Ancient Egypt. Fig. 1 Lateran obelisk of Thutmose III and IV, Rome.

Obelisks in Ancient Egypt. Fig. 2 Alexandria/Central Park obelisk of Thutmuse III, New York City.

the city today, thanks to the efforts of generations of popes and other patrons who sought to associate themselves with the majesty of the pharaohs and emperors who originally made or appropriated them. Still others may be admired in Istanbul, Paris, London, and New York (Fig. 2), where they testify to the enduring attraction of the obelisk's pharaonic and imperial legacy. In addition to their symbolic power, the obelisks also posed, at virtually all stages of their history, a daunting challenge to the skill and ingenuity of the engineers and builders who sought to move and re-erect them. In a very real sense the story of the obelisks may be understood, at least partially, as a history in microcosm of engineering and transportation technology in the Mediterranean world (on this point see Engelbach 1921, 1922; Fontana 1987; Parsons 1939: 155–173; Dibner 1950; Carugo 1978).

The modern name obelisk derives from the Greek *obeliskos*, a diminutive that means "little spit." It is from this perhaps deliberately ironic term that the Romans derived the Latin *obeliscus*. Among the Ancient Egyptians, these monuments were called *tekhen* – plural *tekhenu* – which derives from a verb meaning pierce (Iversen 2006, "Obelisk," Grove Art website). The precise meaning of their distinctive shape is also uncertain, although the Roman author Pliny the Elder's report that "an obelisk is a symbolic representation of the sun's rays, and this is the meaning of the Egyptian word for it" may have much to recommend it (Pliny, *NH* 36.14.64). Most scholars associate the obelisk's origin with the ancient solar cult at Heliopolis, and it seems like that its prototype was a much older type of stone monument known as the *ben* or *benben*. These cultic stones, which apparently took a pyramidal form, were dedicated to the sun gods Atum and Re or Re-Harakhti in the sanctuary at Heliopolis. The Egyptians believed that the *benben* originated at the beginning of time, when it provided the seat for the Atum's creation of the universe. The *benben* was also associated with the sacred phoenix or Benu-bird, whose cycle of self-creation and resurrection was associated with the cults of the dead and the rising and setting of the sun (Iversen 1968–1972, 1:11–15; Habachi 1984: 3–6).

Both archaeological and inscriptional evidence make it clear that obelisks of various types were being erected by the rulers of Egypt during the later dynasties of the Old Kingdom (2686–2160 BCE). Among these, perhaps the most notable were a pair of obelisks transported on large ships from southern Egypt to Heliopolis by the sixth Dynasty Pharaoh Pepi II (2278–2184 BCE – Habachi 1984: 40–41). During the preceding fifth Dynasty (2494–2345 BCE) a series of solar temples with obelisk-like centerpieces were erected near the pharaonic cemetery at Abu Sir. These "obelisks" were fashioned not from single blocks of stone, but from masonry blocks and sheathed with fine white limestone in the manner of the pyramid tombs of the time. During the same period, diminutive obelisk-shaped stones began to be erected in pairs at the entrances to tombs. These were generally installed facing east, presumably to present themselves to the rays of the rising sun, which represented the resurrection of the deceased in Egyptian belief. These early funerary obelisks were usually fashioned from limestone and were inscribed on one side with the name of the deceased (Kuentz 1932; Habachi 1984: 41–46).

The earliest surviving large-scale, monolithic obelisk was erected by the 12th Dynasty Pharaoh Senusret I (1985–1956 BCE) in the sacred city of Heliopolis on the occasion of his jubilee year. This was originally one of a pair that was carved from the durable mottled-red granite (or *Syenite*) from Aswan in Upper Egypt, where later obelisks of this size were also quarried. They were shipped up the Nile and erected before a new or rebuilt temple dedicated to the sun god Re-Harakhti. The Heliopolis obelisk, like all succeeding obelisks of the "classical" type, is a four-sided monolith, carved from a single piece of Aswan granite. It stands some 67 ft (20.4 m) high on a squared base and weighs some 120 tons (Habachi 1984: 46–50).

Since no other obelisks datable to the Middle Kingdom have survived, the true successors of Senwosret's monuments are the ones produced by the New Kingdom rulers of the 18th and 19th Dynasties (1550–1186 BCE). This great series of obelisks begins with a pair dedicated to Amun-Ra at Karnak by the 18th Dynasty pharaoh Thutmose I (1504–1492 BCE). One of these, which rises nearly 66 ft (20,016 m) high and weighs an estimated 143 tons, still stands on its original pedestal in the temple precinct (Fig. 3), while the other survives only in fragments. Thutmose I was succeeded after the short reign of his son (Thutmose II) by that king's "royal wife" (and half-sister) Hatshepsut (1473–1458 BCE). Hatshepsut erected no less than four large obelisks at Karnak, in two pairs. Of these, only one still stands intact today (Fig. 4). This great obelisk, which rises to a height 96.78 ft/29.5 m and weighs some 323 tons, is one of the pair set up here on the occasion of her Jubilee. The lower part of its companion stands nearby on its original base, and some fragments can also be seen on site and in various museums. Of the second pair that Hatshepsut erected at the beginning of her reign in the eastern section of the temple, only fragments survive today. But a visual record of their transport is preserved in the relief decoration in the Queen's funerary temple at Deir el-Bahari. Here, the obelisks are shown loaded end to end on a large ship pulled by three rows of boats for their journey "down" the Nile from Aswan to Thebes (Habachi 1984: 56–72).

Hatshepsut's successor Thutmose III (1479–1425) was responsible for the production of at least nine

Obelisks in Ancient Egypt. Fig. 3 Obelisk of Thutmose I, Karnak.

Obelisks in Ancient Egypt. Fig. 4 Obelisk of Hatshepsut, Karnak.

obelisks, including seven erected at Karnak and two at Heliopolis. Of these, only the Lateran colossus (see above), the Heliopolitan pair – which were transferred to Alexandria in Augustan times and are now in London and New York City (for the latter, see Fig. 2) and the Hippodrome obelisk in Istanbul – which stood before the seventh pylon at Karnak until it was removed by Constantine and raised in Constantinople by the Emperor Theodosius (379–395 BCE) – survive today (Habachi 1984: 72–77). During the 19th or Ramesside Dynasty, the Pharaohs Sety I (1294–1279 BCE) and Rameses II (1279–1213 BCE) erected obelisks in a number of locations, including Luxor, Heliopolis, and Piramesse. One celebrated survivor is the so-called Flaminian obelisk (ca. 75 ft/22.84 m, 263 tons), which was quarried by order of Sety I and completed and erected in Heliopolis by Rameses II. It was transported to Rome and set up in the Circus Maximus by Augustus, and re-erected in the Piazza del Popolo by Pope Sixtus V in the late sixteenth century (Fig. 5, and see more below).

During later dynasties obelisks continued to be made, sometimes out of different types of stone and in some cases on a smaller scale. The largest surviving specimen from the later periods is the so-called Montecitorio obelisk (21.79 m, 230 tons in its present, reconstructed form), which was one of a pair raised by the 26th Dynasty pharaoh Psamtek II (664–610 BCE) at Heliopolis and also later taken to Rome (see Fig. 6). The last surviving obelisks commissioned by a native Egyptian pharaoh were a much small pair carved from hard black schist for Nectanebo II (360–343 BCE) of the 30th Dynasty. They were dedicated to the Egyptian god Thoth and presumably set up at that god's temple in the city of Hermopolis. At the end of the Napoleonic campaign in Egypt, two fragments of these obelisks were turned over to British forces by the French and sent to the British Museum, where they may be seen today. A third fragment is in Cairo (Iversen 1968–1972, 2:51–61; Habachi 1984: 101–103).

During the rule of the Macedonian Ptolemaic Dynasty (332–30 BCE), temples and monuments continued to be produced in the traditional Egyptian mode. Among the embellishments for these was the pair of smallish obelisks erected at the Temple of Isis in Philae by Ptolemy IX (107–80 BCE). One of these obelisks (22 ft/6.7 m tall, 6 ton) was discovered in 1815 by the British nobleman and scholar William John Bankes (1786–1855). In 1819 Bankes discovered the lower part of its mate and hired the famous Italian strongman turned explorer–excavator, Giovanni Belzoni, to help remove the obelisks and their bases (inscribed in Greek) to his Kingston Lacy estate in Dorset, England. In 1839, Bankes erected the intact

Obelisks in Ancient Egypt. Fig. 5 Flaminian obelisk of Sety I and Rameses II, Piazza del Popolo, Rome.

Obelisks in Ancient Egypt. Fig. 6 Solarium obelisk of Psamtek II, Piazza di Montecitorio, Rome.

obelisk on its pedestal in the garden of the estate. Its hieroglyphic inscriptions and the Greek ones on its base were among the key documents in the decipherment of the Egyptian hieroglyphic script by Egyptologist Jean-François Champollion (1790–1832) in 1822 (Iversen 1968–1972, 2:62–85; Habachi 1984: 105–108).

Manufacture and Installation

The methods the Egyptians used for the manufacture, transport, and erection of obelisks are not fully understood (for what follows, see Engelbach 1922, 1923; Habachi 1984: 15–37; Arnold 1991: 36–40, 47–52, 57–73). Most of the evidence we have comes from the study of extant monuments, investigation into Egyptian building and stone-cutting techniques, and a few visual representations that survive from pharaonic times. But the richest source of information has come from the archaeological study of a large unfinished obelisk, believed to be of Thutmosid (New Kingdom) date, that still lies in one of the granite quarries at Aswan (Fig. 7). This obelisk, which was originally laid out at a height of 41.75 m (ca. 137 ft), would have weighed about 1,168 tons if extracted. It was abandoned – after an attempt to reduce its length – when it developed irreparable cracks in its upper section. Excavation of the monument by Engelbach in 1921–1922 revealed that the ancient workmen began by cutting test shafts into the rock. Then, after laying out the obelisk's shape on the surface, they began removing the upper layer of uneven stone to expose a suitable piece for excavation. Then came the arduous task of digging trenches on all four sides to provide work areas for the quarrymen to form and separate the block (see Fig. 8). From the evidence of surface marks and tools found on the site, it seems clear that this work was done with ball-shaped tools of ultra-hard dolerite stone (Fig. 9). When the trenches reached the required depth, the workers had to undercut the shaft to extract the obelisk from the bedrock. Then the obelisk had to be pulled or lifted from the quarry bed, smoothed and polished on site (in at least one case, parts of the hieroglyphic inscription were added at this phase) and prepared for transport. At all stages of work, including the carving of hieroglyphic inscriptions, the work was done with stone tools and abrasives like emery, since the copper and bronze tools of the time were not strong enough to cut the hard granite.

Visitors to the site may be surprised to discover that the unfinished obelisk was carved at a considerable angle longwise, with the pyramidion at the highest point on the east side and the bottom much lower on the west. By removing the deposit of granite at the opposite (bottom) end, it seems that the workers could have pulled the great stone out of the quarry with the help of its own

Obelisks in Ancient Egypt. Fig. 7 Unfinished obelisk, Aswan.

Obelisks in Ancient Egypt. Fig. 8 Trench of unfinished obelisk, Aswan.

Obelisks in Ancient Egypt. Fig. 9 Dolerite hand-tool, Aswan.

massive weight. But Engelbach has argued that the failure to remove the rock from the west end, coupled with the removal of stone from the area of the pyramidion on the east side, suggests that the workers planned to lift the obelisk from the bed with the help of large wooden levers and remove it from the front end of the trench (Engelbach 1923: 41–51).

Once the obelisk had been removed, the workmen loaded it onto a large sledge, which was pulled by a team of laborers on a track or ramp to the riverbank for transfer to a specially constructed transport ship. Upon arrival, it was rolled off and dragged in the same manner to the site where it was to be erected. At this stage, the builders faced the difficult (and potentially dangerous) task of raising the monument to an upright position on its pedestal block. Direct evidence for how this was done does not survive, but a number of plausible hypotheses have been put forward. We know that Egyptian builders used three main methods for raising large stones – levering, pulling with ropes, or drawing them up a ramp-like incline. It was the opinion of Engelbach that the workers dragged the monument bottom-end first up a ramp-like incline to a point some height above the base, after which it was pulled upright by ropes and lowered onto the pedestal, where it was positioned by levers and the gradual removal of sand. A version of this method was represented in suitably dramatic terms in the 1956 film, *The Ten Commandments*. A series of attempts to duplicate this method with a modern obelisk finally succeeded in 1999 (see Handshouse Projects 1999; Nova Online: Mysteries of the Nile, http://www.pbs.org/wgbh/nova/egypt/raising/).

Obelisks in Ancient Egypt. Fig. 10 Vatican obelisk, Rome.

Rome and the First Afterlife of the Obelisks

Obelisks continued to be erected, moved, and in a few cases, manufactured anew during the Roman era, which followed the defeat of Cleopatra VII (51–30 BCE) and her ally Marc Anthony by Octavian, who became known as the Emperor Augustus in 28–27 BCE. Egypt became a province of the Roman Empire, and the granite quarries at Aswan came under Roman control, providing a rich supply of monolithic columns and other products for the great building projects of Rome and its empire. The first prefect of Egypt under Augustus, Cornelius Gallus (30–26 BCE), was responsible for laying out a new forum complex, called the *Forum Julium*, at a site near the Ptolemaic capital of Alexandria. As an ornament to this space, Gallus ordered the erection of the so-called Vatican obelisk – the big, 331 ton, 83 ft (25.31 m) colossus that now stands in the Piazza di San Pietro in Rome (Fig. 10). Since it lacks a hieroglyphic inscription, is not known when or by whom this most celebrated of obelisks was originally quarried. Pliny the Elder reports that it had been originally raised in Egypt by the pharaoh "Nencoreus, the son of Sesostris," but it has been persuasively argued (Alföldy 1990) that it was originally quarried by Cleopatra VII as a monument to Julius Caesar and appropriated by Gallus, who added an inscription in bronze letters to the lower-end of the shaft that essentially dedicated the obelisk to himself. The letters were removed after Gallus was forced out of office on charges of corruption and took his own life to avoid prosecution (the fastening holes for the inscription were discovered during analysis of the obelisk's surface in1959). Sometime after this, presumably during the reign of emperor Tiberius (14–37 BCE), a second inscription, now eroded but still visible, was carved on the lower east and west faces of the monument (Fig. 11) which rededicated the monument to Augustus, "son of the divine Julius," and to Tiberius himself (for the Vatican obelisk, see Iversen 1968–1972, 1:19–21; D'Onofrio 1992: 97–185; Alföldy 1990).

In 13–12 BCE, Augustus ordered a pair of obelisks originally raised by Thutmose III (with later inscriptions of Rameses II) in Heliopolis to be transferred to Alexandria, where they were set up – facing the sea – before the so-called Caesareum, a complex dedicated to the cult of Julius Caesar. These had apparently been begun as a mausoleum for Marc Antony toward the end of Cleopatra VII's reign. The obelisks were set on their bases with their corners bronze, crab-shaped astragals – one of which, now in the Metropolitan Museum in

Obelisks in Ancient Egypt. Fig. 11 Latin Inscription, Vatican obelisk, Rome.

New York – was inscribed in both Greek and Latin to commemorate its dedication by Publius Rubius Barbarus, prefect of Egypt. In the later nineteenth century, these obelisks, one of which had fallen but remained intact, were presented as "gifts" from the Egyptian authorities to the British and American governments and transported to London and New York City (Fig. 2), respectively (Gorringe 1882; Iversen 1968–1972, 2:90–147; Habachi 1984: 165–182; D'Alton 1993).

In 10 BCE, 20 years after the defeat of Antony and Cleopatra, Augustus ordered the transport of two large obelisks from Heliopolis. By this time, according to contemporary reports, this great Egyptian city had fallen on bad times, and its marvelous temple had fallen into disrepair. The first, originally carved by order of Rameses II and his father Sety I (and now in the Piazza del Popolo, Fig. 5), was erected on the *spina* of the Circus Maximus (see Iversen 1968–1972, 1:64–75; D'Onofrio 1992: 260–266). The second, the aforementioned obelisk of Psammetichus II (now in the Piazza di Montecitorio, see Fig. 6), became the *gnomon* of a gigantic sundial in the Campus Martius (Iversen 1968–1972, 1:142–160; D'Onofrio 1992: 369–421). Both were capped by gilt-bronze spheres with obelisk-shaped pointers and provided with identical inscriptions on their red granite bases:

> IMP. CAESAR. DIVI. FIL. AVGVSTVS. PONTIFEX. MAXIMUS. IMP. XII. COS. XI. TRIB. POT. XIV. AEGVPTO. IN. POTESTAM. POPVLI ROMANI. REDACTA. SOLI. DONVM. DEDIT.

> When Imperator for the twelfth, consul for the eleventh, and tribune of the people for the fourteenth time, Imperator Augustus, son of the divine Caesar, dedicated this obelisk to the sun when Egypt had been brought under the sway of the Roman People (Iversen 1968–1972, 1:65, 142).

As the inscription makes clear, Augustus' obelisks were intended to commemorate his conquest of Egypt. In both cases, the new installations corresponded to the original Egyptian dedication of these monuments to the sun, but gave this theme a new and distinctly Roman spin. In the case of the Circus Maximus, which was traditionally associated with the solar cult, the obelisk took it its place on the spina or median strip as an embodiment of the sun's power, while the chariots that raced around it came to be considered symbols of the planets moving around it. In the Campus Martius, the Psamtek obelisk was put to use as a solar instrument, as described by Pliny the Elder (1938–1963): (*Natural History*, Ed. Rackham and Eichholz, 10:55–57).

> The one in the Campus Martius was put to use in a remarkable way by Augustus of Revered Memory so as to mark the sun's shadow and thereby the lengths of days and nights. A pavement was laid down for a distance appropriate to the height of the obelisk so that the shadow cast at noon on the shortest day of the year might exactly coincide with it. Bronze rods let into the pavement were meant to measure the shadow day by day as it gradually became shorter and then lengthened again. This device deserves to be carefully studied, and was contrived by the mathematician Novius Facundus. He placed on the pinnacle a gilt ball, at the top of which the shadow would be concentrated, for otherwise the shadow cast by the tip of the obelisk would have lacked definition (Pliny, *NH* 36.14.69–72).

It is unclear from Pliny's description whether this device was designed as a *solarium* (which measured the daily length of the sun's shadow on a meridian) or a *horologium* (a more elaborate device capable of measuring the length of the hours of the day), but his admiration for the device was undiminished by his observation that "the readings thus given have for about thirty years past failed to correspond to the calendar." During the fifteenth and sixteenth centuries, pavements with "lines of gilt metal" and mosaics representing the winds were thought to be remains of the device described by Pliny (Iversen 1968–1972, 1:144–149). In 1979–1981, a section of travertine pavement, with a meridian strip with Greek inscriptions in bronze letters (denoting signs of the zodiac and the Etesian winds), was discovered in the area immediately north of the obelisk, confirming the basic veracity of Pliny's account, although problems of interpretation and function remain (Buchner 1982; Schütz-Tübingen 1990). As for the obelisk itself, it was still standing in the eighth century but was thrown down and broken at some later date and discovered (and reburied) in about 1512. It was finally excavated in 1748, and after several abortive attempts, repaired (with fragments of a large granite column) and re-erected in the Piazza di Montecitorio in 1789 by order of Pope Pius VI. It was intended to lay a modern meridian to track the obelisk's shadow at this time, but the idea was not realized until 1998, when the pavement was restored to designs by the architect Franco Zagari (see Zagari, http://www.francozagari.it/HOME/Piazza%20Montecitorio/montecitorio.htm).

But impressive as these installations undoubtedly were, it was the feat of transporting them across the Mediterranean to Rome that impressed Roman commentators on the subject. Pliny reports that the ship that was specially constructed to carry Augustus' obelisks to Rome was considered such a wonder in its own right that it was placed on display in a "permanent dock" at Puteolis (modern Pozzuoli) to commemorate the achievement – although it was later destroyed by fire. He adds that the ship used by Gaius (Caligula) to move the third (Vatican) obelisk to Rome was likewise preserved until it was filled with concrete and sunk as part of the Claudian harbor-works at Ostia. Excavations in 1957–1960 near Rome's Fiumicino airport near Rome Ostia in 1957–1960 uncovered the concrete core of the Vatican obelisk ship, which preserved a partial "impression" of the vessel that once had borne it. From a reexamination of this and other evidence from Egyptian and Roman sources, Wirsching (2000) has proposed reconstructions of both Egyptian and Roman obelisk and column-carrying ships – and has concluded that both riverine and seagoing vessels used a ballasted double hull to control the level of the ship for loading and unloading the monoliths.

When it came time to transport and raise the obelisks on land, the Romans were able to use a variety of techniques that had not been available to the Egyptians, including iron tools and heavy lifting cranes Employing ropes and pulleys. The most extensive description of the Roman procedure is provided by the fourth century historian Ammianus Marcellinus, in his account of the transport and erection of the Lateran obelisk (Fig. 1) in the Circus Maximus under Constantius II in 359. He reports that upon its arrival in Italy, the obelisk was put on a *chamulcus* (a kind of sled or cradle) and "carefully drawn" through the Ostian gate to the Circus Maximus, where it was raised using a device resembling a "veritable grove" of beams and derricks and powered by an army of men turning wheels "that resembled millstones" (Ammianus, 17.4.14–15; *Ammianus*, Rolfe 1950–1952, 1:325–327). The great stone was gradually raised and lowered on its base on the *spina* of the circus, where it joined (and to a certain extent upstaged) the obelisk erected by Augustus over three and a half centuries earlier. Ammianus' description of the Roman "obelisk-raising" machine corresponds in general terms to the equipment depicted on the base of the Hippodrome obelisk in Constantinople, erected by Theodosius I, 379–395 (Bruns and Krauss 1935: 47–53; Iversen 1968–1972, 2:15–16; Killerich 1998: 69–72). It is also the same basic method that was successfully employed by Domenico Fontana to move the Vatican obelisk in 1586 (see below).

As the story above illustrates, later Roman emperors emulated Augustus' taste for transporting obelisks. The next to be moved to Rome after Augustus (that we know of) was the one in the *Forum Julium* at Alexandria, which was shipped to Rome and raised on the spina of the Vatican Circus by order of Gaius Caligula (37–41 BCE, see more below). These were followed by some 45 others in the three and a half centuries that followed. Among them were at least six small obelisks of 19th and 26th Dynasty vintage that were installed (at an unknown date) in the Roman sanctuary of Isis in the Campus Martius: the Iseum Campense (Iversen 1968–1972, 1:93–114, 174–177; Roullet 1972: 35, 72–77-cat nos. 73–80; Lembke 1994: 202–210-cat nos. 48–53). These include the obelisk now in the Piazza della Rotunda in front of the Pantheon (Fig. 12), which was originally raised in Heliopolis by Rameses II and set up at the beginning of the fifteenth century in the nearby Piazza di San Macuto (which marked the northernmost section of the Isis sanctuary). Its fragmentary counterpart, now in the gardens of the Villa Celimontana in Rome (Fig. 13), had been restored and set up even earlier, during the

Obelisks in Ancient Egypt. Fig. 12 San Macuto obelisk of Rameses II, Piazza della Rotunda, Rome.

twelfth to thirteenth centuries, on the Capitoline Hill. Other obelisks from the Iseum, discovered in the sixteenth to nineteenth centuries, can be seen in other locations in Rome, Florence, and Urbino. The last obelisk to be transported out of Egypt by a Roman emperor was raised in the Hippodrome of Constantinople by Theodosius I in 390 BCE. Originally one of a pair set up at Karnak by Thutmose III, this 30 m, nearly 400-ton colossus (it apparently broke during transport and now stands some 19.5 m–65 ft) was one of at least five obelisks that once stood in the city. Most of these have disappeared without a trace.

In addition to importing obelisks from Egypt, the Romans also produced their own new obelisks when the circumstances required it. Two that may have been produced directly for Roman use are the pair of uninscribed obelisks that were placed before the mausoleum of Augustus in Rome. They were erected at an unknown date (probably the first century BCE) and fell into the debris of the city sometime during the middle ages. In the sixteenth century, one of them was excavated and after years of neglect, was erected by Pope Sixtus V on the Esquiline Hill. In the eighteenth century, the second was discovered and installed in the Piazza del Quirinale by Pope Pius VI (Iversen 1968–1972: 47–54, 115–127).

A more certain case of Roman manufacture is the so-called Pamphilian obelisk, which was inscribed with vignettes and hieroglyphic inscriptions of the emperor Domitian (81–96) in honor of the Egyptian gods. During the fifteenth and sixteenth centuries, this medium-sized and exceptionally slender obelisk (16.54-m tall) lay broken in the ruins of the Circus of Maxentius on the Via Appia outside the walls of Rome. It remained there until the middle of the seventeenth century, when it was repaired and erected as the centerpiece of Bernini's Fountain of the Four Rivers in the Piazza Navona (Fig. 14). It has been proposed that the Pamphilius was originally raised in the central entrance-court of the Iseum Campense when it was rebuilt by Domitian after a fire in 80 BCE, but this is by no means certain. The inscriptions mention Isis and allude to the emperor's restoration of "that which had been destroyed," but the principal dedication is to the sun god Re-Harakhte. It is possible that it was made for another Roman site, or even – as seems to be the case with the obelisk of Antinous (see below) – for dedication in an Egyptian setting, and only later found its way to Rome.

During the reign of Hadrian (117–138), a smaller obelisk was carved in honor of the emperor's late companion Antinous, who drowned in the Nile during an Imperial visit to Egypt and was deified as a kind of modern Osiris in Egypt and elsewhere in the Empire. This obelisk was originally manufactured and, according to most recent theories, probably set up in Egypt

Obelisks in Ancient Egypt. Fig. 13 Capitoline Obelisk of Rameses II, Villa Celimontana, Rome.

Obelisks in Ancient Egypt. Fig. 14 Pamphilian obelisk of Domitian, Fountain of the Four Rivers, Rome.

Obelisks in Ancient Egypt. Fig. 15 Obelisk of Hadrian and Antinous, Monte Pincio, Rome.

near the site of the unfortunate boy's tomb. But it was eventually brought to Rome and erected in the third century in the Circus Varianus near the Via Labicana, where two fragments of its broken shaft were visible in the fifteenth and sixteenth centuries. These pieces were excavated and partially re-erected by the Saccocius brothers, who owned the property, in 1570. Then, after a period of neglect, the obelisk was purchased by Cardinal Francesco Barberini in 1632, and after some further peregrinations, was installed in Rome's Pincian gardens by Pope Pius VII in the early nineteenth century (Fig. 15).

Obelisks from the Middle Ages to Modern Times

During the middle ages, the obelisks continued to attract their share of interest from learned observers, even while many of them were toppled and otherwise neglected or vandalized in Egypt and Rome. They also acquired new names that continued to emphasize their needle-like shape. The common Medieval (and modern) Arabic word for an obelisk is *mislah* or *missala*, which refers to a "patching needle" and thus, like the Greek *obeliscos*, emphasizes the slender, needle-like shape of these monuments. During the middle ages, the obelisks of Senusret at Heliopolis (along with the Alexandrian pair) were popularly known as *Messalat Far'un* (Needles of Pharaoh). Arabic scholars called the hieroglyphic carvings on the obelisks and other Pharaonic monuments by a variety of names, including "bird's script" (*qalam al-tayr*), "temple-script" (*al-qalam al-birbawi*), and "hieratic" script (*al-qalam al-kahini*) (Habachi 1984: 3–5, 48; Haarmann 1996; El Daly 2003).

In Egypt, then, it is clear that the obelisks, like the pyramids and other monuments, retained their Pharaonic associations into the Medieval period. But the situation was more complicated for the "obelisks in exile" in Rome. It is true that thanks to the writings of scholars like Isidore of Seville the Egyptian origins and traditional name of *obeliscus* was never entirely forgotten in the Latin west (Isidore of Seville, *Etymologiae* 18.28–31). But in the ancient capital itself, as the obelisks fell victim to the indignities of neglect, earthquake, and vandalism, the memory of their Egyptian origins also began to fade, and was superseded by new or alternate associations with Roman history and legend. By the middle of the twelfth century, the only obelisk of great size that was still standing in Rome was the *Vaticanus* (Fig. 10), which by this time was believed to mark the site of the Apostle Peter's martyrdom in the Vatican circus. According to a second tradition set out in the *Mirabilia urbis Romae*, an influential twelfth century guide to the antiquities of Rome, the obelisk had originally been raised as the monument and tomb of Julius Caesar, whose ashes were believed to be interred in the bronze globe at the monument's summit. Although other texts of the time referred to this and other monuments in Rome as pyramids or obelisks, the preferred name for the Vatican monument, and later, for other Roman obelisks, was the *guglia* or "needle" of Caesar (variants of the term include *agulia* and *aguglia*). Derived in part from a misreading of a passage in Suetonius' *Life of Caesar* and the Latin inscription on the monuments' shaft, the association with the "Divine Julius" and the name *guglia* persisted in common parlance long after both the true origin and function of the monument had been established by Renaissance admirers (Iversen 1968–1972, 1:22–28; Curran and Grafton 1995).

By the middle of the fifteenth century, Italian humanists had identified the obelisks in Rome as the Egyptian monuments "in exile" described by Pliny and Ammianus, and had already embarked on the earliest stages of a long and complicated effort to understand and decipher their hieroglyphic inscriptions. In the early 1450s, builders working for the "humanist" Pope Nicholas V (1447–1455) conducted the first archaeological investigation of the Vatican obelisk in relation to the Pope's plan to move the great stone from the remains of the circus on the south side of St Peter's basilica to the piazza in front of it – a distance of some 275 yards. Accounts of the papal architects' claims to have devised machines capable of lifting and moving the great stone spread as far as the northern court of Ferrara, and inspired a host of imaginative obelisk projects – most of them quite impossible to realize, on the part of Renaissance artists and architects (Curran and Grafton 1995: 242–244). But this and other plans to move the obelisk or erect other ones that were discovered in the ruins of Rome were delayed for many years, until 1586, when the transport of the Vatican obelisk was achieved, with great fanfare, by Pope Sixtus V (1585–1590) and his architect-in-charge, Domenico Fontana (1543–1607). To achieve this long-postponed goal, Fontana devised a great obelisk-lifting and lowering machine – called a *castello* – that resembled a wooden siege-tower about 92 ft tall – just tall enough to life the obelisk from its base and lower it to a horizontal position, using a system or ropes and pulleys powered by capstans turned by teams of some 900 men and 74 horses. The obelisk was then transported to the piazza on a specially constructed causeway and raised on its original (albeit restored and elevated) base by reversing the lowering process. The obelisk was solemnly rededicated to the Holy Cross and ceremonially exorcized of all pagan, demonic forces, and Fontana himself was lauded as the hero of the moment and showered with titles and gifts appropriate to his achievement. During the next 3 years, Fontana used his obelisk-lifting machine to raise and repair the broken fragments of three more obelisks – the two large ones excavated from the Circus Maximus (which he raised in the Lateran and the Piazza del Popolo, respectively) and a smaller specimen that had been discovered decades earlier in the ruins of the Mausoleum of Augustus, which was set up on the Esquiline hill, near the apse of the Basilica of Santa Maria Maggiore (for Fontana's account and later studies, see Fontana 1978; Parsons 1968: 155–173; Dibner 1970: 21–43; Iversen 1968–1972, 1:29–40; D'Onofrio 1992: 71–92).

During the later seventeenth and eighteenth centuries, a series of smaller and/or broken obelisks were repaired and re-erected in Rome, including the Obelisk of Domitian (Fig. 14), which was restored under the supervision of the Jesuit polymath Athanasius Kircher (1601/1602–1680) and installed as the centerpiece for Bernini's richly allegorical Fountain of Four Rivers in 1649 (see Iversen 1968–1972, 1:76–92; Preimesberger 1974; Rowland 2001; Parker 2003); and the reconstructed fragments of the Campus Martius sundial obelisk, which was repaired with red granite from the damaged column of Antoninus Pius and set up in the Piazza di Montecitorio by order of Pope Pius VI in 1786 (Fig. 6). It was one of three obelisks re-erected by this pope, whose projects represented the final chapter in grandiose papal appropriation of these monuments (see Collins 2001, 2004). During the nineteenth century, would be European and American obelisk-importers shifted their gaze from Rome to Egypt itself, as the monuments of the country attracted new enthusiasm following the Napoleonic campaign of 1798–1801 and the subsequent decipherment of the hieroglyphic script by Jean François Champollion. The first to arrive in Europe (after the diminutive Philae/Bankes obelisk, see above) was the westernmost of the pair of obelisks inscribed for Rameses II that still stood before the great entrance pylon of the Temple of Amun-Ra at Luxor. Selected as the most beautiful specimen available on the authority of Champollion himself, the 246-ton obelisk was lowered using an elaborate hinged device and loaded onto a specially designed ship for transport to Paris, where it was raised with great ceremony in the Place de la Concorde in 1833 (Lébas 1839; Habachi 1984: 153–164; Porterfield 1998: 13–41; Hassan 2003). The next to arrive was the fallen one of the pair at the Caesareum in Alexandria, which had been offered to the British by the Egyptian authorities early in the century, but arrived only in 1878, after a tragic and nearly catastrophic voyage in a specially designed barge called the Cleopatra. The obelisk was raised on the Thames Embankment on September 13 of that year. The still-standing mate of this obelisk was offered at this time to the United States, and its lowering and transport were supervised by a naval officer and engineer named Henry H. Gorringe, who described his methods in a monumental tome that rivaled the early production of Domenico Fontana. The obelisk was raised with great ceremony in New York's Central Park in the winter of 1881, where it remains today (Fig. 2).

Obscured by trees and mostly ignored by strollers, joggers, and the throngs who crowd the Egyptian collections of the Metropolitan Museum of Art nearby, the New York obelisk provides a somewhat sobering coda for the colorful history of these monuments, whose unique appeal made them the most admired and desired of Egyptian inventions for some 2,000 years.

See also: ►Pyramids in Egypt

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Observatories in India

Virendra Nath Sharma

India has an ancient astronomical tradition. Information on its observatories is meager, however. It is certain that a number of prominent astronomers, patronized by kings, carried out their own observations, which are mentioned in *karaṇas*, or practical manuals. The places of such observations, if operated for a reasonable period of time, technically could be called observatories. A court astronomer, Śaṅkaranārāyaṇa (fl. 869), mentions such a place with instruments in the capital city of king Ravi Varmā of Kerala. Astronomers of the Islamic school of astronomy, such as ʿAbd al-Rashīd al-Yāqūtī (fifteenth century) report an observatory in the city of Jājilī in India. The Emperor Humayun (d. 1556) is said to have had a personal observatory at Kotah, near Delhi, where he himself took observations.

An ambitious program of building observatories was undertaken by Sawai Jai Singh (Savā'ī Jaya Siṃha), an astronomer–statesman of India. Between 1724 and 1735, Jai Singh built observatories at Delhi, Jaipur, Mathura, Varanasi, and Ujjain. His observatories, except for that of Mathura, still exist today in varying degrees of preservation. Sawai Jai Singh's purpose in building observatories was to update the existing planetary tables. Toward this purpose, he designed and built instruments of stone and masonry. These instruments may be classified into three main categories based on their precision which varies anywhere from ±1′ to a degree. Table 1 presents an inventory of his masonry instruments according to their precision, with the low precision instruments listed first. Table 2 lists instruments added after Sawai Jai Singh's death.

Jai Singh constructed 15 different types of masonry instruments for his observatories. Of these, the Samrāṭ yantra, Ṣaṣṭhāṃśa, Dakṣinottara Bhitti, Jaya Prakāśa, Nāḍīvalaya, and Rāma yantras are his most important instruments.

Samrāṭ Yantra

The *Samrāṭ yantra* or the "Supreme Instrument" is Jai Singh's most important creation. The instrument is

Observatories in India. Table 1 Inventory of Jai Singh's masonry instruments

Instrument	No.	Location
Dhruvadarśaka Paṭṭikā (North Star Indicator)	1	Jaipur
Nāḍīvalaya (Equinoctial dial)	5	Jaipur (2), Varanasi, Ujjain, Mathura
Palabhā (Horizontal sundial)	2	Jaipur, Ujjain
Agrā (Amplitude instrument)	5	Delhi, Ujjain, Mathura
S'aṅku (Horizontal dial)	1	Mathura
Jaya Prakāśa (Hemispherical instrument)	2	Delhi, Jaipur
Rāma yantra (Cylindrical instrument)	2	Delhi, Jaipur
Rāśi valaya (Ecliptic dial)	12	Jaipur
Śara yantra (Celestial latitude dial)	1	Jaipur
Digaṃśa (Azimuth circle)	3	Jaipur, Varanasi, Ujjain
Kapāla (Hemispherical dial)	2	Jaipur
Samrāṭ (Equinoctial sundial)	6	Delhi, Jaipur (2), Varanasi (2), Ujjain
Ṣaṣṭhāṃśa (60 degree meridian chamber)	5	Delhi, Jaipur (4)
Dakṣinottara Bhitti (Meridian dial)	6	Delhi, Jaipur, Varanasi (2), Ujjain, Mathura

Observatories in India. Table 2 Instruments added after Sawai Jai Singh's death

Instrument	No.	Location
1. Miśra yantra (Composite instrument)	1	Delhi
2. S'aṅku yantra (Vertical staff)	1	Ujjain
3. Horizontal Scale (known as the seat of Jai Singh)	1	Jaipur

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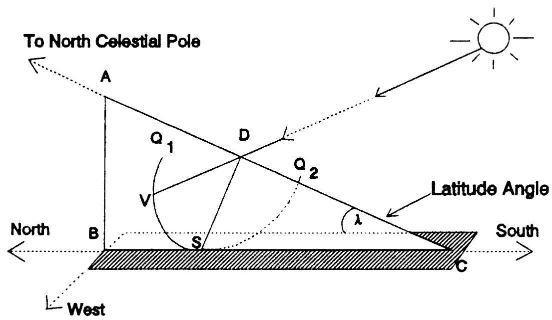
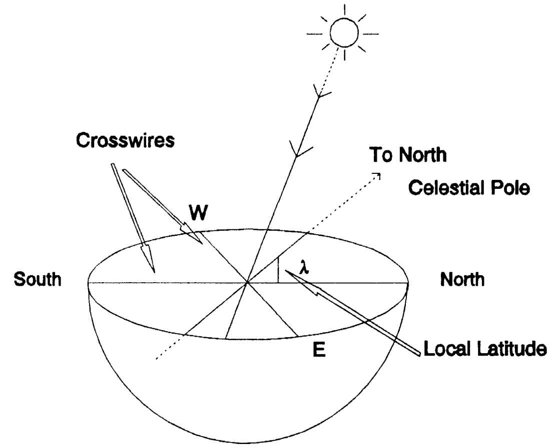
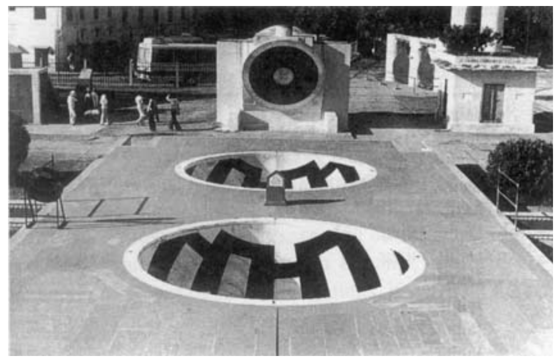


Observatories in India. Fig. 1 *Samrāt yantra:* principle and operation.



Observatories in India. Fig. 2 Jaipur Observatory of Sawai Sai Singh.



Observatories in India. Fig. 3 Jaya Prakāśa at Jaipur. The Nāḍīvalaya is in the background.

basically an equinoctial sundial, which has been in use in one form or another for hundreds of years in different parts of the world.

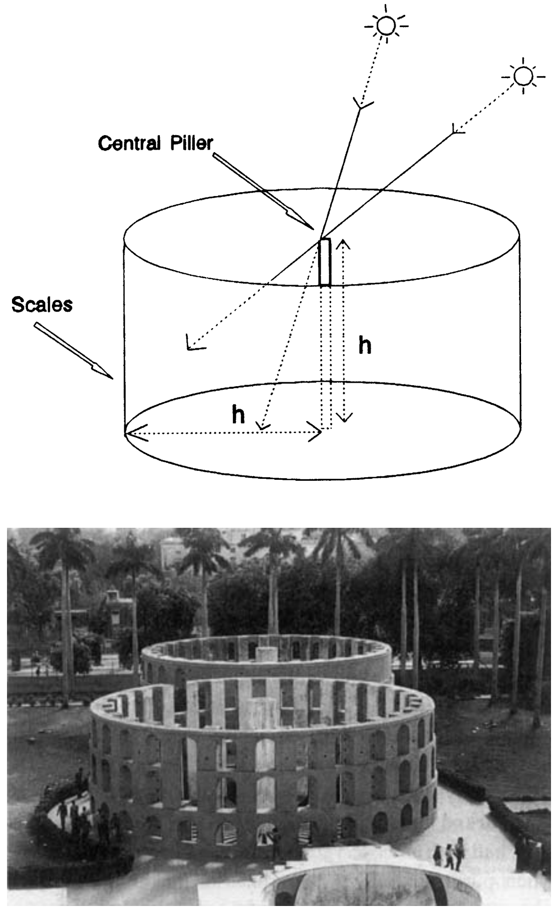
The instrument consists of a meridian wall ABC, in the shape of a right triangle, with its hypotenuse or the gnomon CA pointing toward the north celestial pole and its base BC horizontal along a north–south line. The angle ACB between the hypotenuse and the base equals the latitude λ of the place. Projecting upward from a point S near the base of the triangle are two quadrants SQ_1 and SQ_2 of radius DS. These quadrants are in a plane parallel to the equatorial plane. The center of the two "quadrant arcs" lies at point D on the hypotenuse. The length and radius of the quadrants are such that, if put together, they would form a semicircle in the plane of the equator.

The quadrants are graduated into equal-length divisions of time-measuring units, such as *ghaṭikās* and *palas*, according to the Hindu system, or hours, minutes and seconds, according to the Western system. The upper two ends Q_1 and Q_2 of the quadrants indicate either the 15-*ghaṭikā* marks for the Hindu system, or the 6 a.m. and the 6 p.m. marks according the Western system. The bottom-most point of both quadrants, on the other hand, indicates the zero *ghaṭikā* or 12 noon. The hypotenuse or the gnomon edge AC is graduated to read the angle of declination. The declination scale is a tangential scale in which the division lengths gradually increase according to the tangent of the declination.

The primary object of a Samrāṭ is to indicate the apparent solar time or local time of a place. On a clear day, as the sun journeys from east to west, the shadow of the Samrāṭ gnomon sweeps the quadrant scales below from one end to the other. At a given moment, the time is indicated by the shadow's edge on a quadrant scale.

The time at night is measured by observing the hour angle of the star or its angular distance from the meridian. Because a Samrāṭ, like any other sundial, measures the local time or apparent solar time and not the "Standard Time" of a country, a correction has to be applied to its readings in order to obtain the standard time.

To measure the declination of the sun with a Samrāṭ, the observer moves a rod over the gnomon surface AC up or down until the rod's shadow falls on a quadrant scale below. The location of the rod on the gnomon scale then gives the declination of the sun. Declination measurement of a star or a planet requires the collaboration of two observers. One observer stays near the quadrants below and, sighting the star through a sighting device, guides the assistant, who moves a rod up or down



Observatories in India. Fig. 4 The principle of a *Rāma yantra*.

along the gnomon scale. The assistant does this until the vantage point V on a quadrant edge below, the gnomon edge above where the rod is placed, and the star – all three – are in one line. The location of the rod on the gnomon scale then indicates the declination of the star.

Ṣaṣṭhāṁśa

A *Ṣaṣṭhāṁśa yantra* is a 60° arc built in the plane of meridian within a dark chamber. The instrument is used for measuring the declination, zenith distance, and the diameter of the sun. As the sun drifts across the meridian at noon, its pinhole image falling on the Ṣaṣṭhāṁśa scale below enables the observer to measure the zenith distance, declination, and the diameter of the sun. The image formed by the pinhole on the scale below is usually quite sharp, such that at times even sunspots may be seen on it.

Dakṣinottara Bhitti Yantra

Dakṣinottara Bhitti yantra is a modified version of the meridian dial of the ancients. It consists of a graduated quadrant or a semicircle inscribed on a north–south wall. At the center of the arc is a horizontal rod. The instrument is used for measuring the meridian altitude or the zenith distance of an object such as the sun, the moon, or a planet. According to Jagannātha Samrāṭ, this was the instrument with which Jai Singh determined the obliquity of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), to be 23°28′ in 1729.

Jaya Prakāśa

The *Jaya Prakāśa* is a multipurpose instrument consisting of hemispherical surfaces of concave shape and inscribed with a number of arcs. These arcs indicate the local time, and also measure various astronomical parameters, such as the coordinates of a celestial body and ascendants, or a sign on the meridian. Jaya Prakās'a represents the inverted image of two coordinate systems, namely, the azimuth-altitude and the equatorial, drawn on a concave surface. For the azimuth-altitude system, the rim of the concave bowl indicates the horizon. Cardinal points are marked on the horizon, and crosswires are stretched between them. On a clear day, the shadow of the crosswire falling on the concave surface below indicates the coordinates of the sun. Time is read by the shadow's angular distance from the meridian along a diurnal circle.

The instrument is built in two complementary halves, giving it the capacity for night observations. In the two halves the area between alternate hour circles is removed, and steps are provided in its place for the observer to move around freely for his readings. The space between identical hour circles of the two hemispheres is not removed, however. The sections left behind in the hemispheres complement each other. They do so in such a way that, if put together, they would form a complete hemispherical surface. For night observations the observer sights the object in the sky from the space between the sections. The observer obtains the object in the sky and the crosswire in one line. The coordinates of the vantage points are then the coordinates of the object in the sky. Jai Singh built his Jaya Prakās'as only at Delhi and Jaipur. These instruments survive in varying degrees of preservation. The instrument at Delhi has a diameter of 8.33 m and that at Jaipur, 5.4 m.

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Nāḍīvalaya

A Nāḍīvalaya consists of two circular plates fixed permanently on a masonry stand of convenient height above ground level. The plates are oriented parallel to the equatorial plane, and iron styles of appropriate length pointing toward the poles are fixed at their centers. The instrument Nāḍīvalaya is, in fact, an equinoctial sundial built in two halves, indicating the apparent solar time of the place.

The Nāḍīvalaya is an effective tool for demonstrating the passage of the sun across the celestial equator. On the vernal equinox and the autumnal equinox the rays of the sun fall parallel to the two opposing faces of the plates and illuminate them both. However, at any other time, only one or the other face remains in the sun. After the sun has crossed the equator around March 21, its rays illuminate the northern face for six months. After September 21, it is the southern face that receives the rays of the sun for the next six months. Jai Singh built Nāḍīvalayas at each of his observatory sites except Delhi.

Rāma Yantra

The *Rāma yantra* is a cylindrical structure in two complementary halves that measure the azimuth and altitude of a celestial object, for example the sun. The cylindrical structure of Rāma yantra is open at the top, and its height equals its radius. The accompanying figure illustrates its principle and operation. To understand the principle, let us assume that the instrument is built as a single unit as illustrated.

The cylinder, as in the figure, is open at the top and has a vertical pole or pillar of the same height as the surrounding walls at the center. Both the interior walls and the floor of the structure are engraved with scales measuring the angles of azimuth and altitude. For measuring the azimuth, circular scales with their centers at the axis of the cylinder are drawn on the floor of the structure and on the inner surface of the cylindrical walls. The scales are divided into degrees and minutes. For measuring the altitude, a set of equally spaced radial lines is drawn on the floor.

These lines emanate from the central pillar and terminate at the base of the inner walls. Further, vertical lines are inscribed on the cylindrical wall, which begin at the wall's base and terminate at the top end. These lines may be viewed as the vertical extension of the radial lines drawn on the floor of the instrument.

In daytime the coordinates of the sun are determined by observing the shadow of the pillar's top end on the scales, as shown in the figure. The coordinates of the moon, when it is bright enough to cast a shadow, may also be read in a similar manner. However, if the moon is not bright enough, or if one wishes to measure the coordinates of a star or planet that does not cast a shadow, a different procedure is followed. To accomplish this, the instrument is built in two complementary units.

The two complementary units of a Rāma yantra may be viewed as if obtained by dividing an intact cylindrical structure into radial and vertical sectors. The units are such that if put together, they would form a complete cylinder with an open roof. The procedure for measuring the coordinates at night with a Rāma yantra is similar to the one employed for the Jaya Prakāśa. The observer works within the empty spaces between the radial sectors or between the walls of the instrument. Sighting from a vacant place, he obtains the object in the sky, the top edge of the pillar, and the vantage point in one line. The vantage point after appropriate interpolation gives the desired coordinates. If the vantage point lies within the empty spaces of the walls, well above the floor, the observer may have to sit on a plank inserted between the walls. The walls have slots built specifically for holding such planks.

See also: ►Jai Singh, ►Gnomon in India, ►Time

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Observatories in the Islamic World

GREGG DE YOUNG

The observatory in Arabic/Islamic civilization underwent considerable elaboration from its beginning as a follower of earlier Greek observational posts. The observational instruments used must have been versions of Ptolemaic (Greek) equipment:

- The meridian armillary, for determining solstice points and the obliquity of the ecliptic
- The plinth, used for the same purposes
- The equinoctial armillary, to determine equinox points
- The "parallactic instrument" (or "Ptolemy's Rulers") to determine elevation in relation to the zenith, when heavenly bodies reach culmination
- The armillary or spherical astrolabe, for measuring positions of heavenly bodies relative to fixed or known celestial objects

In the centuries that followed, the physical equipment of observatories underwent continuous evolution. Arabic/Islamic observers required precision in their work and usually tried to obtain it by increasing the size of instruments. Large instruments had to be carefully fixed in place and required skilled craftsmen for their construction and maintenance, as well as a staff of observers and mathematicians skilled in reducing the observational data to mathematical models. In general, observation programs were initiated for correcting or improving the accuracy of existing astronomical tables (*zīj*). The production of a zīj was useful, not only for astrological/astronomical predictions, but also for encouraging the collection of data that could support alternative cosmographical schemes that avoided the embarrassment of Ptolemy's equant theory, especially in centers such as Marāgha.

Most observatories, because their operation involved production and use of large and expensive instruments, were supported by state funds, although there is some evidence that private institutions existed as well, such as the observatory of al-Battānī (d. 317 AH/AD 929) at Raqqa. The majority, however, survived at the mercy of their royal patrons. It was very rare for an observatory, such as the institution at Marāgha, to be assigned *waqf* income. Since the waqf was intended to be a grant of property in perpetuity for the sake of generating income for charitable institutions, the observatory at Marāgha (as well as one in Tabriz) must have been seen as providing an essential public service, perhaps through educational programs.

The first true observatories were founded under the patronage of the 'Abbāsid Caliph al-Ma'mūn (198–218 AH/AD 813–833), who also supported numerous translations from Greek into Arabic. The Shammāsiyya (in Baghdad) and Mount Qāsīyūn (near Damascus) observatories operated for a year, it seems. Although the sites may have lacked purpose-built structures, both employed permanent observational staff and instrument makers and technicians. Their purpose appears to have been the collection of accurate observations of sun and moon only, although there are some records of other observations. These observations were presented in the *Zīj Mumtaḥan*.

Sharaf al-Dawla (372–378 AH/AD 982–989) built an observatory in the garden of his Baghdad palace. It was housed in a purpose-built structure and equipped with instruments, some of which seem to have been quite large. This institution marks an advance in several respects (1) it had a specific physical structure, (2) it had as director/administrator, Abū Sahl al-Qūhī, a famous geometer and astronomer, in addition to a staff of astronomers and technicians, and (3) its research program involved collecting data on the motions of all planets. Its activities began with great fanfare, but seem to have died out quickly, perhaps due to the death of the royal sponsor.

The observatory at Marāgha, founded by the Mongol conqueror-prince, Hūlāgū, was one of the biggest and best equipped observatories prior to the modern era. Founded in 657 AH/AD 1259, the construction was overseen by Mu'ayyad al-Dīn al-'Urḍī, from whose autobiographical account we learn many details about the observatory and its operation. The physical plant included several purpose-built structures and an extensive collection of instruments, many of them large. There are also reports of an extensive library. The staff, under the direction of Naṣīr al-Dīn al-Ṭūsī, included a number of leading mathematicians and astronomers from all parts of the Islamic world and beyond. (There are even reports of Chinese astronomers visiting and assisting at this observatory.) Once again, the purpose was to acquire the most accurate observational data in order to correct earlier astronomical tables. The result was the *Zīj Ilkhānī*, completed in 670 AH/AD 1271. After completion of these tables, work on the site seems to have slowed, although the institution continued to exist for at least three more decades.

Another major observatory was founded in 823 AH/AD 1420 in Samarqand by Ulugh Beg, governor of Khurasān, who was himself well versed in mathematics and astronomy. Like the Marāgha observatory, it had a staff of mathematicians, observational astronomers, instrument makers, and technicians, although it seems to have been a more compact operation. The most famous of its instruments was a huge meridian arc enclosed within a large masonry structure. The observatory enjoyed the active support and participation of Ulugh Beg until his assassination in 853 AH/AD 1449. Thus, it functioned for nearly 30 years, during which time the *Zīj-i Jurjānī*, which was widely circulated in Arabic, Persian and Turkish, was produced. Not only was this one of the longest-lived of all Islamic observatories, it was also the site of the most extensive collection of data on the fixed stars ever attempted in the Arabic/Islamic world.

In 983 AH/AD 1575, Taqī al-Dīn Muḥammad al-Rashīd ibn Ma'rūf, with the support of the Ottoman Grand Vizier, successfully petitioned the Sultan for permission to build an observatory in Istanbul in order to produce a new set of astronomical tables, the older tables being inaccurate and in need of revision. His request was successful and, in 985 AH/AD 1577, the Istanbul Observatory, with Taqī al-Dīn as its head, began operations. Like its predecessors, this institution had a permanent building housing observational instruments, a staff of astronomers and support personnel, and a library. Three years after its inception, the observatory was demolished. Contemporary reports differ on whether this action was undertaken with or without the support and encouragement of Taqī al-Dīn. Debate also continues about the possible influence of his account of observatory organization and instrument construction on Europe's greatest naked-eye observer, Tycho Brahe.

With the destruction of the Istanbul observatory, the great premodern period of observatory construction came to an end. The observatories of Jai Singh II, Maharaja of Jaipur (AD 1686–1740) at best represent the dying embers of the tradition. These five observatories (located at Jaipur, Delhi, Benares, Ujjayin, and Mathura) contained enormous masonry instruments, many still extant today. Jai Singh's *Zīj-i Muḥammad Shāhī*, named after the emperor to whom it was dedicated, was largely patterned after the earlier work of Ulugh Beg. This has prompted some to conclude that these late observatories mark a period of decadence and derivative astronomy. This judgment is probably too harsh. These observatories, begun nearly a century after the founding of the Paris Observatory (which marks the beginning of a new era in astronomical technique and organization in support of a new interpretation of celestial phenomena) stand today as monuments to a brilliant, but now abandoned, intellectual, and social tradition within the history of science.

See also: ►al-Ma'mūn, ►Armillary Spheres, ►Astrolabe, ►Astronomical Instruments, ►Zīj, ►Astronomy, Astrology, ►al-Battānī, ►Marāgha, ►Ulugh Beg, ►Taqī al-Dīn, ►Jai Singh

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Optics in China

JINGUANG WANG, CAIWU WANG

Before AD 1911, optics in China went through four stages. The first stage was from remote antiquity to the Spring and Autumn Period (770 BCE), the second ended in AD 220 (end of the Dong Han Dynasty), the third ended in AD 1380 (end of the Yuan Dynasty), and the fourth stage ended in 1911 (end of the Qing Dynasty).

In the first stage, the Chinese began to develop a philosophy of nature. The ideas of optics were in their infancy. In remote antiquity, the Chinese germinated basic knowledge of light sources, vision, shadow formation, and reflection. In addition, there were some inventions such as artificial light sources and reflectors. The artificial light sources or fire source were obtained from striking stones, drilling wood, and focusing sunlight. The reflectors included water mirrors which were plane mirrors (Fig. 1) and bronze mirrors which were plane mirrors and convex mirrors. Even though all these achievements were superficial, they laid foundations for later studies on shadow formation and optical images.

The second stage took place within an important period for Chinese science and technology. During that time, optical technology developed very rapidly. As an example, techniques to make mirrors matured. Numerous studies led to deep understandings of light reflection and rectilinear propagation as recorded in the *Mo Jing* (Mohist Canon), which was written between 450 and 250 BCE. There were eight sections in the book:

1. Processes of shadow formation and vanishing
2. Umbras and penumbras

Optics in China. Fig. 1 Water mirror. The water surface was utilized as a reflecting surface. Such a water mirror was called *Jian*.

3. Rectilinear propagation of light and pinhole image
4. Sunlight reflection and formation of an inverted shadow
5. Changes of shadow sizes (length and width)
6. Image formation and symmetries due to plane mirrors
7. Two image variations from concave mirrors (erect image and inverted image)
8. One type of image formed by convex mirrors

These eight propositions systematically described theories in geometrical optics. Technically, *Mo Jing* had achieved a level very similar to that of Euclid's *Optics*.

During the third stage, Chinese scholars discovered various optical phenomena. For example, aspects of atmospheric optics were studied in detail, including halo maps and rainbow formation. Since image formation had been a hot subject in Chinese optics, it was further advanced during this stage. Most of the records can be found in a book called *Mengxi Bitan* (Meng Xi Essays) by the scientist Shen Guo (1032–1096), in the Song Dynasty (960–1279). Among hundreds of sections in the book, there were more than ten dealing with optics. Sections 44 and 330 are the most important. In Section 44, Shen discussed image formation by pinhole and concave mirrors in terms of a terminology called *ai*, or pinhole and focal point. He named such mathematical generalization *ge shu*. In Section 330, Shen discussed light penetrating mirrors, which were also called *tou-guang jian* or "magic mirrors." There were more than 20 characters inscribed on a magic mirror. When sunlight shone on the mirror, all the characters were clearly projected on to a wall. There were three magic mirrors in Shen's family. He also saw other mirrors in his friends' homes. However, some other extremely thin mirrors did not allow sunlight to pass through. The magic was in the inscription of faint lines on the back side of the mirror. (Based on Shen's descriptions, modern Chinese shops are able to reproduce such magic mirrors by several techniques.) Besides those two sections, Shen presented quantitative relationships between image sizes and curvatures of convex mirrors. He introduced a postmortem examination method in which a red light was utilized. He also attributed rainbows to the shadows of the sun during rain.

After Shen's work, another scientist, Zhao Youqin, carried out a famous optical experiment. Zhao lived in the thirteenth century, and recorded this experiment in his book, *Ge-Xiang Xin-Shu* (New Astronomy). In a chapter entitled "Pinhole Image," Zhao detailed a systematic study carried out in a two story house. There were two rooms on the first floor, one on the left and one on the right. To make two light sources in these two rooms, two boards were "planted" with thousand of candles. On the top of each light board, an additional covering board was placed. There was a hole in the center of the additional board. If the candles were lit, light could pass through the hole and then was projected on to a screen. The screen was either the fixed ceiling or an adjustable screen suspended from the ceiling so that the distance between the light source and the screen could be adjusted. The following observations were made in the experiment:

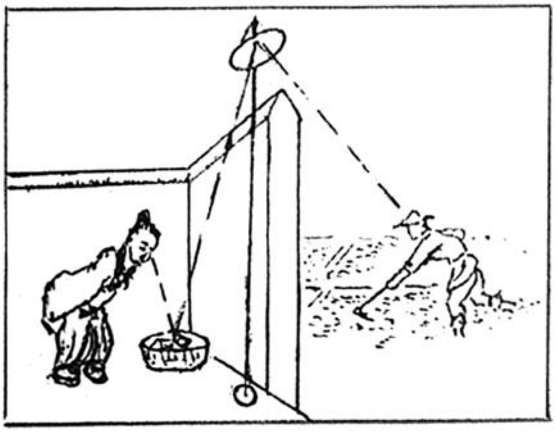
1. Shapes of the pinhole images are independent of the shapes and sizes of the small hole in the covering board.
2. The brightness of the image depends on the size of the hole. The larger the hole, the brighter the image.
3. When the source strength (number of candles) increases, the brightness of the image increases.
4. When the distance between the light source and the image screen increases, the image brightness decreases.

Zhao's experiment provided a lot of information on pinhole images. From the experiment, he proposed this idea. On the image screen, there was a light spot corresponding to a single candle. If a thousand candles were lit on a source board, there would be a thousand images of the candles. These images would overlap each other. The final appearance of the image would depend on the distribution of lit candles. In addition to basic optics, Zhao utilized his pinhole image theory to study eclipses of the sun and the moon and other astronomical phenomena.

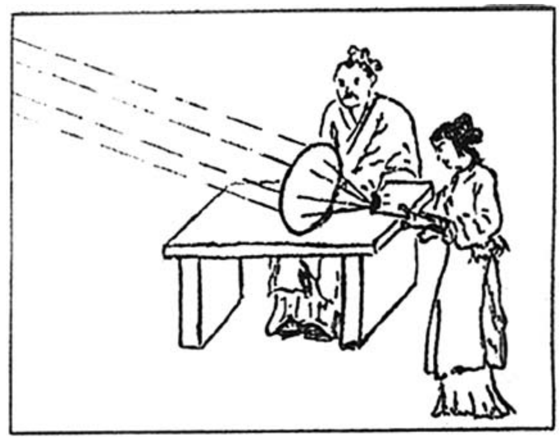
The fourth stage marked the end of traditional Chinese optics. The new trend both continued the Chinese system and adapted the Western system imported from Europe. During this period, Fang Yizhi (1611–1671) wrote a book called *Wuli Xiaozhi* (Small Encyclopedia of Physical Principles). In the book, Fang pointed out that light travels in wave forms, and he carried out an experiment to study the diffraction of light.

Several books and many articles on optics were translated from Western languages to Chinese languages, such as *Yuan Jing Shuo* (Telescopium) by the Germany Missionary Johanna Adam Schall Von Bell (1591–1666), and *On Optics* by Zhang Fuxi (d. 1862) and Englishman Joseph Edking (1823–1905). Another book entitled *Six Lectures on Light*, written by English physicist John Tyndall (1820–1893), was translated by Card T. Kreyer and Zhao Yuanyi in 1876.

Several monographs on optics were written by Chinese authors. In a book entitled *Jingjing Lingchi* (Treatise on Optics by an Untalented Scholar) by Zheng Fuguang (b. 1780), geometric optics was systematically introduced. In another monograph entitled *Geshu Bu* (Supplement to Geometric Optics) written by Zou Boqi (1819–1869), optical theorems and principles were discussed.



Optics in China. Fig. 2 Open-tube periscope in Han Dynasty. This illustration is based on a description in *Huai Nan Wan Bi Shu*, a book published in Xi Han Dynasty. By hanging a big mirror on the top of a pole and using a water-reflecting surface, one could watch a neighbor's actions. The object outside of the wall would form the image in the mirror, which in turn would form another image by reflecting. In this illustration, a person inside is watching a farmer outside of the wall. This is actually the earliest periscope in the world.



Optics in China. Fig. 3 Ice lens experiment. In *Huai Nan Wan Bi Shu*, there was a "miracle" experiment using an ice lens. One would make a spherical lens with a piece of ice by polishing both sides. Facing the lens to the sun and placing a piece of *moxa* at the focal point of the lens, one could light this piece of *moxa*.

Several different kinds of optical instruments or devices were improved. For instance, an optical expert, Sun Yunqiu (seventeenth century), made spectacles, telescopes, microscopes, and distorting mirrors.

The Chinese achieved high levels of understanding in optics, as illustrated by *Mo Jing*, *Mengxi Bitan*, and *Gexiang Xinshu*. The ancient Chinese paid attention to both theories and applications. A unique characteristic of Chinese optics is related to experimental approaches. All eight propositions in *Mo Jing* were based on experimental observations. Between the Qing and Han Dynasties, the Chinese mastered the concept of "focal distance" when they ignited fires from a spherical mirror. They created several novel devices such as the open-tube periscope and ice lens. Both devices were recorded in a book entitled *Huai Nan Wan Bi Shu*, published in Xi Han Dynasty. The open-tube periscope consisted of a big mirror, a basin filled with water, and a pole. As shown in Fig. 2, by hanging the big mirror on the top of the pole, one could watch the actions of the neighbors with the water surface. To make a spherical ice lens, one would use a piece of ice and grind it into a proper shape. As shown in Fig. 3, one could hold the ice lens toward the Sun and place a piece of *moxa* (mugwort, or *artemesia vulgaris*) at the focal point. Thus, this piece of *moxa* could be lit. Chinese observed similarities among rainbows, waterdrop dispersion, and crystal dispersion. Several Chinese scientists conducted high level experiments during their times, such as the "spherical mirror images" experiment by Shen Guo, and the "pinhole images" experiment by Zhao Youqin. The ancient Chinese optics system was based on empirical observations, which was short of theoretical abstraction and quantitative description. For example, no laws of reflection were proposed even after the phenomena of reflections had been observed for 2,000 years. As Western optics was imported to China, the entire foundation of traditional Chinese optics was changed.

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Optics in the Islamic World

Elaheh Kheirandish

The science of optics entered the Islamic world primarily through Greek sources, during the ninth century transmission of ancient scientific and philosophical texts. As such, it was unlike other mathematical sciences such as astronomy and algebra, which being based on Indian and Persian sources as well, involved a "non-Western" intellectual and practical dimension, in addition to physical and cultural settings. As further distinct from these and other fields, what emerged as the so-called science of "aspects" or "optics" from a subdivision of Greek geometry, transformed its parent field quickly and significantly, starting with the translation of the relevant texts (Kheirandish 1996, 1999, 2001a). Indeed, if one field were to be singled out in the Islamic world for having left the most influential mark on the development of a discipline, this might be *ʿilm al-manāẓir*, as Greek *optika* came to be called in Arabic. During the earliest phases of the discipline, a decisive theory about the nature and manner of vision, which was the main subject of optics for some time, developed after a long period of debate. The domain of the field also expanded from a geometrical study of vision to one into which not only theories of light, mirrors, rainbows, and shadows, but also the psychology of visual perception, were integrated as common subjects of investigation. Some of these added inquiries produced impressive results, but as the field turned from a branch of mathematics into a discipline closer to physics, its methodology also left the purely geometrical world to enter an experimental realm.

Works that represent some highlights of these developments include the *De aspectibus* of Yaʿqūb al-Kindī (d. AD 870) (Rashed 1997, Adamson 2006), the *Kitāb al-manāẓir* of Ibn al-Haytham (d. AD 1039), and its rich commentary, *Tanqīḥ al-manāẓir* of Kamāl al-Dīn Fārisī (d. AD ca. 1320) (Schramm 1963, Sabra 1989, 1994, 2002).

A supplementary list of optical works by these and other authors, composed in both Arabic and Persian, from the early ninth century all the way to about hundred and fifty years ago, are representative of the quantitative developments of the field (Kheirandish 1998, 2001b, 2002, 2004).

Disciplinary Developments

One would expect the science of optics to have embraced a variety of phenomena from light and shadows, halos and rainbows, mirrors and burning instruments, some observable from the beginning of human history. But this was not always the case even in ancient and medieval times. For ancient Greek scholars, from mathematicians such as Euclid (ca. 300 BCE) and Ptolemy (second century AD), to philosophers and physicians like Aristotle (ca. 400 BCE) and Galen (second century AD), the focus of what was called *optika* and classified under geometry was vision, not light. Greek optics was primarily concerned with theories of vision, as the close association of the term *optika* with the eye indicates, and in the case of the geometrical tradition in optics – the only tradition treating the subject in independent works with that title – the proposed theories of vision were even expressed in terms of visual rays (*opseis*) extending from the eye to the object. Greek writings did go beyond the realm of direct vision, to include reflection from a polished surface (as in Euclid's *Optics*, or Hero of Alexandria's *Catoptrics*) or refraction through a different medium (as added in Ptolemy's *Optics*). But works titled *Optika* still dealt primarily with vision – leaving the domain of the field largely determined by the relevancy of its subjects to what was long considered the "most noble of the senses."

Early Islamic scholars inherited this particular orientation, which initially determined the focus of their own optical inquiries, even the classification and study of related subjects concurrently received from ancient sources, from reflection and refraction to shadows, rainbows, colors, sighting instruments, and burning mirrors. But there was soon a considerable change in optics' scope and profile. With the *Optics* of Ibn al-Haytham (also known as Alhacen or Alhazen, ca. eleventh century AD) the extended disciplinary boundaries left an immediate trace on subsequent developments of a field, now called *Perspectiva*, one that was largely carried over to the seventeenth century when optics acquired its current name and general character.

The change in the scope of *ʿilm al-manāẓir*, which occurred alongside other theoretical and methodological developments, was itself a gradual process. Major works on optics proper, often identifiable by the term *al-Manaẓir* in their titles (corresponding to the *Optika* in the titles of Euclid's and Ptolemy's texts), slowly came to expand the meaning of the study of vision. Works from the *De aspectibus (Ikhtilāf al-manāẓir?)* of Yaʿqūb al-Kindī (d. AD 870) and *Kitāb al-manāẓir* of Ibn al-Haytham, to *Tanqīḥ al-manāẓir* of Naṣīr al-Dīn al-Ṭūsī (d. AD 1274) and *Tangīḥ al-manāẓir* of Kamāl al-Dīn Fārisī (d. AD 1320), spanning a period of about 500 years, well represent the changing disciplinary boundaries. Al-Kindī included in his *De aspectibus* surviving only in Latin a range of related discussions from shadows and mirrors to the clarity of perception,

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but left a number of others out. Ibn al-Haytham discussed in the seven books of his *Kitāb al-Manāẓir* a wide range of other subjects: the properties of light (and color) (Book 1), visual perception and visual illusions (Books II and III), and reflection and refraction (Books 4–7), but wrote separately on burning instruments, halos and rainbows, or *camera obscura*. Kamāl al-Dīn Fārisī's critical study of this same work, supplemented by a few of Ibn al-Haytham's independent optical writings (*On the Quality of Shadows, On the Form of the Eclipse*, and *On Light*), together with an examination of his own treatises (*On Burning Sphere* and *On the Rainbow and Halo*), expanded the topical range of his *Tanqīḥ al-manāẓir* to include all but the study of burning mirrors. The disciplinary developments are also reflected through a variety of related sources. Al-Fārābī's (d. AD 950) *Iḥṣā' al-'ulūm* (Enumeration of the Sciences) describes *ʿilm al-manāẓir* as including not only the science of mirrors (*'ilm al-marāyā*), but also such topics as the vision of distant objects and the application of vision in surveying. At the same time as the combination of the subjects of mirrors, or even burning mirrors with that of vision was not so uncommon, treatments of what are now considered optical problems often appeared in their own "proper place." Thus theories of light and perception were treated in philosophical works (following Aristotle), as in the related works of Ibn Sīnā (Avicenna, d. AD 1037), or Ibn Rushd (Averroes, d. AD 1198). Treatments related to the anatomy of the eye appeared in medical treatises (following Galen), as in the works of Ḥunayn ibn Isḥāq (d. AD 877). Such subjects as burning instruments were more commonly treated as part of the respective traditions of Diocles and Anthemius on *Burning Mirrors*, as in the case of Abū Saʿd Ibn Sahl (ca. AD 984). Shadows continued to be treated in books called *kutub al-aẓlāl* (Books on Shadows), as in Bīrūnī's (d. AD 1048) work devoted to this subject, and halos and rainbows often appeared in meteorological and astronomical literature, as in the case of Ibn Sīnā and Quṭb al-Dīn Shīrāẓī (d. AD 1311). It was not until the conscious effort of Shīrāẓī's student, Kamāl al-Dīn Fārisī, that most of these subjects were integrated into optics Sabra 1987a, 1987b, 1989.

Theoretical Developments

At the very beginning of the text which set out to place the science of optics on a new foundation and was instantly recognized and utilized as the most complete work on the subject in Europe, Ibn al-Haytham wrote: "For two opposite doctrines, it is either the case that one of them is true and the other is false; or they are both false,… the truth being other than either of them; or they both lead to one thing which is the truth each of the groups holding the two doctrines must have fallen short of completing their inquiry" (Sabra 1989). Here, Ibn al-Haytham was reflecting on a long controversy in visual theory, which had taken shape between the mathematicians and physicists before him and for which he managed to find a lasting solution.

The Greek mathematicians had explained vision through the assumption of visual rays extended from the eye towards the visual object. The best known among these were Euclid, whose *Optics* represents a geometrical approach to the study of vision, and Ptolemy, who had added an experimental and psychological dimension in his own *Optics*. The Galenic version of the visual-ray hypothesis as contained in *De usu partium* included the anatomical aspects of vision and stressed the role of medium through its own physiological approach. So did, Aristotle's language of the reception of forms which was more adopted by the physicists, or natural philosophers, in matters regarding vision. Islamic theorists writing in the tradition of each of the major Greek philosophers on vision did not always fall strictly into one group or another (Lindgberg 1978). The visual-ray theorists (*aṣḥāb al-shu'ā*) and the upholders of the theory of forms (*aṣḥāb al-inṭibā'*), to which Ibn al-Haytham repeatedly refers in his search for a systematic solution, often consisted of more than one group. The first included in addition to mathematicians (*ta'limiyyūn*), the followers of Plato or Galen or even theologians (*mutakkalimūn*), while its immediate rival, natural philosophers (*ṭabī'iyyūn*) covered both Aristotelians and atomists. The illuminationists (*ishrāqiyyūn*), who proposed an alternative form of perception altogether, had their own forms and variations. Ibn al-Haytham's solution to many complex problems raised by the first two groups was not only an attempt to determine such central questions as the direction of radiation in vision. The significance of his most celebrated work, *Kitāb al-Manāẓir*, goes much beyond treatments of the problems of vision. Having been translated into Latin in the late twelfth or early thirteenth century and then into Italian in the fourteenth century, with a printed Latin version in the sixteenth century, the book had an impact on the epistemology of late medieval Europe, the linear perspective of Renaissance artists, and study of light all the way to the seventeenth century, with a list of figures including Roger Bacon, Witelo, Pecham, Ockham, Oresme, Ghiberti, Snellius, Kepler, Descartes, Barrow, and Huygens. Ibn al-Haytham's contribution to the study of light included the assumption that light requires a body (a medium) for its transmission, that its movement from the object to the eye is not of infinite speed, though too quick to be perceived by sense, and it is "easier" and "quicker" in rarer media. His non-traditional conception of a finite, imperceptible interval of time for the movement of light was defended and advanced by a few in the Latin West, and his appeal to mechanical analogies to explain reflection and refraction were adopted by many later thinkers (Sabra 1962, 1967). The earlier independent researches of the tenth century mathematician Abū Sa'd Ibn Sahl and his anticipation of Snell's law have been the subject of a recent study (Rashed 1993). Earlier developments upon which Ibn al-Haytham's concepts of light and vision are clearly dependent include a principle now referred to as the "punctiform analysis of light radiation" (Lindberg 1976, Adamson 2006). An ancient conception based on rectilinear radiation, it grew on the assumption of a one-to-one correspondence between points on a visible surface and the eye, laying the foundation for the geometry of sight of the Western perspectivists and of Kepler. The principle can already be traced not only in the works of earlier Arabic authors such al-Kindī, but even in the way Euclidean assumptions were translated into Arabic, thereby stretching the period and importance of theoretical developments to the early ninth century. Immediate preoccupation with crucial questions about the exact nature of visual clarity and the structure of the visual cone (the role of central ray, the shape of its base), goes back to this same early period. Sometimes, concepts were positively affected by the adopted Arabic terminology: the expression for visual "clarity," for example (kathrā, also meaning multitude and magnitude), led to questions that were themselves the staring points for many later discussions in medieval Europe. Other times, word choices had an opposite effect: in the case of "refraction", the non-standard adoption of its terminology (in 'itāf) for reflection (in'ikās), led to a particularly problematic treatment of indirect vision (i.e. vision through mediums), in addition to the poor reception of the relevant parts of the *Optics* of both Ptolemy and Ibn al-Haytham in some parts of the Islamic world (Kheirandish 1996, 2004). But the limited understanding of concepts such as "refraction" did not provide a major obstacle for important theoretical developments later, including the correct explanation of the theory of rainbow formation. Explanations of the primary and secondary bows in terms of the refraction of light in raindrops were offered by Quṭb al-Dīn Shirāzī and later refined through experimental means by his own student, Kamāl al-Dīn Fārisī in Islamic Persia, almost at the same time as Theodoric of Freiberg's (d. ca. AD 1310) theory of rainbows was being offered. A major obstacle, however, did prevent proper treatment of inverted images within the eye in direct vision (i.e. vision through air), an obstacle occasioned by physiological shortcomings in Ibn al-Haytham's otherwise "revolutionary" achievements in optics (Sabra, 2002). Kepler's much later treatments provided the necessary breakthroughs in involving upright retinal images and focal properties of lenses; but they are also notable for representing theories of vision and light in a manner that has made their respective treatments viewed as a continuation and break with the past, depending on their perceived stress on vision and light respectively (Lindberg 1976; Smith, 2004). The earlier Islamic authors, both before and after Ibn al-Haytham, have their own share of historical achievements and contributions: they not only changed the face of the theoretical and disciplinary problems in optics, they also lay new methodological standards for optical inquiries.

Methodological Developments

The historical relationship between the sciences of optics and astronomy had a particularly important effect on the development of the methodological dimensions of the field. Euclid's *Optics* was among the Intermediate books (*mutawassiṭāt*), studied after his own *Elements* and before Ptolemy's *Almagest*. But optics was also to borrow from astronomy, though in a markedly different form and pace. The notion of *i'tibār* (experiment) was adopted and transformed by Ibn al-Haytham from astronomical works to be used in optics, as a methodological measure to replace geometrical demonstrations related to light and vision with experimental ones (Sabra 1971, 1994). This, however, occurred only after the old Aristotelian superior–subordinate relationship of disciplines was replaced first by their cooperation (*ishtirāk*) (in the ninth century), and then by their combination (*tarkīb*) (in the eleventh century). So the full service of astronomy to optics came relatively late. The imported experimental dimension was a significant step for the methodological transformation of the science of optics (Sabra, 1989).

Before this transformation, the discipline's methodical guidelines relied heavily on the teachings of Aristotle. For Aristotle, optics was a branch of geometry and one of "the more physical of the mathematical sciences" (*Physics*, 194a 6–11). The method of applying geometrical demonstrations to propositions on vision was adopted by Euclid, and through him more directly by Arabic optical authors. But alternative methodological approaches had already begun with a few early Islamic scholars. Al-Kindī, who reminded the reader in the preface of his *De aspectibus* that "geometrical demonstrations would proceed in accordance with the requirement of physical things," supplied geometrical demonstrations with experimental ones throughout his text. About the same time, Qusṭā ibn Lūqā spoke in a text on optics and its application to mirrors about "the cooperation" of natural philosophy (from which we acquire sense perception) and geometry (for its geometrical demonstrations). Even in the early text of Aḥmad ibn ʿĪsā, specifically titled as being "in the tradition of Euclid," Euclidean examples were sometimes supplemented by "sense-based examples" – those to be set up (Kheirandish 2002).

Ibn al-Haytham would continue to regard experimental optics as a mathematical inquiry. But in the course of his attempt to examine the study of vision and its foundations, the methodology of the mathematical science of optics was to be transformed radically. The synthesis (*tarkīb*) of physics (involving questions concerning the nature of light), and mathematics (dealing with manner of its propagation), following his explicit division between physical (*ṭabī'iyya*) and mathematical (*ta'līmiyya*) inquiries as two separate criteria, was at the heart of a new methodology that was to change the discipline. Ibn al-Haytham's contemporary, Ibn Sīnā, adopted a somewhat different methodological approach when he supplemented his critical remarks on previous treatments of rainbows with detailed observations of his own. Kamāl al-Dīn al-Fārisī, acknowledging the guidance of his predecessor, and inspired by his teacher, Quṭb al-Dīn al-Shīrāzī, added an unmistakably modern experimental touch to such observations. He reproduced an artificial object, such as a spherical globe filled with water to represent raindrops, as part of a conscious shift from traditional explanations of the phenomenon of the rainbow in terms of clouds acting as a concave mirror, to one in terms of the passage of light through a transparent sphere. By this later period, the field not only included subjects and theories more easily associated with optics today; it had also acquired the more modern methodological approach of "controlled" experimentation.

See also: ►al-Kindī, ►Ibn al-Haytham, ►Naṣīr al-Dīn al-Ṭūsī, ►Qusṭā ibn Lūqā, ►Ibn Sinā, ►Ibn Sahl, ►al-Bīrūnī, ►al-Shīrāzī, ►Ḥunayn ibn Isḥāq, ►Ibn Rushd, ►Physics

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Origami

THOMAS HULL

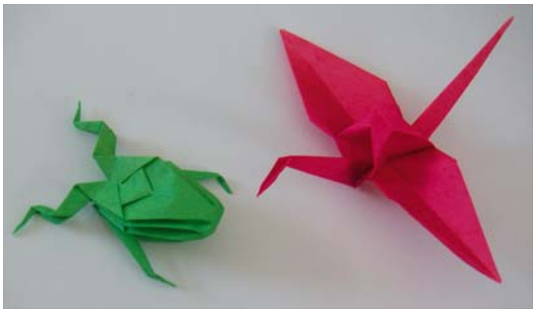
Origami is the art of folding paper into works of sculpture. No one knows when or where the art of paper folding started, but many scholars believe that the invention of paper in China around 100 BCE (see the Institute of Paper Science and Technology website) had to have coincided with the first attempts at paper folding.

However, while there is evidence of paper folding developing around the world as paper making technology spread, it was the Japanese who embraced the art form as part of their culture. In fact, *origami* is a Japanese word made up of two characters: *oru* meaning "to fold" and *kami* meaning paper. The Japanese language has many homonyms–words that sound the same but mean different things. *Kami* is one such word; in addition to "fold" it also means "god" or "deity." Some people have conjectured that this is not a coincidence, and that this reflects why the Japanese Shinto religion uses folded paper to symbolize the spirits of deceased relatives. However, the Japanese language simply has so many homonyms that this might actually be a coincidence.

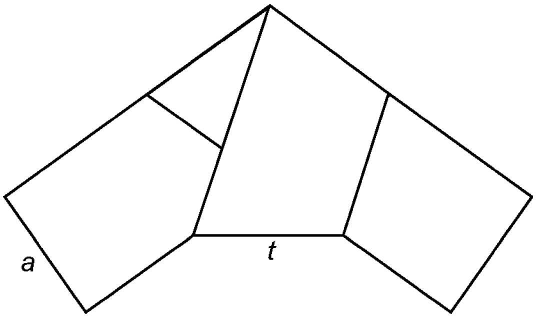
Records of ancient Japanese folding are hard to find. Certainly by the Edo period (1603–1867) in Japan numerous paintings and woodcuts can be found depicting upper class women folding the traditional crane, or *orizuru*. Also in the 1800s a few books on recreational origami were produced in Japan. Most references historians have found to origami prior to the 1800s are religious and cultural-based. As far back as the 1600s origami butterflies were placed over the stoppers of sake bottles for wedding ceremonies, and folded paper streamers called *go-hei* were hung in Shinto temples to represent spirits of the dead. Such streamers can still be found in modern Shinto shrines (Fig. 1).

The fact that by the 1800s people in Japan were folding paper recreationally, as opposed to only for ceremonies and religion indicates that origami had grown into a standard art form by this time. It is in the Edo period that one finds references to the classic Japanese crane and frog models (Fig. 2). However, there is also evidence that some Edo-era Japanese

Origami. Fig. 1 *Go-hei* Paper Streamers at a Small Shinto Shrine Outside of Tokyo, Japan. Photo by Thomas Hull. Used with permission.



Origami. Fig. 2 The Classic Japanese Frog and Crane (*orizuru*) Models. Photo by Thomas Hull. Used with permission.



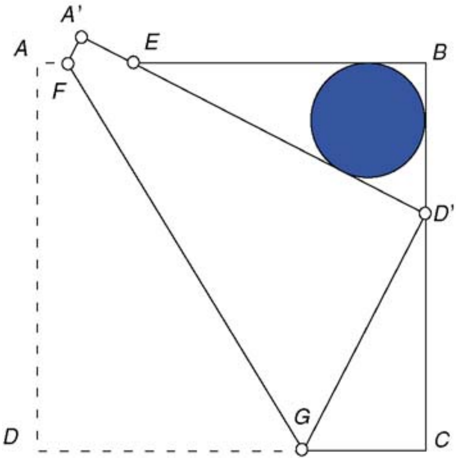
Origami. Fig. 3 The pentagon knot *sangaku*. "Construct a Regular Pentagon by Tying a Knot in a Strip of Paper of Width a. Calculate the Side t of the Pentagon in Terms of a." (Fukawaga 1989: 49)

origamists were exploring the science and mathematics of paper folding–something which modern mathematicians have only been researching in depth for the past 30 years. In Edo-era Japan there was a practice of placing artistically painted geometric problems on small wooden panels in Shinto temples. These tablets, called *sangaku*, were displayed to be read by the temple visitors as challenges to solve. This practice was prevalent throughout Japan, and it indicates some level of public interest and education in geometry–enough to solve such problems recreationally in the same way that people today buy puzzle books for mental challenges. In his book *Japanese Temple Geometry Problems*, Hidetosi Fukagawa describes over 250 examples of *sangaku*, some of which are extremely sophisticated. Two of his examples are based on origami. One, shown in Fig. 3, illustrates how to tie a strip of paper into a pentagonal knot (Fukagawa 1989: 49). The challenge is to prove that this knot makes a regular pentagon (all sides of equal length).

The second example, in Figure 4, shows a much more complicated instance of paper folding geometry. Here we are asked to take a square piece of paper and fold one corner to an arbitrary point on the opposite side. The text of this *sangaku* is more elaborate.

A square sheet of paper $ABCD$ is folded as shown in the figure with D falling on D', which lies on BC, with A falling on A', and $A'D'$ intersects AB at E. A circle is inscribed in triangle EBD'. Show that the radius of this circle is equal to $A'E$ (Fukagawa 1989: 37).

Amazingly, the geometric principles at play in the *sangaku* of Figure 4 were independently discovered over one hundred years later by Kazuo Haga, a Japanese teacher who specializes in origami geometry. In fact, the geometric property that triangles $CD'G$ and BED' and $A'EF$ are all similar is known as Haga's Theorem. That ancient paper folders were exploring the same kind of origami geometry as modern investigators

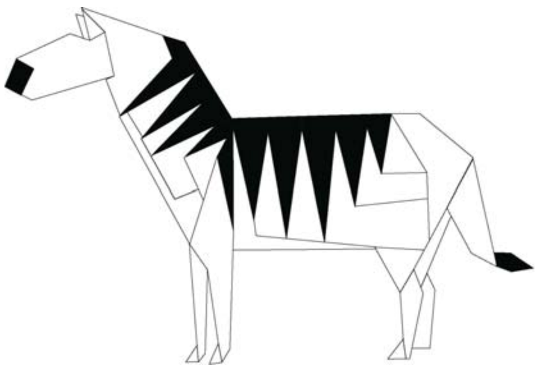


Origami. Fig. 4 A More Intricate Origami *sangaku*.

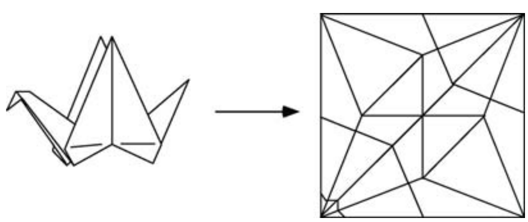
is a testament to the powerful utility of origami as a device for exploring mathematics.

The Meji Restoration (1866–1869) and aftermath saw the decline of a number of classic Japanese arts, including origami. But the practice did continue, and after World War II origami emerged again as an art form. The most influential person in this effort was Akira Yoshizawa, who tried to popularize origami in his country by creating hundreds of new models, holding exhibitions, and creating the International Origami Association. He also began important correspondences with people from other countries, in particular Lillian Oppenheimer of New York, Robert Harbin of the UK, and Gershon Legman of France. This helped spread the art of origami to other countries, and these same people were pivotal in the creation of the organizations Origami USA, the British Origami Society, and the Mouvement Français des Plieurs de Papier.

Partly due to the work of these organizations, origami art went through a renaissance in the late twentieth century. In 1979 American paper folder John Montroll published his first book (Montroll 1979) which contained origami models at a level of complexity never before seen in the origami world. For the first time, paper folders began to see that it was possible to, for example, fold a grasshopper, complete with six legs, wings, abdomen, thorax, head, and two antennae, all from a single square of paper with no cuts involved. The techniques with which he used to do this, which blended methods from classic Japanese models with brand new approaches, were mined by other origamists, starting a wave of complex-level origami design. Among the artists who emerged during this period was Robert Lang, who began systematically, analyzing the mathematics behind such complex designs. In addition, numerous Japanese folders, like Jun Maekawa, Fumiaki Kawahata, and Toshiyuki Meguro, developed their own methods and raised the level of complex origami to new heights (Fig. 5).



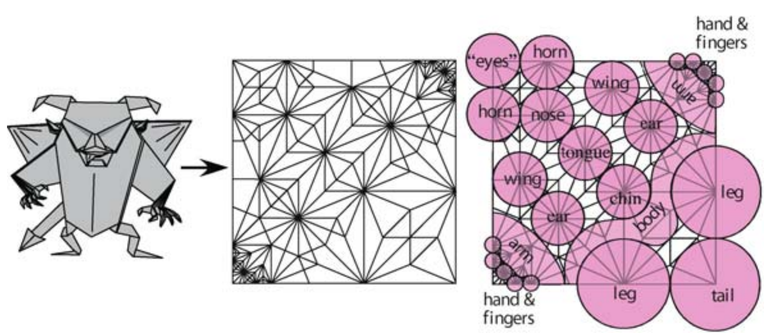
Origami. Fig. 5 John Montroll's Zebra Model (Montroll 1991), Folded from a Square Sheet of Paper, Black on One Side and White on the Other, with no Cuts.



Origami. Fig. 6 The Crease Pattern for the Classic Flapping Bird.

These design methods can be understood by considering the *crease pattern* of an origami model (Fig. 6). This is a diagram of a piece of paper with lines representing the creases used in the final origami model. This can be thought of as a blueprint for the design. In particular, modern origami designers can plan their design by thinking of any appendage that they need, be it the leg of an insect or the head of a horse, as requiring a circle of paper in the square to be devoted to that appendage. In other words, that circle, when folded, can be thought to collapse like an umbrella to create the appendage. This turns origami design into a problem of packing circles of different sizes into a square, and many modern origami designs can be analyzed in this way. Fig. 7 shows a model by Jun Maekawa from the mid 1980s with its crease pattern and circle decomposition.

Complex design methods have been developing and becoming more popular in the origami community since the 1980s, culminating in Robert Lang's compendium on the subject (Lang 2003), where he describes how much of origami design can be done on a computer. Some origami artists have complained that paying such attention to complexity is forcing paper folders to forget the more subtle, artistic expression that origami can achieve. Others have been using computer methods as a quick way to get a design, and then focus on artistry as they try to achieve this design in actual paper. In any case it is clear that origamists today are folding things that people 10 or 20 years ago never would have thought possible.



Origami. Fig. 7 Jun Maekawa's Winged Demon (Kasahara et al, 1983) with its Crease Pattern and Circle. Decomposition.

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Pakṣa

K. V. Sarma

Pakṣa (Half) refers, in Indian astronomy, to half the lunar month. The lunar month, which is the interval between two successive new moons (*amāvāsyā*) or full moons (*paurṇamāsyā*), is a visible natural phenomenon, which occurs at regular intervals and, as such, has been used for reckoning time in all ancient civilizations, including that of India. For the people of India of the Vedic times, the two *pakṣas*, one *śukla* (bright) and the other *kṛṣṇa* (dark), provided an easy and most convenient instrument for reckoning time. From actual observation, it was found that a *pakṣa* was completed in 15 lunar days (*tithis*) and these were named after their serial numbers, as *prathamā* (first), *dvitīyā* (second), *tṛtīya* (third), *caturthī* (fourth), etc., up to *caturdaśī* (14th), and the 15th was *amāvāsyā* or *paurṇamāsyā*, according to whether it was the dark fortnight or the bright fortnight.

The moon moves about 13° in its orbit, eastward, in a day of 24 h, but since the sun also moves in the same direction, 1°, during the same period of 24 h, the moon's resultant displacement, which constitutes the *tithi*, is about 12°. A lunar month of 30 *tithis* would be around 29 and a half solar days, and in a solar year of 365 days, the moon would have completed its 12 months in about 354 days, and would have moved further by 11 *tithis*. In order to correlate and bring together the solar and lunar years, the astronomical practice is to expunge and leave uncounted 1 lunar month every 3 years, when the extra 11 *tithis* would have accumulated to 1 month. This expunged month is called *adhika-māsa* or "added" or "intercalary" month.

Time reckoning by *tithi* and *pakṣa* is very much in vogue, even today, among Hindus, for fixing auspicious times for ritual, religious, and social functions, and for horoscopic astrology.

Pāṇini

George Cardona

Pāṇini was a grammarian (Sanskrit *vaiyākaraṇa*) who lived around the early to mid-fifth century BCE in the extreme northwest of the Indian subcontinent. He was native to Śalātura (Cardona 1976: 260–268), and composed a grammar (*śabdānuśāsana*, *vyākaraṇa*, Cardona 1997: 564–572) of early Indo-Aryan. The main part of Pāṇini's work is the *Aṣṭādhyāyī* ("group of eight [*aṣṭan*] chapters [*adhyāya*]"). This consists of approximately 4,000 statements called *sūtra* (Cardona 1997: 4, 6) organized in eight chapters, each of which is further subdivided into four quarter chapters (*pāda*). The corpus of sūtras is complemented by three ancillaries: an inventory of sounds (*akṣarasamāmnāya*), consisting of 14 sets organized in accordance with the manner in which Pāṇini formulates rules of phonology (Cardona 1997: 80–84); an inventory of underived verbal bases (*dhātu*), divided into ten groups in accordance with the manners of forming present stems (Cardona 1997: 85–129); and groups of items – predominantly nominal bases (*prātipadika*) – associated with particular operations and hence recited together with pertinent sūtras (Cardona 1997: 130–135). The rules in question account not only for the language (*bhāṣā*) current in Pāṇini's time and place – conventionally called Sanskrit (*saṁskṛta* "adorned, perfected") – but also for archaic forms proper to earlier stages of Old Indo-Aryan as found in Vedic texts.

Pāṇini accounts for such speech by means of a derivational system from the point of view of a speaker (Cardona 1997: 136–400; Junnarkar 1977–1988). In doing so, Pāṇini continues a procedure known to him from the earlier procedure followed by grammarians who composed analyzed texts (*padapāṭha*, literally "word recitation") corresponding to the continuously recited versions (*saṁhitāpāṭha*) of Vedic texts (see Jha 1987). One of these, the padapāṭha to the *Ṛgveda*, the earliest known Vedic corpus, was definitely known to

Pāṇini, who refers to a dialectal feature observed by Śākalya, the author of this padapāṭha. In addition, Pāṇini formulates phonological rules but assumes a knowledge of phonetics (*śikṣā*).

Pāṇinian rules serve to account for Sanskrit utterances in terms of their being generated from the point of view of a speaker. The derivational process starts with a weak semantics, particular meanings serving as conditions (*nimitta*) for introducing affixes (*pratyaya*) to bases (*prakṛti*), which are either verbal or nominal bases. The meanings in question are of two general kinds: those which Pāṇini can assume known to native speakers from their knowledge of the language and those which require explanation. Among the former are notions such as time references, number, and gender; chief among the latter are categories to which are assigned participants in actions, so that they are given class names such as *kartṛ* ("agent"), *karman* ("object") (see Cardona 1997: 137–139). The general scheme for any simple sentence is thus

(1) $B^n–A^n…B^n–A^n…B^v–A^v$,

in which nominal and verbal bases are to be followed by specified affixes. Moreover, the introduction of postnominal affixes is subordinated to that of verbal affixes, and abstract L-affixes are first introduced, later to be replaced by finite verb endings or participial suffixes. For example

(2a) $B^n–s^1…B^n–am^2…B^v–1$,
(2b) $B^n–ā^3…B^n–s^1…B^v–1$

are schemata for alternating active and passive sentences such that an L-affix is introduced to signify either (a) an agent or (b) an object, consequent upon which differing nominal affixations apply: if (a), a second-triplet nominal ending is introduced to signify an object but no nominal agent-signifying affix is introduced; if (b), a third-triplet nominal ending occurs to signify an agent but an object signifier is not introduced after a nominal. As noted, L-affixes are abstract elements, subject to replacement by finite verb endings and participial suffixes. For example

(3a) devadatta-s^1odana-am^2pac-ti,
(3b) devadatta-$ā^3$odana-s^1pac-ta

are strings such that the specific bases *devadatta* "Devadatta," *odana* "cooked rice," and *pac* "cook" are used. The verb is followed by the endings *ti* and *ta*, which replace the L-affix ***laṭ*** introduced to signify alternately an agent or an object, on condition that the action is referred to current time. Starting with these strings, subsequent operations apply resulting in the final utterances

(4a) *devadatta odanam pacati* "Devadatta is cooking rice."
(4b) *devadatenaudanaḥ pacyate* "Rice is being cooked by Devadatta."

In addition, the same types of derivational procedures serve to derive other, related, utterances such as

(5a) *devadatta odanam pakṣyati* "Devadatta will cook rice."
(5b) *devadatenaudanaḥ pakṣyate* "Rice will be cooked by Devadatta."
(6a) *devadatta odanam apākṣīt* "Devadatta cooked rice."
(6b) *devadatta odanam pakvavān* "Devadatta cooked rice."
(6c) *devadatenaudano' pāci* "Rice was cooked by Devadatta."
(6d) *devadatenaudanaḥ pakvaḥ* "Rice was cooked by Devadatta."

(6a) and (6b) differ in that the former contains the finite verb form *apākṣīt* (third sg. aor. act.) "cooked" and the latter has *pakvavān* (nom. sg. masc.), a form of the agentive past participle *pakvavat-*, itself derived from *pac-tavat-*, with the participial affix *tavat**u*** following the base *pac*. Similarly, (6c) and (6d) differ in that the first has the finite verb form *apāci* (third sg. aor. pass.) "was, has been cooked" and the second contains the passive participle *pakva-* (nom. sg. masc. *pakvaḥ*), from *pac-ta*, with the participial affix ***k****ta* (see Cardona 1997: 144–158, 198).

Further, the selfsame system accounts also for an infinite number of possible correct utterances of Sanskrit. Moreover, this system is recursive in that strings like (1) and constituents within them are the basis for deriving additional elements – derived verbal and nominal bases – which enter into the same derivational system. For example

(7) *ātmanaḥ putram icchati* "… wishes a son of his own (*ātmanaḥ* [gen. sg.] 'self')."

is related to

(8) *putrīyati* "… wishes a son of his own."
(7) contains a form *icchati* (third sg. pres.) of the verb *iṣ* "wish" in construction with the accusative singular *putram* "son." This sentence is derived from an abstract string
(8) ātman-as^6 putra-am^2 iṣ-1(=l**aṭ**).

The constituent *putra-am* of (8) is now allowed optionally to be followed by the affix ***k****yac* to form a derived verbal base *putra-am-ya-* with the meaning of *putra-am* in construction with *iṣ*. The nominal ending *am* of *putra-am-ya-* is dropped and an additional operation applies, yielding *putrīya* – a derived base subject to operations which apply to primitive verbal bases. Again, to a string *rājan-as*^{6} *puruṣa-s*^{1} operations can apply which result in *rājñaḥ puruṣaḥ* "servant (*puruṣaḥ* [nom. sg. masc.])" of the king (*rājñaḥ* [gen. sg.]), as in.

(9) rājñaḥ puruṣaḥ kutra gacchati "Where (kutra) is the king's servant is going?"
(9) derives from an abstract sting
(10) rājan-as^6 puruṣa-s^1 kutra-s^1 gam-1(=l**aṭ**)

Instead of applying the operations that serve to give *rājñaḥ puruṣaḥ*, the related constituents *rājan-as puruṣa-s* can optionally be combined to form a compound (*samāsa*) *rājan-as-puruṣa-s*, the nominal endings included within which are then deleted to give *rājan-puruṣa-*. The status of the original constituent *rājan-as* as a syntactic word (*pada*) is conventionally maintained, so that the final *-n* of this item is dropped, resulting in the compound *rāja-puruṣa-*. Such a derivation accounts for the fact that anywhere one can use a string such as *rājan-as puruṣa-s* one can alternatively use of form of the corresponding compound, as in

(11) rājapuruṣa-s^1 kutra-s^1 gam-1

whence is derived

(12) *rājapuruṣaḥ kutra gacchati* "Where is the king's servant going?"

(9) and (12) contain *kutra* "where," another type of derived nominal base. This is formed from a syntactic constituent *kim-i*^{7}, with the locative singular ending ***ṅi*** following the base *kim* (interrogative pronoun). To this complex, the affix *tra**l*** is optionally introduced, resulting in a derived nominal base *kim-i-tra-*, the ending in which is deleted (→ *kim-tra-*); the base *kim* is itself then replaced by *ku*. The derivate *kutra* alternates with locative forms, e.g., *kutra nagare* "in which town" is a variant of *kasmin nagare*, with the locative singular masculine–neuter form *kasmin*. There are also derivates formed from constituents of strings of the type *aupagava-* "descendent of Upagu." Any form of this derived nominal base alternates with a complex that includes a genitive form of *upagu-* "Upagu" and a term meaning "descendent"; for example

(13) *aupagavam ā nagay* "Bring a descendent of Upagu."
(14) *upagor apatyam ā naya* "Bring a descendent of Upagu."

The derivation of *aupagava-* is comparable to the formation of compounds like *rājapuruṣa-* in that the former is accounted for by introducing an affix *aṇ* after a constituent *upagu-as*^{6} of a sting

(15) upagu-as^6 apatya-am^2 ā^1 nī-loṭ

from which (14) derives. The complex *upagu-as-a* is a derived nominal base in which the affix *aṇ* is considered to have the meaning of a term denoting a descendent, such as *apatya-*, so that *aupagava-x* is equivalent to *upagu-as*^{6} *apatya-X*. Since the derived item is a nominal base, the ending included within it is deleted: *upagu-as → upagu-a- → · · · aupagava-*.

The Pāṇinian system involves the use of rules of different kinds and these must apply in such a manner as to ensure that they account for the proper results, namely possible correct Sanskrit utterances and no incorrect ones. Moreover, Pāṇini's grammar is intended to be understood by native speakers of the language it describes. Accordingly, the metalanguage used is the same as the object language. On the other hand, since he is dealing specifically with grammatical procedures and he must generalize as much as possible, Pāṇini also has both to deviate from established conventions of the object language and to formulate specific practices allowing users to interpret his rules where the native command of usage does not suffice to allow a single unambiguous interpretation. For example, in normal usage a term like go "cow, ox" is used to signify its meaning. In addition, Sanskrit has a quotation particle *iti*, which can be used to show that one is referring to a term and not its meaning: *gav iti* (← *go iti*) refers to the term *go*. In his grammar, Pāṇini reverses the normal convention, so that words other than those used as technical grammatical terms are regularly self-referring: go refers to the term go, not to its meaning. Making use both of the conventions known to any native speaker and of those which Pāṇini states by metarules of his grammar, one can expand and interpret *Aṣṭādhyāyī sūtras* unambiguously (see Cardona 1997: 75–79).

As noted earlier, Pāṇini had predecessors, including the author of the padapāṭha to the *Ṛgveda*. There is no doubt that pre-Pāṇinian grammarians had already recognized some important facts and concepts concerning grammatical procedures. The analyzed text of a Veda presupposes a relation between this text and the continuously recited text with which it is associated. In accordance with authors such as Śaunaka, who composed the *Ṛgvedaprātiśākhya* – a work that includes rules for converting the *Ṛgveda* padapāṭha to the saṁhitāpāṭha of this text – it is appropriate to consider that one text is theoretically derived from the other by rules of phonological change. Such a system involves recognizing classes of entities with respect to operations as well as relations among rules which state these operations. This also involves recognizing the distinction between the use and the mention of linguistic units. Thus, many of the principles which Pāṇini adopts were recognized before him. Pāṇini nevertheless stands as a major innovator. His grammar includes not only a complete phonology, but also goes beyond this to account for Sanskrit syntax. He does not begin, as do padapāṭhas, with words, but with bases, to which affixes are introduced under given conditions to form words. Most importantly, Pāṇini's grammar accounts for a language, not merely for a specific corpus.

Pāṇini's work was the basis of a long commentatorial tradition, including the *Mahābhāṣya* ("great commentary") of Patañjali (mid-second century BCE), which was the basic work for later commentators. Part of this tradition deals with what is generally called philosophy of grammar. A fundamental work in this sphere is the *Vākyapadīya* of Bhartṛhari (fifth century AD; see Cardona 1976: 298–299), which was the basis for later work and influenced not only Pāṇinian grammarians, but also scholars in other fields. Thus, Indian scholars of *Nyāya* (some schools of logic), *Mīmāṁsā* (ritual exegesis and related areas), Buddhism, and Jainism concerned themselves with issues concerning language, semantics, and ontology, and in the course of their discussions make frequent use of Pāṇini's work and the work of later Pāṇinīyas.

See also: ►Nyāya

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Paper and Papermaking

Pan Jixing

Paper is a felted sheet of plant fibers formed from a water suspension using a sieve-like screen. When water escapes and dries, the layer of interwoven fibers becomes a thin-matted sheet and is called *paper*. It is one of the four great inventions of China, along with gunpowder, the compass, and printing. Traditionally, paper was thought to be invented by a eunuch, Cai Lun (ca. 60–121), in the year 105. But according to recent archaeological discoveries, paper made of hemp fibers from rags had already been made in the second century BCE as a new type of writing material. After that papermaking was further improved and popularized in the second to the third centuries in China. During the third to the sixth centuries the raw materials for making paper were expanded. Apart from hemp, paper made from paper mulberry bark and rattan was produced. This marked an important stage in the history of papermaking. Meanwhile, paper converting was developed, such as sizing with starch, coating with white mineral powder, and dyeing with various dyestuffs, especially cork tree bark (*Phellodendron amurens*) which makes paper yellow and moth-proof. Movable types of screens were generally used for making paper. The development of papermaking promoted the flourishing of education, culture, and science. Paper was widely used in daily life to make umbrellas, fans, kites, paper-cuts, toilet paper, and others.

The next important stage (sixth to tenth centuries) was the Tang dynasty (618–907), in which papermaking was greatly developed. In addition to the abovementioned kinds of paper, some new kinds appeared, such as bamboo paper and bark paper made of *Hibiscus mutabilis* and plants of the Thymelaeceae family, such as Daphne. Paper coated with colored wax or powder and wax, as well as that decorated with gold or silver dust, gelatin sized, water-marked, embossed, and marbled were also made in this period. Meanwhile, paper was used for clothing, furnishings, visiting and playing cards, lanterns, armor, window posters, and in commercial activities as a medium of exchange. A large amount of paper was used for ceremonies and sacrificial purposes, as was the so-called "fire paper." The development of block printing also stimulated the manufacture of paper. Another achievement was the production of large-size paper more than 3-m long. The Tang dynasty truly entered the "Age of Paper".

After papermaking was perfect and popularized in China, it was spread in all directions throughout the world. It arrived first in Korea and Vietnam in the third to the fourth centuries, then in Japan and India in the seventh. Paper reached the Arabian world in the mid-eighth century and Africa in the tenth. The Arabs monopolized papermaking in the West for 500 years. Only in the twelfth century was it manufactured in Spain and France, then in Italy in the thirteenth. In the seventeenth century, paper was made in most European countries and even in America; in Australia it was produced in the nineteenth. Thus it took more than 1,000 years for paper to spread from China to almost every part of the world. Paper and other Chinese inventions played a considerable role in the flourishing of medieval Arabic culture and in the development of European society after that. From the eighteenth century during the Industrial Revolution papermaking itself went through a number of technical reforms in Europe. Chemical pulp appeared in Europe in the mid-nineteenth century, although traditional handmade paper persisted by virtue of its artistic value and elegant appearance. It continues to be produced in China, Japan, Korea, and many Western countries including the United States. In fact, China remains the biggest supplier of handmade paper today. Well-known varieties include xuan paper from Anhui, mulberry bark paper from Zhejiang, hemp paper from Shan-xi, and bamboo paper from Sichuan.

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Parameśvara

K. V. Sarma

Among Indian astronomers hailing from Kerala, Parameśvara (ca. AD 1360–1465), promulgator of the Kerala Dṛggaṇita School, and author of over a score of works on astronomy and astrology, holds a prominent place. He was a resident of Ālattūr, his house being situated on the northern bank of the river Bhāratappuzha, where he conducted his astronomical experiments and observations for over 55 years.

Parameśvara was a prolific writer. Some of his works still remain in manuscript form, while a few are yet to be found. His works on astronomy are:

1. *Dṛggaṇita* (Computation True to Observation), AD 1431, his magnum opus, a practical manual, in two versions
2. *Goladīpikā* I (Illumination on Spherics), in 302 verses, on spherical astronomy
3. *Goladīpikā* II (Illumination on Spherics), in four chapters, on the same subject as above, but different from it
4. *Grahaṇamaṇḍana* (Ornament on Eclipses), in two versions, of 89 and 100 verses
5. *Grahaṇanyāyadīpikā* (Illuminator on Rationale of Eclipses) in 85 verses
6. *Grahaṇāṣṭaka* (Octad on Eclipses), on the computation of eclipses
7. *Vākyakaraṇa*, on methods for the derivation of several astronomical tables

Parameśvara also commented on several standard works on astronomy that were popular in Kerala. These include: *Āryabhaṭīya* of Āryabhaṭa, *Laghubhāskarīya* and *Mahābhāskarīya* of Bhāskara I, *Mahābhāskarīya-Bhāṣya* of Govindasvāmin, *Laghumānasa* of Muñjāla, *Sūryasiddhānta*, *Līlāvatī* of Bhāskara II, and his own *Goladīpikā* II. All these commentaries except that on *Līlāvatī* have been published.

Although he was primarily an author of astronomical works, Parameśvara also wrote on astrology:

1. *Ācārasaṇgraha*, a popular text
2. *Jātakapaddhati*, in 44 verses
3. Commentary on the *Muhūrtaratna* of Govinda
4. Commentary on the *Jātakakarmapaddhati* of Śrīpati
5. Commentary on the *Praśnaṣ-aṭapañcāśikā* of Pṛhuyaśas
6. *Muhūrtāṣṭaka-dīpikā*, *Vākyadīpikā* and *Bhādīpikā*, mentioned by Parameśvara at the end of his commentary on the *Mahābhāskarīya*

These works are not extant.

In his works Parameśvara evinces a refreshingly scientific outlook. He avers at the beginning of his *Grahaṇamaṇḍana* that he was setting out to compose the work after closely watching the movements and positions of the planets in the skies for a long time. At the beginning of his *Dṛggaṇita*, he says that, in real astronomy, computation should match observation. He enumerates a number of solar and lunar eclipses which he had observed between 1393 and 1432, and gives details about them in his *Grahaṇanyāyādīpikā*. He also points out the error between computed and observed readings and offers corrections and instructs that similar observations should be made at intervals and corrections enunciated for computation and observation to be identical.

See also: ►Astronomy in India

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Pauliśa

K. V. Sarma

Pauliśa, of Greek origin, is the originator of the *Pauliśa Siddhānta*, one of the five systems of astronomy of the early centuries of the Christian era. These were selectively redacted in the *Pañcasiddhāntikā* of Varāhamihira, the prodigious Indian astronomer–astrologer of the sixth century AD. According to a traditional verse attributed to the sage Kāśyapa, Pauliśa is one of the eighteen originators of Indian astronomical systems. Al-Bīrūnī, the Persian scholar, who sojourned in India from 1017 to 1030, stated that *Pauliśa Siddhānta* was written by Paulus-ul-Yunani, i.e. 'Paulus, the Greek'. Probably the Hindus prepared an Indianized Sanskrit *Pauliśa Siddhānta* on the basis of the Greek work. This original Sanskrit work is no longer available, and neither is the commentary on that work by Lāṭadeva which was referred to by Varāhamihira in *Pañcasiddhāntikā* I.3. However, the redaction of the *Siddhānta* in *Pañcasiddhāntikā* is fairly full and provides ample details about the nature and contents of the work. The Pauliśa system has certain things in common with the *Romaka Siddhānta* and with the *Vāsiṣṭha Siddhānta*, two of the other systems redacted in *Pañcasiddhāntikā*.

The epoch of the *Pauliśa Siddhānta*, which *Pañcasiddhāntikā* says is the same as that of *Romaka Siddhānta*, is the Hindu *caitra-śukla-pratipad* (first day of the bright fortnight of the month of Citrā) in the Śaka year 427 elapsed (*Pañcasiddhāntikā* I.8–10), which corresponds to mean sunset at Yavanapura (modern Alexandria in Egypt), or modern Sunday, March 20, 505. It is interesting that the same moment was adopted by Varāhamihira as the epoch of the *Saura Siddhānta* redacted in the *Pañcasiddhāntikā* (i.e. the old Ś*urya Siddhānta*). The Indian time then was 37–20 *nāḍīs* from mean sunrise in Ujjain, on Sunday, March 20, 505. (*Pañcasiddhāntikā* III.13). In *Pañcasiddhāntikā* III.13, it is stated that the *deśāntara-nāḍīs* (longitudinal difference in terms of time, expressed in *nāḍīs*) from Yavanapura to Ujjain is 7–20, while that to Varanasi is 9. The actual intervals according to modern calculations are 7–38 and 8–50, the difference being 18 *vināḍīs* and ten *vināḍīs*, respectively. One minute being equal to four *vināḍīs*, the difference works out only to 4.5 min and 2.5 min, which is remarkable.

At the commencement of the *Pañcasiddhāntikā* (I.4), Varāhamihira gives a pat to the *Pauliśa Siddhānta* for the accuracy of the *tithi* (lunar day) calculated according to it, though he adds that the *tithi* derived through the *Saura Siddhānta* is much more accurate. In fact, it is these two schools, the Pauliśa and the Saura, one representing the Greek and the other the Indian, that Varāhamihira depicts rather fully in *Pañcasiddhāntikā*, allotting them entire sections. Thus the entire third chapter of *Pañcasiddhāntikā* is devoted to the depiction of planetary computation and allied matters according to the *Pauliśa Siddhānta*, Chapter 5 to the Moon's cusps, Chapter 6 to lunar eclipses, Chapter 7 to solar eclipses, and much of the long Chapter 18 to the motion of the planets. Although the *Pauliśa Siddhānta* was based on a Greek original, the text was painstakingly Indianized, both in the matter of content and presentation.

See also: ►Varāhamihira, ►Astronomy in India, ►al-Bīrūnī, ►*Deśāntra*

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Pest Control in India

P. Narayanasamy

Field and horticultural crops in India are under threat from many insect pests. Some of them are American bollworm, pink bollworm, spotted bollworm, and white fly on cotton; brown planthopper, green leafhopper, leaf folder, stem borer, and ear head bug on rice; different kinds of stem borers and pyrilla on sugarcane; red hairy caterpillars and leaf miners on groundnuts; leafhoppers and fruit flies on mangoes; green scale on coffee; tea mosquito bug on tea; thrips on cardamom; fruit borers on vegetables and diamond back moths on cruciferous vegetables.

In storage warehouses, food grains are damaged by varieties of insects and non-insect pests. The majority belong to the orders Coleoptera and Lepidoptera, accounting for 60 and 8–9% of the total number of pests respectively. In India, pests like the Angoumois grain moth, rice moth, Indian meal moth, khapra beetle, rice weevil, rust red flour beetle, lesser grain borer on rice and wheat, and pulses beetle on pulses are very important.

Metamorphosis of Pest Control

Pest control techniques in India have undergone sequential metamorphoses during the ancient, medieval, British, and modern periods.

Protohistoric Period

Protohistory has been defined as the period of human history between prehistory, when no written records existed, and history in the strict sense, when records are the main source. In India, the term protohistoric period is applied to the post-Mesolithic and pre-Mauryan cultures, between 3,500 or 3,000 and 600 BCE (Ranjit Pratap Singh 1990).

Following is an account of various kinds of farm pest control practices adopted during the Protohistoric–Neolithic periods.

Grains of primitive wheat species, einkorn, emmer, and spelt have a very tough and sturdy spikelet which does not release the grains in ordinary threshing; such spikelets are beaten to pieces but the grains still remain enclosed in their individual husks. If the spikes are heated however, the solid portion of the spikelet becomes dry and brittle and then it is possible to crush them. Grain drying was a common practice then; it also kept the seed-infesting insects away during storage. The paleoethnobotanical record consisted of mummified and carbonized food grains, imprints of grains on potsherds, silica skeletons, etc.

Harappan Period

Cylindrical pits lined with lime plaster sufficiently wide and deep were likely to have been used for storage of food grains. The lime, besides absorbing moisture, might have deterred the pests.

To the southeast of the pre-Harappan settlement, ploughed furrow marks were still intact in a field with one set of furrows oriented east–west while the other ran north–south. Individual furrows were interspaced at 30 cm in the former and 1.9 m in the latter. Horse gram[1] was grown in short distanced furrows and mustard in the long distanced ones. This prompted the idea of mixed cropping perhaps to manage pest problems.

Terracotta sling-balls were found in all the Harappan excavations. Possibly the farmers used these sling-balls for scaring away pests such as birds, parakeets, or deers. Slings and sling balls are used even now by the farmers of rural India for protecting maize, sorghum, pearl millet, and other crops.

The best evidence of agriculture in the Harappan areas lies in granaries. These granaries, each 50 × 20 ft, were arranged symmetrically in 2 rows of 6, with a central passage, which was 23-ft wide. They were built upon a podium of rammed mud, some 4-ft high, riveted with baked bricks. This kept pest infestation away from the seeds.

Deccan Chalcolithic Period

The wood of *Acacia* spp. was used to fabricate all tillage tools such as ploughs, yokes, and spokes. The wood kept all the timber-infesting pests at bay. This practice existed during 1500–1000 BCE.

Cultivation of two cereals (wheat and barley) and pulses (horse gram, hyacinth bean, lentil, and pea) suggests that the farmers made use of the available water resources very intelligently (Raychoudhary 1964). There was a guide bund and a diversionary channel to support this. This scheme of growing two different species of plants sequentially is called" "crop rotation" and this practice helps to make the next crop free from pest damage.

[1] A small pulse (legume), which is grown as a crop in India, is used as a food for both human and animal consumption. They are small, thin, and oval shaped, which may be light to dark colored in shades of red, brown, and black. When cooked it provides a slightly strong, somewhat earthy flavor. It is consumed as a whole bean as a sprout, or as whole meal when prepared as a side dish or as a main dish with other ingredients. In some regions, the horse gram is boiled and then crushed with salt after which it is allowed to ferment in order to produce a sauce that is used in the same manner as soy sauce. Somewhat similar to the moth bean, which is considered the "poor man's food," horse grams also have the same connotation.

Storage bins had low mud walls 30-cm high, over which was mud plastered with bamboo screens. The structure contained a number of pit silos and round mud platforms for storing different kinds of grains. In some cases, the sides and the bottoms of the pits were lined with lime whereas in others the bottom was full of sand. In both, insect entry was deterred thus saving the grain from damage.

Straw from threshing floors was mixed with moist clay to make mud bricks, which were used to build multiroomed buildings and storage bins. In the storehouse, the silica content of the straw could have acted as a barrier for pest invasion.

Vedic Period

The Vedic literature quotes various laws and instructions regarding protection of crops from damage by insect pests and diseases. The Atharvaveda (Hymn 50 of book VI) describes the destruction of corn by locusts, mice, and borer.

Following are some pest control practices:

In the Rigveda, the cultivators kept birds away from their cornfields by making noise. In Matravagga, scarecrows were used for the purpose.

In Jataka, cultivators set traps and dug pit falls in their fields to protect the crops from wild animals.

Plastering with the powder of Aragvadha, Arista, Kareniya, Saptaparma, Cinnamon, and Vidanga (*Embelia ribes*) dissolved in cow urine and kept over night would destroy the insects that attacked the trees from outside.

Plaster of Vidanga, white mustard, black pepper, long pepper, and dry ginger, ballata and vaca prepared in cow urine, when applied to branches, kills the stem-boring insects and restores the tree to its natural colour.

Plastering with a paste made of cats, jackals, and pigs along with mustard and cow urine kills tree-boring insects.

Paddy seeds were preserved in receptacles like Kathinya (a storage structure) or in well-baked clay pots or in vessels of strong glass or containers woven of ropes and plastered with mud. In this way, the pests were less able to damage the crops.

A pit was dug in the hard earth and provided with descending steps. People were able to store rice seed in it, taking care that it was safe from damp, thieves, parrots, and rats. The sages advocated that presentation of the best kind of seeds conscientiously brought prosperity to their cultivators.

The ancient texts of India – *Bṛhat-saṃhitā* of Varāhamihira (fifth century AD), *Vṛksha Āyurveda* of Lokapakra (ninth century AD) and *Vṛkṣāyurveda* of Sarangadhara saṃhitā (thirteenth century AD) provide instances of plant protection practices based on indigenous knowledge. They provide indication of an integrated approach to control crop pests and diseases through soil, seed, plant, and environmental treatment. Seed treatment with cow dung, milk, juice of *Solanum indicum*, tender coconut water, *Embelia ribes,* and cow ghee were prescribed. Prophylactory pest control measures included soil application of a mixture of *Ferula narthex* Boiss, *Acorus calamus* L., pepper, *Embelia ribes*, cashew seed, *Chelianthes farinosa*, mustard, and cow horn powder in cow urine.

History of Entomology in India

A chronology of events concerning entomological science in India is presented in Table 1 (Atwal and Dhaliwal 2002; Vasantharaj David 2001).

Pest Eradication Era

There were only a few insect pest problems in India during ancient times and when they occurred, they were exterminated by the "slash and burn" concept. Most of the practices involved were traditional. The reason for the success of these measures was that they were all ecofriendly.

Pest Control Era

When the concept of the green revolution came to be regarded as a solution for the duelling population, Indians used high-yielding crop varieties under intensive and extensive types of cultivation. Misuse of the chemical pesticides damaged the environment, and the pests' natural enemies were also at risk. In some cases, insect pests in many crops warranted consumption of more pesticides. This led to a change from the pest eradication to pest control. The pest problems could be curtailed or controlled with various strategies including pesticides with economic return. This happened during 1940–1970.

Pest Management Era

In the aftermath of using chemical pesticides for pest control, many pest species became immune to many of the pesticides used. Many actually resisted and resurged which ultimately increased the pest population manifold. This population upsurge became uncontrollable with then available pesticides, thus culminating in complete crop failure. This pest situation existed from 1970–1985, forcing Indians to change their efforts from pest control to pest management.

Integrated pest management

Integrated pest management (IPM) is a broad ecological approach which employs cultural, mechanical, physical, genetic, and biological methods, including application of chemical pesticides as a last resort, in a harmonious and compatible manner with a view to suppress the pest population below the economic injury level. IPM is a dynamic approach and process, which

Pest Control in India. Table 1 Events in Entomology 1758–1939

Year	Scientist or organization	Contributions
1758	Linnaeus	Included 12 insects from India in his 10th edition of *Systema Naturae*.
	Dr. J. G. Koenig (Tamil Nadu, South India)	Published first scientific work on insects in India.
1779	Koening	Published an account of termites of Thanjavur (Tamil Nadu).
1782	Dr. Kerr	Published a special publication on the lac insect.
1785		Asiatic Society of Bengal was formed.
1791	Dr. J. Anderson, Physician General to East India Company at Madras	Published a monograph on the cochineal insect.
1800	Buchman	Wrote on cultivation of lac in India and silkworms in South India.
	Denovan	Published *Natural History of Insects*, covering insects of Asia (later revised by Westwood in 1842).
1840	Rev. Hope	Presented a paper, "Entomology of the Himalayas and India" in the *Madras Journal of Literature and Science*.
1847	Westwood	Made a cabinet of Oriental Entomology and *Arcana entomologica.*
1875		Indian Museum was founded at Calcutta.
1883		Bombay Natural History Society was established.
1887	Baltour	Published *Agricultural Pests of India and Eastern and Southern Asia* and *Indian Ants*, the first case of biological control in which a small red ant kept away white ants. Government of India commenced the publication of the *Fauna of British India* series.
1889–1903	Indian Museum Calcutta	Published Indian Museum Notes on Economic Entomology.
1892	Hampson	Issued four volumes on Moths of India.
1905		Imperial Agricultural Research Institute was established at Pusa, Bihar State.
	Lionel de Nicevelle	Appointed as the first Imperial Entomologist.
	Indian Tea Association	Commenced entomological work.
1906	Prof. Harold Maxwell–Lefroy	Second Imperial Entomologist (1903) Published two books, *Indian Insect Pests* and *Indian Insect Life* in 1909. Punjab was first to initiate work on agricultural entomology followed by Tamil Nadu (1906), Uttar Pradesh (1906), Karnataka (1908).
1914		Government of India enacted "Destructive Insect Pests and Diseases Act." T. B. Fletcher, first Government Entomologist of the then Madras State became the third Imperial Entomologist (1913–1932).
1916	Zoological Survey of India	Founded Indian Museum.
1921	Indian Central Cotton Committee	Funded projects on cotton pests in Uttar Pradesh.
1925		Indian Lac Research Institute, Ranchi was founded.
1926–1932		The Locust Plague led to the establishment of a "Locust Warning organization" in 1939.
1937		Entomological Society of India was inaugurated in Calcutta.
1938	Dr. T. V. Ramakrishna Ayyar	Published *Hand Book of Economic Entomology for South India.*
1939		Indian Journal of Entomology was launched.

varies from area to area, time to time, crop to crop, and pest to pest. It aims at minimizing crop losses with consideration to human, animal, and environmental health and safety.

Current Pest Management in India

Herbal Pesticides

Use of plant products has attained importance and practical utility in pest management. More awareness has been created among the farmers to use herbal-based pesticide preparations. Plant species like Neem (*Azadirachta indica* A.), Indian privet (*Vitex negundo* L), (Fig. 1) Adhatoda (*Adhatoda vasica* Nees), Holy basil (*Ocimum sanctum* L), Sweet flag (*Acorus calamus* L), Turmeric (*Curcuma domestica* L), Wild chilli (*Capsicum frutescens* L), Onion (*Allium cepa* L) a conifer, Cycas revoluta (Thumb) (Fig. 2) and Garlic (*Allium sativum* L) are used increasingly in pest management. Indian pesticide markets trade in numerous herbal pesticides, especially from plants like neem.

Pest Control in India. Fig. 1 *Vitex negundo L.*

Pest Control in India. Fig. 2 *Cycas revoluta*.

Traditional Knowledge

In recent times, there has been increased awareness of indigenous pest control practices. Concerted efforts are being made to document and revalidate pest control knowledge. Scientific institutions and non-governmental organizations play vital roles in applying the indigenous pest control knowledge with the goal of diminishing consumption of the chemical pesticides. Traditional pest management packages have been created for specific pests in crops such as rice and some vegetables (egg plant) bhendi, and tomato (Narayanasamy 1999). Application of indigenous tribal knowledge in pest control has enabled us to fabricate rat traps (Fig. 3) for rice and other crops (Kathirvelu et al. 2004).

Pest Control in India. Fig. 3 Tribal rat trap.

Biological Pest Suppression

The Project Directorate of Biological Control at Bangalore has developed strains of an egg parasitoid, *Trichogramma chilonis*, with physiological tolerance to Endosulphan 0.07% and high levels of temperature.

The Bhabha Atomic Research Center, at Mumbai, has identified a new variety of *Bacillus thuringiensis* var *kenyae*.

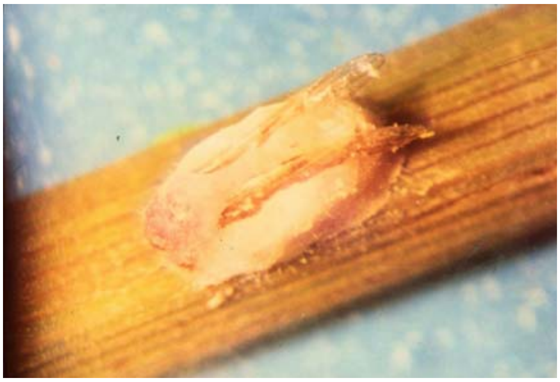
Muralirangan et al. (1996) recorded new species of microsporidians such as *Nosema locustae, N. acridophagus, N. cuniatum, Perezia dichloroplusae* and a recent discovery of Cephalogregarine and Gregarine species on nymphs and adults of 15 species of grasshoppers.

Applications of Nucleopolyhedro viruses infecting *Amsacta albistriga, Spodoptera litura,* and *Earias vittella* have been standardized for various crops.

Thirty groups of fungal pathogens have so far been recorded on key pests in rice, which included *Pandora delphacis* (Hori). Humber on brown planthopper (BPH) (Fig. 4) and green leafhopper (GLH), *Zoophthora radicans* (Brefeld) Batko on leaf folder and *Nomuraea rileyii* (Farlow) Samson on cutworm. A Mycoinsecticide 70% wettable powder with sorghum grains as a carrier has been developed with spores of *Pandora delphacis* and found effective against BPH and GLH (Narayanasamy 2001). Recently for the first time, infection of adult moths of lepidopterous insects of rice ecosystem with certain fungal pathogens including Fusarium moniliformae (Fig. 5) has been reported (Yasodha and Narayanasamy 2004).

Pheromones

Pheromones act as potential tools for monitoring, surveillance, predicting population threat levels, and thresholds for applications of control measures for pests such as *Helicoverpa armigera, Pectinophora gossypiella* in cotton, *Spodoptera litura, Plutella xylostella*, *H. armigera* in vegetables, and *Lymantria pomonella* in apple.



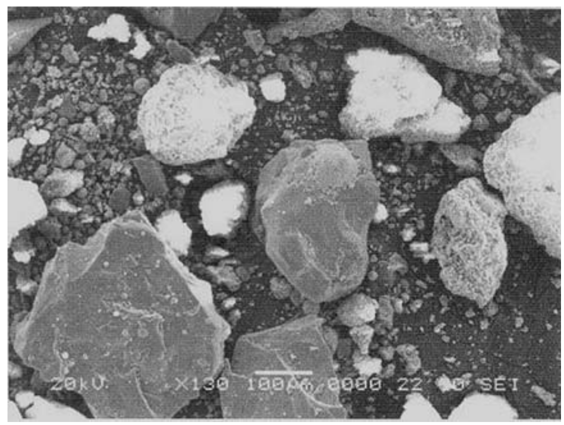
Pest Control in India. Fig. 4 Rice BPH adult infected by *Pandora delphacis*.

Pest Control in India. Fig. 5 Rice yellow stem borer infected by *Fusarium moniliformae*.

Biotechnological Innovations

- Attempts to develop transgenic maize, wheat, cotton, brassica, mungbean, potato, apple, broccoli, walnut, and alfalfa are underway.
- The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), in Hyderabad is in the process of testing GM pigeon pea, sorghum, pearl millet, and groundnut for the first time (Sharma et al. 2002).
- Transgenic rice with resistance to insect pests and pathogenic viruses are being tested. They include Bt genes like Cry 1 Ab, Cry 1 Ac, conferring resistance against stem borers and leaf folders or GNA (*Galanthus agglutinin*) gene, conferring resistance against sucking pests and potato protease inhibitors for insect resistance (Mishra 2004).
- Entomotoxin gene(s) from *B. thuringiensis* has been transferred to tobacco, rice, cabbage, cauliflower, eggplant, and chick pea (Bhatia 1996).
- Cowpea trypsin inhibitor (CpTI) gene, which also provides a high degree of resistance against many insect pests, has been isolated and transferred to tobacco (Bhatia 1996).

Pest Control in India. Fig. 6 Coal flyash.



Pest Control in India. Fig. 7 Lignite flyash.

Agenda for the Future

If the green revolution is to sustain itself, it is necessary to adapt to the ecology-based IPM strategy for various crops. In this context, the traditional wisdom of agricultural practices should be the foundation and the modern advancements of science the superstructure to usher in a sustainable food security system. It is of interest to note that flyash (Figs. 6 and 7), a waste from coal or lignite based thermal power plants would be a potential dust insecticide and a carrier in pesticide formulations for tomorrow's agriculture.

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Physics

Julian A. Smith

Most histories of the exact sciences consider "physics" to have begun with the ancient Greeks, especially with the work of Aristotle (384–322 BCE). Classical physics is usually said to have been developed during the European "Scientific Revolution" by figures like Galileo Galilei (1564–1642) and Isaac Newton (1642–1727), and modern physics is commonly introduced with accounts of the discovery of relativity and quantum mechanics around 1900. Few histories of physics consider developments outside Europe; and of those that do, non-Western physics is often presented as "derivative" of European work.

However, recent scholarship has made it clear that this European view is incomplete, and that numerous non-Western cultures, including those of China, India, the Islamic world, and others, developed sophisticated physical theories independently of Europe. In this expanded view, physics began in prehistoric times. From its origins in Africa, China, and India, physics developed to a surprisingly advanced level before its incorporation into the European scientific tradition.

Very little historical research into prehistoric African physics has so far been done, but the development of mathematics and astronomy has been dated back to very early times by archaeoastronomers such as Alexander Marshack. The bone tool handles of the Ishango culture of Lake Edward are inscribed with various collections of notches suggesting knowledge of abstract mathematical operations, and knowledge of astronomical events like new and full moons. These bones have been dated anywhere from 8500 to 25000 BCE. American physicist John Pappademos argues for a similar early start to African physics. He argues that the earliest dynamical experiments began with prehistoric African inventions like the spear and the bow and arrow, and that "the practical mastery of the principles of mechanics – the oldest branch of physics – grew as man learned to make flint weapons, tools, dwellings, boats, etc." Similar arguments, of course, have been made concerning the prehistory of physics in other early cultures.

Pappademos further argues, based on archeological, linguistic, and historical evidence, that "ancient Egypt was essentially an African civilization," and upon this basis he ascribes priority to African cultures for the early development of astronomy, geometry, and measurement. "To the Egyptians," he concludes, "we owe the concepts of most of the fundamental physical quantities: distance, area, volume, weight, and time. Europe is indebted to Egypt for the invention of standards, units and methods for accurate measurements of all these quantities." If this view is correct, it sheds new light on the development of the sciences among the ancient Greeks, whose indebtedness to Mespotamian astronomy and Egyptian geometry has long been acknowledged.

China

A similar "prehistoric origin" may be claimed for physics in China, whose history has been dramatically advanced with the publication of Joseph Needham's multivolume *Science and Civilisation in China*. Needham argues that traditional Chinese interest in physics was not particularly strong. Yet despite this, Chinese physics developed several interesting and original insights into various physical phenomena.

Chinese physicists, Needham says, were hampered by their lack of an atomic theory, used with great success by both early Greek and Indian, as well as later European scientists. However, their view of the physical universe as a "perfectly continuous whole" rather than as a collection of atoms meant that Chinese scholars were pioneers in understanding action-at-a-distance, and the connection of various forces. Chinese physics tended to emphasize waves rather than particles, and this dominance led to several early discoveries in magnetism, optics, dynamics, acoustics, and many other fields.

Among the earliest Chinese texts on physics are the writings of the Mohist schools of philosophy in the Warring States Period (480–221 BCE). Followers of philosopher Mo Zi (ca. 479–381 BCE), the Mohists made pioneering discoveries in statics and hydrostatics, dynamics, and especially optics, many of which are described in the *Mo Jing* (third–fourth centuries BCE).

One of the areas of physics most successfully tackled by the Mohists was the field of optics. Now while Chinese optics never reached the theoretical level of medieval Arab sources, it is clear that optics in the East was at least as advanced as parallel developments in Ancient Greece.

The propositions of the *Mo Jing* tell us that Mohist physicists made considerable experimentation in their efforts to construct a coherent theory of light and optics. Mohist physicists clearly understood that light travels in straight lines, and by using fixed light-sources, screens with pinhole apertures, and possibly the camera obscura, were able to study the formation of inverted images and the idea of the focal point. The camera obscura is certainly known from the eighth century AD onwards, and is mentioned in the ninth century *Yuyang Za Zi* (*Miscellany of the Yu Yang Mountain Cave*), though the theoretical explanation of its operation is incorrect. By the *Meng Qi Bi Tan* (*Dream Pool Essays*) of Shen Gua in AD 1088 we see an active interest in experiments involving pinhole apertures in screens to pass cones of light into darkened rooms.

Back in the Warring States period, by examining combinations of plane mirrors, Mohists also studied the phenomenon of lateral inversion (left becoming right in an image). They measured refraction in different media by examining the apparent bending of a stick in a glass of water. In addition, they used concave and convex mirrors to determine the properties of real and inverted images, and to differentiate between what we now know as the center of curvature and the focal point.

Concave mirrors were also used by ancient Chinese physicists to start fires by sunlight. Bronze mirrors are described as far back as 672 BCE; surviving dated mirrors occur from AD 6 to 10, and many exist from later Han times. Multiple reflections were studied in the second century BCE, and Han accounts of concave "burning mirrors" in the *Huai Nan Zi* (Book of Huai-Nan) of 120 BCE demonstrate they knew of the focal point of a concave mirror. Besides starting fires, concave mirrors were used with the moon in the later Han era to collect dew.

An interesting development of the fifth century AD was the use of "light-penetrating mirrors". These "magic mirrors" were inscribed on their backs with written characters; when held to the light, these otherwise-invisible letters would "shine through" the mirror and become legible. A 1932 investigation revealed these mirrors were made of more than one curvature, with the designs on the back imposing unequal strains on the mirror. The mirror would differ imperceptibly in thickness from place to place, with the convex reflecting surface on the front varying in curvature, and thicker areas having flatter curvatures than thinner areas. They were described in the eleventh century AD by Shen Gua.

Alongside mirrors, early Chinese opticians made considerable experiments with lenses. Glass was known to the Zhou dynasty, which began several hundred years before the Warring States period. A glassmaking industry began around 500 BCE, and by the AD 83 *Long Heng* (Discourses Weighed in the Balance) of Wang Chung, there are descriptions of glass lenses used to bring sunlight to a focus to start fires. In the third century AD *Bo Wu Zhi* (Notes on the Investigation of Things), burning lenses of rock crystal are mentioned. Finally, the 940 *Hua Shu* (*Book of Transformations*) of Tan Qiao describes the various real and inverted images produced by all four types of lenses, the planoconcave, planoconvex, biconcave, and biconvex.

There also appears to be some evidence for an independent Chinese development of the telescope by Bo You and Sun Yun Qiu in the early seventeenth century. However, as for spectacles, though they are often considered a Chinese invention, they in fact originated in Europe, and were imported overland into China soon after their invention around AD 1286.

In mechanics, the Mohists performed many experiments to determine the properties of levers and balances. They defined forces and weights, knew the laws of levers, balances, and pulleys, and developed a simple version of what came to be known in Europe as the "Atwood's machine" (named after English physicist George Atwood in 1780). They also invented the steelyard, and used it in weights and measures. Mohists seem to have been familiar with the "parallelogram of forces", and may have been in possession of the full theory of equilibrium (ca. 287–212 BCE).

Early Chinese physicists did not discuss theoretical centers of gravity, but they do appear to have done some practical research on centers of gravity in their "trick vessels", that is, jugs which incline or sway depending on the amount of water they contain. Trick vessels were known to Confucius (551–479 BCE), and were explicitly described in texts of the third century BCE. Siphons were constructed since antiquity, and were used for irrigation around the end of the Eastern or Later Han dynasty (AD 25–220). They were later employed (ca. 450 AD) by Daoist scientists and inventors like Li Lan in their balanced clepsydra, or water-clocks. Clockmaking is an ancient art among the Chinese, and attained great precision in the eleventh century mechanical and astronomical clocks of Su Sung (AD 1090).

As for specific gravity, it was known to the ancient Chinese, and was discussed by the philosopher Mencius (374–ca. 291 BCE), cofounder of Confucianism and one of the students of Confucius' grandson. "Archimedes' Principle" appears to have been known to Han technicians (AD 221–264), according to accounts in the *Zhou Li* (Record of the Institutions of the Zhou Dynasty). Han physicists and engineers also knew how to measure specific gravities in liquids, and were familiar with the use of the principle of bouyancy to weigh heavy objects.

Mohists approached the atomic theory in their discussion of the strengths of materials, but never articulated it clearly or developed its consequences. In the explanation of why a fiber breaks under tension, Master Lieh, in the *Lie Zu* book, argues the fiber is composed of unequally strong or cohesive elements, so that a breaking-plane forms somewhere in the fiber. This view is in essence a particulate theory of matter, but Lie uses the example to argue for a continuous universe.

The *Mo Jing* contains some remarkable statements about the study of motion. Though Chinese physics did little theoretical dynamics, they did consider forces in some detail, and appear to have come remarkably close to the principle of inertia as stated by English physicist Isaac Newton (1642–1727) as the first law of motion in his *Principia Mathematica* of 1687. Newton stated that "every body continues in a state of rest, or uniform motion in a right (straight) line, unless it is compelled to change that state by forces impressed on it." According to Joseph Needham, the Mohists argued that

> motion is due to a kind of looseness [the absence of an opposing force]… the cessation of motion is due to the [opposing force] of a 'supporting pillar' [a force that changes the moving body's otherwise-permanent state of motion]… If there is no [opposing force] of a 'supporting pillar', the motion will never stop… If there is [some kind of] 'supporting pillar' [some other force interfering with the motion], and nevertheless the motion does not stop [it may still be called motion but it will not be a straight-line motion because there will have been a deflection].

Mohist Chinese physicists also investigated the relativity of motion, and motion along inclined planes or slopes; they also studied particular problems of moving spheres.

As for Chinese acoustics, its history extends back more than two millennia. Second century BCE philosopher Dong Zhongshu studied sympathetic resonance in musical instruments; indeed the entire history of Chinese acoustics is intricately tied up with musical instruments, especially lutes and bells. Chinese physicists first classified sounds based on the four materials (stone, metal, bamboo, and skin) which made up the musical instruments producing them; later, they extended their classification to an eightfold scheme tied to the eight directions of the wind. Chinese musicians used resonance phenomena to tune their instruments, and were well aware of the fact that sound was caused by vibrations. Chinese military strategists even used resonance in the fourth century BCE to construct primitive geophones to listen for the tunneling of an enemy besieging a city.

Chinese investigation of magnetism and electricity is similarly ancient, but is better known in the West than acoustics. Almost all physics textbooks note Chinese priority in the magnetic compass. Lodestones and magnets are mentioned in the third century BCE *Lo Shi Chun Qiu* (Master Lu's Spring and Autumn Annals), as well as in the later *Huai Nan Zi* (Book of (the Prince of) Huai-Nan). By the fifth century, Chinese physicists knew of the directive property of the lodestone, and had begun to measure magnetic forces; and by the eighth or ninth centuries, they had discovered both magnetic polarity and variation. Engineer–astronomer Shen Gua discussed both in his *Dream Pool Essays*; his descriptions indicate considerable experimentation on the magnet. As for the magnetic compass, it is clear that the Chinese were using it for geomancy and divination by the first century AD. Their earliest use of the compass in navigation is unclear; the first datable references occur in about the eleventh century, but it is certain that Chinese mariners used compasses many years earlier. As in Europe, Chinese physicists used both "wet" and "dry" compasses; the former were made by floating magnetized needles in bowls of water whose rims were inscribed with directions, and the latter by carefully mounting the needle on an upright pivot.

What about the physics of surface phenomena? As in the West, its study was long delayed in China. Of course, knowledge of friction was very old among both cultures. Ancient Chinese, for example, knew how to use friction to make fires; and the friction of wheels was discussed in the *Han Zou Li*. By the Tang dynasty (AD 618–906), prince Li Kao studied the fit of smooth surfaces, and in the thirteenth century, Zhou Mi studied monomolecular films. And, during the Sung dynasty (AD 960–1279) Zhang Shi-Nan's 1233 treatise, *Yu Huan Zhen Wen* (Things Seen and Heard on My Official Travels), discusses the ring-test to determine the quality of lacquer. The ring-test was a method of quality control for centuries; it was not until 1878 that it was applied to measuring surface tension by finding the force to break the surface.

In China as in Europe, heat and combustion were a comparatively late interest. Making heat and sparks by rubbing wood and striking flint were techniques known to the ancient Chinese, and medieval texts give priority to the Chinese in the invention of the match (Northern Qi, AD 577). Candles were known to the Mohists in the Warring States period, and lamps since ancient times. But by the early eighth century AD, Chinese lamp-makers had cleverly designed an oil-cooling water reservoir below the lamp to reduce evaporation. The use of natural gas for fuel goes back to the first few centuries BCE, and Chinese inventors applied this knowledge on an industrial scale.

Some knowledge of the practical principles of steam power may go back as far as the second century BCE, based on a passage in the undated Daoist alchemical and technical recipe book, the *Huai Nan Wan Bi Shu* (Ten Thousand Infallible Arts of the Prince of Huai-Nan). Interest in spontaneous combustion is also very old, and is discussed in accounts of the third century AD. Chinese physicists also looked at successive boiling phases of liquids (particularly water for tea).

On the theoretical side, Li Shizhen's sixteenth century *Bencao Gangmu* (Great Pharmacopoiea) of 1596 attempts to classify types of fire. Fire is of two varieties, *Yin* and *Yang*, with many subdivisions; in general, it has *qi* (energy) but not *chi* (matter). Shizhen could not classify luminescent "fires" like fluorescence, phosphorescence, electro-luminescence, and piezo-luminescence.

Electro-luminescence was described by Chinese physicists of the third century AD. The *Bo Wuzhi* (Record of the Investigation of Things), of approximately AD 290, describes sparks created by contact with charged objects, such as drawing combs through the hair. As for other electrostatic phenomena, the ability of amber to attract objects when rubbed was known very early. Amber was first described by first century AD philosopher Wang Chong, and its properties were discussed in more detail around AD 500 by alchemist–physician Tao Hong Jing. But there was little progress in electrostatics until the eighteenth century. Meanwhile, piezo-luminescence, caused by rubbing certain types of crystals, was known in the Tang dynasty. Artificial phosphors may have been studied in the Sung period; the eleventh century *Xiangshan Yelu* (Rustic Notes from Xiang Shan) of monk Wen Rong explains the making of a phosphor from oyster shells. Some of these crystals and phosphors may have been imported overland from Arabic cultures, Needham argues; and if so, they may well have similarly influenced Indian physics on the way.

India

There is still much historical research to be done on the growth and development of science in India. Hindu scientists have been justly celebrated for their early contributions to mathematics (including the Hindu–Arabic number system, the use of zero, trigonometry, series summation, algebraic operations, and so on) and astronomy (elaborate computational techniques to determine the positions of celestial objects), but until recently little has been written on their physics, which is both sophisticated and extensive.

Early Indian physics is concerned with the "doctrine of the five elements" (*pannĩcamahabhūtas*); that is, the interplay between the elements of earth, water, fire, air, and a nonmaterial substance (*pṛthvī, ap, tejas, vāyu and ākāśa*, respectively). Among the earliest treatises of the Ṛgveda period (2000–1500 BCE) we see the emergence of primeval water as the "first cause" of all other elements, rather like the simple cosmologies of ancient Greek scientists like Thales (ca. 624–545 BCE) and Anaximander (ca. 611–575 BCE).

The five element theory was later developed by the Vaiśeṣika School of about 700–600 BCE, which also began the study of atomism. The introduction of Buddhism and Jainism brought new inquiries into the problems of atomism, matter, and motion (ca. 600–200 BCE); this was followed by the systematic formulation of atomic theories among Indian physicists between 200 BCE and AD 400. Indian science made its greatest advances between the period AD 400 and 1200, especially among the Jaina and Buddhist schools, as well as the Nyāya-Vaiśeṣika commentators. These medieval Indian physicists refined atomic theory, and made detailed investigations into gravity, motion, and impetus.

Physicists first began to explain the natural world in terms of atomic theories after 700 BCE. For the Vaiśeṣika School, atoms were eternal or indestructible, indivisible, and infinitely small. These atoms (*pramāṇus*) had vibratory and rotational motions, along with inherent impulses to form binary molecules (*dvyaṇuka*). Various combinations of atoms made up all the diverse substances in our world. Interestingly enough, this theory explained chemical reactions by supposing that these substances were broken up into their original atoms (the *pramāṇu* state) before they could be recombined to make a new material.

Physical and chemical change, meanwhile, was closely linked to the theory of heat. The first century AD philosopher Vātsyāyana argued that chemical change occurs as a result of either internal or external heat; moreover, during combustion, heat trapped inside the fuel in a latent form is released, allowing chemical reactions to proceed. The *Kiranāvali* of Udayana ultimately traced all forms of heat back to their source in the Sun.

Ancient Hindus believed that both heat and light were composed of streams of infinitely small particles radiating in all directions from sources like the sun. These particles move at inconceivably high speeds, and, when they strike molecules, break them down into smaller atoms, promoting chemical change. This theory was described in detail in the eleventh century AD *Nyāyamanjari* of Jayanta.

Other factors governing matter and physical change included gravity (*gurutva*), fluidity (*dravatna*), viscosity (*sigdha*), and elasticity (*sthitishāpaka*). For the Vaiśeṣika, gravity was seen as a causal factor resulting in the fall of bodies; it is not a force in the modern sense. Moreover, only earth and water possess it. The later Nyāya-Vaiśeṣika school of physicists (ca. 400–1200) add that gravity could be cancelled out by the effects of conjunction (a object supported on a stand) or impetus (an arrow flying through the air). They argued that gravity is eternal for primeval atoms, but temporary for compounds.

Fluidity was of two types, natural and incidental, with the former reserved to water, the latter to water, earth, and fire. Viscosity governs cohesion and smoothness, and is a property of water, preventing particles in it from dispersing. Elasticity is a quality of earthy substances.

How did Indian physicists handle the problem of matter in motion? The Vaiśeṣika held that matter was naturally static or stationary. It could be moved by some physical quality, like gravity in a falling body, but this motion would be temporary; and perpetual motion was impossible. Interestingly enough, it seems that gravity was only required to set the falling object in motion. Once it had started moving, impetus is generated, which keeps it falling without any additional help from gravity.

The fifth century AD philosopher Praśastapāda made a detailed study of motion and impetus in his *Pradārtha dharma saṁgraha*, a revision of the much older *Vaiśeṣikasūtra*. He divided motion into five categories: *utkṣepaṇa, avakṣepaṇa, prasāraṇa, ākuñcana*, and *gamana*, or, respectively, lifting up, throwing down, expansion, contraction, and action (gyrations, evacuations, quivering, and the like). Motion can be caused, says Praśastapāda, by six things: gravity, fluidity, volitional effort, conjunction (such as impact or striking), impetus or unseen causes. His use of impetus (*vega*) is rather close to our modern momentum, and is illustrated by the examples of throwing a heavy shot or firing an arrow. When the shot is thrown, the first impelling push begins its motion; then the shot's internal impetus takes over, and maintains its motion. Once the impetus is exhausted, the shot falls back to the ground.

Praśastapāda also had a relatively modern conception of sound. He realized sound was produced by vibrations in air, and added that these vibrations travel "like a series of water-ripples… or a series of waves" to the ear.

Indian physicists had many contacts with Chinese developments in the East, but they were equally well connected to Arabic work in the West. The relations between Indian and Islamic science in the Medieval period has recently been the focus of much scholarly work (Needham, Chin, Filliozat, Sen).

Islam

Islamic physicists, mathematicians, and astronomers such as Ibn Sīnā, Ibn al-Haytham, al-Bīrūnī and al-Kindī have long been known to Western historians for their influences on scholastic science in the Medieval Latin West. Arabic scientists frequently criticized and extended the physics of Aristotle, Archimedes (ca. 287–212 BCE), and other ancient physicists and often provided the original roots for many physical ideas, such as force and momentum.

In mechanics and dynamics, Muslim physicists developed several important concepts. Ibn Sīnā or Avicenna (980–1037) invoked the idea of *mayl* (Latin *inclinatio*, or inclination) to explain projectile motion; this theory was further developed by al-Baghdādī before its transmission to the Latin West. Ibn Sīnā and Ibn-al-Haytham developed the concept of momentum, and did pioneering research into the theory of gravity. Muslim philosophers knew that falling bodies accelerated independently of their mass, and that the attractive power between two objects increased as their masses got larger, but decreased with their separation.

Arabic physicists extensively studied the theory of weights, densities, buoyancy, and measures. They were familiar with the law of the lever and Archimedes' principle, and developed the balance as a scientific instrument to study topics such as specific weights. Thābit ibn Qurra (836–901) worked extensively on the law of the lever, and his ideas were later quite influential in the West. Meanwhile, al-Khāzinī's (fl. 1115–1130) celebrated *Kitāb mizān al-ḥikmah* (Book of the Balance of Wisdom) developed formulae for the specific and absolute weights of various alloys. Al-Khāzinī's work also discusses centers of gravity, hydrostatics, and other physical concepts.

Many Islamic scientists extended the theory of simple machines. Among these researchers were Baghdad's Banū Mūsā, and the many Arabic scientists involved with the development of various mechanical gadgets, automata, trick devices, and other complex machines. This branch of physics, called *ʿilm al-ḥiyal*, was developed by the Banū Mūsā, the school of Ibn Sīnā, Ibn-al-Sāʿāti, and many more. It reached its climax in the famous *Kitāb fī maʿrifat al-ḥiyal al-handasiyyah* (Book of Knowledge of Ingenious Mechanical Devices) of al-Jazarī.

Among the most influential researches of Muslim physicists were their pioneering inquiries into light and optics, which virtually established this branch of physics as an organized discipline. Al-Kindī's (fl. 790–866) early treatises introduced Euclidean optics to the Medieval Latin West. His theories of vision influenced Islamic writers for several centuries, including al-Fārābi (d. 950), al-Ṭūsī (1201–1274), and many more.

Opticians such as Ibn Sīnā and al-Bīrūnī (973–ca. 1050) studied particular problems like the speed of light from ancient sources, usually declaring it to be finite. Meanwhile, doctors like al-Rāzī or Rhazes (ca. 854–935) and Ḥunayn ibn Isḥāq inquired into human eye physiology, making their own contributions to the theory of vision. However, the most significant figure in Muslim optics was the Egyptian physicist Ibn al-Haytham (ca. 965–1039), better known in the West as Alhazen.

Many historians consider Ibn al-Haytham to be the most important optician between Euclid and Johannes Kepler (1571–1630). Historian of science David C. Lindberg argues that "Alhazen was undoubtedly the most significant figure in the history of optics between antiquity and the seventeenth century." This is because Ibn al-Haytham successfully integrated not only competing mathematical and physical approaches to light in his new intromission theory of vision, but also harmonized his views on sight with the anatomical work of earlier Muslim physicians. A prolific writer, Ibn al-Haytham is credited with more than 200 treatises on all branches of the sciences, including almost two dozen dealing with light and optics.

Ibn al-Haytham's most important optical work was his *Kitāb-al-manāẓir* (Book of Optics), which was translated into Latin as *De Aspectibus* or *Perspectiva*. This treatise had a profound effect on optics in the Latin West, influencing the work of Witelo (ca. 1230/5–1275), Roger Bacon (ca. 1220–1292), John Pecham (fl. 1250–1292), and many more. Traces of Ibn al-Haytham's theories are even found in the seventeenth century optical writings of Kepler and Newton.

Alongside his intromission theory, Ibn al-Haytham also studied various celestial and atmospheric phenomena such as twilight, refraction, atmospheric thickness, and optical illusions. He also contributed to the theory of catoptrics and dioptrics and extensively researched the laws of parabolic and spherical mirrors. "Alhazen's problem", which he solved geometrically, involved taking a spherical mirror and placing an object before it so that its image was reflected in the mirror; to find the point of reflection, one must solve the equivalent of a fourth degree equation. Ibn al-Haytham also demonstrated various reflection laws, including the significant finding that incident, normal and reflected rays all lie in the same plane. In his study of refraction, he discovered the equivalent of Pierre de Fermat's (1601–1665) "principle of least time": that a ray of light always takes the shortest and easiest path. Much of Ibn al-Haytham's work in this area was based on direct experimentation; glass cylinders immersed in water revealed refraction laws, and homemade lenses helped him determine the laws of magnification. Ibn al-Haytham even did early research into the camera obscura.

Islamic optics declined after Haytham's synthesis, though there was a revival of interest during the rise of the *ishrāq* (School of Illumination) in the thirteenth century. Al-Shīrāzī extended Ibn al-Haytham's account of the rainbow, arriving at essentially our modern understan that its colors are due to a combination of light reflection and refraction through suspended water droplets. Al-Shīrāzī's explanation was confirmed experimentally by his student, al-Farīsī (d. ca. 1320). But by the fifteenth century, leadership in optics had passed to the West, and by the following century, European scientists were making discoveries in physics, astronomy, and mathematics that were to usher in the "Scientific Revolution".

See also: ►Geomancy in the Islamic World, ►Clocks and Watches, ►Acoustics, ►Compasses, ►Li Shizhen, ►*Yinyang*, ►Ibn Sīnā, ►Ibn al-Haytham, ►al-Kindī, ►al-Shīrāzī, ►al-Rāzī, ►Ḥunayn ibn Isḥāq, ►Banū Mūsā, ►Thābit ibn Qurra, ►Nyāya

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Physics in China

R. A. Uritam

An account of physics, as well as of any other science, in a prescientific revolution era or civilization does not present a meaningful picture without an understanding of the views of nature that are embedded in various natural philosophies that develop in each civilization and that are the most comprehensive account of natural phenomena before "physics" as a distinct discipline existed. In the West most of these natural philosophies had their origins in Greece, and included Pythagoreanism, Atomism, Platonic idealism and dualism, and Aristotelianism, each of which introduced distinct elements into Western science. However, they largely agreed that the final ground for understanding physical reality was substance, or "stuff." Additionally, in due course, rational proof, Euclidean geometry, reductionism, mechanistic materialism, and atomism became principal determinants of Western science.

In a similar way at about the middle of the first millennium BCE various schools of natural philosophy arose in China. These included Daoism, Naturalism, Mohism, Legalism, and (much later) Sung Neo-Confucianism. The central concept of Daoism, systematized by Laozi (a contemporary of Aristotle) is the *Dao* (the way), the "way the universe works." It is the unifying principle of the universe, akin to the "One" of Parmenides. This natural, noncoercive, nonanthropomorphic principle encompasses all phenomena, and invites study of all aspects of nature. Human standards are irrelevant in nature; one is to subject oneself to the harmonies of nature (*wu wei*).

Naturalism, represented by its early proponent, Zou Yan (fl. 300 BCE) introduced the doctrines of *Yin* and *Yang* and the *Wuxing* (Five Elements or Phases). Yin and Yang are the two fundamental forces, the expression of the basic dualistic principle, two forces existing not in conflict, but in a balance or a cooperative tension of opposites. Yang represents light, heat, dryness, hardness, activity, heaven, sun, and south. Yin stands for dark, cold, wetness, softness, quiescence, earth, moon, and north. The Five Elements invite comparison with the four elements of Empedocles. In China the five are water, fire, wood, metal, and earth, representative less of substances than of processes of nature. The elements are further arranged into the Mutual Production Order: wood, fire, earth, metal, water, wood, etc., where each element produces the subsequent one. In the Mutual Conquest Order, each element dominates over the subsequent one.

The less prominent school of Mohism introduced more formal, abstract, and geometrical notions such as a dimensionless geometrical point in space and time. Somewhat in the same vein, the Legalists discussed formal logical propositions, paradoxes, and syllogisms. Curiously, modern Chinese writers during the Cultural Revolution were fond of heaping fulsome praise on the Legalists for their supposed kinship to the scientific materialism of Marxism.

Mohism and Legalism waned in importance, and after centuries of evolution indigenous Chinese natural philosophy reached its most mature form in the twelfth century AD in the Sung neo-Confucian synthesis, best represented by the natural philosopher Zhu Xi (AD 1131–1200). This school combined the attention to nature present in Daoism and Naturalism with the heretofore society-centered official Confucianism that governed human conduct and interaction. In this way the human world and the world of nature were unified and investigation progressed at each "level of integration" from inanimate to human. The synthesis introduced two other fundamental principles of *qi* and *li*, roughly similar to Aristotelean matter and form.

The picture or model of nature that emerges is quite different from the Western one. It is not mechanistic, legalistic, geometrical, linear, or even materialistic. The leading twentieth century student of Chinese science, Joseph Needham, described that picture of nature in China as being one of a harmoniously functioning organism, an interconnected, interdependent whole. Reductionism and analysis into parts will not yield an understanding of nature because each entity is defined by the role it plays in relation to the pattern it fits into, by the web of relationships it has. The principal element of explanation is not substance but relation and pattern. As in Chinese society, so also in nature there is "order without law". The legal metaphor is absent in statements about nature ("laws" of nature); the order of nature is not as that of citizens subject to universal law but as that of musicians in an ensemble or dancers in a pattern. For these reasons, traditional Chinese thought found no problem in retroactive causality, since temporal succession is unimportant compared to the interdependence of the system as a whole, as a pattern in space and time.

With a world picture so different from the Western one, it is difficult even to match traditional Chinese activity in some realm with "physics", itself a term that acquired a recognizable meaning only fairly recently. Nathan Sivin has proposed the following divisions for Chinese science: medicine, alchemy, astrology, geomancy, natural philosophy and physical studies, mathematics, harmonics and acoustics, and mathematical astronomy. Present-day "physics" corresponds to parts of "physical studies" and "harmonics." Also, the strong and weak branches of physics are reversed in China and in the West. There was no Chinese achievement in mechanics, dynamics, or kinematics, nothing at all to rival Aristotle or the medieval precursors of Galileo. This is consistent with the absence in China of geometrical, corpuscular, and mechanistic ideas. Instead the preference was for continuum theories, pneumatic models, waves, vibrations, and resonances, all consistent with interrelation, pattern, and meaning only for a system as a totality. Thus, the highest achievements in indigenous Chinese physics were in the areas of optics, acoustics, and magnetism. Of the three, optics was the weakest, and ironically, its best practitioners were the Mohists, a school generally atypical of Chinese scientific philosophy. Although, lacking Greek geometry, Chinese optics never attained the level of medieval Islamic optics, it began at least as early as its Greek counterpart, with an account of light-sources, mirrors, and, later, lenses.

The fourth-century BCE Mohist text *Mo Jing* describes shadow formation, the distinction between umbra and penumbra, and discusses the dependence of the size of the shadow on the position of the object and of the source of light. Properties of light passing through a pinhole are discussed, including the definition of a focal plane and the inversion of the image. Reflection from a plane mirror and from a combination of plane mirrors is treated. Refraction of light at the plane boundary between air and water is described, including the resulting phenomenon of the apparent reduction in depth of an object in water. Also, the formation of images by spherical concave and convex mirrors is discussed in some detail.

Of even greater antiquity in China was the practical use of burning-mirrors for igniting fires from the sun's rays. The earliest such mirrors, made of bronze, date from the Chinese Bronze Age, in the seventh century BCE. A more difficult technological achievement was the production of lenses and burning-lenses. Rock-crystal, i.e., pure transparent quartz (SiO_2) was used; glass was produced as early as the sixth century BCE, and lenses were in use from the time of the Han dynasty of the first century AD. By the tenth century AD the four fundamental types of lenses (plane-concave, biconcave, plano-convex, and biconvex) were produced and their properties analyzed. Eye-glasses and spectacles, as well as magnifying glasses were in use by the fifteenth century AD.

Progress in the fields of sound and acoustics followed naturally from the fundamental orientation of Chinese natural philosophy. The alternation between Yin and Yang implies a cyclic, recurring process between opposites, reminiscent of harmonic oscillation or wave motion. Also, sound was likened to waves in a pool, caused by friction, and to a resonance in the fundamental neo-Confucianist substance, *qi*.

In the description and classification of musical sound and in the construction of instruments, the Chinese displayed their characteristic tendency to emphasize the whole and the complex, instead of isolating the simple. To Western thought the primary attributes of sound are pitch (frequency) and loudness (amplitude). By contrast, Chinese acoustic theory concentrated from the beginning on timbre (the overtone structure) as the primary attribute or parameter describing sound. Sounds were classified according to timbre according to the "eight sources of sound." metal, stone, earth-clay, skin, silk-thread, wood, gourd, and bamboo. As can be expected, these timbres were correlated, like the five elements, with seasons, compass points, and, naturally, musical instruments.

The influence of the concept of pattern and organic unity was at work in the ready acceptance of the spontaneous resonances of two musical instruments, this being merely a corroboration of a resonance in the cosmic organism. In a similar vein, sounds were not classified by pitch; rather, the names of notes in the early five-note scale arose from the mutual arrangement of musical instruments in archaic ceremonies.

A distinctive later achievement of Chinese acoustic theory is less closely related to the organic view of nature. In the sixteenth century AD, Zhu Zaiyou (b. AD 1536) provided the earliest solution to the classic problems of rendering melodies in several keys on one musical instrument, without retuning the pitches. The natural scale is one where the frequencies of the sounds, and the associated lengths of strings in a musical instrument are in "just intonation," following Pythagorean ratios (e.g., 2 : 1 for octave to tonic, etc.). If the ratios are true for one scale they cannot be so for a scale that begins one note higher. Zhu's solution was to have frequencies of all adjacent notes, differing in pitch by half a tone in a twelve-note scale, differ by a ratio $2^{1/2}$ to 1. This system of equal temperament, in use on a modern piano, was introduced considerably later in Europe, becoming popular only in the eighteenth century, and is familiar to music lovers from early examples of its use by composers, such as in Johann Sebastian Bach's *Well-Tempered Klavier*.

The most prominent achievement of traditional Chinese physics, however, was in magnetism. That phenomenon is totally harmonious with a model of the world as organism, with resonances and intangible influences on the parts from the pattern as a whole. Also, China, not knowing the Aristotelian concepts of natural place, natural and enforced motion, did not have to explain magnetic phenomena, as did the West, as deviations from this scheme. Even more to the point, action at a distance, or the concept of a field, was no problem in China, whereas Cartesian mechanicists saw these as throwbacks to scholasticism when used to account for gravitational, electrical, and magnetic phenomena.

Historically, the discovery of every significant magnetic phenomenon – attraction, directivity, polarity, thermoremanence, declination, as well as application to a working compass – considerably antedates comparable advances in the West. Chinese texts of the third century BCE describe the simplest effect, the attraction of iron by natural magnetite (lodestone). The directional, north–south seeking property of the lodestone was observed about the first century AD and first demonstrated by a lodestone placed on a very smooth bronze surface. (Modern replicas of this arrangement have verified that friction can be made low enough to display the effect.) Subsequently, the lodestone was balanced on a pin, or floated on wood in water. In the early centuries of the first millennium AD the directive property of the lodestone was transferred to iron by rubbing. By the eleventh century AD the more sophisticated method of magnetization, thermoremanence, was in use, consisting of allowing a red-hot piece of iron to cool rapidly through the Curie point while it is oriented along the earth's magnetic field.

By about AD 1100, a useful magnetic compass was in use in navigation, although the traditional inward-looking agrarian economy and dependence on river, rather than ocean, transportation did not thereby lead to extensive global exploration. Beginning in the ninth century AD magnetic declination was observed. Subsequent recordings of declination chronicle a variation of declination over time, for example, the declination being to the east prior to about AD 1050, and to the west after AD 1050.

Philosophers of science differ on whether the fundamental concepts of Chinese natural philosophy, such as relation, pattern, and organism could have furnished an alternative but adequate basis for a model of scientific explanation. On this question, in his extensive writings, Needham has probably overstated the case in favor of the Chinese potential for doing this.

In terms of transmissions from China to the West, the technological contributions are well-known; printing, gunpowder, and the magnetic compass are always at the head of the list. Many scholars also attribute to Chinese science a role in promoting the development, after Newton, of nonmechanistic concepts in physics, such as field, wave, fluids such as caloric and ether, to say nothing of the loss of distinction between matter and energy in relativity and between wave and particle in quantum mechanics.

See also: ►Environment and Nature in Chinese Thought, ►*Yinyang*, ►Five Phases, ►Optics, ►Magnetism, ►East and West, ►Acoustics, ►Zou Yan

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Physics in India

William T. Johnson

Early Indian thinkers developed a number of theoretical systems which centered around two main themes: elements and atoms. Based upon a relatively broad review of the ancient philosophies, we will discover a rich scientific tradition in India.

Ancient India (2000 BCE–AD 800)

Early Indian explanations about the physical makeup of the universe were religious and philosophical in nature. The oldest literary record of this period, the *Ṛgveda*, presents several fundamental concepts related to physical science such as *ap* (primeval water), which was considered the basic element of matter. Gradually, the doctrine of five fundamental elements emerged, as seen in the Upaniṣadic literature of around 700 BCE. The five elements were *pṛthvī* (earth), *ap* (water), *tejas* (fire), *vāyu* (air), and *ākāśa* (a nonmaterial substance). The Sanskrit terms have a wider connotation than the English translation, so it is essential to present the original terms.

Much of this early literature was concerned with the attributes associated with each of these elements. They had both common as well as distinctive attributes, many coincident with the five senses, as follows: *pṛthvī* (earth) sound, touch, color, taste, and odor; *ap* (water) sound, touch, color, and taste; *tejas* (fire) sound, touch, and odor; *vāyu* (air) sound and touch; and *ākāśa* (nonmaterial) sound. Different combinations of these five elements yielded certain products. The human body is a good example. The human embryo has energetic principles which are separated into form by *vāyu* (air). *Tejas* (fire) subsequently transforms the embryo. *Ap* (water) maintains moisture while *pṛthvī* (earth) gives it shape and size. Finally *ākāśa* expands the embryo and develops it.

Many of today's scholars question the notion that scientific inquiry only found fertile ground in the minds associated with the Greek tradition. In fact, a number of diverse systems of scientific inquiry were developing in India coincident with the Greek philosophies by 500 BCE. Those which presented five fundamental elements were the *Sāṃkhya, Nyāya*, and *Vaiśeṣika*. The *Jaina, Bauddha*, and *Cārvāka* schools, like many of the Greek thinkers, presented four fundamental elements. It is difficult to say with certainty which school or culture developed these ideas first, therefore who influenced whom, or if they developed independently.

The *Nyāya-Vaiśeṣika* school, prominent among early Indian systems, was popularized by an individual who came to be known as Kaṇāda. He and his followers extended the concept of five elements and built a comprehensive theory of atoms. The first four elements of this system (*pṛthvī, ap, tejas*, and *vāyu*) were material and considered either eternal or temporal. The fifth element, *ākāśa*, was considered eternal only. The eternal form consisted of imperceptible atoms, while the temporal form arose when these atoms joined to create perceptible products. This view of five elements was part of a much larger conceptual picture, that of *dravya* (substance). There were nine types of substances. In addition to the five elements or substances already mentioned, there was *dik* (space), *kāla* (time), *ātman* (self), and *manas* (mind). Each of these substances was considered inseparable from its respective set of attributes. In other words, they were one and the same.

The word used for atom was *aṇu* or *pramāṇu*. The *Nyāya-Vaiśeṣika* school held that the atom was indestructible, indivisible, without magnitude, spherical, and in constant motion. Two atoms of the same substance could join to form a dyad. Atoms of different substances could not join together, yet they could play a supportive role in the combination of materially compatible atoms. The dyad was regarded as too small to be perceived. The smallest visible structure was a triad (three dyads). This structure was referred to as *trasareṇu* or *tryaṇuka* which was about the size of a speck floating through a sunbeam. The principle of causality was crucial to the *Nyāya-Vaiśeṣika* school. Atoms were the material cause for the dyad, the effect. The dyads were the cause for the production of a triad which was another effect. The individual atoms lost their causative property once the triad was formed. The reason for atoms joining in the first place was attributed to *aḍṛṣta*, an unseen force.

Jaina philosophers held that atoms were both cause and effect. They theorized that atoms joined to form aggregates in response to attractive and repulsive forces which were inherent characteristics of the atoms themselves. Jaina atoms were all of one class. There was no distinction, qualitatively, or quantitatively, between types of atoms such as earth-atoms, water-atoms, etc. According to the Buddhists, the atom was indivisible, unable to be analyzed, invisible, inaudible, unable to be tested, and intangible. Neither were these atoms eternal. The Buddhists did not speak of atoms in terms of particles. They thought of them as a force of energy.

The *Nyāya-Vaiśeṣika* school was distinct from other Indian schools in that it placed much more emphasis on the attributes of matter. There were five general qualities possessed by all nine substances: number, dimension, distinctness, conjunction, and disjunction. Other qualities, more closely associated with modern physics included, *gurutva* (gravity), *dravatva* (fluidity), *sigdha* (viscosity), and *sthitishāpaka* (elasticity). Gravity, or the cause of falling, was not considered a force but a quality which resided in a whole object. No apparent correlation between gravity and the mass of a particular object was presented. Fluidity was a quality of only three substances – earth, water, and fire – and was of two kinds. Natural fluidity was a specific quality of water. Incidental fluidity was associated with fire in the case of some melted substances. Viscosity was specific to water, causing cohesion and smoothness. Elasticity was only a quality of earthy substances as in the branch of a tree which was caused to return to its original condition if displaced. Another fundamental concept considered by ancient Indian thinkers was that of motion.

The *Nyāya-Vaiśeṣika* concept of karma (motion) was represented by three actions: *utkṣepaṇa* (throwing upward), *avakṣepaṇa* (throwing downward), *prasāraṇa* (going). Only one kind of motion was considered possible at a time and a substance experienced motion only for a moment. This motion was subsequently destroyed or rendered ineffective once completed. The motion of free atoms made possible by *aḍṛṣta* (unseen force) caused the material world to be formed.

Among Indian physical concepts, that of *ākāśa* should not be overlooked. Its special quality was sound. Though considered a nonmaterial substance, it was believed to play a role in the formation of material objects. A modern physics concept which some have equated with *ākāśa* is that of ether, which is conceived to be a vast expanse or continuum. Sound moved through *ākāśa* like ripples across the surface of a pond. Unlike the ripples, sound moved through *ākāśa* in a succession of points. The first sound caused the second, and once the second sound was created, the first was destroyed.

Heat and light were understood in relation to one of the five basic elements, *tejas* (fire). When an object was heated it went through a series of distinct changes, each one lasting a prescribed number of moments. A clay pot for example, if heated, would in the first moment experience the production of atomic motion. The second moment would be characterized by the destruction of the clay's original color. In the third and fourth moments one would find that the color red would be produced followed by the destruction of the atomic motion created earlier. A new type of atomic motion, creative in nature, occurred in the fifth moment. A series of two disjunctions between the atoms and *ākāśa* was followed by a conjunction in the sixth through eighth moments. The final two moments consisted of the formation of a red colored dyad followed by a triad. The ultimate source of all heat was thought to be the sun. Light, though often associated with heat in many modern physical systems, possessed many qualities, distinctive from heat, in the early Indian systems.

Light was thought to consist of rays which emanated from the eyes just as a candle casts its light throughout a room. If an obstruction prevented the rays from touching an object, then that object simply could not be perceived. Mirrors were thought to possess particular attributes of color which caused the light rays from one's eyes to return to one's face upon striking the surface.

Medieval India (AD 800–1800)

It is a common misconception that there was a lack of scientific inquiry during the Middle Ages. While India experienced great change during this time, such as the introduction of Islam, there was a continued advance and assimilation of scientific information with an ever increasing number of collaborators. New cultural influences, changing technologies, and language barriers challenged as well as fostered scientific advances.

Physics was viewed as a distinct branch of study during the early part of the Middle Ages. Though experiments were still quite rare, use of this scientific technique began. A large number of texts were translated into different languages. A scholar named Ḥunayn ibn Isḥāq translated Aristotle's works into Syriac and his son Isḥāq ibn Ḥunayn followed suit, translating Euclid's *Elements*. Ideas were shared, expanded upon, and refined. A number of original inquiries were also initiated.

Among the more notable individuals describing physics research in India as well as Middle Asia at this time was Abū Rayḥān al-Bīrūnī. He authored many books devoted to the scientific achievements of the Indian people.

The latter part of this period experienced an influx of European influences. Educational institutions, scientific journals, and professional societies each played a role in the development of what was to become modern India. New political and economic structures, in the face of new language barriers between the educated few and the illiterate masses, threatened to disassemble the rich scientific heritage of the Indian people. Yet India assimilated the old and the new to emerge strong with an outstanding future of scientific inquiry before it. Much of that future rested in the hands of a few visionaries who understood the significance of science in India's future.

Modern India (AD 1800–Present)

The outstanding efforts of many have contributed to India's rich past and promising future. The following few individuals are some of the physicists who have exemplified the level of achievement found throughout modern India.

Jagdish Chandra Bose (1858–1937) was a biophysicist who explored the response of plants and animals to electrical stimulation. Like many pioneering physicists active at the turn of the century, Bose used instruments of his own design in his work. He was elected a Fellow of the Royal Society of London in 1920. C. V. Raman (1888–1970) investigated optics, including diffraction, molecular scattering of light, and magneto-optics. He was awarded the Nobel Prize in 1930 for the discovery which bears his name, the Raman Effect. This pioneering work described the molecular scattering of light and explained, among other things, why the ocean appears blue. Finally, Jawaharlal Nehru, the first Prime Minister of India, worked hard to foster what he described as a "scientific temper." He believed that for science to succeed in modern India, as it had in its past, there had to be strong support for the scientific enterprise from all segments of society.

The history of physics in India is a vast subject, offering extensive opportunities for further study. It is hoped that this brief presentation has encouraged some to explore the ancient philosophies, medieval refinements, and modern achievements.

See also: ►al-Bīrūnī, ►Ḥunayn ibn Isḥāq, ►Isḥāq ibn Ḥunayn

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Physics in the Islamic World

Timothy J. McGrew

With the rapid expansion of the Arabian tribes into western Asia and northern Africa in the early seventh century, the Islamic world fell heir to the documentary remains of Greek science and mathematics. Scientific research had grounded to a halt in the Byzantine Empire, and in a very real sense the intellectual center of gravity was transferred to the East, where, despite occasional upheavals, learning flourished under a series of enlightened patrons for over five hundred years.

In contemporary usage, the word "physics" denotes an autonomous and highly specialized branch of science which deals with the behavior of non-living systems, bringing them under the scope of the most general natural laws. There was no parallel to this discipline in medieval Islam, yet from the eighth century onwards there was a profusion of translations, commentaries, and learned writings on topics which would today fall under the broad heading of physics.

The contributions of Islamic thinkers to astronomy and mathematics were of the first importance. Optics, which would today be considered a branch of physics, was studied in close conjunction with both geometry and medicine, since various problems regarding vision remained unresolved in the Greek scientific literature. The contributions of Ibn al–Haytham to the problem of refraction are particularly noteworthy.

Astronomy and optics aside, Islamic scholars wrote profusely on the nature of matter, causality, the theory, and practice of mechanics, and dynamics.

The Nature of Matter and Causal Laws

The dominant philosophical school in Islamic physics was the Aristotelians or *Falāsifa*, Prominent members of this school included al–Kindī (d. 873), al–Fārābī (d. ca. 950), Ibn Sīnā (Avicenna, d. 1037), and Ibn Bājja (d. 1138). While the *Falāsifa* held Aristotle in the highest respect, their work was somewhat syncretistic. The Greek philosophical corpus was often taken to be an integrated whole, and diverse elements of Plato and the Neoplatonists found their way into the synthesis of the Arabic Aristotelians. Al-Fārābī went so far as to write a book entitled *Jamʿ bayna raʾyay al-ḥakīmayn Aflāṭūn al-ilāhī wa-Aristūṭalīs* (The Harmony between Plato and Aristotle). Most Arabic scholars who sought to reconcile these strands of thought relied heavily on a work known as the *Theology of Aristotle*, in which Aristotle himself seemed to provide a bridge between his technical and logically rigorous work and the more literary and imaginative work of Plato. But modern scholarship has established that the *Theology* was wrongly attributed to Aristotle and is actually a compendium of the writings of the Neoplatonist Plotinus.

In physics, the doctrine held that every object could be analyzed as a composite of matter, which is the locus of its potency or possibilities, and form, which is the actualization of some of those potencies. Matter, like space itself, was believed to be infinitely divisible. Physical bodies behaved in qualitatively predictable ways because of their innate tendencies. Hence, a stone falls

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because it seeks its natural place at the center of the earth, and water seeks its lowest level in lakes and oceans because its attraction to the center of the earth is slightly less strong than that of the stone.

The infinite divisibility of space led to some perplexing dynamical difficulties, first noted by the Greek philosopher Zeno of Elea, which induced some Islamic physicists to question the coherence of the Aristotelian concept of space. Al-Bīrūnī (d. after 1050), a prominent critic of Aristotelian physics, posed this dilemma in a letter to Ibn Sīnā: If the sun is west of the moon in the sky, with a definite space between them, then even though the moon moves much faster than the sun, it should never be able to catch it. For the space between them can be conceived as divisible into an infinite number of parts; but how can a body moving with a finite speed cross an infinite number of spaces? In al-Bīrūnī's view, this paradoxical consequence reflected poorly on the Aristotelian concept of the infinite divisibility of space. After all, anyone can see that the moon does in fact overtake the sun.

A competing school of thought was inspired by Sunni theology, with its strict insistence on divine omnipotence. In this view, all bodies consist of a finite number of indivisible atoms, and the behavior of these atoms is not the consequence of any causal relations between them but is governed directly by the divine will. What appear to be causal connections are only regularities which we are in the habit of calling laws; there is no connection discoverable by reason between separate events, and Aristotelian explanations for the behavior of bodies in terms of natural tendencies are therefore hopelessly misguided.

The controversy between the theologians and the Aristotelians came to its climax in the *Tahāfut al-Falāsifa* (Self-Destruction of the Aristotelians) of al-Ghazālī (ca. 1058–1111), in which he maintained that philosophers could not know, for example, that fire causes cloth to burst into flame but only that the combustion of the cloth occurs at the moment that it makes contact with the flame. Ibn Rushd (ca. 1126–1198) responded with a *Tahāfut al-Tahāfut* (Self-destruction of the Self-destruction) in which he claimed that such skepticism regarding the efficacy of reason would undermine itself. In contemporary philosophy of science, a similar controversy is still raging over the nature of causality and our knowledge of causal connections, though the arguments arise not out of theological considerations but rather from Hume's skeptical doubts about induction and the verificationism of the logical positivists.

Mechanics

One of the simplest of mechanical devices, the lever, had been investigated mathematically by the Greek polymath Archimedes, who gave an elegant proof that the forces required to keep the unequal arms of a lever in balance were inversely proportionate to the length of the arms. In the course of his proof, Archimedes assumed that two equal weights located at different points on one arm of the lever produced the same effect as if they were both located at the midpoint between them – an assumption which is intuitively plausible but for which he gave no rigorous justification. Thābit ibn Qurra (d. 901) provided an intriguing argument for this assumption in his *Kitāb al-qarasṭūn* (Book of the Balance).

The balance was investigated very thoroughly in Islam. Al-Bīrūnī worked out a general method for determining the specific gravity of an irregular solid which he published in his *Maqala fī'l-ḥisab allatī bayn al-filizzāt wa'l-jawāhir fī'l-hajm* (Treatise on the Ratios Between the Volumes of Metals and Jewels). In later years, the best-known work on the subject was the *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom) of al-Khāzinī (fl. ca. 1115–30), a careful though not very original treatise which covers the theory of balances (relying heavily on the work of al-Bīrūnī), the practical details of their construction, and their use for determining proportions of metals in alloys. In the course of his discussion, al-Khāzinī notes that heat decreases the density of metal objects. The *Kitāb* of al-Khāzinī is among other things a source of alchemical lore, and it is no accident that it became a standard text on the construction of equipment among alchemists in succeeding generations.

Islamic scientists were aware of more complex mechanical contraptions, and a few works described windmills, clocks, and other marvelous devices. The most lavishly illustrated volume on this subject, the *Kitāb fī maʿrifat al-ḥiyal al-handasiyya* (Book of Knowledge of Ingenious Mechanical Devices) of al-Jazarī, describes some fifty mechanical devices including several different types of fountains. But they made no systematic effort to apply the principles utilized in these devices on a broad scale. The knowledge of the principles of mechanics did not generate a technological revolution.

Dynamics

The Aristotelian theory of motion was a source of considerable difficulty for Islamic thinkers. Apart from the "natural motion" by which objects seek their natural place, the Aristotelians viewed motion as the result of the application of a force. In the absence of the force, motion ceases, as a cart grinds to a halt when the rope connecting it to the horse is broken. But this commonsense theory generates serious problems when applied to projectile motion. Why should a flung stone hurtle through the air when it leaves the hand? Why should an arrow continue to fly when it has left the bowstring? Aristotle's own suggestion was that somehow the air rushes around to the rear of the object in a way which prolongs its flight. But this was both vague and apparently irreconcilable with the facts; the flight of a javelin is not appreciately improved by design changes at its back end which would help it to "catch" the air.

In place of this unsatisfactory explanation, Ibn Sīnā and Abū'l-Barakāt al-Baghdādī (ca. 1080–ca. 1165) developed a theory of "violent inclination" which matches very closely the impetus theory first suggested by the Alexandrian Neoplatonist John Philoponus (d. ca. 570) and which was widely held until the seventeenth century. According to this theory, the agent of motion (the hand which flings a stone, for instance) imparts to the object a temporary inclination to continue moving, an inclination which partly counteracts the tendency of the object to seek its natural place and which is gradually dissipated through its flight.

Aristotle's notions regarding free fall also came under critical scrutiny by Islamic thinkers. According to Aristotle (*Physics*, Book 4, chapter 8), the motion of a falling object is directly proportional to its natural inclination (the tendency it has to seek its natural place) and inversely proportional to the resistance offered by the medium through which it moves, an account which strongly suggests the mathematical formulation

$$M \propto \frac{F}{R},$$

where M is motion, F is force and R is the resistance. Ibn Bājja (better known in the West as Avempace), though working within the broadly Aristotelian framework, criticized this view on the grounds that, if Aristotle's account were correct, unresisted motion (such as that of the heavenly bodies) would be instantaneous – which it clearly is not. In place of the Aristotelian law of motion, he suggests the formula

$$M \propto F - R,$$

which has the advantages that motion in the absence of resistance need not be instantaneous but rather proportional to the impressed force, and that when force and resistance are balanced, the result is not motion at all but cancellation of motion. Ibn Bājja's views here closely resemble some arguments advanced earlier by John Philoponus, but it was through Ibn Bājja's writings, preserved in a commentary on Aristotle's *Physics* by Ibn Rushd, that these views were transferred to the west and influenced the early work of Galileo.

Abū'l-Barakāt's reflections on motion in his *Kitāb al-Muʿtabar* (Book of What has been Established by Personal Reflection) are also remarkable as precursors of a radical departure from the Aristotelian view. In explaining the motion of a flung stone, he appeals not only to the dissipation of the violent inclination but also to a compounding of successive natural inclinations which increases the overall strength of the natural inclination during the fall. This idea of the compounding of the force through small intervals represents a serious advance over Aristotle's view that the distance travelled by an object in free fall per unit time is directly proportional to the weight of the object. It appears not to have occurred to Aristotle to consider the question of instantaneous velocity. Abū'l-Barakāt's explanation for free fall is thus one of the first hints that the constant action of a force might produce not merely motion but an acceleration.

See also: ►Mathematics in Islam, ►Astronomy in Islam, ►Optics, ►Ibn Sīnā, ►al-Jazarī, ►Atomism, ►al-Kindī, ►Ibn al-Haytham, ►Ibn Rushd, ►al-Bīrūnī, ►al-Khāzinī, ►Thābit ibn Qurra

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Pi in Chinese Mathematics

LAM LAY YONG

In the earliest existing mathematical texts, *Zhoubi suanjing* (The Mathematical Classic of the Zhou Gnomon) and *Jiuzhang suanshu* (Nine Chapters on the Mathematical Art), the ratio of the circumference of the circle to its diameter, or π, was taken to be three. Liu Xin, who lived in the first century BCE and was an astronomer and an expert on calendrical calculations, was mentioned in *Suishu* (Standard History of the Sui

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Dynasty) as being among the earliest to improve on this value. This arose from the construction of a standard measure called *jia lianghu* which he prepared for Emperor Wang Mang.

In his commentary on a problem concerning a sphere in *Jiuzhang suanshu*, Liu Hui of the third century referred to Zhang Heng's (AD 78–139) empirical deduction which implied a value of $\sqrt{10}$ for pi. The eighth century book, *Kaiyuan zhanjing* (Kai Yuan Treatise on Astrology), expressed Zhang Heng's estimation in the ratio of 736–232. A century later, Wang Fan improved this to the ratio of 142–45.

However, it was Wang Fan's contemporary, Liu Hui, who succeeded not only in attaining a better estimate for pi, but also in writing down the detailed method of how he arrived at the result.

His method commenced with a regular hexagon inscribed in a circle. This was extended to a 12-sided polygon where the length of one side and its area were calculated from the hexagon based on the properties of the right-angled triangle. Next, a polygon of 24 sides was constructed and the length of its side and its area were calculated from the data of the dodecagon. Regular polygons inscribed in the circle were in this manner continuously constructed; the number of sides of one polygon was always double that of the previous polygon and the area of a polygon was formulated as one half the perimeter of the previous polygon multiplied by the radius of the circle. Liu Hui pointed out that if this process was repeated long enough, eventually there would be a polygon whose sides were so short that they would coincide with the circle. He concluded that this explained why the area of a circle was one half the circumference multiplied by the radius. He further pointed out that when the ratio of the circumference to the diameter was taken as 3–1, this value was in fact the ratio of the perimeter of the hexagon to the diameter.

Lui Hui reached a polygon of 192 sides when he calculated pi to lie between 3.14 64/625 and 3.14 169/625. From these figures he deduced an approximate value for pi of 157/50 or 3.14. He gave another value of 3927/1250 or 3.1416 which he said could be verified when calculations reached the polygon of 3,072 sides.

Computations were performed through the rod numeral system which was not only a medium for whole numbers but also one for common fractions and decimal fractions. The knowledge of Lui Hui's method and the rod numeral system would enable the value of pi to be calculated to any desired degree of accuracy. It was therefore not surprising that Zu Chongzhi (AD 430–501), the most distinguished mathematician, astronomer and engineer of his time, found π to lie between 3.1415926 and 3.1415927 and also gave it a value of 355/113. These values were not surpassed until a thousand years later when al-Kāshī evaluated pi correctly to sixteen decimal places. Zu's values were recorded in *Suishu* but no method was given, and Zu's own work had long been lost.

See also: ►Liu Hui and the *Jiuzhang suanshu*, ►*Zhoubi suanjing*, ►Zhang Heng, ►Zu Chongzhi, ►Computation

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PI in Indian Mathematics

R. C. Gupta

Undoubtedly *pi* or π is the most interesting number in mathematics, and its history will remain a never-ending story. It occurs in several formulas of mensuration and is variously involved in many branches of mathematics, including geometry, trigonometry, and analysis.

The earliest association of π is found in connection with the mensuration of a circle. The fact that the perimeter or circumference of any circle increases in proportion to its diameter was noted quite early. In other words, in every circle, perimeter/diameter = constant, or $p/d = \pi_1$, where π_1 is the same for all circles.

After knowing the perimeter, the area of the circle was often found by using the sophisticated relation

$$\text{area} = \left(\frac{p}{2}\right)\left(\frac{d}{2}\right) = \frac{pd}{4}.$$

But the earliest rules for determining area were of the form area $= (kd)^2$ where k is a constant prescribed variously. Both these methods imply that the area of a circle is proportional to the square of its diameter (or radius r), or area $= \pi_2 r^2$.

We know that π_2 is the same as π_1, but this was not always known. Similarly, π_3 may be defined from the volume of a sphere. In this article, the symbol π is used to denote all the above three values, as well as for their common value, which is now known to be not only an irrational, but also a transcendental number.

Since the Indus Valley script has not been deciphered successfully, we cannot say any final thing about the scientific knowledge of India of that time (about the third millennium BCE). Some conjectures about the value of π used in the *Ṛgveda* (about the second millennium BCE) have been made. Definite literary evidence is available from texts related to *Vedāṅgas*, especially the *Śulbasūtras* which contain much older traditional material. In the *Baudhāyana Śulbasūtra*, the oldest of them, the perimeter of a pit is mentioned to be three times its diameter, thereby implying $\pi_1 = 3$. This simplest approximation is found in almost all ancient cultures of the world. In India, it is found also in classical religious works such as *Mahābhārata* (Bhīṣmaparva, XII: 44), and certain *Purāṇas*, as well as in some Buddhist and Jain canonical works.

Different approximations to π_2 are implied in the various Vedic rules for converting a square into a circle of equal area and vice versa. If r is the radius of the circle equivalent to a square of side s, the usual *Śulba* rule is to take $r = s(2+\sqrt{2})/6$, which implies the approximation $\pi_2 = 18(3-2\sqrt{2}) = 3.088$. Recently, a new interpretation of the *Mānava Śulba Sūtra* has yielded the relation $r = 4s/5\sqrt{2}$, thereby implying $\pi_2 = 25/8 = 3.152$, which is the best *Śulba* approximation found so far.

The ancient Jain School preferred the approximation $\pi = \sqrt{10}$, which they considered accurate and from which they derived the value $\pi = \sqrt{3^2+1} \approx 3 + 1/6 = 19/6$. This value ($\sqrt{10}$) continued to be used in India not only by the Jains but also by others, such as Varāhamihira, Brahmagupta, and Śrīdhara, even when better values were known.

With Āryabhaṭa I (born AD 476), a new era of science began in India. In the *Āryabhaṭīya*, he gave a fine approximation of π_1, surpassing all older values. It contains the rule that the perimeter of a circle of diameter 20,000 is close to 62,832, so that $\pi_1 = 62,832/20,000 = 3.1416$ *nearly*, which is correct to four decimal places, and he still calls it close and not exact.

This value had a respectful place in Indian mathematics and exerted greater influence. How Āryabhaṭa obtained it is not known. It was known in China, but evidence of borrowing lacks documentary support. On the other hand, the two typically Indian values $\sqrt{10}$ and $62,832/20,000$ appear in many subsequent Arabic works.

In India, the Archimedean value 22/7 for π first appeared in the lost part of Śrīdhara's *Pāṭī* (ca. AD 750). A Jain writer, Vīrasena, quotes a peculiar rule in his commentary *Dhavalā* (AD 816). It is equivalent to $\rho = 3d + (16d + 16)/113$. If we leave out the redundant dimensionless number +16 in the brackets, this rule will imply a knowledge of the value $\pi_1 = 355/113$ which was known in China to Zu Chongzhi (AD 429–500). In explicit form, this value is found in India much later, e.g., in the works of Narāyaṇa II, Nīlakaṇṭha, and others. The simplified or reduced form $3,927/1,250$ of Āryabhaṭa's value of π occurs in the works of Pauliśa, Lalla, Bhaṭṭotpala, and the great Bhāskara II.

Most significant contributions on the computations of π were made by the mathematicians of the late Āryabhaṭa School of South India. Mādhava of Saṇgamagrāma (ca. AD 1340–1425), the first great scholar and founder of the School, gave the value $\pi_1 = (2,827,4,333,8,823,3)/(9 \times 10^1)$ as known to the "learned men". This value yields an approximation correct to 11 decimals. Mādhava also knew the series $\pi/4 = 1 - 1/3 + 1/5 - 1/7 + \cdots$ which was rediscovered in Europe in 1673 by Leibniz.

In discovering various series for π and in evolving techniques for improving their convergence, a great theoretical breakthrough was attained in sixteenth-century India.

See also: ►*Śulbasūtras*, ►Varāhamihira, ►Brahmagupta, ►Śrīdhara, ►Āryabhaṭa, ►Nīlakaṇṭha, ►Pauliśa, ►Bhāskara, ►Mādhava

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Pirī Reis

SEVIM TEKELI

Pirī Reis, Muhyī al-Dīn Pirī (1465–1554), was born in Gallipoli, a naval base along the Marmara coast. He was an important admiral, cartographer, and geographer of his time. His fame depends on two world maps and a book named *Kitāb-i Bahriye*.

The First World Map (1513)

In 1929 a map was found in Topkapi Palace, on a piece of parchment 90 × 60 cm in size. It had been drawn in 1513, and later presented to Sultan Selim in 1517 in Egypt. This portion shows only the coast of South Western Europe, West Africa, the Middle East, and Central America. On the map, mountains were drawn in outlines, and the rivers marked with thick lines. Shallow places were indicated by red dots, and rocky places in the sea with crosses. Notes were added concerning different regions, and they were decorated with illustrations of special plants, and animals.

This map is a *portolano*, a navigation manual illustrated with charts, with no lines of longitude and latitude. Instead there are two wind roses, one in the North and the other in the South. Each of these roses is divided into 32 parts, and lines are extended beyond these roses; there are two scales indicating mileage. The lines that are extended from the wind roses and the scales are used in measuring the distances between the ports.

Pirī Reis made use of 34 maps in drawing his own. Of these, 20 had no dates. Eight of them were maps that were called *Jaferiyye* by Muslim geographers. Four were new maps drawn by the Portuguese, and one was the map of Christopher Columbus. Since this last is now lost, the only original document we have today is the map of Pirī Reis. When he was drawing the coasts of America, he remained faithful to Columbus' map, and copied it from several points. The Antilles and Cuba are shown as continents on his map, which was what Columbus believed. When Columbus was near the coast of Cuba in 1494, he had the firm belief that Cuba was a continent. As a result, he had his conviction recorded by the notary public on board, Ferdinand Perez de Luna, and asked all the crew to sign it. Columbus had shown South America as a group of islands. Inspired by this, Pirī too drew lot of imaginary islands opposite Trinidad. This map is a very valuable historical map for two reasons. First of all, it was the most correct and scientific map of the time, and secondly it was the only map which was drawn using Columbus' map, of which neither the original nor the copy exists today.

The Second World Map (1528)

Fifteen years after his first map, Pirī Reis drew a second world map. Today we have only a small portion of it, 68 × 69 cm in size. On this portion, there are the northern parts of the Atlantic Ocean and the newly discovered regions of North and Central America.

The map starts with Greenland, in the north. Toward the south there are two pieces of land. The first is called Baccalo; the second one, further down, is called Terra Nova, and it is mentioned that these were discovered by the Portuguese. Further south there is the peninsula of Florida drawn quite correctly. The pieces of land at the side are the peninsulas of Honduras and Yucatan, discovered in 1517 and 1519, respectively.

Cuba and Haiti are drawn quite accurately. The errors on the previous map were corrected on this one.

There is a slight distortion on the map from the true positions as we know them today. This error was committed because of neglect in not taking into consideration the 10°–13° of difference in angle on contemporary compasses. This error is true for all Western-originated maps.

In this second map, the drawing of the coastlines shows greater improvement when compared with the inaccuracies of the first one. Only the parts of the world that were discovered were shown; the unexplored areas were left blank.

Kitāb-i Bahriye

Pirī made a book of all his notes, revised and expanded it, and in 1525 presented it to Süleyman the Magnificient. He analyzed the geographic works of his time and, with his sharp faculties of observation, he set down everything he came across in his travels. In the preface of his book, he said that his purpose in writing such a book was to give information about ports, coasts, and islands by drawing them on maps known as portolanos in the west. However, he added that no matter how big the scales of maps were, it was impossible to show enough of the vital details on them. This lack of important information made him see the necessity of writing a book to compensate for this insufficiency. This, then, is the novelty *Bahriye* brought to the science of navigation.

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Potato: Origins and Conservation of Potato Genetic Diversity

TIMOTHY JOHNS

The Origins and Conservation of Potato Genetic Diversity When the conquistador Francisco Pizzarro and his men overran the Inca Empire in the 1530s they stumbled upon the potato, a vegetable with an annual crop value that today far exceeds that of all the gold the Spaniards ever removed from the New World. While the first potatoes that were taken to Europe in 1537 were regarded suspiciously or as just a curiosity, the potato is now the most important tuber crop globally, exceeded only in its contribution to human subsistence by the cereals wheat, rice, and maize.

What global humanity assumed from the Andeans was not just an important nutrient source, but also several millennia of accumulated empirical experimentation through which Amerindian farmers molded wild species of tuber-bearing members of the genus *Solanum* into the domesticated potato. This is a process determined by biological and environmental forces and by the intelligence and cultural traditions of these people in relation to plant biology and ecology. The Andeans made good use of the natural vegetative propagation method of potato plants, and altered it to their own advantage. They chose those tubers that were most favorable, and by planting the same preferred types year after year maintained their favorable characteristics.

Through time, human selection has resulted in specific changes in the potato plant. In comparing the potato of commerce, *Solanum tuberosum*, with its wild relatives, a botanist might first observe the changes in the length of the underground stems, or stolons, that bear the tubers. These are invariably short in modern cultigens. When wild and primitive plants are pulled up, the stolons are likely to break; tubers from plants with long stolons are more likely to be left in the ground, and less likely to be planted the next year. The result is an unconscious selection for shorter underground stems, and a plant that conveniently produces a mass of easily harvestable tubers close to its base. The typical wild potato is golf ball-sized or smaller. Selection for greater tuber size and plant yield improved the output compared to wild types.

In South America, several thousand different landraces and eight species of potatoes are presently cultivated. Farmers recognize them by differences in color, size, shape, and flavor as well as numerous agronomic traits. Most North American consumers are familiar with two or three colors of potatoes. In the Andes selection by humans has resulted in cultivars in which the skin and flesh color may be black, purple, red, yellow, or white, and spotted combinations of any of these colors. Many wild plants, in order to avoid being eaten by herbivores, produce unpleasant-tasting chemicals. Glycoalkaloids, steroidal nitrogen-containing compounds, are normally found in wild species of potatoes in concentrations high enough to be toxic or potentially fatal to humans or animals. These toxins have posed particular problems for Andean peoples and have been dealt with in various ways, including the selection of genes conferring lower glycoalkaloid content.

Andeans make good use of the knowledge that different potato varieties grow best under different environmental conditions. Even if one type fails due to adverse weather or diseases caused by viral, bacterial, or fungal pathogens, others with specific resistances

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produce enough tubers to sustain the human population until the next season. Not surprisingly Andean potatoes are a source of invaluable germplasm from which plant breeders obtain sought after traits such as resistance to frost and disease.

Modern potato fields in the high Andes of Peru and Bolivia exist in the very locale from which wild plants were originally taken (the center of diversity for potatoes) and wild plants, growing around fields, or even within fields, hybridize with cultivated plants. This creates a dynamic situation which produces, from seed, new genetic types. These plants will have valuable traits of the cultivated parent and perhaps valuable traits of the wild parent. Some of them will have a combination of characteristics superior to earlier types; they will often grow as weeds in fields and from them farmers continue to choose new varieties that constantly improve the nature of the cultivars.

Essential to this process of crop evolution is the intimate knowledge farmers have of their potatoes. Andean cultivators recognize clones of potatoes for their various qualities and may grow up to 35 different landraces together in one field. Aymara and Quechua Indians know tubers by name, e.g., *laram imilla* (blue girl), and have detailed taxonomies to describe the multitude of types.

The dynamic situation that created this diversity continues to the present day and is an essential resource both for ensuring human survival in the Andes and for maintaining potato genetic diversity. However, commercial interests which supplant this variation with new high-yielding varieties of potatoes, and introduce modern technologies, are bringing rapid change to the traditional agricultural system in the Andes; it is with alarm that scientists view the loss of potato landraces and the farming systems that guarantee the long-term survival of this crop upon which humankind is heavily dependent.

The conservation of biodiversity of both crop and wild species of plants is of global concern. However, the most obvious beneficiaries of the use of plant genes to produce new pharmaceuticals or improved crops are in the industrialized countries of the world. Fewer of the financial benefits derived from patented products are returned to the countries from which the germplasm was obtained. More importantly little recognition or compensation is provided to the communities who maintain the essential indigenous knowledge about plant properties. Indeed with economic development the marginalization of indigenous peoples in society is often increased rather than diminished; while indigenous peoples have traditions of conserving natural resources, changing economic conditions force them to adopt practices that are often destructive to their traditional systems.

In addition to the potato, the first peoples of the Americas were the domesticators of numerous crops including tomatoes, maize, and chili peppers. From their knowledge systems humanity learned the use of traditional medicines such as curare and ipecac which have provided valuable pharmaceuticals. Recognition of the true value of the intellectual property of indigenous people is the first step to settle the debt established in 1537; international governments and institutions need to seek in conjunction with these communities means to conserve in situ the valuable resources that are maintained within their cultural traditions.

See also: ►Agriculture, ►Environment and Nature in the Andes, ►Crops

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Precession of the Equinoxes

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Precession of the equinoxes, which in Indian astronomy is called *ayanacalana* (shifting of the solstices), refers to the slow but continuous backward movement of the point of intersection of the ecliptic (which is a fixed circle) and the celestial equator (which keeps on moving backward). This effectively means that the first point of Aries, which is the traditional point of the commencement of the Indian year, is really shifting backward continuously. This shifting is, however, so slow, being a meager 50.2 s per annum that it comes to be noticed only when it accumulates over several years, and takes about 25,800 years to complete one circle.

Such a shift seems to have been noticed in India even during the Vedic times, as is evidenced by the Vedic priests' changing the beginning of their year backward, from the constellation Mṛgaśiras (Delta Orionis) to the next previous constellation Rohiṇī (Alpha Tauri), and again backward, to Kṛittikā (Eta Tauri) in the course of time. But no measurement of it was made. Precession was not apparent during the time of astronomer Āryabhaṭa (AD 499), since at that time the First point of Aries coincided with the equinox. However, later astronomers noted it and also measured its rate. The first Indian astronomer who gave a rule for finding the value of precession seems to be Devācārya, who, in his *Karaṇaratna*, I.36 (AD 689), gives the rate of precession which works out to 47 s per annum. The magnitude of the precession, called *ayana-aṃśa* (degrees of precession) of a celestial body would be the angular distance between its computed longitude and the first point of Aries on the zodiac (which Hindu astronomy takes as fixed).

Hindu astronomers did not conceive the shifting of the equinoxes as a continuously regressing phenomenon, which it really is. They understood it as an oscillatory motion, with the beginning of the Kali era (3102 BCE) as the "zero-precession year", when the Sun and other planets were at the first point of Aries (Aśvinī), i.e., at the end of Zeta Piscium (Revatī). According to the *Sūryasiddhānta*, an oscillation of amplitude 27° to and fro would take 7,200 years to complete. Thus, during the first 1,800 years, the equinox moved forward by 27° and during the next 1,800 years it moved backward, coming back to the zero position at the end of the Kali year 3,600 (which corresponds to AD 499, when Āryabhaṭa composed his work *Āryabhaṭīya*). It will continue to regress for 1,800 years more, till AD 2299, when its forward motion for 1,800 years would commence, again reaching the zero position at the end of 7,200 years, covering, in all, 108°. Certain other texts, such as the *Karaṇaratna* and *Vākyakaraṇa* take the amplitude of the oscillation as 24°, the period for one complete oscillation being 7,380 years. Among Indian astronomers, it was only Muñjāla (AD 932) who conceived precession as a continuous motion.

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Proofs in Indian Mathematics

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Alleged Absence of Proofs in Indian Mathematics

Most of the scholarly works on history of mathematics assert that Indian Mathematics, whatever its achievements, does not have any sense of logical rigour. For instance, we may cite the following as being typical of the kind of opinions commonly expressed about Indian mathematics:

> As our survey indicates, the Hindus were interested in and contributed to the arithmetical and computational activities of mathematics rather than to the deductive patterns. Their name for mathematics was *gaṇita*, which means "the science of calculation". There is much good procedure and technical facility, but no evidence that they considered proof at all. They had rules, but apparently no logical scruples. Moreover, no general methods or new viewpoints were arrived at in any area of mathematics (Kline 1972: 190).

While modern scholarship seems to be unanimous in holding the view that Indian mathematics lacks any notion of proof, even a cursory study of the source works that are available in print reveals that Indian mathematicians place much emphasis on providing what they refer to as *upapatti* (proof, demonstration) for everyone of their results and procedures.

Some of these *upapattis* were noted in the early European studies on Indian mathematics in the first half of the nineteenth century. For instance, Colebrooke notes the following in the preface to his widely circulated translation of portions of *Brāhmasphuṭasiddhānta* (ca. AD 628) of Brahmagupta, and *Līlāvatī* and *Bījagaṇita* of Bhāskarācārya (ca. AD 1150):

> On the subject of demonstrations, it is to be remarked that the Hindu mathematicians proved propositions both algebraically and geometrically: as is particularly noticed by Bhāskara himself, towards the close of his algebra, where he gives both modes of proof of a remarkable method for the solution of indeterminate problems, which involve a factum of two unknown quantities (Colebrooke 1817: xvii).

Around the same time, Whish (1835) pointed out that infinite series for π and the trigonometric functions were derived in texts of Indian mathematics much before their discovery in Europe. It would indeed be interesting to find out how the currently prevalent view, that Indian mathematics lacks the notion of proof, obtained currency in the last 100–150 years.

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The Tradition of *Upapattis* in Mathematics and Astronomy

A major reason for our lack of comprehension, not only of the Indian notion of proof, but also of the entire methodology of Indian mathematics, is the scant attention paid to the source works so far. Much of the methodological discussion is usually contained in the detailed commentaries, whereas modern scholarship has concentrated almost exclusively on translating and analysing the original works, without paying any heed to the commentaries. Traditionally, the commentaries have played at least as great a role in the exposition of the subject as these original texts.

Among the source works available in print, there are about 25 commentaries which present detailed *upapattis* of results and processes in mathematics and astronomy (see References, Primary Sources). Amongst these, the earliest expositions of *upapattis* are to be found in the *Bhāṣya* of Govindasvāmin (ca. 800) on the *Mahābhāskarīya* of Bhāskarācārya I, and the *Vāsanābhāṣya* of Caturveda Pṛthūdakasvāmin (ca. 860) on *Brāhmasphuṭasiddhānta* of Brahmagupta. We find a very detailed exposition of *upapattis* in the works of Bhāskarācārya II (ca. 1150): his *Vivaraṇa* on *Śiṣyadhīvṛddhidatantra* of Lalla (ca. 800) and his *Vāsanā* on his own *Bījagaṇita* and *Siddhāntaśiromaṇi*. Bhāskarācārya notes that the exposition of *upapattis* goes back to the ancient teachers and is handed down by the teaching tradition (Bhāskarācārya II, *Vāsanā* on *Bījagaṇita* 1949: 125–127).

Mathematical Results Should be Supported by *Upapattis*

The following passage from Kṛṣṇa Daivajña's commentary *Bījapallava* (ca. 1600) on *Bījagaṇita* of Bhāskarācārya, clearly brings out the basic understanding of Indian mathematical tradition that citing any number of instances (even an infinite number of them) where a particular result seems to hold, does not amount to establishing that as a valid result in mathematics. Only when the result is supported by an *upapatti* or a demonstration, can the result be accepted as valid:

> How can we state without proof (*upapatti*) that twice the product of two quantities when added or subtracted from the sum of their squares is equal to the square of the sum or difference of those quantities? That it is seen to be so in a few instances is indeed of no consequence. Otherwise, even the statement that four times the product of two quantities is equal to the square of their sum, would have to be accepted as valid. For, that is also seen to be true in some cases. For instance take the numbers 2, 2. Their product is 4, four times which will be 16, which is also the square of their sum 4. Or take the numbers 3, 3. Four times their product is 36, which is also the square of their sum 6. Or take the numbers 4, 4. Their product is 16, which when multiplied by four gives 64, which is also the square of their sum 8. Hence, the fact that a result is seen to be true in some cases is of no consequence, as it is possible that one would come across contrary instances (*vyabhicāra*) also. Hence it is necessary that one would have to provide a proof (*yukti*) for the rule that twice the product of two quantities when added or subtracted from the sum of their squares results in the square of the sum or difference of those quantities. We shall provide the proof (*upapatti*) in the end of the section on *ekavarṇa samīkaraṇa* (Kṛṣṇa Daivajña, *Bījapallava* 1958: 54).

Upapatti for the *Kuṭṭaka* Process

To understand the nature of *upapattis* in Indian mathematics, we have to analyse some of the lengthy demonstrations which are presented for the more complicated results and procedures. We also have to analyse the sequence in which the results and the demonstrations are arranged to understand the method of exposition and logical sequence of arguments. For instance, we may refer to the demonstration given by Kṛṣṇa Daivajña of the celebrated *kuṭṭaka* procedure, which has been employed by Indian mathematicians at least since the time of Āryabhaṭa (ca. AD 499), for solving first-order indeterminate equations of the form $(ax + c)/b = y$, where a, b, c are given integers and x, y are to be solved for integers. The *upapatti* is rather lengthy (Kṛṣṇa Daivajña, *Bījapallava* 1958: 85–99; Srinivas 1987), and we merely recount the essential steps here.

Kṛṣṇa Daivajña first shows that the solutions for x, y do not vary if we factor all three numbers a, b, c by the same common factor. He then shows that if a and b have a common factor, then the above equation will not have a solution unless c is also divisible by the same common factor. Then follows the *upapatti* of the process of finding the greatest common factor of a and b by mutual division, the so-called *Euclidean algorithm*. He then provides an *upapatti* for the *kuṭṭaka* method of finding the solution by making a series of transformations on the *vallī* (column) of the quotients obtained in the above mutual division, based on a detailed analysis of the various operations in reverse (*vyasta-vidhi*). The last two elements of the *vallī*, at each stage, are shown to be the solutions to the *kuṭṭaka* problem for the successive pairs of remainders (taken in reverse order from the end) which arise in the mutual division of a and b. Finally, Kṛṣṇa Daivajña explains why the procedure differs depending upon whether there are odd or even number of coefficients generated in the above mutual division.

Yuktibhāṣā Proofs of Infinite Series for π and the Trigonometric Functions

One of the most celebrated works in Indian mathematics and astronomy, which is specially devoted to the exposition of *yukti* or proofs, is the Malayalam work *Gaṇita-yuktibhāṣā* or *Yuktibhāṣā* (ca. 1530) of Jyeṣṭhadeva. Jyeṣṭhadeva states that his work closely follows the renowned astronomical work *Tantrasaṅgraha* (ca. 1500) of Nīlakaṇṭha Somasutvan and is intended to give a detailed exposition of all the mathematics required thereof. The first half of *Yuktibhāṣā* deals with various mathematical topics in seven chapters and the second half deals with all aspects of mathematical astronomy in eight chapters. The mathematical part includes a detailed exposition of proofs for the infinite series and fast converging approximations for π and the trigonometric functions, which were discovered by Mādhava (ca. 1375); it also includes proofs of Brahmagupta's results concerning the diagonals and the area of a cyclic quadrilateral. Some of the proofs in this part have been studied in recent times, after the pioneering work of Rajagopal and his collaborators over 50 years ago (Marar 1940; Rajagopal 1949; Rajagopal and Venkataraman 1949; Rajagopal and Aiyar 1951; Saraswati Amma 1979; Katz 1995; Paramesvaran 1998; Raju 2001; John 2002; Srinivas 2005). The proofs of *Yuktibhāṣā* have also been expounded in the form of Sanskrit verses (*kārikas*) by Śaṅkara Vāriyar in his commentaries *Kriyākramakarī* (ca. 1535) and *Yuktidīpikā* on *Līlāvatī* and *Tantrasaṅgraha*, respectively.

Upapatti and "Proof"

The Raison D'être Of *Upapatti*

The notion of *upapatti* is significantly different from the notion of "proof" as understood in the Greek and modern Western traditions of mathematics. The ideal of mathematics in the Greek and modern Western traditions is that of a formal axiomatic deductive system. This ideal of mathematics is intimately linked with another crucial philosophical presupposition that mathematics constitutes a body of infallible eternal truths. It is this quest for securing absolute certainty of mathematical knowledge, which has motivated most of the foundational and philosophical investigations into mathematics and has shaped the course of mathematics in the Western tradition, from the age of Greeks to contemporary times.

Indian epistemological position on the nature and validation of mathematical knowledge is very different from that in the Western tradition. This is brought out for instance by the Indian understanding of what indeed is the purpose or raison d'être of an *upapatti*. In the beginning of the *golādhyāya* of *Siddhāntaśiromaṇi*, Bhāskarācārya says (Bhāskarācārya II 1981: 326):

> Madhyādyaṃ dyusadāṃ yadatra gaṇitaṃ tasyopapattiṃ vinā
> prauḍhiṃ prauḍhasabhāsu naiti gaṇako niḥsaṃśayo na svayam
> gole sā vimalā karāmalakavat pratyakṣato dṛśyate
> tasmādasmyupapattibodhavidhaye
> golaprabandhodyataḥ
>
> Without the knowledge of *upapattis*, by merely mastering the *gaṇita* (computational procedures) described here, from the *madhyamādhikara* (the first chapter of *Siddhāntaśiromaṇi*) onwards, of the (motion of the) heavenly bodies, a mathematician will not have any value in the scholarly assemblies; without the *upapattis* he himself will not be free of doubt (*niḥsaṃśaya*). Since *upapatti* is clearly perceivable in the (armillary) sphere like a berry in the hand, I therefore begin the *golādhyāya* (section on spherics) to explain the *upapattis*.

Thus, as per the Indian mathematical tradition, the purpose of *upapatti* is mainly (a) to remove confusion and doubts regarding the validity and interpretation of mathematical results and procedures; and (b) to obtain assent in the community of mathematicians. Further, in the Indian tradition, mathematical knowledge is not taken to be different in any "fundamental sense" from that in natural sciences. The valid means for acquiring knowledge in mathematics are the same as in other sciences: *Pratyakṣa* (perception), *Anumāna* (inference), and *Śabda* or *āgama* (authentic tradition).

The Limitations of *Tarka* or Proof by Contradiction

An important feature that distinguishes the *upapattis* of Indian mathematicians is that they do not generally employ the method of proof by contradiction or *reductio ad absurdum*. Sometimes arguments, which are somewhat similar to proof by contradiction, are employed to show the non-existence of an entity, as may be seen from the following *upapatti* given by Kṛṣṇa Daivajña to show that "a negative number has no square root":

> The square-root can be obtained only for a square. A negative number is not a square. Hence how can we consider its square-root? It might however be argued: 'Why will a negative number not be a square? Surely it is not a royal fiat'... Agreed. Let it be stated by you who claim that a negative number is a square as to whose square it is; surely Not of a positive number, for the square of a positive number is always positive by the rule... not also of a negative number. Because then also the square will be positive by the rule... This being the case, we do not see any such number whose square becomes negative... (Kṛṣṇa Daivajña, Bījapallava 1958: 19).

Such arguments, known as *tarka* in Indian logic, are employed only to prove the non-existence of certain entities, but not for proving the existence of an entity,

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whose existence is not demonstrable (at least in principle) by other direct means of verification.

In rejecting the method of indirect proof as a valid means for establishing existence of an entity whose existence cannot even in principle be established through any direct means of proof, the Indian mathematicians may be seen as adopting what is nowadays referred to as the "constructivist" approach to the issue of mathematical existence. But the Indian philosophers, logicians, etc., do much more than merely disallow certain existence proofs. The general Indian philosophical position is one of eliminating from logical discourse all reference to such *aprasiddha* entities, whose existence is not even in principle accessible to all means of verification (Srinivas 1986). This appears to be also the position adopted by the Indian mathematicians. It is for this reason that many an "existence theorem" (where all that is proved is that the non-existence of a hypothetical entity is incompatible with the accepted set of postulates) of Greek or modern Western mathematics would not be considered significant or even meaningful by Indian mathematicians.

Upapatti and "Proof"

We now summarise the classical Indian understanding of the nature and validation of mathematical knowledge:

1. The Indian mathematicians are clear that results in mathematics, even those enunciated in authoritative texts, cannot be accepted as valid unless they are supported by *yukti* or *upapatti*. It is not enough that one has merely observed the validity of a result in a large number of instances.
2. Several commentaries written on the major texts of Indian mathematics and astronomy present *upapattis* for the results and procedures enunciated in the text.
3. The *upapattis* are presented in a sequence proceeding systematically from known or established results to finally arrive at the result to be established.
4. In the Indian mathematical tradition, the *upapattis* mainly serve to remove all ambiguity and doubts and obtain assent for the result among the community of mathematicians.
5. The *upapattis* may involve observation or experimentation. They also depend on the prevailing understanding of the nature of the mathematical objects involved.
6. The method of *tarka* or "proof by contradiction" is used occasionally. But there are no *upapattis* which purport to establish existence of any mathematical object merely on the basis of *tarka* alone.
7. The Indian mathematical tradition did not subscribe to the ideal that *upapattis* should seek to provide irrefutable demonstrations establishing the absolute truth of mathematical results. There was apparently no attempt to present the *upapattis* as a part of a deductive axiomatic system. While Indian mathematics made great strides in the invention and manipulation of symbols in representing mathematical results and in facilitating mathematical processes, there was no attempt at formalisation of mathematics.

The classical Indian understanding of the nature and validation of mathematical knowledge seems to be rooted in the larger epistemological perspective developed by the *Nyāya* school of Indian logic (Bhattacharya 1987; Mohanty 1992). Some of the distinguishing features of *Nyāya* logic, which are particularly relevant in this context, are:

1. That it is a logic of cognitions (*jñāna*) and not "propositions".
2. That it has no concept of pure "formal validity" as distinguished from "material truth".
3. That it does not distinguish necessary and contingent truth or analytical and synthetic truth, that it does not admit, in logical discourse, premises which are known to be false and terms that are non-instantiated.
4. That it does not accord *tarka* or "proof by contradiction", a status of independent *pramāṇa* or means of knowledge, and so on.

Towards a New Epistemology for Mathematics

Mathematics today, rooted as it is in the modern Western tradition, suffers from serious limitations. First, there is the problem of "foundations" posed by the ideal view of mathematical knowledge as a set of infallible eternal truths. The efforts of mathematicians and philosophers of the West to secure for mathematics the status of indubitable knowledge has not succeeded, and there is a growing feeling that this goal may turn out to be a mirage.

Apart from the problems inherent in the goals set for mathematics, there are also other serious inadequacies in the Western epistemology and philosophy of mathematics. The ideal view of mathematics as a formal deductive system gives rise to serious distortions. Some scholars have argued that this view of mathematics has rendered philosophy of mathematics barren and incapable of providing any understanding of the actual history of mathematics, the logic of mathematical discovery and, in fact, the whole of creative mathematical activity. There is also the growing awareness that the ideal of mathematics as a formal deductive system has had deleterious consequences on the teaching of mathematics.

Notwithstanding all these critiques, it is not likely that, within the Western philosophical tradition, any radically different epistemology of mathematics will emerge and so the driving force for modern mathematics is likely to continue to be a search for absolute truths and modes of establishing them, in one form or the other. This could lead to "progress" in mathematics, but it would be progress of a rather limited kind.

If there is a major lesson to be learnt from the historical development of mathematics, it is perhaps that the development of mathematics in the Greco-European tradition was seriously impeded by its adherence to the cannon of ideal mathematics as laid down by the Greeks. In fact, it is now clearly recognised that the development of mathematical analysis in the Western tradition became possible only when this ideal was clearly given up during the heydays of the development of "infinitesimal calculus" during sixteenth, seventeenth and eighteenth centuries. As a historian of mathematics notes:

> It is somewhat paradoxical that this principal shortcoming of Greek mathematics stemmed directly from its principal virtue – the insistence on absolute logical rigour … Although the Greek bequest of deductive rigour is the distinguishing feature of modern mathematics, it is arguable that, had all the succeeding generations also refused to use real numbers and limits until they fully understood them, the calculus might never have been developed and mathematics might now be a dead and forgotten science (Edwards 1979: 79).

It is of course true that the Greek ideal has gotten reinstated at the heart of mathematics during the last two centuries, but it seems that most of the foundational problems of mathematics can also be perhaps traced to the same development. In this context, study of alternative epistemologies, such as that developed in the Indian tradition of mathematics, could prove to be of great significance for the future of mathematics.

See also: ►Nyāya

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Putumana Somayāji

K. V. Sarma

Putumana Somayāji (ca. 1660–1740), author of the work *Karaṇapaddhati* (Methodology for Astronomical Manuals) was a *nampūtiri* (the appellation of the Brahmin community of Kerala in South India), who belonged to a family which bore the name Putu-mana (New House). He was of Ṛgvedic denomination, and secured the surname Soma-yāji by having performed the Vedic *Soma* sacrifice. His real name remains unknown. The date of Soma-yāji is surmised on the basis of the chronogram which gives the date of completion of his *Karaṇapaddhati* (as 17,65,653) of the Kali era, stated in the *kaṭapayādi* notation of expressing numerals, which is in the year AD 1732. Again, in the concluding verse, Somayāji states that he hailed from the village named Śivapura, which has been identified as Covvaram in Central Kerala, where his descendants still reside.

Somayāji was a prolific writer, mainly on astronomy and astrology, his only work in a different discipline being *Bahvṛcaprāyaścitta*, a treatise which prescribes expiations (*prayāścitta*) for lapses in the performance of rites and rituals by Bahvṛca (Ṛgvedic) Brahmins of Kerala. In addition to his major work, Somayāji is the author of several other works. In *Pañca-bodha* (Treatise on the Five), he briefly sets out computations at the times of *Vyatipāta* (an unsavory occasion), *Grahaṇa* (eclipse), *Chāyā* (measurements based on the gnomonic shadow), *Śṛṅgonnati* (elongation of the moon's horns), and *Mauḍhya* (retrograde motion of the planets), all of which are required for religious observances. His *Nyāyaratna* (Gems of Rationale), available in two slightly different versions, depicts the rationale of eight astronomical entities: true planet, declination, gnomic shadow, reverse shadow, eclipse, elongation of the moon's horns, retrograde motion of the planets, and *Vyatipāta*. Three short tracts on the computation of eclipses, including a *Grahaṇāṣṭaka* (Octad on Eclipses), are ascribed to Somayāji. He also composed a work called *Veṇvārohāṣṭaka* (Octad on the Ascent on the Bamboo), which prescribes methods for the computation of the accurate longitudes of the moon at very short intervals. A commentary in the Malayalam language on the *Laghumānasa* of Muñjāla is also ascribed to him. On horoscopy, Somayāji wrote a *Jātakādeśa-mārga* (Methods of Making Predictions on the Basis of Birth Charts), which is very popular in Kerala.

The *Karaṇa-paddhati*, in ten chapters, is his most important work. The work is not a manual prescribing computations; rather it enunciates the rationale behind such manuals. Towards the beginning of the work, the author states that he composed the book to teach how the several multipliers, divisors, and R sines pertaining to the different computations and the like are to be derived. Thus, the work is addressed not to the almanac maker but to the manual maker. All the topics necessary to make the daily almanac are not treated in *Karaṇapaddhati*, whereas several other items not pertaining to manuals are dealt with. The work takes as its basis the parameters and postulates of the Parahita system of astronomy promulgated by Haridatta, except for the section on eclipses, where the more accurate system from the *Dṛgganịta* of Parameśvara is taken as the basis.

In Chapter I, the *Karaṇapaddhati* sets out the planetary parameters, the computation of the mean planets, and the corrections to be applied thereto. Chapter II is devoted to the derivation, by means of pulverization (*kuṭṭaka*), of the multipliers and divisors necessary for planetary computations. Chapter III is concerned with various aspects of the computation of the moon, and Chapter IV deals with miscellaneous matters relating to the determination of suitable epochs for commencing computations. Chapter V mentions methods for correlating observed results with computed results, while Chapter VI depicts such matters as the circle and the circumference, and the R sines pertaining to various entities for different purposes. Chapter VII is devoted to the rationale of the derivation of the mnemonics relating to the epicycles, their R sines, and allied matters. Chapter VIII describes varied derivations using the gnomonic shadow. Chapter IX is devoted to stellar declination and latitudes. The last chapter is concerned with certain derivations from the shadow of the gnomon.

As a work on astronomical rationale and exposition of the logic of several practices, the *Karaṇpaddhati* is highly important. A very significant statement made by the Putumana Somayāji, towards the close of Chapter V, is that the conception of eons and eras, the measures therefore, and the various derivations based on them are not really true; they are only a means to compute the positions of celestial bodies and matters related to them. What is really important is the correlation of computation with observation, and to effect the same a practical astronomer is authorized to make changes as necessary. This is a highly significant statement, maybe even revolutionary, which was made in a forthright manner by an orthodox Hindu astronomer.

See also: ►Parameśvara, ►Haridatta, ►Eclipses

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Pyramids in Egypt

GREGG DE YOUNG

The pyramids of ancient Egypt still stand beside the Nile, bearing mute testimony to the civilization that constructed them nearly 5,000 years ago. Considering the magnitude of the effort expended, it seems surprising that no information about their planning or construction has been preserved. Such mysteries have generated an incredible array of hypotheses and suppositions concerning both construction techniques and cultural implications of the pyramid.

History

The origins of pyramid construction are obscure. The stepped pyramid of Third Dynasty Djoser (ca. 2667–2648 BCE) at Saqqara appears to be an elaboration of earlier funerary architecture, combining First Dynasty *mastaba* (low, flat mud brick, or stone superstructure above a subterranean burial vault and storage compartments) forms with large, mud-brick walled funerary enclosures of the Second Dynasty. This pyramid appears to be a first experiment in large-scale stone construction. Beginning as a mastaba, it was enlarged horizontally several times before building upwards, perhaps because the original low mastaba was not visible behind the wall surrounding the complex. A passage on the north led to a subterranean burial chamber with 11 subsidiary burial chambers. The adjoining of storage chambers and corridors were decorated with blue faience tiles and relief sculptures of Djoser.

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The Step-Pyramid is only the most obvious structure on the site. Also inside the enclosure wall were a complex of temples, pavilions, mastaba-like tombs, chapels, as well as extensive storage structures. Most important of these was the mortuary temple, possibly in imitation of the offering chapels attached to archaic mastabas, where offering on behalf of the dead Pharaoh might be made, placed on the northern side of the pyramid. (In later pyramid complexes, this mortuary temple was typically moved to the eastern side.)

The experiment in stone construction must have been regarded as a success, for the pyramid was rapidly developed in the Fourth Dynasty. The Pharaoh Sneferu (ca. 2613–2589 BCE) erected two pyramids at Dahshur, south of Saqqara. The Bent Pyramid's distinctive outline, with its shift from 54° to 43° showed the necessity for a solid foundation. Built with much larger stones than the Step Pyramid of Saqqara placed directly on the desert surface, subsidence, combined with carelessly laid core blocks, soon introduced internal stresses that caused fissures to appear in the structure. Learning from experience, Sneferu's architects constructed the Red Pyramid somewhat to the north of the Bent Pyramid. These early Fourth Dynasty pyramid complexes reveal the basic features of most later attempts. The pyramid is the focal point of an east–west oriented rectangular enclosure, which also contains an offering temple on the east side of the pyramid, and often one or more subsidiary pyramids. A causeway, usually covered, led from the pyramid complex down to a valley temple.

Following on these early experiments, the great pyramids of Giza were constructed. The largest was created by Sneferu's son, Khufu (ca. 2589–2566 BCE). Two somewhat smaller pyramids belong to his successors, Khafre (ca. 2558–2532 BCE) and Menkaure (ca. 2532–2503 BCE). These mark a high point in terms of sheer physical size and engineering prowess. The Fifth Dynasty pyramids at Abu Sir are often held to represent the highest development architecturally of the pyramid complex and associated valley temple, although they are distinctly smaller in size. They also reveal a significant decline in workmanship, perhaps paralleling the decline of centralized authority in the state. Their interior blocks were scarcely shaped, and the removal of the limestone casing blocks has left most of them looking like little more than piles of rubble.

Royal burials between the Sixth and Twelfth Dynasties largely abandoned the pyramid form. When it was revived in the Twelfth Dynasty (ca. 1895–1795 BCE), construction techniques had changed considerably. The interior structure often consisted of little more than stone cross walls to give solidity and rigidity to the mud brick or rubble-filled structure. The pyramids continued to be faced with high-grade limestone, however, and so would externally have looked very similar to earlier pyramids. They would have been more economical to build, however, since they require a considerably smaller work force, as well as utilizing cheaper building materials.

By the end of the Thirteenth Dynasty, pyramid building had once again been abandoned for royal burials. In the New Kingdom, however, there is evidence that the pyramid structure was reduced to a decorative architectural element of the superstructure of the funerary chapels for nonroyal burials. Important examples appear in the cemetery associated with Deir el-Medina, the town housing the workers who constructed the tombs in the Valley of the Kings and Valley of the Queens, the new royal necropolis on the west bank of the Nile across from Thebes.

Nearly a 1,000 years passed before the pyramidal form was reclaimed for royal burials by the Nubian kings. These pyramids are constructed from blocks of local sandstone. They have steep sides (approximately 70°) and are relatively small. Their apex is often flat. The burial chamber was not constructed inside or underneath the pyramid. Rather, the burial chamber, often decorated in Egyptian style motifs, was constructed and then the pyramid was erected above it. The pyramid fields at Nuri and el-Kurru (above the fourth cataract) were constructed mainly between 770 and 400 BCE. Meroe (between the fifth and sixth cataracts) was an active necropolis until nearly 350 AD. These sites contain more pyramids than have been discovered in the Nile Valley.

Construction Techniques

The pyramid of Khufu involved quarrying nearly 2.5 million blocks of limestone weighing on average between two and three tons, transporting them to the building site, and raising them into place. If the report of Herodotus, that the pyramid was completed in 20 years, is to be believed, this would require moving a block into place roughly every 3 min – a remarkable achievement indeed.

There is ample evidence to suggest that these pyramids were carefully planned, taking into account what had been learned in earlier construction attempts. The builders constructed a level foundation directly on the bedrock. The early suggestion that the site was leveled through surrounding the entire site with a low mud wall, filling the enclosure with water, and digging a series of trenches at uniform depth below the surface of the water (the intervening material could easily be removed later) no longer appears credible, but the precise technique remains rather mysterious. Most probably it was done by adjusting the foundation stones to provide a flat plane on which to build.

These pyramids are also remarkable for their accurate alignment with the four cardinal directions.

This alignment must have involved some sort of astronomical technique, since the Egyptians did not know the magnetic compass. One suggested technique involved bisecting the angle between the rising and setting point of a star in order to determine true North. Even this simple-sounding method would require the construction of an artificial level horizon and very precise observations in order to obtain the observed accuracy of alignment. A somewhat easier technique would require erecting a gnomon perpendicular to the surface of the earth and a circle constructed about it with some convenient radius. It is then necessary to mark the two points during the day when the shadow of the gnomon touches this circle, connect these two points to the gnomon and bisect the angle so produced in order to determine true North. Although requiring simpler equipment, the observations must still be made with careful accuracy in order to produce the orientation we observe in Khufu's pyramid.

Large quantities of stone had to be quarried and transported to the building site. Extracting blocks of relatively soft local limestone for use in the core of the structure posed no technical difficulty for the ancient Egyptians. The stone block could be defined using bronze tools and separated from the rock matrix with wedges. Facing blocks of higher-grade limestone were brought from Tura, on the other side of the Nile. Granite used in facing the corridors and chambers within the structure had to be quarried in Aswan and transported to Giza. A very hard Plutonic stone, it required use of dolerite stone tools to work, since copper and even bronze were too soft to be effective.

Once separated from the bedrock, the core blocks were transported to the building site on wooden sledges pulled by teams of men. The sledges could travel across firm surfaces using sets of wooden rollers as a kind of primitive wheel. If it were necessary to transport the blocks over sand, friction might be reduced by constructing a kind of roadway, embedding timbers in the surface on the pattern of railway ties. When wet, the wooden sledge would slide quite easily across these wooden beams. There is still no conclusive evidence to indicate whether dressage occurred at the quarry sites or at the construction site.

Once at the pyramid site, the blocks had to be raised into position. The most prevalent view is that this involved recourse to a system of ramps, although there is no agreement on straight or helicoidal ramps spiraling around the exterior of the pyramid. Either proposal requires considerable construction of an ancillary structure that would later need to be removed. Opponents of ramps question where the evidence is for removal of such large-scale ramps. The most common alternative suggestion has been the use of some form of jacking mechanism, either directly through levering or indirectly through use of "cradles" equipped with rockers that could be pushed to one side or the other while wooden planks were placed under the elevated side to raise the structure. (Examples of such rocker cradles have been found near construction sites.) In practice, however, raising blocks to the level of about a meter is difficult because the supporting structure becomes less stable with increased height.

More recently, a suggestion has been made that the "cradles" were not intended for rocking the stone upward, but that four cradles, attached to the faces of the block, might function as a kind of primitive wheel. A few preliminary tests indicate that such a configuration might work to move stones up a ramp. Another recent suggestion does away with both jacking and ramps, arguing that the blocks were simply pulled up the side of the pyramid mounted on their sledges and lubricated with water. Such an hypothesis would explain why there is little evidence of ramps surviving at the work site. It would also presuppose that the finished casing blocks must have been put in place immediately on completion of each course of core blocks. It also leaves open questions about the upper courses, where men would have had less room for maneuvering while raising the blocks a longer distance. Each theory has some merit to recommend it, as well as difficulties in application. It is likely that there was no single method used in every pyramid; probably an array of techniques was employed to solve these technical problems in various contexts.

In addition to the physical problem of raising heavy stones to a considerable height, it was necessary to control the shape of the pyramid in order to avoid deformations. Once again, we do not know exactly how the ancient Egyptians solved such problems. One of the simple-sounding techniques would be to measure the sides at each course of stone to make sure they are still square (assuming that one had successfully laid out a square base), perhaps checking by sighting across the pyramid on the diagonals. But actually carrying out such operations might prove difficult. Measurement would require either the repeated application of a measuring rod, which would allow small errors to cumulate over long distances, or by use of a measuring rope, which would be subject to stretching or sagging and so also allows for incursions of significant error. Again, we have no conclusive direct evidence. In this case, too, it is possible that various techniques were tried in various combinations on each pyramid that was constructed.

From very early dynastic times, there was a clear concern for security of tombs (including burial chambers within or below pyramids). Considerable treasure was interred with royalty, and wealth inevitably attracts robbers. Already at the construction of the Fourth Dynasty Bent Pyramid, we find use of a portcullis system by which large usually granite blocks could be lowered to block passages leading to the burial chamber. Sometimes these portcullis blocks came with a kind of locking device to prevent robbers from lifting them with levers: a short rod would be placed in a small shaft at the side of a portcullis channel of the same height and angled so that when the portcullis was lowered, the wooden rod would protrude into the channel, thus blocking any attempt to raise the portcullis. In practice, such devices rarely delayed robbers long. They simply tunneled around or over the portcullis. No more effective were the efforts to provide a means to block entrance tunnels with great blocks of granite drawn into the passage from the side or the use of gravity to slide granite blocks into a passageway, blocking access to the door to the burial chamber. Again, robbers were likely simply to tunnel past these obstacles. The lure of riches left no pharaoh undisturbed for long.

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Pyramids of Mesoamerica

Geoffrey McCafferty

The construction of monumental architecture is one of the archaeological hallmarks of social complexity. It involves the ability to mobilize and coordinate labor; it requires surplus manpower and material; it implies sophisticated knowledge of architecture and engineering; and it assumes a fair degree of administrative control. In evolutionary terms, monumental architecture appears when there is a fairly high degree of complexity, with multitiered political organization in what can be characterized as "chiefly" or "stratified" society. In pre-Columbian Mesoamerica, this level of complexity first appeared in the Early Formative period, ca. 1200 BCE, among the Olmecs of the southern Gulf Coast. In time other cultures also adopted monumental architecture for primarily religious purposes but also as a legitimation of political authority.

The most typical form of monumental architecture used in Mesoamerica was the pyramid. Pyramids were often perceived as artificial mountains, and they represented attempts by the ruling elites to construct a symbolic landscape. Most pyramids were built to correspond to cosmological principles, such as astronomical orientation. They also represented the recreation of an *axis mundi*, a world axis where the pyramid became the cosmic center around which the rest of the universe revolved both vertically and horizontally. Mesoamerican pyramids were literally a "stairway to heaven" where a select few could rise above the mortal plane to communicate with deities of the multitiered heavens in temples on top of the pyramid platforms. Similarly, many pyramids were constructed over natural springs, caves, or artificially created portals into the underworld for access to the deities residing there. A pyramid, therefore, was a conduit linking the three planes of the cosmos, where powerful ruler/priests could communicate with the gods and petition them for supernatural assistance. In part because of this symbolic centrality, Mesoamerican pyramids were often rebuilt by encasing the old structure within new layers of fill and façade to enhance the cosmic significance with a connection to the ancestral past, and thereby adding a temporal dimension as well.

Pyramids were fairly basic in their architectural form, with simple mounds of packed earth as the most simple style. Others were made of mounded earth and rubble, sometimes segregated in cells for internal integrity. The most elaborately built pyramid was the Great Pyramid of Cholula, where the internal structure is made up of stacked adobe bricks to create a remarkably stable interior. Note that with very few exceptions the interior of pyramids was solid, lacking inner chambers. The importance of a Mesoamerican pyramid was as a platform for one or more temples located on top.

Despite the relatively simple internal construction, however, Mesoamerican pyramids were often elaborately decorated on the exterior. The staircase was a natural focus of the building program, since it was the means of ascending to the temple. Staircases were often quite steep, making a direct vertical climb difficult, particularly for heavily robed priests. One speculation is that ascent was made in a serpentine fashion, moving up diagonally. Priests in colorful robes and elaborate feathered headdresses, climbing in procession, would appear to spectators below as a polychrome feathered serpent undulating up to the inner sanctum of the temple. As will be discussed below, the Feathered Serpent god was a unifying theme of Mesoamerican religion, particularly as it relates to political legitimation and priestly knowledge.

Pyramid façades were generally finished in cut stone and covered with layers of stucco. Particularly in the Maya area they were often elaborated with symbolically significant carvings, often depicting powerful deities. The temples themselves were occasionally decorated with the image of the earth monster whose open mouth formed the temple entrance, a portal into the underworld. Maya temples also featured elaborate roof combs of stone rising high above the temple itself, created in lattice format to depict further cosmological images visible from great distances (Fig. 1). The Maya temples were constructed using the corbeled vault technique so that the weight of the roof and roof comb was transferred to the thick walls, in what was the crowning achievement of Maya structural engineering.

Mesoamerica, consisting of central and southern Mexico, Guatemala, Belize, Honduras, and parts of El Salvador, Nicaragua, and Costa Rica, is a culturally complex region that, during the pre-Columbian era, was often characterized by overarching similarities. Religious beliefs were one of these, and the use of pyramids was common to Mesoamerican cultures for over 2,500 years. Other commonalities included the calendar system, ritual ballgame, maize/beans/squash as dietary staples, and human sacrifice to appease the gods. Nevertheless, due to the cultural diversity some regional and temporal variations arose. The following is a brief survey of some of the important pyramids of Mesoamerica within their cultural contexts.

The earliest clear pyramid is known from La Venta and corresponds to the Olmec culture of the Middle Formative period (900–500 BCE). The pyramid itself is just one manifestation of a massive landscape modification as the ruling elite transformed the ceremonial center into a cosmogram that constructed their capital as the center of the universe. The pyramid itself is made of packed earth, and has been compared to an effigy volcano. The Olmec heartland is in the swampy lowlands of the Gulf Coast, so this pyramid may be a reference to the volcanic Tuxtla Mountains to the north, from which much of their building stone was imported. A more revealing monumental construction was intentionally buried beneath the plaza in front of the pyramid, where thousands of imported jadeite bricks were formed into a mosaic image of the jaguar-like earth monster and then covered by layers of imported, colored clays to symbolize the layers of the underworld. Taken as a meaningfully constructed building program, the La Venta ceremonial center represents the symbolic relationship between the three levels of the cosmos, as well as a major investment in labor and resources.

In the Maya lowlands, sites such as Uaxaxtun, Nacbe, and El Mirador demonstrate monumental architecture during the Late Formative period. El Mirador features the El Tigre pyramid complex, one of the earliest Maya pyramids that was also the largest in terms of volume at 380,000 m^3. Another early Maya pyramid is found at Cerros, where elaborate building façades are interpreted as representations of astronomical passages as the sun traveled from east to west on its daily journey. A symbolic reading of this again suggests that the universe revolved around the Cerros pyramid. This probably relates to both religious beliefs as well as political propaganda, as jadeite jewelry cached at the site has been interpreted as an indication of the creation of a Maya *ahaw*, or king, suggesting a new level in political complexity.

Monte Albán, located in the southern highland valley of Oaxaca, represents another example of monumental architecture that was begun in the Late Formative period (500 BCE–200 CE), though modifications continued through the Classic period (200 CE–800 CE). Located on a ridge high above the valley floor, Monte Albán's acropolis was created first by flattening the ridge top

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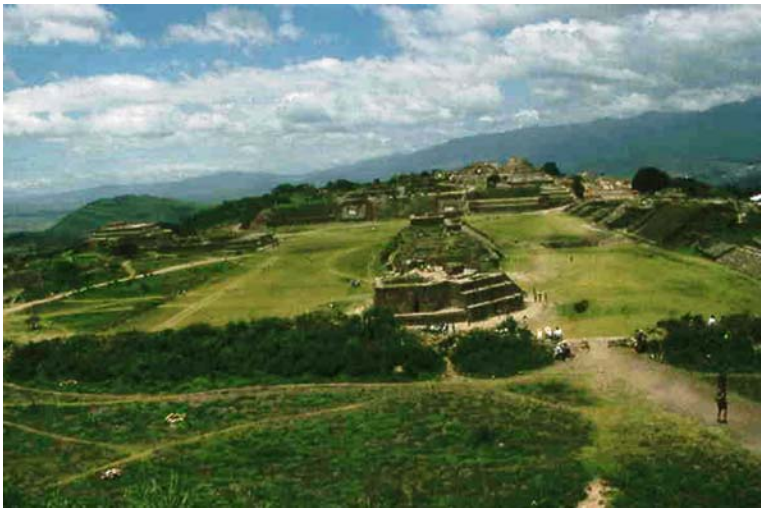
Pyramids of Mesoamerica. Fig. 1 Example of a Maya temple with roof comb (Palenque).

to form a level surface, then by building numerous large buildings around a rectangular plaza (Fig. 2). The largest pyramid is the South Platform, that in its final manifestation consisted of a massive platform with a smaller pyramid located on top. While religious practices were probably paramount on this structure, numerous carved stone slabs depict political scenes including captives and an emissary from Teotihuacan, emphasizing the interwoven nature of Mesoamerican religion and politics. The North Platform is even more massive, but probably had a more secular function. A wide staircase leads to a plaza where public rituals were likely held, before smaller passageways lead to a more restricted area that may have been the royal residence. Other smaller pyramids delimit Monte Albán's plaza, which is clearly outlined on the horizon and visible from the valley floor as a sort of "Big Brother is watching" political message.

In central Mexico the great urban center of Teotihuacan arose in the Late Formative period, and around 100 CE embarked on a major urban renewal program that included a rigorous grid system based on its Avenue of the Dead. The Avenue is oriented at 16° east of North, with a pecked cross marker in the bedrock of Cerro Gordo mountain as a datum point for aligning the Avenue. At the northern end of the Avenue is the Pyramid of the Moon, framed by Cerro Gordo behind it and actually designed to mimic the form of the mountain (Fig. 3). To the south is the Pyramid of the Sun, the largest of Teotihuacan's pyramids, and it too mimics the shape of Otumba mountain in the distance. A third pyramid in the western part of the city is similarly set in relation to the natural landscape, perhaps as an intentional cosmogram in which the hills and the pyramids represent the three hearth stones symbolic of symbolic centrality.

Excavations beneath the Pyramid of the Sun discovered a long passageway, excavated into the volcanic bedrock for building materials but then modified into an artificial cave where rituals were performed. The form of the inner chamber resembles the flower shape of Chicomoztoc, the cave of origin



Pyramids of Mesoamerica. Fig. 2 Acropolis of Monte Albán.

Pyramids of Mesoamerica. Fig. 3 Teotihuacan's Pyramid of the Moon.

Pyramids of Mesoamerica. Fig. 4 Serpent/Axolotl on façade of Teotihuacan's Feathered Serpent Pyramid.

from later Aztec mythology, suggesting that later peoples may have continued to worship in the artificial cavern at Teotihuacan. The entrance to this tunnel is beneath the west facing staircase onto the Avenue of the Dead, and therefore faces 16° north of west, the orientation of the setting Pleiades constellation which marks the beginning of the rainy season. It is possible, therefore, that the entire urban renewal program around the Avenue of the Dead makes Teotihuacan an elaborate celestial almanac relating to the all-important rains.

Recent investigations into Teotihuacan's Pyramid of the Moon, as well as the Pyramid of the Feathered Serpent, have discovered sacrificial burials of warriors, perhaps as dedicatory offerings to the lords of the underworld. These burials are clustered in groups of 9, 13, and 20, numbers symbolic of cosmological principles including the sacred 260-day calendar. The stone façade of the Feathered Serpent Pyramid features a long rattlesnake body (covered in feathers) undulating in profile but with a front-view head surrounded by more feathers (Fig. 4). This image is generally identified as a "feathered serpent" but is also similar to the *axolotl*, a species of salamander that lives in the lakes of central Mexico and has feathery gills that encircle the head. On the back of the serpent is an elaborate mosaic headdress representing political office (a similar scene adorns the mosaic façade of the Nunnery Compound at the Maya site of Uxmal). Curiously, the west façade of the Pyramid of the Feathered Serpent was covered over by later construction to obscure, and thereby unintentionally preserve, this iconographic program.

Pyramids dot the Classic Maya landscape where, because of the prevalence of textual evidence on carved stone markers, they can occasionally be related to the particular ruler who commissioned their construction. Some of the most impressive pyramids come from Tikal, the capital of a Maya "superpower" of the sixth through ninth centuries. For example, Temple I reached 52 m in height, with its temple structure and roof comb reaching above the current jungle canopy (Fig. 5). Contemporaneous with these is the Temple of the Inscriptions from Palenque, where extensive hieroglyphic texts record the lineage history of King Pakal. A trapdoor in the floor of the temple led to a passageway down through the pyramid itself to a subterranean chamber where Pakal's sarcophagus was

Pyramids of Mesoamerica. Fig. 5 Tikal Temple I.

found (Fig. 6). This use of a pyramid to enshrine a ruler is unusual in Mesoamerica. Other pyramids at Palenque include the Cross Group, where three small temples represent the three hearth stones, a Mesoamerican metaphor for the cosmic center. Another major Maya center was Copán, located in modern Honduras. It is famous for its elaborately decorated architecture and the many carved stone stelae that recount dynastic histories. Its largest pyramid was Temple 26, known for its hieroglyphic staircase representing the longest known text in the Mayan language; unfortunately early explorers stripped the carved stairs from their original position before randomly replacing them out of order so attempts at decipherment are still furtive.

Following the collapse of Teotihuacan and Monte Albán at the end of the central Mexican Classic period (ca. 700–800 CE), Maya influences in the central highlands of Mexico resulted in architectural innovations that affected pyramids at sites such as Xochicalco, Cacaxtla-Xochitecatl, and Cholula. Similar to Monte Albán for the scale of modifications to the natural hilltop, Xochicalco is best known for its Temple of the Feathered Serpent. Large feathered snakes curl around the walls of the pyramid base, with Maya-style lords seated within the curves of the serpent's body (Fig. 7). Glyphic inscriptions in a non-Maya – and as yet undeciphered – script likely describe conquests and/or political alliances. Cacaxtla boasts beautiful polychrome murals, again in Maya style, on the walls of Building B at the north end of its acropolis. The murals depict the aftermath of ethnic conflict between an army with Maya costume and physiological traits, who have been defeated by another group. As a result of this battle the female war-chief of the Maya group is

Pyramids of Mesoamerica. Fig. 6 Palenque's Temple of the Inscriptions, indicating passage to a subterranean crypt.

Pyramids of Mesoamerica. Fig. 7 Temple of the Feathered Serpent at Xochicalco.

Pyramids of Mesoamerica. Fig. 8 Great Pyramid of Cholula with church to the Virgin of the Remedies on top.

captured, perhaps to become the founding queen of a new, united lineage. On the adjoining hill of Xochitecatl, the Pyramid of the Flowers was likely dedicated to a goddess cult. The staircase is made up of basalt grinding stones, an artifact closely associated with female domestic practice. On top of the pyramid, caches contained dozens of female figurines depicting different phases of the female life cycle, especially motherhood, and also hundreds of clay spindle whorls, another characteristic of female practice.

The largest pyramid in Mesoamerica is at Cholula, located in the Puebla/Tlaxcala valley east of Mexico City. It was built in successive stages over a period of over 1,000 years (Fig. 8), and it remains an important religious site with its Colonial church dedicated to the Virgin of the Remedies perched on top and attracting tens of thousands of pilgrims annually. The Great Pyramid of Cholula is known as *Tlachihualtepetl*, literally an artificial mountain. Its construction history has been studied using 8 km of tunnels cut through the adobe brick construction to reveal at least four major construction stages. The final stage measured at least 400 m on a side, and 65 m in height (although the construction of the Colonial church undoubtedly destroyed the uppermost levels). The Great Pyramid was oriented toward the setting sun at summer solstice, the longest day of the year, so that the temple on top of the pyramid would have been the last place illuminated by the setting sun.

The relationship between Maya and central Mexican architecture is particularly strong at the sites of Chichen Itza, in northern Yucatan, and Tula, located far to the west. Chichen Itza features Puuc style architecture with elaborate stone mosaic work to create geometric patterns and visages of deities (Fig. 9). But it also has other architecture with distinctive features that have traditionally been labeled "Mexican" following ethnohistorical accounts that Toltecs from central Mexico invaded the region. This interpretation has been challenged, however, with new dates that suggest that Chichen predates Tula, the highland capital of the Toltecs. Numerous decorative features from both Chichen Itza and Tula are virtually identical, including the use of reclining Chacmool thrones, feathered serpent columns, and colonnaded areas. The close similarities between the two sites has led many to suspect that the two were eastern and western capitals of an extensive Toltec empire, but a near total lack of related elements in the intervening territory adds to the enigmatic status of the two sites. The large pyramid at Chichen Itza is notable because of the feathered serpents that flank the radial staircases (Fig. 10). The pyramid is oriented so that, at the spring equinox, shadows formed by descending serpents appear to undulate down to earth; this phenomenon is a popular tourist attraction drawing thousands to witness the illusion, including living Maya who continue to revere the site. At Tula, north of modern Mexico City, the ceremonial center has a nearly identical plan (albeit 90° off from Chichen Itza). Pyramid B closely resembles Chichen Itza's Temple of the Warriors, with stone warriors as building columns that must have supported the roof (Fig. 11).

The Gulf Coast site of El Tajín does share some iconographic characteristics with Chichen Itza, especially in the use of elaborately carved columns and ball court. Narrative qualities of the carvings seem to relate to political legitimation and alliance building, again emphasizing the ideological content of the built environment. The major pyramid at El Tajín is known as the Pyramid of the Niches, named for 365 empty niches that decorate the façade (Fig. 12). Conceivably these would have originally held idols of gods associated

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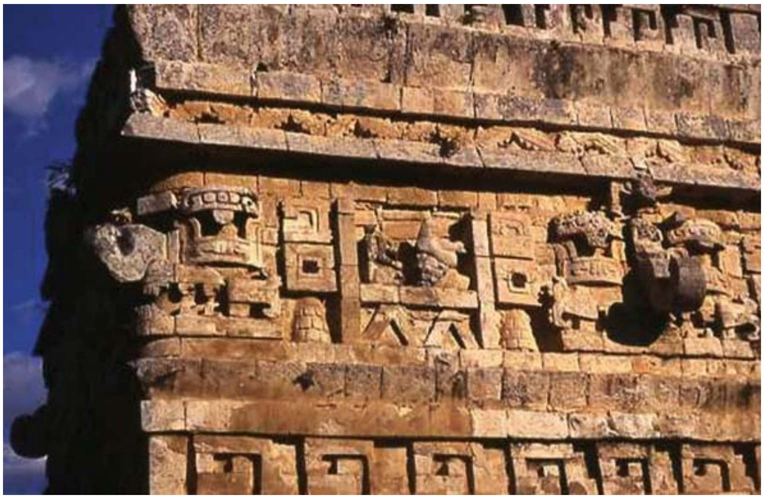

Pyramids of Mesoamerica. Fig. 9 Puuc architecture at Chichen Itza.

Pyramids of Mesoamerica. Fig. 10 The Castillo pyramid from Chichen Itza.

Pyramids of Mesoamerica. Fig. 11 Pyramid B from Tula, showing warrior columns.

with different days of the solar year. Large slabs at the base of the pyramid were drilled with holes where banners representing conquests or forged alliances would have been raised.

The final pyramid to be discussed is also the best known, though ironically it is almost invisible today. When the Spanish entered the Aztec capital of Tenochtitlan in 1519, the Great Temple was the ceremonial center of the Aztec empire. Spanish conquistadors described the temple and associated rites of sacrifice, and artists in the early Colonial period illustrated the Temple. Typical of Aztec pyramids, the Great Temple featured two temples atop a single pyramid base. These were dedicated to Huitzilopochtli, the patron god of war, and Tlaloc, god of storms and rain (Fig. 13). However, shortly after the Spanish defeated the Aztecs they tore down the Great Temple to build their own Colonial capital. Fortunately for later archaeologists the lowermost levels of the pyramid were preserved beneath the rubble (Fig. 14). When utility workers dug at the site in the 1970s they chanced upon a massive carved stone representing the dismembered moon goddess Coyolxauhqui, and based on this discovery a monumental excavation project was begun by the Mexican government to expose the remains of the Great Temple. According to Aztec myth, the Great Temple represented the serpent mountain, Coatepec, where Huitzilopochtli killed his sister, Coyolxauhqui, while defending his mother, Lady Serpent Skirt/Coatlicue. This mythico-historical drama was played out at the Great Temple, which featured serpent head iconography to make it "Serpent Mountain," while the dismembered moon goddess lay at the base of the staircase. Archaeologists have found hundreds of ceremonial offerings at the Great Temple that further emphasize the symbolism of the site. For

Pyramids of Mesoamerica. Fig. 12 Pyramid of the Niches at El Tajin.

Pyramids of Mesoamerica. Fig. 13 Depiction of Great Temple in Codex Duran.

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Pyramids of Mesoamerica. Fig. 14 Excavated Great Temple of Tenochtitlan.

example, stone boxes contain layered dioramas of the three-tiered cosmos represented by successive layers of sea, land, and sky creatures. Sacrificial victims climbing the steps of the pyramid, only to have their hearts removed and their bodies hurled back down the bloody steps, were themselves participating in the mythic drama of creation and rebirth.

The Pyramids of Mesoamerica are among the most visible monuments of the ancient cultures of the region, and the stories that they tell are important clues to the belief systems of the people. Modern tourists marvel at the grandeur of these structures, built using Stone Age technology and without the benefit of draft animals or complex engineering. In fact, the pyramids of Mesoamerica are relatively simple mounds of rock and rubble, albeit decorated with often elaborate stucco façades. What is truly remarkable about these monuments is the meaning content that they embody, as cosmograms reenacting and centering cosmic forces, and as political narratives to legitimize the ruling elite. These pyramids encode important messages about Mesoamerican belief systems, and the critical yet imaginative interpretation of these monuments reveal the mythstories of the Mesoamerican world.

See also: ►Calendars, ►Time, ►Cosmology

Qāḍīzāde al-Rūmī

Gregg De Young

Qāḍīzāde al-Rūmī was born in Bursa, in Turkey, about 765 AH/AD 1364. His talent for scholarship was early recognized, and he was recommended to continue his studies of mathematics and mathematical astronomy among the scholars of Transoxiana (a portion of Central Asia that corresponds today with parts of Uzbekistan and Kazakhstan), then a major center of scholarship. Consequently, about 814 AH/AD 1410, he went to the court of Ulugh Beg, governor of Samarqand (in what is now Uzbekistan) and serious amateur astronomer, and joined his retinue.

In 824 AH/AD 1421, 4 years after establishing a major *madrasa* (school of advanced studies), Ulugh Beg decided to establish an observatory in Samarqand in order to complete and improve the data collected by Naṣīr al-Dīn al-Ṭūsī and his assistants in the *Zīj al-Ilkhānī*. Al-Rūmī, along with his younger contemporary, Ghiyāth al-Dīn Jamshīd al-Kāshī (d. 832 AH/AD 1429), played an important role in both institutions. When al-Kāshī died, al-Rūmī succeeded him as director of the observatory. The work was still incomplete at the time of al-Rūmī's death in 840 AH/AD 1436. It was finally completed under ʿAlī Kushjī under the title *Zīj-i Jurjānī*. In addition to his role in producing these tables, al-Rūmī authored *Sharḥ Mulakhkhaṣ fī'l-Hay'a* (Summary Commentary on Hay'a/Mathematical Cosmography), an influential commentary on ʿUmar al-Jaghmīnī's (d. ca. 745 AH/AD 1345) compendium of cosmography.

In the field of mathematics he is best known historically for his commentary on al-Samarqandī's *Ashkāl al-Taʾsīs* (Fundamental Theorems). His *Risālat al-Jayb* (Treatise on the Sine) displays a greater independence of thought, but even here he relies on the iterative techniques developed by al-Kāshī in order to find the sine of one degree.

See also: ►Ulugh Beg, ►al-Kāshī, ►Naṣīr al-Dīn al-Ṭūsī, ►al-Samarqandī, ►Hay'a, ►Observatories in the Islamic World, ►Zīj

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Qanat

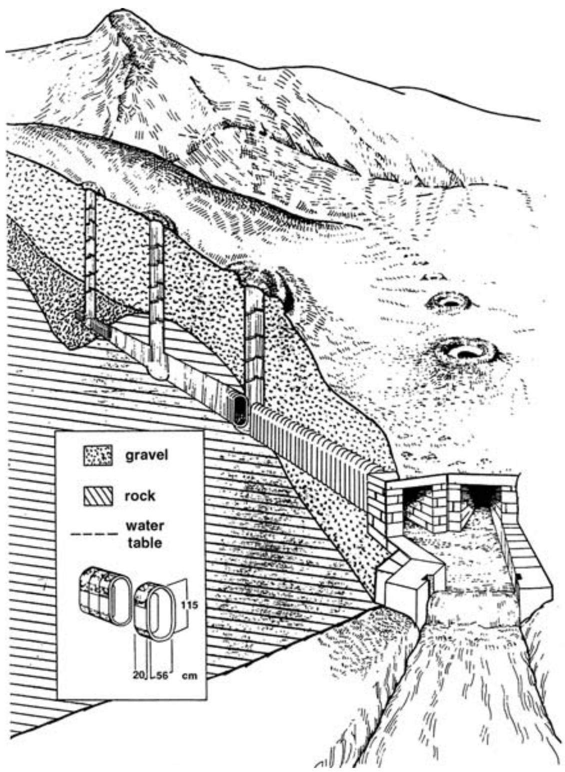
Arnold Pacey

The *qanat*, invented in Iran, is a tunnel that allows a well in hilly country to supply water to users on lower ground by gravity flow.

Once the well has been sunk and has proved to be a good source of water, the route of the tunnel is carefully surveyed, and a series of further wells or guide shafts is dug, each one about 300 m from the next. Excavation of the tunnel begins at the intended outlet and proceeds from the foot of one guide shaft to another. The depth of these shafts has previously been set, so that when the tunnel links them all together, it will have an even gradient of about 1:500. The head well may be anything from 15 to 100 m deep, and tunnels are frequently 2,000 m or more in length (Fig. 1).

As Andrew Watson points out, the history of the qanat can be clearly illustrated by a distribution map showing where water supplies of this kind are to be found. Before the time of Alexander the Great, i.e., before 330 BCE, about the only qanats known to have existed were in Iran. A thousand years later, around AD 700, qanats had been constructed in the Arabian Peninsula and Syria as well as in Persia. But then the Islamic people took up the qanat in a big way. Books were written on the subject in AD 840, and by al-Ḥasan al-Ḥāsib around AD 1000. Knowledge of the technique spread east to Afghanistan and west through North Africa to Morocco, Mauretania, and Spain.

Qanats continued to be developed in later centuries. By the sixteenth century, potteries were making earthenware rings for lining the tunnels where they passed through soft ground. In 1960, three-quarters of all water used in Iran came from qanats, with Tehran



Qanat. Fig. 1 Two qanat tunnels in a typical landscape, where rainwater running off mountains replenishes groundwater beneath the sand and gravel of the lower slopes. (Water-bearing gravel is shown darker than the dry gravel layer above.) The ground penetrated by one of the qanats is shown in cut-away section to demonstrate how the tunnel gives access to water trapped by impervious rock. The section also shows how the tunnel is lined with earthenware rings when passing through sand or gravel layers which might otherwise cave in. Qanat tunnels were excavated from the bottoms of a series of well shafts, with the "mother well" at the upstream end dug first to prove the existence of water. The tunnels were sometimes several kilometers long with their route evident on the surface from the line of well shafts, as on the right of the picture. (Illustration by Hazel Cotterell based on sketches by Arnold Pacey. Reproduced from Pacey 1990: 86.)

alone having 36 of them bringing water from hills several miles away.

The word "qanat" in Arabic is said to be the source of the English word "canal," which was initially used to mean a pipe or tube or tunnel carrying liquid; it retains that usage in anatomy – hence, alimentary canal.

See also: ►Agriculture in Islam, ►Technology in Islam, ►Irrigation in Islam

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Qi

Steven Klarer, Ted J. Kaptchuk

In Chinese culture, *qi* is the common denominator that underlies all being and all behavior and that allows for their interaction and their interpenetration. *Qi* enables seeds, air, and soil to become plants, a mountain range to produce good fortune, or a human being to cultivate wisdom and human kindness. It is what makes possible the processes of chemistry and the researches of the alchemists. *Qi* is the fundamental Chinese articulation of what underlies the universe, what is the universe, and what is the reality of the universe.

Given the key position the concept of *qi* holds in explaining the process of change in Chinese scientific, medical, psychological, and spiritual thought, one is tempted to assume that it is one of the oldest and most central concepts in the Chinese world view. A look at the history of both the character and the concept shows otherwise.

The oldest inscriptions in Chinese, the bones used in the Shang dynasty oracle, are concerned with understanding the process of change in such uncertain areas as agriculture and illness. Nowhere in the more than 200,000 known extant oracle bones can one find the character *qi* or anything which might be its close antecedent or relative. Throughout the oracle bone inscriptions we see that, in Shang culture, change was brought about by the actions of spirits rather than by naturalistic forces.

The character *qi* is composed of an element which signifies vapors which rise to form clouds and another element which means grain. The character may mean vapors arising from cooked food or simply steam. At this level of the character's history *qi* is a simple notion. *Qi* is what makes the lid on a pot of boiling water rattle.

In the course of its development Chinese thought began to look for the origins of change in sources other than the spirits. For a time change, especially illness, was understood to come from the winds of the eight directions, each of which was responsible for causing particular diseases at particular seasons and each of which was personified as a deity. Although this model of change brought about by wind is a step toward a world of naturalistic causality and away from a world of spirit causality, it still has a strong component of the latter. It is probably, however, a major step in the development of the concept of *qi* which later comes to permeate all of Chinese thought.

By the time of Confucius (551–479 BCE), the word *qi* appears in literature but it is rare and its meaning is confined to purely human qualities. The *Analects*, the record of Confucius' teachings, use the word four times, each of which is distinctly related to some aspect of human behavior, such as appetite, tone of voice, breath, and physical stamina. In none of these does it refer to anything beyond a specific physical quality of human life. At this stage in its history *qi* still shows its origin as a common, ordinary term.

The several centuries following Confucius were a critical time of change in Chinese culture. One of the key concepts to emerge at this time was *qi*. Mencius (371–289 BCE), the follower of Confucius, refers to *qi* 19 times and each time it is a concept of major philosophical import. *Zhangzi*, between 399 and 295 BCE, a major Daoist text, refers even more frequently to *qi*. In this text we see one of the earliest and clearest uses of *qi* to refer to a natural force, something which, although an attribute of human beings, is also a power which makes things happen in the world. We see this conceptualization of *qi* (although still connected to wind) as a moving power in the universe in a famous passage from the *Zhangzi*.

> The great clod belches out breath (*qi*) and its name is wind. So long as it doesn't come forth nothing happens, but when it does, the ten thousand hollows begin crying wildly.

Here *qi* is a conceptual model for explaining and understanding the process of change in the observable world. The Shang world of a supernatural spirit causality which had developed into the world of semisupernatural wind causality has now become a world of natural causality. The *qi* model explains the process of change and development in a naturalistic way which is conducive to the expansion of philosophic and scientific thought and inquiry.

By the late third century BCE we see *qi* becoming a concept used throughout Chinese thought. This conceptualization/experiential model is used to explain the qualities of plants and animals, the uses of herbs, and the influences of climate, weather, and geographic location on people. From its use to explain the process of disease and illness comes psychological insights into character and personality types. Eventually, through philosophers such as Wang Yangming (1472–1529), *qi* becomes an essential quality which enables all change since, no matter how they seem to differ, all things share the same *qi*. It also becomes a moral spiritual quality allowing for the oneness of all being.

In recent times, possibly under the influence of Western thought, *qi* has frequently been identified with the Western concept of energy. Westerners are by no means the only ones to make this equation. To characterize *qi* as energy is to invoke a worldview which the Chinese never had, a worldview in which matter and energy are different things. While it is true that modern scientific theory no longer holds that matter and energy are separate entities the words have come, through several centuries of use, to connote, in common parlance, distinct, and separate entities. To the Chinese matter was never inert; it always had dynamic and teleological properties.

As Western concepts of physics have caused some to think of *qi* as energy, nineteenth century western concepts of vitalism have caused it to be identified, especially in medicine, as some form of vital force, distinguishing living things. Historically, however, *qi* has been as much an attribute of a rock or river as of a person or animal. To call *qi* energy or life force is as erroneous as it is to call it matter. It is all and it is neither. *Qi* is the fundamental Chinese articulation of the interconnectedness of the universe, of what the Chinese call the 10,000 things. *Qi* is the cause, process, and outcome of all activity in the cosmos.

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Qianjin Yaofang

Richard Bertschinger

The *Qianjin Yaofang* (Remedies Worth their Weight in Gold), and its sequel the *Qianjin Yifang* (More Remedies Worth their Weight in Gold), were written by the physician and alchemist Sun Simiao (also called Sun Simo) in 652 and 682, respectively, during China's Tang dynasty.

These books are especially valuable for the breadth of their content. They described the medicine of the day, both the systematic acupuncture and herbal tradition, and the less organized folk tradition. Unfortunately neither has as yet been translated into a Western language.

Sun built on the work of Zhang Zhongjing's earlier *Shanghan Lun*, especially in advocating the careful selection, picking and preparation of herbs. In acupuncture he devised the system of *ahshi*! (ow! that's it!)

points, or needling at the tender muscle nodules. These books also contained the author's newly verified and drawn charts of the channels and points on the body, with front, side, and back views – the earliest-known point charts to have been produced. The 12 channels were shown in five colors, while the eight extraneous channels were depicted in green.

Many of Sun's ideas were closer to Western notions of common sense. For instance he put disease down more to incorrect diet than to the influence of evil ghosts and spirits. He advocated general cleanliness to protect against the development of sores and ulcers, and he urged rinsing the mouth out several times after a meal to keep the teeth healthy and the breath fresh. During childbirth he said not more than two or three people should be allowed into the delivery room, to keep the mother quiet and the atmosphere calm, and he excluded anyone who had recently survived a fatal illness. He thus showed an awareness of complications arising in labor through the nervousness of the mother, and of infection spreading to the mother or newborn child. He also advocated the use of gentle exercise in imitation of animals in order to prevent disease and combat the process of aging. He introduced the treatment of night-blindness with goat or ox liver (which is rich in Vitamin A), the use of the thyroid glands of sheep or deer (equally rich in iodine) for a swollen thyroid, and abstaining from salt in cases of edema.

He innovated a clear ethical stance on medical practice, urging the doctor to be vigorous in investigating the disease and finding a suitable treatment. Many of his methods are in line with modern thinking. His work was equally valued in both Japan and Korea and works in these countries quote extensively from his tracts.

See also: ►Sun Simo

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Qibla and Islamic Prayer Times

MOHAMMAD ILYAS

Ṣalāt (prayer) is one of five pillars of Islam. Islam requires all adult sane, healthy, and able-bodied Muslims to perform five daily prayers. The corresponding time intervals are commonly known as "Islamic prayer times."

Muslims are enjoined to face the *Kaᶜba* in Mecca during their prayers. It is believed that *Kaᶜba*, the cubical shaped edifice, was built by the Prophet Abraham. The direction to the *Kaᶜba* from a place is known as its *qibla* direction. Mosques are built with a clear pointer in the qibla direction. Knowledge of the qibla direction is also important for certain other acts, including the call to prayer (*Adhān*), the ritual slaughter of animals for food, and burial of the dead. Muslim astronomers from early times dealt with the determination of the *qibla* and produced highly sophisticated trigonometric and geometric solutions.

The time intervals of the specified daily prayers are clearly specified. The intervals are exclusive of each other; the end of one time interval marks the beginning of the next. Besides regular prayers, there are supplementary prayers, and some of these follow specific time intervals. There are also certain periods of the day during which prayers are prohibited. All this reflects the need for a clear understanding of diurnal phenomena and the proper determination of the time of day. The way in which the various Islamic prayers are distributed throughout the day further emphasizes the treatment of day and night as a single time unit, in contrast to the practice of earlier civilizations in treating them separately. Also, the mutually exclusive time intervals for each regular prayer, which depend upon the specific (local) positions of the sun, introduced a new way of dividing the day.

The Islamic prayer times are so defined that they can be easily ascertained by observation on a clear day. However, under cloudy conditions, one has to resort to some sort of a time clock and mathematical computation. Since the performance of regular prayers within the specified time intervals is a most serious matter, advance determination of the intervals is of great importance. From the very beginning, Muslim scientists were engaged in mastering the techniques of positional and observational astronomy, including instrumentation, and went on to develop this and allied fields. It is not surprising to find that almost all major astronomical works during that period of 500 years incorporated a discussion relating to the Islamic prayer times, which came to be known as *ᶜIlm al-mīqāt* or the times of "fixed positions" of the sun. Closely associated with the Islamic prayer times is the matter of determining the direction of Mecca. Elaborate tables showing the direction of the *Kaʾba* from different parts of the world became an integral part of Islamic astronomical works.

The demarcation of various time intervals is based on the guidelines contained in the *Qurᶜān* and elaborations given in the *Ḥadīth* (Traditions) of Prophet Muḥammad. Based on these, the time intervals were subsequently translated into more precise definitions by the theological jurists of the early centuries of Islam. Muslim astronomers helped to translate these into equivalent astronomical definitions.

In Islam, the day begins at sunset and the time for the first prayer (*maghrib*) begins after the sun has set. The second (*ʿishāʾ*) and third (*fajr*) prayers then follow, the latter ending before the sun begins to rise. The fourth prayer (*ẓuhr*) is performed after midday and is followed by the fifth and last obligatory prayer (*ʾaṣr*) in the afternoon. The optional prayers performed after midnight (*tahajjud*) and a little after sunrise (*chasht*) have special importance. The time durations during which the sun rises, sets, and crosses the local meridian are prohibited times and no prayers are generally allowed during these periods. Thus, one has to determine the various portions of the day in a sequential and somewhat symmetrical way.

As we know, the "true" solar day-length keeps changing through the seasons. Therefore, on a 24 hour civil clock, the solar phenomena, such as midday and midnight, keep moving backward and forward. However, as the Islamic time intervals are related directly to the true natural (solar) phenomena and not to the day length, it simply boils down to the daily determination of the times of various astronomical phenomena according to whatever day-time system is used, e.g., time-hours or time-degrees would be equally applicable. This situation obviously laid down strong foundations for mathematical–dynamical astronomy. Also we can recognize that the "day-time" length depends upon the season and the latitude and varies from a winter minimum to a summer maximum. For Islamic fasting, which is done from dawn to sunset, some countries are favored (shortest duration) in one season and others in a different season. In Islam, this situation has been fully taken care of through the rotation of the Islamic (lunar) months through the seasons.

Muslim astronomers during the medieval period made considerable efforts to construct tables of Islamic prayer times according to the defined solar positions. The data on the solar position (azimuth) at different altitudes was also used for observationally determining the direction of the *qibla*. It was important to present the prayer times in the form of basic universal tables which would remain unchanged over a long time. These tables could then be used through secondary and smaller tables which could be recomputed if necessary.

These tables were universal, since the Muslims used a purely lunar calendar independent of solar calendar dates. For each new day/date, one simply needed to ascertain the solar longitude by direct measurement or through the simultaneous measurement of positional parameters at meridian passage.

Muslim astronomers' interest in regulating daily time went beyond the determination of prayer times to include overall time measurement. Their tables contained information on various time parameters, such as length of daylight and duration of the fasting period (from morning twilight to sunset), auxiliary tables on various functions needed in computations, and special tables on parameters such as the solar azimuth and solar altitude in certain azimuths for use in *qibla* determination, besides supplementary information on such parameters as horizontal refraction. The prayer tables were generally produced with great computational skills and care and in a comprehensive way. A study of Cairo's tenth-century astronomer Ibn Yūnus' *Kitāb Ghayat al-intifa' fi ma.'rifat al-da'ir wa-faḍlihi wa-l-samt min qibal al-irtifāʿ* (Very Useful Tables for Finding the Time since Sunrise, the Hour Angle, and the Solar Azimuth, from the Solar Altitude), one of the major *mīqāt* tables, shows that Ibn Yunūs' values were, in general, very carefully computed. The tabular works incorporating *ṣalāt* times and other auxiliary tables were prepared for various major localities of the Muslim world, such as Cairo, Mecca, Medinah, Jerusalem, Damascus, Tripoli, Aleppo, Tunis, Istanbul, Baghdad, and towns in West Africa, Andalusia and the Indian subcontinent. Later work by a Damascus astronomer, al-Khalīlī (fourteenth century), greatly expanded the dimension of *mīqāt* tables by latitude and longitude degree of the globe. David King's comparison of al-Khalīlī's data with modern calculations shows his work to be remarkably accurate. Al- Khalīlī's tables may thus be considered to present the first global data set on the *qibla*.

We noted how, through the ingenious use of solar longitude, the Tables were made time-invariant and independent of the solar calendar, and the computational system was further expanded to determine the solar altitude for a specific solar azimuth, giving the direction to Mecca. In this way, an accurate astronomical method was developed to meet an additional need. The remarkable achievements in mathematical astronomy mark the high points of Islamic astronomy.

In the period after the introduction of the mechanical clock, a 24-equal-hour civilian day took over from the 12-hour daytime and 12-hour nighttime day which had dominated civilian timekeeping systems well into the fourteenth century. Although Muslim scientists had started to utilize an Islamic equal hour day, the use of true solar time and sundials prevailed in non-European and Islamic countries for quite a while. The detailed tables of Islamic prayer times constructed for specific localities of the Muslim world in the early centuries have remained in effective use right into modern times.

We are aware that as we go toward the higher latitudes, the usual cycle of daylight, twilight, and night begins to change during certain parts of the year. First, the night gets shorter and shorter with the increasing latitude, until the evening twilight merges with the morning twilight. In other words, the clear distinction of the end of the evening twilight from the beginning (or end – depending how one looks at it) of morning twilight no longer exists, and the determination of times for the beginning of *ishā*, *fajr*, and fasting cannot be done through the conventional solar position basis. As one moves toward the higher latitudes, even the twilight period gets shorter, to the extent that the end of the day merges with the beginning of the day, so that the sun does not set (or rise) but remains continuously above the horizon. In a situation like this, with 24 hours of daylight, how is one to determine the times of *fajr* and *maghrib* prayers and how is one to fast a "nonending daylight" day? This is one of the questions that needs to be tackled within the theological rather than the scientific arena.

See also: ►Ibn Yūnus, ►al-Khalīlī, ►Religion and Science in Islam I

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Qin Jiushao

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Qin Jiushao is one of the few mathematicians in China of whom we have fairly detailed biographical data, since he held subsequent positions in government administration. Although not mentioned in the biographies of the official Song dynasty historical annals, numerous references to Qin Jiushao can be found in local monographies or writings by his contemporaries.

Qin was in all probability born in 1202 in Puzhou (now Anyue in Sichuan province). In his youth he was commander of the "patriotic soldiers", an armed force outside the regular military establishment, in his native place. In 1224–1225 his father was given an appointment in the capital of Southern Song, Hangzhou. In the preface to his *Shushu Jiuzhang* he says, "In my youth I was living in the capital, so that I was able to study in the Board of Astronomy; subsequently, I was instructed in mathematics by a recluse scholar". According to analysis of his mathematical work he must have studied the *Jiuzhang suanshu*. In 1226 he was staying with his father in Tongchuan (now Santai in Sichuan province). When the Mongols began their conquest of Sichuan and destroyed its capital Chengdu in 1235, Qin was at the frontier as a military official.

According to his own preface it was during this period of distress that his mind went back to the mathematical studies started in his youth. He escaped calamities by going to the southeast. He was appointed subprefect in Qizhou (now Qichun in Hubei), where he behaved badly, causing a military revolt. Later he was appointed prefect in Hezhou (now Hexian in Anhui), where he was responsible for the salt trade and sold salt illegally to the people, so that he left the southeast as a rich man, settling in Huzhou in Zhejiang. In 1244, he was named Court Gentleman for Comprehensive Duty in the prefecture of Jiankang (now Nanjing in Jiangsu). After three months he resigned because of his mother's death and returned to Huzhou. It was during this 3-year mourning period that he wrote his mathematical work, which appeared in 1247. As a consequence he was recommended to the throne on account of his calendrical science, and he was allowed to take part in the examinations. We can only suppose that something went wrong, as we find him as consultant of the Directorate of Military Affairs in Jiankang from 1253 until 1259. However, after that he resigned and went back to his native place. He paid a visit to chancellor Jia Sidao, and he got an appointment as prefect of Qiongzhou (now Qiongshanxian) in far Hainan. But after a few months he had to leave Qiongzhou because he was impeached for corruption and exploitation of the people. He followed his friend Wu Qian, who was a naval officer in the district of Yin in Zhejiang, and in 1259 he was appointed assistant in the Court of the National Granaries there. Wu Qian subsequently became a minister, but when he was disgraced in 1260, chancellor Jia Sidao also collected data about Qin, and put him away in Meizhou (now Meixian in Guangdong), where he died in 1261 at the age of 60.

See also: ►Shushu jiuzhang, ►Liu Hui and the *Jiuzhang suan-shu*, ►Salt

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Quadrant

RICHARD P. LORCH

The quadrant is an instrument which was used for measuring angles and for making astronomical calculations. Apart from those for the accurate observation of altitude, known to us almost entirely from written descriptions, the quadrants of the Arabic Middle Ages were portable. They fall into three categories: those carrying a projection, or two-dimensional representation, of the celestial sphere (the imaginary sphere containing the stars and celestial circles); those designed for astronomical calculations; and horary quadrants, i.e., those used specifically for telling the time by the altitude of the Sun. Most have a thread fixed at the vertex carrying a movable bead for transferring distance from the vertex from one point of the instrument to another. Of the first type the best known is the astrolabe quadrant, invented before 1100. These are essentially the plate and rete of a standard astrolabe overlaid on one another. The motion of a star (or the Sun) is imitated by the motion of the bead, which has been set by putting it over the representation of the star, about the vertex. In the *shakkāzīya* plate associated with the name of ʿAlī ibn Khalaf (eleventh-century Toledo) and taken over by al-Zarqāllu (Arzaquiel), celestial coordinates may be converted (e.g., ecliptical coordinates into equatorial) either by moving one projection over another or by using one twice and transferring one set of coordinates to the other by means of the thread and bead.

The second type of quadrant is closely related to graphical solutions of astronomical problems by ruler and compasses, the function of the compasses being taken over by the string and bead (or ruler) fixed at the vertex. Many astronomical calculations involve the use of sines of arcs in a standard circle (a sine is half the chord spanning double the arc) and these may be drawn as lines parallel to one side of the quadrant. Multiplication may be achieved by the help of scales and the thread and bead. The sine quadrant is well attested in the tenth century and was probably known in ninth-century Baghdad.

The horary quadrant was a quadrant on which "hour-lines" were represented on the face of the instrument by circular arcs issuing from the vertex. The altitude of the Sun is taken by using sights on one side of the instrument and seeing where the thread, weighted with a plumb-bob, falls on the markings. When the position of the bead has been set for the day (e.g., by the noon altitude and the corresponding hour-line), the time can be read off from its position among the hour-lines. In some forms of the instrument a ruler or alidade takes over the functions of the thread and bead. The hours measured by the instrument are "seasonal" hours, for which 1 h = 1/12 time of daylight. The instrument, which is universal, is inaccurate in high latitudes. Underlying the instrument is an approximate formula, which probably came from India, used for calculating tables and also applied to a type of sine quadrant. Horary quadrants and related instruments were often provided with a cursor, or sliding plate carrying markings to facilitate the initial placing of the bead.

There were several further varieties of quadrant – e.g., horary quadrants for fixed latitudes – and also numerous mixed forms. Much of our knowledge of the rarer forms comes from the encyclopedic treatises of al-Marrākushī (thirteenth-century Cairo) and Ibn al-Sarrāj (fourteenth-century Aleppo). The "new" quadrant of Jacob ben Machir (thirteenth-century France), with its combination of horary quadrant and astrolabe projection, appears not to be of Arabic origin.

See also: ►Celestial sphere, ►Astronomy, ►Time, ►Astrolabe, ►al-Zarqāllu

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Quarries in Harappa

Paolo Biagi

It is surprising to note that one of the most important raw materials exploited by the III millennium BCE Bronze Age Harappans of the Indus Valley and its related territories was flint. Although the importance of this siliceous stone has never been pointed out even in the most recent publications on the subject (see for instance Lahiri 1992), nevertheless the research carried out mainly during the last 20 years in the Rohri Hills (Biagi 1997) and also in the artisan workshops of the metropolis of Mohenjo-daro (Vidale 2000) have shown the fundamental role played by flint in the wider context of this highly developed urban civilisation of the Indian subcontinent.

Although the Rohri Hills have been known since the end of the 1980s as a raw material source, systematic surveys and excavations in the region were undertaken only in the 1990s by the Ca' Foscari University of Venice (Italy) and the Shah Abdul Latif University, Khairpur (Sindh, Pakistan; Biagi and Shaikh 1994). The first to report the presence of flint artefacts from this region was Blandford (1880: 103), who, in his *Geology of Western Sind*, describing the flat tops of the Rohri Hills south of Rohri, wrote that, "the surface of the limestone consists in general of a series of low slopes, corresponding in direction to the dip of the rock. The flints weather out and cover the surface throughout a large area; cores and flakes split from them being scattered about in abundance in some places" (Fig. 1). The same author mentions the recovery of "some flint cores, from which flakes have been chipped, obtained from Lieutenant Twemlow, R. E., in the bed of the Indus. The cores were remarkable for their regularity" (Blandford 1880: 20). These latter cores were first illustrated by Evans (1886: 28) who was "superintendering excavations connected with a canal, near Shikarpoor, in Upper Scinde". Furthermore Blandford (1880: 20) reports that "large quantities of flint cores have been found near Sukkur and Rohri, and there is a good collection in the Geological Museum Calcutta" (Figs. 2 and 3).

Quarries in Harappa. Fig. 1 A Harappan flint workshop mainly composed of debitage flakes.

Quarries in Harappa. Fig. 2 The Indus at Rohri.

Quarries in Harappa. Fig. 3 Fishermen flat-bottomed boats in the Indus at Sukkur.

Apart from the re-discoveries made by Cousens (1929) and De Terra and Paterson (1939), Allchin (1976: 477) of the University of Cambridge visited the northernmost edge of the hills, near Sukkur and Rohri, in December 1975. Here she noticed "extensive Harappan working floors on the top of several of them", which were illustrated by the same author in another of her papers (Allchin 1979), where she describes each of them as "an area large enough for a man to sit cross-legged", which "had been completely cleared of stones" (Allchin et al. 1978: 276).

Before the complete destruction of this important archaeological area, due to industrial quarrying, the limestone mesas south of Sukkur were visited by the present author in April 1985 and again in 1986, when groups of large flint quarries were discovered by the present writer and Professor M. Cremaschi of Milan University in the Shadee Shaheed region (Figs. 4–6).

The Rohri Hills

The Rohri Hills, which are some 40 km long and 16 wide, extend in a north–south direction between the course of the Indus and the cities of Sukkur and Rohri, in the north, and the westernmost fringes of the Thar Desert, in the south (Fig. 7), which, in this part of the country is very rich in salt-lake basins (Figs. 8 and 9). The hills consist of fossiliferous limestone rocks of the Brahui formation attributed to the Middle Eocene/ Early Oligocene period, very rich in seams of good quality flint, which attracted the prehistoric populations from the Early Palaeolithic onwards (Biagi and Cremaschi 1988) (Fig. 10). They separate two very different environmental regions, the Indus Valley to the west and the Thar Desert to the east. Their eastern fringes are lapped by the Nara Canal, which flows inside the old bed of the Hakra–Ghaggar River. The hills are limestone mesas (Fig. 11), dissected by erosion and

Quarries in Harappa. Fig. 5 A concentration of debitage flakes along the edge of a Harappan flint quarry-pit on the Shadee Shaheed Hills.

Quarries in Harappa. Fig. 6 The circular appearance of a flint quarry-pit at Shadee Shaheed.

Quarries in Harappa. Fig. 4 The hill to the east of the Shrine of Shadee Shaheed where the first Harappan flint quarries were discovered in 1986.

Quarries in Harappa. Fig. 7 The southwestern fringes of the Rohri Hills party covered by the Thar Desert sand dunes.

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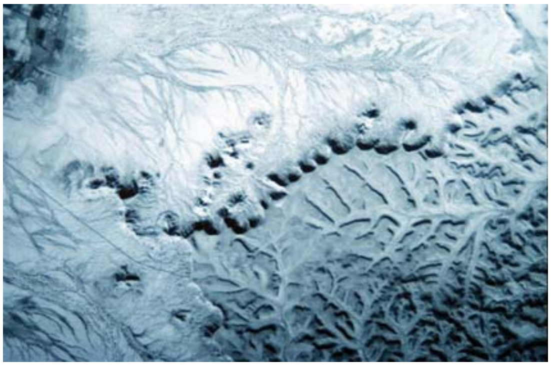
Quarries in Harappa. Fig. 8 A salt-lake basin near the caravan city of Thari, south of the Rohri Hills.

Quarries in Harappa. Fig. 11 The western fringes of the central part of the Rohri Hills.

Quarries in Harappa. Fig. 9 The high sand dunes surrounding the salt-lake basin of Sāin Sim.



Quarries in Harappa. Fig. 12 An aerial view of the Rohri Hills at Shadee Shaheed and their very corrugated system.

Quarries in Harappa. Fig. 10 Acheulian Bifaces on the surface of a workshop near the tomb of Ziarāt Pir Shabān on the Rohri Hills.

deeply incised by old river courses (Fig. 12) (Biagi 2004).

As mentioned above, the surveys carried out in 1986 led to the discovery of groups of Harappan flint quarries and workshops in the Shadee Shaheed area of the hills (Biagi and Cremaschi 1991). Here the most impressive structures were located along the edges of the limestone plateau (Fig. 13). From the surface the quarries consisted of almost circular empty areas, representing the quarry–pits, filled with aeolian sand, blown from the Thar Desert dunes, and heaps of limestone block, deriving from the prehistoric mining activity (Fig. 14). All around these structures flint workshops were noticed (Fig. 15), represented by scatters of flint flakes and blades among which were typical Harappan-elongated blade cores and characteristic bullet cores with very narrow bladelet detachments (Fig. 16). During the same survey, it was possible to observe that large areas of this part of the hills had already been highly damaged by illegal activities carried out by limestone quarriers (Figs. 17 and 18), and that even wider devastations were in progress by modern industrial quarrying (Fig. 19). Nevertheless it was possible to notice that the area covered by the

Quarries in Harappa. Fig. 13 Professor Cremaschi positioning the first Harappan flint quarries at Shadee Shaheed in January 1986.

Quarries in Harappa. Fig. 14 Aerial view of part of the main system of Harappan, flint quarry-pits on the hills near Shadee Shaheed.

presence of groups of prehistoric quarries was very wide and extended all over the central-western region of the hills. Harappan quarries were discovered also in the valleys of the internal mesas (Fig. 20).

The Excavation of Quarry–Pit 862

The excavation of Quarry–pit 862 was carried out between 1995 and 1998. This quarry lies along the western edge of the Shadee Shaheed Hills, some

Quarries in Harappa. Fig. 15 Very wide, circular concentration of Harappan debitage flakes near Shadee Shaheed.

Quarries in Harappa. Fig. 16 Harappan bullet cores with very narrow bladelet detachments.

Quarries in Harappa. Fig. 17 Large area cleaned by the quarries. The modern heaps of flints are clearly visible.

3.5-km south of the shrine that bears the same name (Fig. 21). "The site is part of an impressive, wide ring-shaped group of features, some 120 m in diameter, related to a Harappan flint quarrying activity area"

Quarries in Harappa. Fig. 18 Modern hand-made quarrying along the fringes of the Rohri Hills mesas.

Quarries in Harappa. Fig. 19 Machine quarrying in the central part of the Rohri Hills as it was in 1999.

Quarries in Harappa. Fig. 20 An internal region of the central part of the Rohri Hills rich in groups of Harappan flint quarries and workshops.

(Starnini and Biagi 2005: 1). The quarry was surrounded by several flint scatters and workshops (Negrino et al. 1996), one of which was connected with the production of narrow bladelets from typical bullet cores (see Fig. 16). As mentioned above, the

Quarries in Harappa. Fig. 21 The beginning of the excavation of the Harappan flint quarry pit 862 in the Rohri Hills.

excavation was carried out during four fieldwork seasons. It was aimed at the understanding of the quarrying techniques employed by the Harappan workers and the understanding of its chronological attribution. Thanks to the discovery of two small pieces of *Zyzyphus* cf. *nummularia* charcoal it was possible to obtain an AMS radiocarbon date of the main quarry–pit. It gave the result of 3,870 ± 70 uncal BP (GrA-3235), which attributes the structure to the Mature Harappan Civilisation (Biagi 1995). The excavation covered an area of some 60 m^2 down to a depth of 1.5 m, where the floor reached by the Harappan workers was found (Fig. 22), inside which dozens of extractive holes containing flint nodules still in situ (Figs. 23 and 24) were discovered (Starnini and Biagi 2005, Fig. 4). The excavation did not yield any metal or other extractive tool which might have been employed for breaking the fissured limestone and reaching the flint seam. In contrast it produced a huge amount of flint debitage (Fig. 25) and several hammerstones and cores from the same material. On the basis of the field observations, "the preparation of the precore rough-outs was most probably performed inside the quarry trench, or along its edge, as many decorticating flakes, pre-forms and typical crested blade-like-flakes found inside the ditch fill should indicate" (Starnini and Biagi 2005: 5).

The Daphro Hill

The surveys carried out on the Daphro Hills, south of Hyderabad, in Lower Sindh, led to the discovery of other flint extractive quarries also in this region (Biagi 2006). At least three different points of this hill revealed the presence of flint extractive systems similar to those observed along the western mesas of the Rohri Hills in Upper Sindh (Figs. 26 and 27). Apart from ditches excavated along the edges of these limestone mesas, the surveys revealed the presence of flint

Quarries in Harappa. Fig. 22 The flint seam reached by the Harappan quarries during the mid III millennium BCE with many nodules still *in situ*, ready for extraction at quarry-pit 862.

Quarries in Harappa. Fig. 23 A large flint nodule discovered in the bottom layer of the excavation carried out at quarry-pit 862.

Quarries in Harappa. Fig. 24 A small flint nodule prepared for its extraction in the bottom layer of the excavation carries out at quarry-pit 862.

Quarries in Harappa. Fig. 25 Concentration of flint debitage flakes discovered during the excavation of quarry-pit 862.

Quarries in Harappa. Fig. 26 A large, Harappan flint workshop discovered in the Daphro Hill in 2006.

Quarries in Harappa. Fig. 27 Three parallel, Harappan flint extraction trenches opened along the edge of the Daphro Hill.

workshops (Fig. 28), undoubtedly attributable to the Harappan Civilisation, as indicated by the occurrence of characteristic elongate, subconical, flint cores with long blade detachments (Fig. 29). At Daphro, the presence of large-sized pre-cores (Fig. 30), already prepared for being transported, is of major interest.

Quarries in Harappa. Fig. 28 A long Harappan flint extraction trench excavated along the edge of the Daphro Hill.

Quarries in Harappa. Fig. 30 Harappan flint pre-core already oval-shaped for its exportation to one of the Harappan urban centres of the Indus Valley.

Quarries in Harappa. Fig. 29 Harappan elongated core for the production of long, narrow flint blades with parallel edges.

Single pre-core specimens have been found at Mohenjo-daro, the Rohri Hills and Kahiro Bhandari near Badin, close to the Runn of Kutch. This discovery is particularly important because it indicated that not only the final products, such as well-defined types of blades and bladelets were transported to the major centres of the Harappan Civilisation for being transformed into instruments for craft production around the middle of the III millennium BCE, but also complete, large blocks of flint already prepared for their transport.

Considerations

The discoveries made in the Rohri and Daphro Hills have demonstrated that flint was still extremely important during the flourishing of the III millennium BCE Harappan Civilisation. Flint was extracted not only from the Rohri Hills quarries, but also from Daphro and possibly other outcrops during this period and traded over long distances at least as far as Harappa, to the north, and the cities located along the north Arabian Sea coast, to the south. The complicated extractive system, which undoubtedly involved a great number of workers and knappers, and the extraordinary great number of quarries discovered on the Rohri Hills indicate that this raw material was of primary importance at least during the Mature Harappan Civilisation. Although the extraction systems have not been fully understood and the trade routes are still badly known, there is no doubt that the role played by this raw material has so far been underestimated by archaeologists.

Furthermore the damage to a more comprehensive knowledge of the Harappan Civilisation caused by the systematic devastation, for illegal industrial activities, of both the aforementioned archaeological areas of Upper and Lower Sindh is remarkable.

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Quipu

MARCIA ASCHER, ROBERT ASCHER

Quipus were the logical–numerical recording devices of the Incas, a civilization that dominated western South America from about 1400 to 1560. In almost every respect, the Incas are comparable to other early civilizations. They maintained a highly developed bureaucracy with strong centralized authority. They built an extensive road system, maintained a state religion, and supported a large mobile army. They constructed and regulated irrigation systems, built storage facilities, and organized distribution networks, and they forged communications linking cities and villages, up, down, and across a terrain that included mountains, tropics, desert, and seacoast.

The Incas differed from other early civilizations in one crucial respect – they had no writing as we generally understand the term. We generally understand writing to be a system based on the sounds of speech. But writing can also be based on units of meaning. This latter form, called *concept writing*, is used, for example, in chemistry and choreographics. Quipus are no doubt the most highly developed and widely applicable known use of concept writing (Ascher 2002). In Inca civilization, quipus served the important ends that sound-based writing served elsewhere. Quipus were, for example, used to keep track of agricultural yields and population sizes. There is good reason to believe that they were used to follow astronomical events. Also, they may have been used for planning purposes, such as laying out structures to be built or scheduling amounts and types of goods to be moved from one location to another.

The Inca state had existed for about 100 years when the Spanish arrived to conquer. A short time after that, Inca civilization collapsed. Knowledge of quipus was largely lost with the conquest. We have no sure way, for example, to assign a specific meaning or usage to a particular quipu. What we can know now comes from two sources: writings in Spanish, mostly by the conquerors; and quipus that were already in graves and then excavated at a much later date. Both sources pose problems of interpretation, but studies of the quipus themselves have proved most fruitful. Some 475–500 quipus are now located mostly in museums spread across three continents. About 400 of these have been studied and 200 recorded in detail (Ascher and Ascher 1978, 1988). These extensive, detailed descriptions are available at ►http://instruct1.cit.cornell.edu/research/quipu-ascher/.

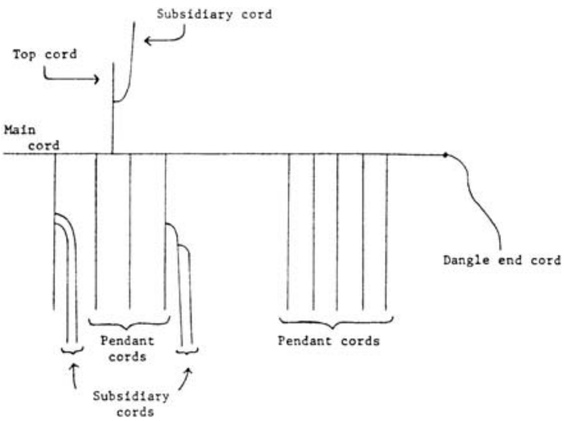
The generalizations that follow are based largely on this quipu corpus.

A quipu is a spatial array of multicolored knotted cords. In general, a quipu has a main cord from which other cords are suspended. Most of the suspended cords fall in one direction (pendant cords); sometimes a few fall in the opposite direction (top cords). Often other cords (subsidiary cords) are suspended from some or all of the pendant or top cords. And, there can be subsidiaries of subsidiaries, and so on. (Notice in Fig. 2 that the first pendant has two subsidiaries on the same level while the fourth pendant has two levels of subsidiaries.) Occasionally there is a single cord distinctively attached to the end of the main cord (dangle end cord). A quipu can be made up of from as few as three cords or as many as 2,000. On some, there are as many as ten levels of subsidiaries and, on others, as may as 18 subsidiaries per level. All cord attachments are tight so that the spacing between cords is fixed and serves to group or separate the cords. Color is another important means of associating or differentiating cords within a single quipu. For example, ten cords can be formed into two groups by having five yellow pendants followed by five red pendants, or by a five-color sequence repeated twice. In the latter case, each cord is not only associated with its group, but also with the like-colored cord in the other group. In all, a complex logic of associations and distinctions is created by combining cord type, cord spacing, cord level, and cord color.

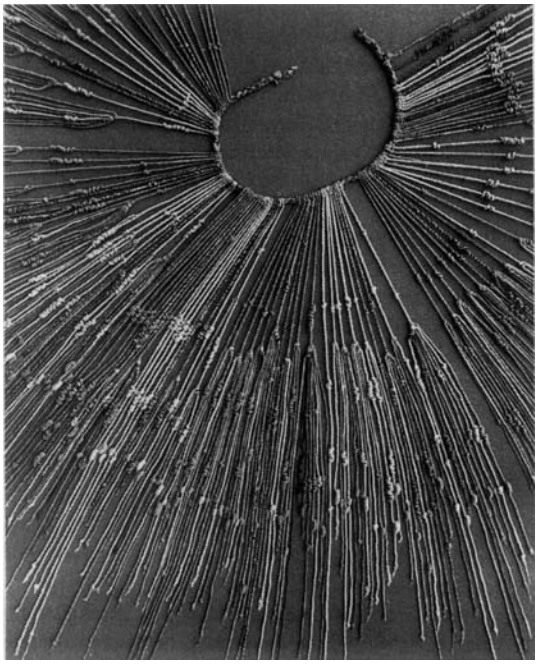
Within this logical array, numbers are represented by spaced clusters of knots on the cords. Only three types of knots appear: simple overhand knots, long knots of two or more turns, and figure-eight knots. Depending on the knot types and relative cluster positions, each cord can be interpreted as one number or multiple numbers. If it is one number, it is an integer in the base 10 positional system. Each knot cluster represents a digit and each consecutive cluster, starting from the free end of the cord, is valued at one higher power of 10. The units position is always a long knot or a figure-eight knot; all other positions are clusters of simple knots. When, instead, the cord carries multiple numbers, they are still base 10 integers, but each of the interspersed long knots or figure-eight knots signals the start of a new number (Fig. 1–4).

Crucial to a base positional system is the concept of zero, namely that "nothing" is identified in some way. On the quipus, careful knot cluster alignment from cord to cord makes evident a position with no knots within a number. This is further supported by the identification of the units position by knot type. What is more, the color coding of the cords enables the distinction between a cord with value zero and an intentional omission or blank.

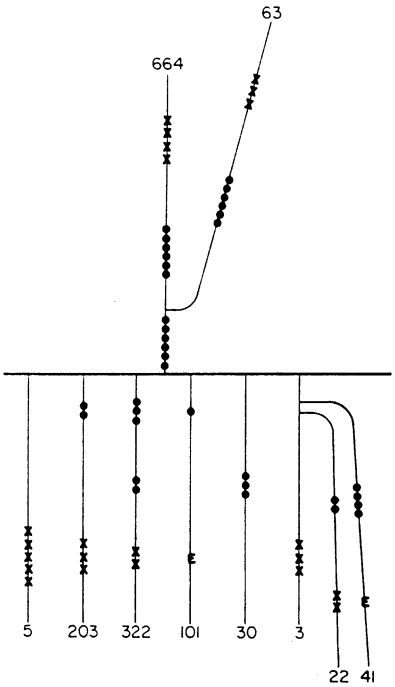
In Fig. 3, the top cord carries the sum of the pendant cord numbers. When top cords appear, that is generally their role. This relationship between cord types and cord values was first observed by Locke (1923),



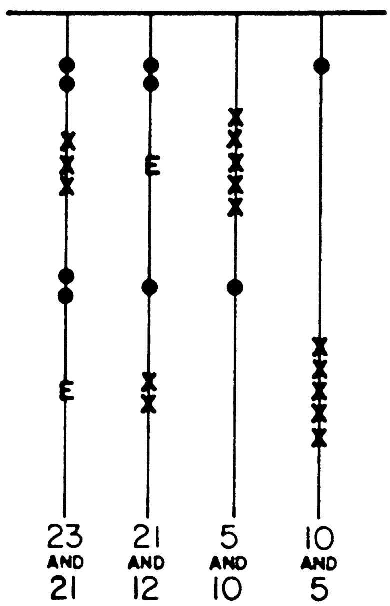
Quipu. Fig. 2 A schematic of a quipu.



Quipu. Fig. 1 A quipu in the collection of the Museo Nacional de Anthropología y Arquelogía, Lima, Peru (photo by Marcia and Robert Ascher).



Quipu. Fig. 3 A schematic showing numbers represented by knots (● = simple knot; x = one turn of a long knot; E = figure-eight knot).



Quipu. Fig. 4 A schematic showing multiple numbers represented by knots (● = simple knot; x = one turn of a long knot; E = figure-eight knot).

corroborating the numerical interpretation of the knots. Consistent with the structural indicators of cord type, color, and placement, many arithmetic relationships are found on quipus. There are, for example, groups that sum values in other groups which, in turn, are summed elsewhere, and sets of values with consistent ratios. There are even numerical relationships that involve several linked quipus. Some of the data structures are analogous to spreadsheets, matrices, and tree diagrams. But what makes the quipus a general recording device is that numbers are used as labels as well as magnitudes. This usage of numbers has recently become prevalent in our culture where, for example, 1-207-667-4854 identifies a type of phone call, a geographic region, a locale within that region, and a specific telephone within that locale.

The logical–numerical system of the quipus was sufficiently standardized to be read and interpreted by the community of trained quipu-makers. The quipus were not ad hoc personal mnemonic devices; they were the means of communication and record keeping of a large bureaucratic state. Both quantitative and nonquantitative information are a part of these records. Most recently the nonquantitative aspects are receiving more scrutiny (Ascher 2002; Brokaw 2003; Quilter and Urton 2002). And there is a unique case where apparently Inca period quipus are venerated in a contemporary Andean community (Salomon 2004). In a very real sense, quipus are the quintessence of, or metaphor for, Inca civilization. Like the civilization itself, quipus emphasize regularity, spatial arrangement, and portability, and their construction is highly methodical and conservative.

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Q

Qusṭā ibn Lūqā

E. Ruth Harvey

Qusṭā ibn Lūqā is one of the important figures in the transmission of Greek scientific writings to the Muslim world and subsequently to the Latin west. The ancient Arab biographers say that he was a Christian of Greek origin from Baalbek (Heliopolis) in Lebanon; he visited the Byzantine empire and brought back Greek texts which he then translated into Syriac and Arabic. He worked for the Caliph al-Mustaʿīn (862–866) in Baghdad, where he may well have known al-Kindī and Thābit ibn Qurra; he died in Armenia (ca. AD 912/300 AH) where he had been an honored guest of the ruler Sanharib.

Qusṭā is important both for his translation and for his original works. The transition of Greek science and philosophy into the Arab world resulted in the development and preservation of traditions largely lost to the west. Most western medieval science owes a great debt to the Arab scholars who kept alive this vital link with ancient learning. Qusṭā provided versions of Diophantos' *Arithmetica*, Hypsícles' *Liber…de ascensionibus*, Autolycus' *De ortu et occasu*, Theodosius of Bithynia's *De sphaeris*, and Hero of Alexandria's *Mechanics*; Qusṭā's Arabic version of this last work is the only text extant today. He is credited with other translations, notably some of the works of Aristotle with the commentaries of Alexander of Aphrodisias and John Philoponos, but they do not appear to have survived.

The biographers provide a list of over 60 original works by Qusṭā; the titles suggest that most are medical, but some are clearly works on mathematics, astronomy, logic, and natural science. Sezgin provides a list of the medical works of Qusṭā which are known to survive in manuscript. Very few of them have been printed, although interest in Qusṭā's treatises is increasing. His little monograph on infection (*Kitāb fī al-iʿdāʾ*) explains in terms of the medicine of the day how some diseases are contagious, and his *Viaticum*, explaining various principles of health and hygiene for travelers are both now available. His work on sex has been published in Germany, but is not readily obtainable. A work on the efficacy of amulets is extant only in the Latin translation of Arnald of Villanova (called both *De physicis ligaturis* and *De incantatione*); the Arabic text of his work on the celestial globe still exists and there are in addition medieval translations of the treatise in Latin (*De sphaera solida*), Hebrew, Spanish, and Italian.

Probably the most famous and influential of all Qusṭā's works is the short treatise on the difference between the spirit and the soul (*Kitāb fī 'l-farq baina 'l-nafs wa 'l-rūh*), which, in the Latin translation of John of Seville, was used as an authority by almost all medieval Western physicians and by some of the philosophers. It distinguishes carefully between the immortal soul and the bodily "spirit of life" within man. The idea that a material but gaseous substance existed inside the human frame and made possible the functions of life, sensation, and motion was an essential part of medical doctrine in the days before the discovery of electricity. Qusṭā's lucid explanation was received as a kind of gloss or commentary on Aristotle's *De anima*. It was frequently misattributed to Constantine the African.

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Rainwater Harvesting

Arnold Pacey

Throughout history people have lived in areas where there are few rivers and where the direct collection of rainwater from roofs, paved courtyards, hillsides, or rock surfaces is one of the best available methods for securing a water supply. By extending this principle to provide water for crops, early civilizations practiced agriculture much further into the semidesert areas of Arabia, Sinai, North Africa, India, and Mexico than has been possible in modern times – and this is not explicable by changes in climate.

Agriculture in the Old World originated in climatically dry regions in the Middle East and may have depended to some degree on rainwater running off nearby slopes almost from the start. Evidence is lacking until a later period, however, when some of the most striking applications of rainwater harvesting were related to crop production in the Negev Desert between 200 BCE and AD 700. One technique would be to dig a channel across a hillside to intercept water running downslope during storms. The water would be directed onto fields which, in the Negev, were carefully leveled and enclosed by bunds (an embankment or dike). Further west, steeper hillsides were used in Morocco, with cultivation on flat terraces formed behind stone retaining walls. In Tunisia, French travelers in the nineteenth century noted fruit trees being grown at the downslope end of small bunded rainwater catchment areas or microcatchments.

In India, one common technique is simply to build a bund across a gently sloping hillside, so that runoff flows originating from rainfall collect behind the bund, where water is left standing until the planting date for the crop approaches; then the land is drained, and the crop sown. This land behind the bund which is seasonally flooded and then later planted with a crop is known as an *ahar* in Bihar, or a *khadin* in Rajasthan. Although some *ahars* may be only one hectare in extent with a bund 100 m long, others are very large and account for 800,000 ha of cultivation in Bihar state. In desert areas of Rajasthan, there are many *khadins* of 20 ha or more, some of them having been first constructed in the fifteenth century AD.

In North America, research on the modern potential of runoff farming methods has been stimulated by the realization that people living in what is now Mexico and the southwestern United States prior to European settlement had methods of directing rainwater from hillsides on to plots where crops were being raised, thereby making productive agriculture possible in an otherwise unpromising semiarid environment. On lands occupied by the Hopi and Papago peoples in Arizona, fields were predominantly on alluvial valley soils below hillsides or gullies from which water could flow to the crops during rainstorms. Sites were chosen so that only minimal earthworks were needed to spread the water over the fields. These were short lengths of bund referred to as spreader dikes.

See also: ►Irrigation in India

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Ramanujan

Bruce C. Berndt

Srinivasa Ramanujan was born on 22 December 1887 in the home of his maternal grandmother in Erode, India, a small town located about 250 miles southwest of Madras. Soon thereafter, his mother returned with her son to her home in Kumbakonam, approximately

160 miles south–southwest of Madras. Ramanujan's father was a clerk in a cloth merchant's shop, and his mother took in local college students to augment the family's meager income.

Ramanujan's mathematical talent was recognized in grammar school, and he won prizes, usually books of English poetry, in recognition of his mathematical skills. At the age of 15, Ramanujan borrowed G. S. Carr's *Synopsis of Pure Mathematics* from the local Government College in Kumbakonam. This unusual book, written by a Cambridge tutor to teach students, contained approximately 5,000 theorems, mostly without proofs, and was to serve as Ramanujan's primary source of mathematical knowledge.

With a scholarship, Ramanujan entered the Government College in Kumbakonam in 1904. However, by this time, he was completely absorbed with mathematics and would not study any other subject. Consequently, at the end of his first year, Ramanujan failed all of his exams, except mathematics. He lost his scholarship and therefore was unable to return to college.

For the next 5 years, working in isolation, Ramanujan devoted himself to mathematics. He worked on a slate, and because paper was expensive, recorded his mathematical discoveries without proofs in notebooks. During this time, he attempted once more to obtain a college education, at Pachaiyappa College in Madras, but his singular devotion to mathematics, and illness, deterred him again.

Having married Janaki in 1909, Ramanujan sought employment in 1910. For over a year, he was privately supported by Ramachandra Rao, as he gradually became known in the Madras area for his mathematical gifts. In 1912, Ramanujan became a clerk in the Madras Port Trust Office, and this was to be a watershed in his career, for the manager, S. Narayana Aiyar, and the Chairman, Sir Francis Spring, took a kindly interest in Ramanujan and encouraged him to write English mathematicians about his work.

On 16 January 1913, Ramanujan wrote to the famous English number theorist and analyst, G. H. Hardy. He and his colleague J. E. Littlewood examined the approximately 60 mathematical results communicated by Ramanujan and were astounded by his many beautiful and original claims. Hardy strongly encouraged Ramanujan to come to Cambridge, so that his mathematical talents could be fully developed. At first, Ramanujan was reluctant to accept the invitation, because of orthodox Brahmin beliefs that crossing the seas makes one unclean, but on 17 March 1914 Ramanujan sailed for England.

During the next 3 years Ramanujan achieved worldwide fame for his mathematical discoveries, some made in collaboration with Hardy. However, in the spring of 1917, Ramanujan became ill and was confined to nursing homes for the next 2 years. Tuberculosis, lead poisoning, and a vitamin deficiency were among the many diagnoses made, but a more recent examination of Ramanujan's symptoms points to hepatic amoebiasis. In 1919, he returned to India with the hope that a more favorable climate and more palatable food would restore his health. However, his condition worsened, and on 26 April 1920, Ramanujan passed away.

After Ramanujan's death, Hardy strongly urged that Ramanujan's notebooks be edited and published with his Collected Papers. Two English mathematicians, G. N. Watson and B. M. Wilson, devoted over 10 years to proving the approximately 3,000–4,000 theorems claimed by Ramanujan in his notebooks, but they never completed the task. It was not until 1957 that an unedited photocopy edition of Ramanujan's notebooks was published. In 1977, Berndt, with the help of Watson and Wilson's notes, began to devote all of his research efforts toward editing the notebooks, and in 1998 he completed the task with the publication of his fifth volume on the notebooks. In 1976, Andrews discovered a sheaf of 140 pages of Ramanujan's work, now called the "lost notebook," in the library at Trinity College, Cambridge. In 2005, Andrews and Berndt published their first volume on Ramanujan's lost notebook.

Ramanujan made many beautiful discoveries in several areas of number theory and analysis, in particular, the theory of partitions, probabilistic number theory, highly composite numbers, arithmetical functions, elliptic functions, modular equations, modular forms, q-series, hypergeometric functions, asymptotic analysis, infinite series, integrals, continued fractions, and combinatorial analysis. His influence can be traced to many areas of contemporary mathematics; this is evident in the proceedings of major conferences commemorating Ramanujan on the 100th anniversary of his birth. Although much of Ramanujan's work is quite deep, many of his original discoveries can be understood with a background of only high school mathematics. In particular, his several results on solving systems of equations, representing integers as sums of powers, and approximating π are elementary. In the past few decades, as more of Ramanujan's results have been unearthed, his already great reputation has soared even more.

Most biographical sketches of Ramanujan's life rely chiefly on the obituaries written by Seshu Aiyar and Ramachandra Rao, and the writings of Hardy. However, Robert Kanigel's biography is by far the most complete and detailed description of Ramanujan's life. Much can also be learned from Ramanujan's letters to Hardy, his family, and friends.

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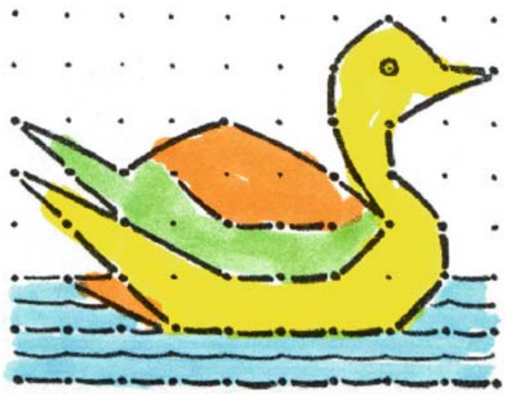
Rangoli: Versatile Domestic Art

JYOTSNA KAMAT

The art of rangoli (also known as alpana, saaz, muggu, kolam, zuti, mandana, and by many other names in India) is a traditional art of decorating courtyards and walls of Indian houses, places of worship and sometimes eating places as well. The powder of white stone, lime, rice flour, and other cheap paste is used to draw intricate and ritual designs. Each state of India has its own way of painting rangoli (Fig. 1).

Women's Art

One characteristic of rangoli is that commoners paint it, without much background in geometry, fine arts or mathematics. Women use their bare fingers or a homemade brush to create various designs from sandstone powder or grain flour. Sometimes colors and petals are used in addition to flour paste. Some women are so skilled with their fingers that they can create figures of deities, chariots, temples, etc., on the finely layered floor. Petals of various flowers, such as oleanders, cosmos, zinnia, chrysanthemums, and green leaves provide the artist with the ability to work out various patterns and colors. Most of the rangoli designs are motifs of plants, flowers, leaves such as coconut, lotus, mango, and ashwath (peepal), animals such as cows, elephants, and horses, and birds like eagles and swans. There are geometrical designs as well. When drawn with the fingers, these acquire different dimensions of their own (Fig. 2).



Rangoli: Versatile Domestic Art. Fig. 1 Example of a Rangoli Design (illustration by K. L. Kamat).

Rangoli: Versatile Domestic Art. Fig. 2 Rangoli to welcome God (photograph by K. L. Kamat).

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The rangoli art is practised as a ritual to welcome the goddess of prosperity, Lakshmi, into the home. Hence the first duty for housewives and young girls in the morning is to sweep the courtyard clean and draw rangoli patterns. Old and young alike participate in this ephemeral domestic art which changes every day. We see that rangoli is predominantly a ritual performed by women. Men draw rangolis in temples and in public places.

History of Rangoli

The history of rangoli is quite ancient. Early rock paintings have symbols and figures of wild animals, hunting scenes, etc., to ward off evil and wish success in hunting expeditions. By the time of the Indus valley civilization (3000 BC), symbols like triangles, circles, and *swastikas* were used to represent supernatural powers. During the Vedic period, places to seat guests and sacrificial altars were decorated with floral designs. By the use of the hand and deft movement of the fingures, rangoli has developed into a fine art over centuries. At times, a simple homemade brush is used (Fig. 3).

Complex Geometry and Philosophy for Common Folk

Almost all of the rangoli patterns involve dots (*bindu*) and lines (*rekha*); joining these creates innumerable patterns. A spot suggests power or life. A line suggests the flow of life. A circle represents the universe and a triangle signifies woman's power or fertility. The swastika stands for the sun's movement. Some interpret that it represents fourfold achievements for householders as laid down by sacred texts. These are *dharma* (virtuous life), *artha* (earning livelihood), *kama* (creature comforts), and finally *moksha* (renunciation in old age). The four corners of the swastika are supposed to symbolize these ideals.

Rangoli: Versatile Domestic Art. Fig. 3 Women joining dots to make complex designs (photograph by K. L. Kamat).

The sun, the moon, the stars, conches, and lotus are considered sacred figures in rangoli. Animals like elephants, cows, horses, tortoises, and birds like parrots, peacocks, and swans, along with plants and creepers, are often included in this art that combines geometry with philosophy and devotion with beauty.

Rangoli in Contemporary India

Festivals dedicated to different gods provide change in the daily routine of rangoli. During Naga panchami, symbols of serpents will appear. On Deepavali, the festival of lights, small earthen lamps will be drawn. On Sankranti festival day, sugarcane, paddy, and wheat sheaves, which are fresh at that time, will find a place of honor in the front door rangoli. Usually every Hindu house has a platform built round the sacred plant of Tulasi. On festival days, this place will also get a special design in addition to the daily ones. Patterns of flowers are popular. Innovative artists paint Christmas and New Year's greetings also in the form of rangolis, depicting Santa Claus and nativity scenes.

During Car festival, the entire village or townspeople will decorate the paths with colorful rangoli designs through which the deity's car (chariot or *ratha*) will pass.

With smaller flats in cities, this temporary and renewable art is disappearing. More and more households find it convenient to decorate their houses with permanent paints; however, they continue to use traditional rangoli designs.

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Rationale in Indian Mathematics

K. V. Sarma

Rationale in Hindu mathematics and astronomy is expressed by the terms *Yukti* and *Upapatti*, both meaning "the logical principles implied". It is characteristic of the Western scientific tradition, from the times of Euclid and Aristotle up to modern times, to enunciate and deduce using step by step reasoning. Such a practice is almost absent in the Indian tradition, even though the same background tasks of collecting and correlating data, identifying and analyzing methodologies, and arguing out possible answers, have to be gone through before arriving at results. However, in the final depiction, only the resultant formulae would be given, and that too in short, crisp aphoristic form, leaving out details of all the background work. Commentaries generally content themselves with explaining the text of the formulae and adding examples. This tendency toward selective depiction of results has resulted not only in blacking out the background, but also in not understanding the mental working of the Indian scientist. It also throws into oblivion the methodologies that had evolved. For this reason, many Indian advances have been branded as unoriginal and borrowed.

The situation is, however, relieved to some extent by the presence of a few commentaries which took pains to explain elaborately the methodologies adopted by the original author and also set out the rationales of the formulae he enunciated. Among such commentaries might be mentioned:

Siddhāntadīpikā on Govindasvāmi's *Mahābhāskarīya-Bhāsya* by Parameśvara (1360–1465)
Āryabhatīya-Bhāsya by Nīlakaṇṭha Somayāji (b. 1444)
Yuktidīpikā on Nīlakaṇṭha Somayạji's *Tantrasaṅgraha* by Śaṅkara Vāriyar (1500–1560)
Vāsanābhāṣya on Bhāskarācārya's *Siddhāntaśiromaṇi* by Nṛsiṃha Daivajña (1621)
Marīcī, again on Bhāskarācārya's *Siddhāntaśiromaṇi* by Munīśvara (1627)

A few texts devoted solely to the depiction of rationale are also known, such as the *Yuktibhāṣā* (Mathematical "Rationale in Language" Malayalam) by Jyeṣṭhadeva (1500–1610), *Jyotirmīmāṃsā* (Investigations on Astronomical Theories) by Nīlakaṇṭha Somayāji (b. 1444), *Rāśigolasphuṭānīti* (True Longitude Computation on the Sphere of the Zodiac) by Acyuta Piṣāraṭi (1600), and *Karaṇapaddhati* (Methods of Astronomical Calculations) by Putumana Somayāji (1660–1740).

However, what is more significant is the occurrence of a number of short tracts giving mathematical and astronomical rationale which are available, some in print and several others in the form of manuscripts. These tracts take up individual topics of importance, analyze the technical principles involved therein, compare the procedures adopted in different texts, and often suggest revisions. To cite an example, the work *Gaṇitayuktayaḥ* (Rationales of Hindu Astronomy) contains a set of 27 tracts providing rationalistic exegeses on several topics including parallaxes of latitude and longitude, elevation of the moon's horns, constitution of epochs for new astronomical manuals, planetary deflections, and equation of the center. It is also noteworthy that some of these exegeses establish the originality of the methodologies and formulae depicted by Indian scientists.

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Rationality, Objectivity, and Method

David Turnbull

Rationality, objectivity, and method are three words that capture the essence of science and at the same time provide its mythic structure. Science has become the authoritative form of knowledge in the world today. The proof of its superiority lies in the ever-expanding body of knowledge we have about reality. We can predict where, when, and how meteorites will collide with Jupiter, and we can build interplanetary spacecraft to send back signals recording the event. We can explore the atomic structure of chemicals and design new ones to suit whatever purpose we have in mind, ecstasy or health. We can map the human genome. We can explain the origins of everything in the universe down to the first few nanoseconds. The source, according to the myth, of this unparalleled success lies in science's embodiment of the highest form of rationality and objectivity in the scientific method. This mythical underpinning of science also provides the rationale for the celebration of modernity and the current domination of the West. This view is unselfconsciously exemplified by the philosopher Ernest Gellner who claims, "If a doctrine conflicts with the acceptance of the superiority of scientific-industrial societies over others, then it really is out" (cited in Salmond 1985).

Therein lies the first set of intrinsic problems and contradictions the myth conceals. Modernity is supposedly synonymous with development and social

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improvement, but it has become apparent in recent times that science and technology are no longer unalloyed agents of progress. They now seem to contribute significantly to the difficulties we are facing in environmental degradation, pollution, climate change, and waste disposal. The other equally difficult emergent problem for the mythological account of science is that it has been seen as quintessentially Western and as absent in the developing countries or an undeveloped possibility in the Islamic, Chinese, and Indian cultures. This can no longer be accepted as a simple fact, but has now to be seen as an ideological marker in the creation of the "other." We have then a joint problem. On the one hand "the future is not what it used to be," courtesy of the negative effects of science and technology, but we will nonetheless have to call on them for their problem solving capacities. On the other hand it is becoming apparent that the grand project of modernity – a universal scientific culture – has failed and ought to be relinquished in favor of encouraging cultural diversity. Just as biological diversity has become recognized as an ecological necessity so too has our cultural survival come to be seen as dependent on a diversity of knowledge (see knowledge systems). Consequently "the central problem of social and political theory today is to decide the nature of communicatory reason between irreducibly different cultures" (Davidson 1994). Given this double difficulty we need to ask ourselves if science can be reconstituted.

Rationality

It is in trying to explicate rationality, objectivity, the scientific method and the nature of science that the myth of science's transcendental supremacy really comes undone. Rationality is a deeply problematic concept. It is profoundly embedded in the hidden assumptions of late twentieth century occidentalism about what it is to be a knowing, moral, sane individual. Indeed it is so embedded that to be anything other than rational is to be ignorant, immoral, insane, or a member of an undifferentiated herd. Hence rationality cannot be treated as simply an epistemological concept about the conditions under which one can know something; it also carries ideological overtones, privileging certain ways of knowing over others. Rationality is a constitutive element in the moral economy.

Yet despite, or perhaps because of, this central role of rationality, there are no fully articulated rules or criteria for being rational in the acceptance of beliefs or in the pursuit of knowledge, nor is there a single type of rationality. This sense of incoherence in the concept reaches total intransigence in the recognition that ultimately there can be no rational justification for being rational. Nonetheless critical rationalism as advocated by Karl Popper has a primal persuasiveness in contemporary Western society. Mario Bunge has captured some of that self-evidentiality and variability in his seven desiderata for rationality:

1. Conceptual: minimizing fuzziness, vagueness, or imprecision
2. Logical: striving for consistency, avoiding contradiction
3. Methodological: questioning, doubting, criticizing, demanding proof, or evidence
4. Epistemological: caring for empirical support and compatibility with bulk of accepted knowledge
5. Ontological: adopting a view consistent with science and technology
6. Valuational: striving for goals which are worthy and attainable
7. Practical: adopting means likely to attain the goals in view

Indeed seeing them set out like this makes their denial seem irrational.

From a relativist's perspective there are no universal criteria of rationality, and even if the claim for rationality's governing role is weakened to talk of desiderata as Bunge does, Wittgenstein's and Godel's point prevails: all formal systems are necessarily incomplete, no body of rules can contain the rules for their application. Rationality consists in the application of locally agreed criteria in particular context or as Foucault puts it, forms of rationalization are embedded in systems of practices (Foucault 1979: 47). Hence it should be acknowledged that science, rather than exemplifying some transcendental rationality, has developed its own rationalities that have in turn served to create a great divide between science and traditional beliefs. There is of course a middle ground, the so-called bridgehead argument which calls for the recognition that all humans have some minimal forms of practical rationality in common. Though this recognition has produced no universal truths and no universal criteria, it nonetheless provides the grounds for a commonality sufficient for partial communication and understanding across linguistic, ontological, and cultural differences.

There is a philosophical tendency to talk of rationality as if it were a problem with no historical or sociological dimensions. This is to ignore the fact that the concept of the individual as a rational actor that is now so basic to Western ways of thought is not derived from first principles; it arose in conjunction with the development of modern science in the seventeenth century. This was a period which saw great debates over the appropriate forms of rationality between the Cartesian rationalists and the Baconian empiricists. Whether true knowledge was to be derived deductively from self-evident first principles or by observation and experiment, it had already been accepted that the acquisition of such knowledge was within the capacity of human individuals. The recognition that human reason and experience was not inherently limited and could be a source of knowledge re-emerged in the twelfth and thirteenth centuries in the West with the separation of the church from the state and with the development of secular law from the accompanying canon law (Berman 1983). The development of this conception of rationality was not universal. For example it was not paralleled in Islamic society where men were denied rational agency; they were held to lack the capacity to change nature or to understand it. Knowledge was instead to be derived from traditional authority. This is not to claim that there has been no Islamic science or any Islamic discussion of rationality (Huff 1993). On the contrary, there have been major achievements in Islamic science but in a radically different moral economy.

While the notion of the rational actor as unconstrained by circumstance or authority and moved only by logic and evidence has become embedded in our legal, economic, and scientific presuppositions, such an idealized conception is at variance with our lived reality both at the societal and the individual level. At the societal level, modern Western capitalism has become a bureaucratic system that, as Weber pointed out, relies on a calculative rationality (Weber 1979). The administration and perpetuation of this system is crucially dependent on a system of rules from which legal and administrative calculations can be derived by professional, objective, experts. Hence modern science and capitalism are interdependent; they were coproduced on the basis of a calculability derived in part from rational structures of law and administration. In Weber's view it is the specific and peculiar rationalism of western culture that makes science unique to the west. Even if Weber was right, what needs further examination is how specific and peculiar that calculative rationalism is. That form of rationality has a number of interwoven components, for example the acceptance of written documents as evidence as opposed to oral testimony. This transition also occurred in the twelfth and thirteenth centuries but required the development of a "literate mentality" before it became self-evident that records and archives were more worthy of belief than the word of "twelve good men and true" (Street 1984). Some, like Goody, have further argued that the accumulation of knowledge and the possibility of criticism and hence rationality are only possible in a literate culture. Similarly vision had to be rationalized to provide grammar or rules for the relationship between the representation of objects and their shapes as located in space. Yet another component of the form of rationality we equate with science was the acceptance of the validity of experimental evidence. Shapin and Schaffer have argued in The Leviathan and the Air Pump that Thomas Hobbes was able to dismiss Robert Boyle's experiments on the vacuum as private, local, and artifactual until Boyle was able to introduce a range of social, literary, and technical practices that enabled the knowledge produced in the isolation of the laboratory to be "virtually witnessed" and reproduced for other audiences and in other laboratories (see Knowledge Systems).

Rationality is not a particular human capacity. Rather there are forms and compounds of rationality which at the societal level, as Foucault has shown, are dependent on particular social and historical institutions, constituted through the interwoven practices, techniques, strategies, and modes of calculation that traverse them. However, at the individual level we do not behave like the ends/means optimization calculators that economic rationalism would have us believe we are. We are at least as interested in meaning, significance, and personal values as we are in economic concerns. Nor are we quite the rational agents basing our knowledge on direct experience that the legal and philosophical theorists claim. A vast preponderance of our knowledge derives not from personal experience but from books, newspapers, journals, teachers, and experts. In other words our knowledge comes, directly or indirectly, from the testimony of others, in particular from those we trust. Thus our individual lived rationality is based in a range of social practices, traditions, and moralities that are suppressed and concealed in the portrayal of rationality as an ahistorical, universalistic form of reasoning exemplified by science.

Objectivity

Much the same can be said of objectivity. Objective knowledge is held to be the product of science that has established methods to ensure that individual, institutional, and cultural biases are eliminated. On closer examination objectivity is not characteristic of one special kind of knowledge – science. Rather it is the result of whatever institutionalized practices serve in a particular culture to create self-evident validity. Objective knowledge, in modern terms, is held to contrast with subjective knowledge. It is knowledge that is not local, that is not contingent on the circumstance, authority, or the perspective of the individual knower. However, the concept of objectivity, like that of rationality, is not immutable; it is an historic compound. In the seventeenth century objectivity meant "the thing insofar as it is known." The concept of aperspectival objectivity emerged in the moral and aesthetic philosophy of the late eighteenth century and spread to the natural sciences only in the mid-nineteenth century as result of the institutionalization of scientific life as a group rather than an individual activity.

This characterization of objectivity as the "view from nowhere" (Nagel 1986) represents one of the essential contradictions of scientific knowledge production. Knowledge is necessarily a social product; it is the messy, contingent, and situated outcome of group activity. Yet in order to achieve credibility and authority in a culture that prefers the abstract over the concrete and that separates facts from values, knowledge has to be presented as unbiased and undistorted, as being without a place or a knower.

Objectivity, like democracy, is at best a worthy goal but one that is never capable of achievement. Since knowledge is the product of social processes it can never completely transcend the social. Objective knowledge cannot, for example, simply be knowledge which is unaffected by nonrational psychological forces, since scientists always have motivations even if they pursue knowledge for its own sake. Nor can objectivity be restricted to the avoidance of dogmatic commitment, because there have been scientists like Kepler whose obsession with regular solids and cosmic harmony led to his derivation of the laws of planetary motion. While it may be possible to avoid personal idiosyncrasy this can only be achieved through the establishment of communal or public knowledge. If knowledge is a communal product, then the question of how the community should be constituted arises. Should the scientific community be an essentially western institution? Consequently objective knowledge cannot simply be "value free" knowledge because what is counted as knowledge is itself a value. Similarly the criterion of practical effectiveness cannot determine objectivity since it too is based in community standards.

The only remaining possibilities for objective knowledge lie in the notions of correspondence with reality and experimental verification. There are well known difficulties here, since correspondent theories of truth and verification are dependent on empiricism and the scientific method, both of which have been subject to powerful criticism in the last half century or so. Essentially, what philosophers like Duhem, Quine, and Wittgenstein have argued is that our ways of knowing about the world are riddled with indeterminacies; which is to say that there is no set of procedures sufficiently powerful to determine which knowledge claims are absolutely true and certain, nor is there a certain way of grounding such claims. There are uncertainties inherent in all our ways of knowing that have to be bridged by a variety of practical and social strategies. Popper and Kuhn have argued that neither deduction nor induction is capable of providing true and certain knowledge. Furthermore observations and theories are interrelated and hence neither can be an independent foundation for the other. Both Popper and Kuhn recognize that observations have point and meaning within the context or framework of a theory: we do not simply observe natural phenomena, we observe them in the light of some theory we already have in mind, or minimally with some set of expectations about what is interesting or what to look for. In this sense our observations of the world are "theory dependent" or "theory laden."

As Duhem points out, all theories are enmeshed in a web of other theories and assumptions. The apparent conflict between an experimental result and a particular hypothesis cannot conclusively lead to the rejection of that hypothesis, since the strongest conclusion that can be drawn is that the hypothesis under test and the web of theories and assumptions in which it is embedded cannot both be true. Since the experimental result by itself is insufficient to tell us where the flaw lies, we can always maintain a theory in the light of an apparently falsifying experiment if we are prepared to make sufficiently radical adjustments in the web of our assumptions. Conversely it is the case that for any given set of facts there is an indeterminably large number of possible theories that could explain them.

In addition to the problematic relationship of theory and observation there is a difficulty concerning the language in which our claims about the world are expressed. All propositions or observation statements contain descriptive predicates which imply a classification or categorization of the world based on postulated essences or natural kinds. We are stuck with some degree of circularity since we gain our knowledge about natural kinds from theories which are in turn based on observations. There is no neutral observation language; our only option is to recognize and acknowledge the conventional character of our linguistic classifications.

Scientific Method

Despite all these difficulties scientists are able to reach firm conclusions about the natural world. How is this possible? Many would claim that even though it may be logically true that there are an indefinite number of possible explanations for a given body of facts, in a given case there are typically a very restricted set of alternatives and there are adequate means of selecting the right theory, or at least the best possible theory in the circumstances, given the application of certain criteria. For example, we obviously desire theories which are internally coherent, consistent with other accepted theories, and simple rather than complex. However coherence, consistency, and simplicity as well as other criteria like plausibility have all proved notoriously difficult to express in a way which can be used to measure all theories in all circumstances. It is, none the less, very tempting from our twentieth century standpoint, imbued as we are with the scientific ethos, to suppose that there must be a particular set of rules, procedures, and criteria to which all scientists adhere. Taken together they should constitute the scientific method, and by diligent application of this method we should be able to arrive at all the scientific discoveries of our age. However, Paul Feyerabend in *Against Method*, for example, argues that no proposed set of rules and procedures has survived criticism or has been universally adopted by all scientists in all circumstances. Likewise he claims that in no case can it be shown that the success of science can be solely attributed to its adherence to the scientific method.

There can of course be endless debates about such claims, but so far no one has been able to identify the one scientific method which has been adopted in all the sciences. Compare for example theoretical physics (mainly mathematical) and biology (mainly observational). Nor is there a method which has been unilaterally accepted in a particular discipline. Compare again, Newton's espoused methodology ("I feign no hypotheses") with Einstein's (bold hypotheses and deductive tests). Further, particular instances of scientific practice under close examination reveal a pragmatic willingness to suspend or modify any particular version of the scientific method if necessary, as Feyerabend has shown in his analysis of Galileo and Copernicus. It seems then that there is no "single, invariant methodology of science." Instead there are series of complex interactions between method and practice. As science and technology develop, so the practitioners develop and negotiate the rules for doing them in a local and contingent fashion. New methodologies are propounded in order to provide support and credibility to a newly preferred scientific theory.

Scientific Practice

It could be argued that the indeterminacies of science and the lack of a specific scientific method are merely philosophical and theoretical problems, and that science is firmly grounded in experimental practice. The best way to know whether a particular knowledge claim about the world is true or false is to subject it to experimental test and then have somebody else repeat the experiment.

There are two kinds of related difficulties with this empirical approach. Experiments are inevitably performed on a simplified, artifactual, and isolated portion of reality. Hence the universal generalizations drawn from them are not indubitable. Cartwright (1983) goes so far as to claim that the Laws of Physics are, in effect, lies. Equally the effectiveness of experimental replication as the litmus test of truth is somewhat undermined by the role of skill or tacit knowledge in scientific practice. "The problem being that, since experimentation is a matter of skillful practice, it can never be clear whether a second experiment has been done sufficiently well to count as a check on the results of the first. Some further test is needed to test the quality of the experiment – and so forth" (Collins 1985). This result in what Collins calls "the experimenter's regress." In the normal course this is resolved by social processes in which the judgment about whether to accept a particular result is based on the relevant community's evaluation of the skills of the experimenter in question. It becomes deeply problematic when the existence of the phenomenon itself is at issue, as in the case of gravity waves. An experiment showing the existence of such waves was followed by others seemingly denying their existence, or at least failing to detect them. Which was correct? The existence of gravity waves turns on the judgment of the community about competently performed experiments, and those judgments of competence are based on the accepted community knowledge about the nature of gravity waves. Replication then is not the test of their existence; rather it reflects the ability of the experimenter to achieve community standards of experimental practice.

Thus it would seem that conceptions of rationality, objectivity, and the scientific method cannot be derived from self-evident epistemological principles. They are instead embedded in the historically contingent processes of scientific practice, whereby the resistances and limitations of reality are encountered and accommodated. Science is a social activity that is essentially dependent on community and tradition, and the practice of science is governed by concrete, discrete, local traditions which resist rationalization.

The notion of a great divide between Western and so-called primitive knowledge systems has turned crucially on the question of rationality of science. If, as the arguments above suggest, science has a rationality of its own, but not one that is especially privileged, how do we both account for and deal with similarity and difference between cultures? How is it, on the one hand, that the peoples of the world are sufficiently alike to have universally developed complex languages, and yet those languages and their accompanying knowledge systems have produced profoundly different cultures? On the other hand, how are we to ensure communication and preserve cultural diversity?

In the entry on local knowledge it is claimed that the common element in all knowledge systems is their localness, and that their differences lie in the way that local knowledge is assembled through social strategies and technical devices for establishing equivalences and connections. It is no small reflexive irony that this entry on rationality and science and the encyclopaedia itself are dependent on unspoken assumptions concerning their credibility and authority which constitute a form of rationality. The encyclopaedia is based on the assumption that widely disparate knowledge can be meaningfully assembled into a volume without loss of coherence due to incommensurability. Furthermore it is assumed that the individual articles, dependent as they are on evidence, analysis, and argument, are capable of being read, understood, and utilized by readers from all cultures. In other words there is a strong resemblance between this encyclopaedia and the practice of science. Science is dependent on the assemblage of heterogeneous inputs, but that assemblage is not achieved by the application of logical and rational rules or conformity to a method or plan. Indeed it is not even dependent on a clearly articulated consensus. Rather the assemblage results from the work of negotiation and judgment that each of the participants puts in to create the equivalences and connections that produce order and meaning. Perhaps then it has to be acknowledged that there is a minimal rationality assumption, and that links between rationalities can either be created or ignored by common human endeavor. So, given the lack of universal criteria of rationality the problem of working disparate knowledge systems together is one of creating a shared knowledge space in which on the one hand equivalences and connections between differing rationalities can be discursively constructed; and on the other hand where no common ground can be created, agreement can be sought to work with the creative tension of difference. A good example of such competing rationalities in tension is the irrigation system of Bali. Stephen Lansing's analysis shows the crucial role of the symbolic system of water temples in managing the flow of the waters, a role that classic Weberian forms of rationality have in the past simply dismissed as irrational (Lansing 1991). Yet the role of the water temples was revealed by Lansing's anthropological and computer-based analysis. Communication, understanding, equality, and diversity will not be achieved by others adopting Western information, knowledge, science, and rationality, it will only come from negotiating ways to work together in joint and multiple rationalities.

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Religion and Science in China

Weihang Chen

"Religion and science in China" is a controversial topic which requires some clarification before the discussion can begin. Because the first serious efforts to bring Chinese classical study to the Western academic world were initiated by Jesuit missionaries in the seventeenth century, it became a Western tradition to look at many Chinese cultural phenomena from a religious point of view and categorize them accordingly. For a long time in the West, the three main *Jiao* (systems of teachings and beliefs) of Chinese traditions, Confucianism, Daoism (Taoism), and Buddhism, were called three religions. However, since the reconstruction of Chinese classical study early in this century, Chinese scholars generally consider Confucianism and Classical Daoism philosophies, popular Daoism a religion, and Chinese Buddhism both a religion and a philosophy. Today in the West there is no consistent way of using these terms. All three are called either religions or philosophies or both, according to the idea or method or focus of the researcher. Furthermore, it is common practice to include other beliefs and activities in the study of religion, such as myths, rituals, customs, popular superstitions, and court divination rediscovered through mythological, linguistic, or archeological findings. These new studies are in fact turning the topic of "religion and science" into a much broader topic of "culture and science."

On the other hand, the concept of "Chinese science" is even more uncertain. There is a strong tendency both in the West and in present-day China to question the possibility of a different kind of science. The underlying implication is the belief that there is only one science for one universe – The Science, which is objective and universal. With this belief in mind, explicitly or implicitly, historians of science generally consider Western modern science as the best approximation of The Science, and use it as a measure to search for relevant materials in Chinese ancient relics and texts. By using the same measure, Chinese ancient ideas, theories, studies of nature, and activities dealing with nature are accordingly classified into "scientific subjects" and thereby evaluated. The same belief also provides criteria for distinguishing nonscience from science. The danger of this viewpoint is that it will miss many of the real merits in cultures other than Western ones. One example is that the deep-set dichotomy of "body and soul (mind)" in the Western culture is typically a Greek tradition and may not be shared by other cultures. This difference will show itself especially in the different medical traditions.

For those who do not accept the idea of The Science, it becomes crucial to establish a reasonable or practical criterion for nonscience and science. Research efforts in this regard have not been successful either. Another confusion comes from the fact that in ancient China achievements in technology and in science are not easily distinguishable. There are doubts about if it makes sense or even if it is possible to define these two concepts separately in the context of Chinese ancient culture.

With all these ambiguities in the main concepts and differences in the basic positions, the interaction between religion and science in China has not been formed into a regular study subject. In this article we will acknowledge that the concepts "religion" and "science" are both Western concepts used in a Chinese context. "Religion" means a system of beliefs and "science" means knowledge, especially theoretical or systematic knowledge about nature, human beings, and life, but not about human beliefs, activities, and relationships. Thus we will be able to achieve some clarity in our discussion.

The question of why the scientific revolution did not take place in China has drawn much attention during recent decades. A generally accepted conclusion is still far away, and may not even be important. In this article we will explore the influence exerted by the main Chinese ideologies on the nature and development of Chinese science. Here "main Chinese ideologies" means Confucianism and Daoism. Also, "Chinese science" means and includes Chinese ideas, theories, and knowledge about nature (including humans as natural beings) which were accepted by Chinese scholars or professionals in corresponding historical periods.

In the West in ancient times, science was under the strong influence of religions, and in modern times, religions were under the influence and pressure of the development of science. In China, science went along a different road; it started under the decisive influence of early Confucianism and philosophical Daoism. These two traditions governed the development of Chinese science. There were no serious conflicts between these governing ideologies and Chinese science until China began to bring in Western science on a large scale in the late nineteenth century. The conflict between Confucianism and Western science at that time has been a much studied topic.

After Buddhism was introduced into China around the first century, it gradually became the primary organized religion. However, little can be found in the development of Chinese science that was affected by the development of Chinese Buddhism. One explanation of this phenomenon is that the characteristics of Chinese science, its subject matter and method, had been firmly established before the Qing dynasty (221–206 BCE). The nature of that science is quite compatible with the philosophy and practice of certain kinds of Indian Buddhism. On the other hand, together with Confucianism and Daoism, Chinese science might have exerted a strong influence upon the development of Chinese Buddhism, especially the Chan sect (the origin of the Japanese "Zen"). Little research has been done on this topic.

Our main concern will be the influence of ancient Confucianism and Daoism on Chinese science. We will begin with ancient cosmological beliefs and the methodology associated with these beliefs. As Confucianism and Daoism are the two schools that have been most influential in the making of Chinese culture, have preserved a great quantity of texts and historical records for their teachings, and have been thoroughly studied, the common features of these two schools will provide a good starting point in searching the origin of Chinese science. After this, we will also discuss how the difference between these two schools influenced the development of Chinese science in their own way.

Chinese Ancient Cosmological Beliefs

It is important to examine the basic concepts that were used in both Confucian and Daoist texts. Those that concern Chinese science are the concepts of Heaven, Earth, Human, *Dao*, *Te*, and Fate. Though Chinese classics do not provide definitions for these concepts, we can study the way they were used in their textual contexts and interpret their meaning approximately by using Western concepts as follows: Heaven and Earth form the natural world that Human lives in. Heaven is the part that is farther away from Human but is more fundamental in the sense that it ultimately governs and decides everything that happens to Earth and Human. Earth is the part of the natural world that surrounds and interacts with Human directly. Human is the concept for every human being, who has a life that has a beginning, a growing process, and an end. The distinction between Heaven and Earth is of great importance in the interactive mechanism between Human and Nature. Human can act directly on Earth and change it and use it for his own purposes, but not on Heaven. Earth is governed by Heaven and not by Human; therefore, the way Human deals with Earth (e.g., agriculture and irrigation) can either be right or wrong according to whether it follows or violates Heaven's way. This sounds quite like the Western idea of natural law and it seems compatible with modern scientific views, but there is a crucial difference. The Chinese "Heaven's way", which is called *Dao*, governs not only Earth, but also Human's life and society, and therefore it is a moral matter whether one follows or violates it. To follow the *Dao* is not only a matter of what to do to achieve a certain purpose, like what science tells us in the West, but also what purposes one should have in all his/her activities including governmental, social, familial, and individual activities. Thus, *Dao* as the most fundamental principle or cosmological law is objective and natural, and governs the whole world which in Western categories splits into the natural world, society, and individual life.

To know *Dao* and therefore to act according to *Dao* is the goal of ancient Chinese study. The result of this study is to gain *Te*. *Te* is both knowledge in the sense of knowing what is right, and virtue in the sense of practicing what is right. Like knowledge and virtue in the West, *Te* can be both innate and acquired. That is, people are born with *Te*, to a greater or less degree, and can acquire and accumulate *Te* through study and practice in their lives. However, unlike the Western concepts of knowledge and virtue, *Te* can neither be defined by a general relationship, either functional or quantitative, nor be abstracted or theorized from its special context – the human conditions which define the reality of the individuals concerned.

The reality of an individual is his/her Fate, which is basically determined by Heaven. That means it is out of human reach to change or control it. On the contrary, Fate is the realization of *Dao* in each individual's life. It can be known either through study and practice, or by divination. Ancient Chinese divination, like a certain kind of Greek oracle, does not tell what will happen in the future but answers if actions are right or wrong according to Heaven's way. Therefore, the concept of "good fortune" is not defined by positive results to individual purposes, nor satisfaction of natural or whimsical human desires, but by the realization of the *Dao*. Therefore, ancient Chinese divination, typically represented by the *Yijing* (I Ching, Book of Changes), has a close relation with the ancient Chinese value system and moral principles as well as understandings of *Dao*, and thus exerts great influence on the development of Chinese science.

Now when we look back at these beliefs, the following conclusions are apparent:

1. Because of the wide variety of its governed phenomena, and because of its moral nature, *Dao* is not a deterministic regularity which decides in every detail what happens in the world. Maybe it is, on the whole and in the long run, but certainly not in the form of an instant causal relationship in everyday phenomena which are available for measurement and observance. *Dao* is not a natural law which is impossible to violate.
2. If *Dao* is ultimately deterministic, it can be seen in history. Therefore, to keep historical records is tremendously meaningful and important for the Chinese, and to study these records, what is called historiography in Western terminology, is especially so.

3. If *Dao* is indeterministic in details, and can be violated by people for their wrong purposes, then it makes no sense to study *Dao* by mechanical experimenting, nor by searching underlying regularities in the observable movements of stars in heaven and things on earth. In other words, one cannot study *Dao* through instant causal relationships, because in these relationships there are no observables which indicate whether what happened was on the *Dao* or against the *Dao*.
4. Chinese divination has a nature of empirical knowledge which comes from generalization of phenomenological and historical observations, and a nature of theoretical knowledge which employs mathematical representation to calculate functional relations in the change of affairs. Not only does it exert great influence on the later development of Chinese science in its conceptual system and methodology, but also it could be looked upon as the earliest achievement of Chinese science.

Confucianism

Confucianism is the English word for *Ru Jia* (the School of Scholars), which was founded by Confucius (551–479 BCE), the first private teacher in China. Confucius is the Latinized form of *Kong Fuzi*, a respectful way of addressing the master. *Kong* was his family name. He lived in a time when the empire was being broken up into numerous feudal states. It was a time of change, disorder, and degeneration of the old moralities. When he started as an officer and political reformer, Confucius' ideas of personal cultivation and moral government failed to attract the rulers of his time. So he turned to teaching and taught a large number of private students, preparing them to be good court ministers as well as good teachers. Thus, he managed to exert an influence by establishing a tradition of individual learning and private education. In the second century BCE his ideas and teachings were made authoritative by the Han emperors, and the Classics Confucius edited and used in teaching became the only official textbooks in China until the beginning of the twentieth century.

Confucianism is *the* Chinese ideology. From the second century BCE to the beginning of the twentieth century, it has been the orthodoxy. In a way, it is the Chinese religion, because it provides a system of beliefs (or disbeliefs) and values which calls for faith and acceptance from students, and also because it is more a way of life for students to follow than a body of knowledge for them to master. There are always scholars who spend their lives studying the text of Confucian Classics, but it is not through these studies that Confucianism exerts its influence on Chinese society and culture. In this regard, Confucianism is more comparable to Western religions than philosophies.

However, Confucianism is not a religion in the Western sense, because it has neither doctrine nor reference to the supernatural. It gives no promise, no reward, and no consolation to its followers either in or beyond this life. It has no God, no church, and no organization. It is only a teaching. It teaches the follower how to be a noble man (a *Junzi*) living a noble life in his special social context.

The ultimate goal of Confucius' teaching, and therefore the goal of Confucian learning, is the benefit of the people. The essence of Confucianism lies in these two doctrines (1) a moral government, i.e., governing by moral examples and education instead of by rules, law, and punishment, is the solution to social disorder and is to the highest benefit of the people; and (2) the cultivation of a group of *Junzi* (noble men) in a society is a practical road toward moral government.

A *Junzi* is an elite scholar. He is elite because he has higher moral standards and is therefore a better person than a common man (*Xiaoren*, the small men); but he is not an elite in the Western sense, because his higher moral standards require that he has no social privileges but only duties and obligations. To be a *Junzi* is both to lead a noble life and to have a noble personality; it is a lifelong task of self-cultivation without personal gains. One will choose to be a *Junzi* because he knows it is his fate.

To be a *Junzi* is the immediate goal for a Confucian. Because Confucians believe that people's benefit will be served best by bettering the government, people are left alone to deal with their own material needs, their production, and their struggle with the natural surroundings. Confucians take it for granted that common people are naturally wise enough to deal with all that and take care of their own needs, and it is not *Junzi's* task to learn and develop knowledge and ability in this regard. Confucians believe that a moral society would naturally become prosperous.

The *Analects*, a basic Confucian classic, recorded that Confucius once refused to teach his student agricultural knowledge, saying the elder farmers and gardeners were better than he in this regard. This shows that *Junzi's* learning should be limited to the scope of human relationships, and science or scientific knowledge has no value to *Junzi's* task of self-cultivation.

This Confucian attitude toward scientific knowledge has its roots in the belief that the world Human lives in is governed by the *Dao*, and the best thing Human can do is to follow the *Dao*. In Chinese cosmology it is a Human choice, therefore a moral matter, to follow or to go against the *Dao*. Therefore, the Western task of changing the world according to man's ideas, or reforming the world to suit man's needs, would sound absurd and dangerous to the ancient Chinese, for it advocates going against the *Dao*. Human is a part of the universe, and not the governing part. Man is not the lord of the earth and cannot give orders to Nature. This is not to say that ancient Chinese did not make efforts to better their living conditions, but it does mean that they did not give these efforts high priority on the scale of social urgencies.

After Confucianism was made authoritative by Chinese emperors in the second century BCE nearly all Chinese intellectuals became Confucians, who formed an elite class in Chinese society. Generally speaking, Confucians looked down on technical and scientific knowledge and achievements because these neither had any use in self-cultivation, nor helped in turning the government into a moral one. This attitude left the development and preservation of scientific knowledge in the hands of professionals, many of whom were illiterate and kept their skills and knowledge as a family tradition. With the exception of astronomy, mathematics, and medicine, Chinese ancient technological and scientific achievements were seldom recorded or their records preserved. When the British scientist and historian of science Joseph Needham started to search extensively through the extant texts for these records, and began to publish the results of his search in the multivolumed *Science & Civilisation in China* (1954–), it shocked the world to see that Chinese themselves did not remember what they had achieved. Certainly the ancient Confucians would not value these "achievements" as much as modern Westerners do.

There is no doubt that this Confucian devaluation of scientific activity, knowledge, and achievements has been a significant hindrance to the development of Chinese science. However, Confucians did value the study of astronomy, mathematics, and medicine, though the former two were not necessarily as urgently needed by the people as the knowledge for agricultural production. The reason Confucians accepted them as a proper scholarly study is for their use in divination. Confucianism included divination in the basic teaching of *Li* (rites). Astronomy and mathematics were needed in making calendars, which were important for the agricultural economy. Medicine was an early tradition and developed into such a complicated system that it became an intellectual profession even before Confucianism gained its orthodox position.

Confucianism did allow for scientific and technological knowledge to grow among the professionals. The Confucian attitude toward science is to leave it alone. Science and technology are not Confucians' proper concerns, but they never go against them. Under the reign of Confucianism there were no known cases in which scientists and innovators were persecuted because of their ideas or inventions. Confucianism created unfavorable social attitudes and conditions for scientific and technological development in China, only because Chinese rulers made Confucianism orthodox and turned the intelligentsia into Confucians. But we cannot oversimplify this situation and accuse Confucianism of smothering a scientific revolution which would otherwise have happened in China. When we study the three branches of science Confucianism valued, and compare them to Western ones, it can be seen that they are metaphysically and methodologically different. What Confucianism did to Chinese science was external and only confined to social factors.

Daoism

The term *Daoism* in English has several meanings. In its basic meaning it is a translation of the Chinese *Dao Jia* (the School of *Dao*), which was represented by two Daoist classics: the *Lao Zi* and the *Zhang Zi*. In this sense, Daoism (also called Classical Daoism or Daoist philosophy) is an ancient philosophical tradition. In its second meaning Daoism is a translation of the Chinese *Dao Jiao* (the religion of *Dao*, or Popular Daoism). It includes a variety of later organizational developments of the Daoist religion, mostly imitating the form of imported Buddhism but incorporating the ideas of the *Lao Zi* and *Zhang Zi*. It was often involved in political issues, sometimes was used to organize and mobilize peasants' uprisings, occasionally was used to seek favors from the court, and was thereby supported by Chinese emperors. It was a folk religion and Confucians looked down on it as low culture and superstition. In its third and very broad meaning, it is a vague concept that includes Classical Daoism, Popular Daoism, and some other schools that were similar to Classical Daoism. These other schools include the School of *Yinyang* and the School of *Huang-Lao* (the School of the Yellow Emperor and *Laozi*). It is in this last sense that we are now using the term Daoism.

Generally speaking Daoists emphasize individual happiness rather than social welfare. They believe in *Dao*, in cutting down one's desires and wants, in living a simple, secluded, and natural life, and in cultivating spiritual as well as physical immortality. In the last aspect it is mysticism from a modern scientific point of view, but the method it uses in seeking the way of immortality, which according to Daoism should be realized in this life on earth, is very much empirical and congenial with the Western development of geography, health care, and elixir alchemy. Thus, the influence of Daoism on the development of Chinese science is substantial.

The central idea that exerts a strong impact on the development of Chinese science is the search for immortality in this life on earth. We do not know what the origin of this idea is and when its practice started. There are three approaches: the first is by cultivating one's *Qi*, the second by making special drugs such as the elixir of life, and the third by going deep into mountains or on the seas to find living immortals to learn from. The concept of *Qi* is one of the most ancient Chinese concepts about nature and life. It was used, in the sense of vitality, in the works of the warring-states philosophers, such as Mencius, Xun Zi, Zhuang Zi, and Lüshi Chunqiu in the fourth and the third centuries BCE. The earliest extant text that mentioned elixir drugs is *Hanfei Zi*, which was in the third century BCE. *Shi Ji* (Records of the Historian, compiled during the second and the first century BCE) recorded that in the fourth and third century BCE the rulers of Chu and Yan states sent envoys sailing to learn about the ways of immortality.

These three approaches led to three developments of Chinese science. The first is Chinese medicine, including health care techniques and *Qigong*. *Qigong* is an Eastern exercise which is based on the theory of interaction between body and spirit and the possibility of controlling one's mental state by manipulating one's body. The second is somewhat connected with the development of Chinese pharmacology, but more so with that of chemistry which led to the invention of gunpowder. The third helped to preserve ancient myths and legends, and initiated the need to exploit the outside world which Confucians neglected. The earliest Chinese geographical work, *Shan Hai Jing*, is basically the result of this effort.

The Daoist influence on Chinese science is more congenial with the criteria of modern science. Daoists believe in the power of true knowledge for their own purpose of immortality and that knowledge can be sought by experimenting or by learning from those who know. They accept that the truthfulness of that knowledge should be tested by the results of its applications. With their beliefs of *Yinyang* and *Wuxing* (Five Phases), which are not religious but ontological and methodological, Daoism is the Chinese system of belief that led to the flourishing of Chinese medical theory and health care practices, which might be considered the highest achievements of Chinese science.

See also: ►Alchemy, ►Medicine in China, ►East and West: China in the Transmission of Knowledge East to West, ►Magic and Science, ►*Qi*, ►Five Phases (*Wuxing*), ►*Yinyang*, ►Geomancy in China, ►Divination, ►Geography, ►Gunpowder, ►*Gaitian*, ►*Huntian*

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Religion and Science in Islam I: Technical and Practical Aspects

David A. King

In Islam, as in no other religion in human history, the performance of various aspects of religious ritual has been assisted by scientific procedures. The organization of the lunar calendar, the regulation of the astronomically defined times of prayer, and the determination of the sacred direction toward the Kaʿba in Mecca are topics of traditional Islamic science still of concern to Muslims today, and each has a history going back close to 1,400 years. But the techniques advocated by the scientists of medieval Islam on the one hand and by the scholars of religious law on the other were quite different, and our present knowledge of them is based mainly on research conducted during the past 30 years on one small fraction of the vast literary heritage of the Muslim peoples. To understand Muslim activity in this domain we must realize that there were two main traditions of astronomy in the Islamic Near East, folk astronomy and mathematical astronomy.

The Regulation of the Lunar Calendar

The Islamic calendar is strictly lunar. The beginnings and ends of the lunar months, in particular of the holy month of Ramadan, and various festivals throughout the 12-month "year," are regulated by the first appearance of the lunar crescent. Since 12 lunar months add up to about 354 days, the 12-month cycles of the Islamic calendar begin some 11 days earlier each year, and the individual months move forward through the seasons.

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For scholars of the sacred law, the month began with the first sighting of the crescent moon. This observation is a relatively simple affair, provided that one knows roughly where and when to look and the western sky is clear. Witnesses with exceptional eyesight were sent to locations that offered a clear view of the western horizon, and their sighting of the crescent determined the beginning of the month; otherwise they would repeat the process the next day. If the sky was cloudy, the calendar would be regulated by assuming a fixed number of days for the month just completed. Also, the crescent might be seen in one locality and not in another. Unfortunately the historical sources contain very little information on the actual practice of regulating the calendar.

Medieval astronomers, on the other hand, knew that the determination of the possibility of sighting on a given day was a complicated mathematical problem, involving knowledge of the positions of the sun and moon relative to each other and to the local horizon. The crescent will be seen after sunset on a given evening at the beginning of a lunar month if it is far enough away from the sun, and if it is high enough above the horizon not to be overpowered by the background sky glow. Conditions required to assure crescent visibility on most occasions can be determined by observations, but the formulation of a definitive set of conditions has defied even modern astronomers. The positions of the sun and moon must be investigated to see whether the assumed visibility conditions are satisfied, but, even if they are, the most ardent astronomer can be denied the excitement of sighting the crescent at the predicted time if clouds or haze on the western horizon restrict his view.

The earliest Muslim astronomers adopted a lunar visibility condition which they found in Indian sources. It was necessary to calculate the positions of the sun and moon from tables and then to calculate the difference in setting times over the local horizon. If the latter was 48 min or more, the crescent would be seen; if it was less, the crescent would not be seen. In the early ninth century the astronomer al-Khwārizmī compiled a table showing the minimum distances between the sun and moon (measured on the ecliptic) to ensure crescent visibility throughout the year, based on this condition and computed specifically for the latitude of Baghdad. During the following centuries Muslim astronomers not only derived far more complicated conditions for visibility determinations but also compiled highly sophisticated tables to facilitate their computations. Some of the leading Muslim astronomers proposed conditions involving three different quantities, such as the apparent angular separation of the sun and moon, the difference in their setting times over the local horizon, and the apparent lunar velocity. Annual ephemerides or almanacs gave information about the possibility of sighting at the beginning of each month.

The Regulation of the Five Daily Prayers

The times of the five daily prayers in Islam are defined in terms of astronomical phenomena dependent upon the position of the sun in the sky. More specifically, the times of daylight prayers are defined in terms of shadows, and those of night prayers in terms of twilight phenomena. They therefore vary with terrestrial latitude, and unless measured with respect to a local meridian, also with terrestrial longitude.

Because the months begin when the new moon is seen for the first time shortly after sunset, the Islamic day is considered to begin at sunset. Each of the five prayers may be performed during a specified interval of time, and the earlier during the interval the prayer is performed, the better. The day begins with the *maghrib* or sunset prayer. The second prayer is the *ishāʾ* or evening prayer, which begins at nightfall. The third is the *fajr* or dawn prayer, which begins at daybreak. The fourth is the *ẓuhr* or noon prayer, which begins shortly after astronomical midday when the sun has crossed the meridian. The fifth is the *ʿaṣr* or afternoon prayer, which begins when the shadow of any object has increased beyond its midday minimum by an amount equal to the length of the object casting the shadow. In some medieval circles, the *ẓuhr* prayer began when the shadow increase was one-quarter of the length of the object, and the *ʿaṣr* prayer continued until the shadow increase was twice the length of the object.

In the first few decades of Islam, the times of prayer were regulated by observation of shadow lengths by day and of twilight phenomena in the evening and early morning. Precisely how either the daylight or the nighttime prayers were regulated is unfortunately not clear from the available historical sources. Muezzins who performed the call to prayer from the minarets of mosques were chosen for their piety and the excellence of their voices, but their technical knowledge was limited.

On the other hand, the determination of the precise moments (expressed in hours and minutes, local time) when the prayers should begin, according to the standard definitions, required complicated mathematical procedures in spherical astronomy, that is, the study of problems associated with the apparent daily rotation of the celestial sphere. Accurate as well as approximate formulae for reckoning time of day or night from solar or stellar altitudes were available to Muslim scholars from Indian sources and these were improved and simplified by Muslim astronomers. Certain individual astronomers from the ninth century onward applied themselves to the calculation of tables for facilitating the determination of the prayer times. The earliest known prayer-tables were prepared in the ninth century by al-Khwārizmī for the latitude of Baghdad. The first tables for finding the time of day from the solar altitude or the time of night from the altitudes of certain prominent fixed stars appeared in Baghdad in the ninth and tenth centuries. The extent to which these tables deriving from mathematical procedures were used before the thirteenth century is unknown. The earliest examples are contained in technical works which must have had fairly limited circulation; the muezzins certainly had no need of them. Only a professional astronomer could use the tables, together with some kind of observational instrument for measuring the sun's altitude and reckoning the passage of time.

It was not until the thirteenth century that the institution of the *muwaqqit* appeared in mosques and madrasas. These professional astronomers associated with a religious institution not only regulated the prayer times, but constructed instruments, wrote treatises on spherical astronomy, and gave instruction to students. In thirteenth-century Cairo, new tables were available, and these set the tone for astronomical timekeeping all over the Islamic world in the centuries that followed. In medieval Cairo there was a corpus of some 200 pages of tables available for timekeeping by the sun and for regulating the times of prayer; in numerous copies the tables are associated with Ibn Yūnus.

Impressive innovations in astronomical timekeeping were made in other medieval cities, especially Damascus, Tunis, and Taiz, although by the sixteenth century Istanbul had become the main center of this activity. Highly sophisticated tables of special trigonometric functions were compiled to solve problems of spherical astronomy for any latitude. Tables for finding the time of day from the solar altitude at any time of year were compiled for Cairo, as we have mentioned, and also for Damascus, Tunis, Taiz, Jerusalem, Maragha, Mecca, Edirne, and Istanbul. Medieval tables for regulating the times of prayer have been found for a series of localities between Fez in Morocco and Yarkand in China. Such tables have a history spanning the millennium from the ninth century to the nineteenth.

Astronomical tables for regulating the prayer times had to be used together with instruments; only in this way could one ascertain that the time advocated in the table had actually arrived. The most popular of these instruments were the astrolabe and the quadrant. Hundreds of Islamic astrolabes and several dozen quadrants are preserved in the museums of the world, only a small fraction of the instruments actually made by Muslim astronomers. An alternative means of regulating the daytime prayers was available to the Muslims in the form of the sundial. Many mosque sundials from the later period of Islamic astronomy survive to this day, though most are now nonfunctional.

The Determination of the Sacred Direction

The Kaʿba in Mecca was adopted as the focal point of the new religion since the *Qurʾān* advocates prayer toward it. For Muslims it is a physical pointer to the presence of God. Thus since the early seventh century Muslims have faced the Sacred Kaʿba in Mecca during their prayers. Mosques are built with the prayer-wall facing the Kaʿba, the direction being indicated by a *miḥrāb* or prayer-niche. In addition, certain ritual acts such as reciting the *Qurʾān*, announcing the call to prayer, and slaughtering animals for food, are to be performed facing the Kaʿba. Also Muslim graves and tombs were laid out so that the body would lie on its side and face the Kaʿba. (Modern burial practice is slightly different but still Mecca-oriented.) Thus the direction of the Kaʿba – called *qibla* in Arabic and all other languages of the Islamic commonwealth – is of prime importance in the life of every Muslim.

During the first two centuries of Islam, when mosques were being built from Andalusia to Central Asia, the Muslims had no truly scientific means of finding the qibla. Clearly they knew roughly the direction they had taken to reach wherever they were, and the direction of the road on which pilgrims left for Mecca could be, and, in some cases, actually was used as a qibla. But they also followed two basic procedures, observing tradition and developing a simple expedient. In the first case, some authorities observed that the Prophet Muḥammad when he was in Medina (north of Mecca) had prayed due south, and they advocated the general adoption of this direction for the qibla. This explains why many early mosques from Andalusia to Central Asia face south. Other authorities said that the Quranic verse quoted above meant standing precisely so that one faced the Kaʿba. Now the Muslims of Meccan origin knew that when they were standing in front of the walls or corners of the Kaʿba they were facing directions specifically associated with the risings and settings of the sun and certain fixed stars. They knew that the major axis of the rectangular base of the edifice points toward the rising point of Canopus, and the minor axis points toward summer sunrise and winter sunset. These assertions about the Kaʿba's astronomical alignments, found in newly discovered medieval sources, have been confirmed by modern measurements.

In addition Arabic folklore associates the sides of the Kaʿba with the winds and rain. These features and associations cast new light on the origin of the edifice, and in a sense confirm the Muslim legend that the Kaʿba was built in the style of a celestial counterpart called *al-bayt al-maʿmūr*: indeed it seems to have been an architectural model of a pre-Islamic Arab cosmology in which astronomical and meteorological phenomena are represented. The religious association was achieved first by a number of statues of the gods of the pagan Arabs which were housed inside it. With the advent of Islam, these were removed, and the edifice has for close to 1,400 years served for Muslims as a physical focus of their worship.

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The corners of the Kaᶜba were associated even in pre-Islamic times with the four main regions of the surrounding world: Syria, Iraq, the Yemen, and "the West." Some Muslim authorities said that to face the Kaᶜba from Iraq, for example, one should stand in the same direction as if one were standing right in front of the north eastern wall of the Kaᶜba. Thus the first Muslims in Iraq built their mosques with the prayer-walls toward winter sunset because they wanted the mosques to face the north eastern wall of the Kaᶜba. Likewise the first mosques in Egypt were built with their prayer-walls facing winter sunrise so that the prayer-wall was "parallel" to the north western wall of the Kaᶜba. Inevitably there were differences of opinion, and different directions were favored by particular groups. Indeed, in each major region of the Islamic world, there was a whole palette of directions used for the qibla. Only rarely do the orientations of medieval mosques correspond to the qiblas derived by computation. Recently some medieval texts have been identified which deal with the problem of the qibla in Andalusia, the Maghrib, Egypt, Iraq and Iran, and Central Asia. Their study has done much to clarify the orientation of mosques in these areas. In order that prayer in any reasonable direction be considered valid, some legal texts assert that while facing the *actual* direction of the Kaᶜba (*ᶜayn*) is optimal, facing the *general* direction of the Kaᶜba (*jiha*) is also legally acceptable.

In various texts on folk astronomy, popular encyclopedias, and legal treatises, we find the notion of the world divided into sectors about the Kaᶜba, with the qibla in each sector having an astronomically defined direction. Some 20 different schemes have been discovered recently in the manuscript sources, attesting to a sophisticated tradition of sacred geography in Islam.

The earliest schemes of Islamic sacred geography date from the ninth century, but the main contributor to its development was a Yemeni legal scholar named Ibn Surāqa, who studied in Basra about the year 1000. Ibn Surāqa devised three different schemes of sacred geography, with the world arranged in 8, 11, and 12 sectors around the Kaᶜba. Each sector of the world faces a particular section of the perimeter of the Kaᶜba. Simpler versions of his 12-sector scheme occur in such popular geographical works as the *Taqwīm al-buldān* of Yāqūt al-Rūmī (ca. 1200) and the *Āthār al-bilād* of al-Qazwīnī (ca. 1250) as well as the encyclopedia *Ṣubḥ al-aᶜshā* of al-Qalqashandī (ca. 1400). From the fifteenth century to the nineteenth, we find a proliferation of schemes with different numbers of divisions between eight and 72 divisions of the world around the Kaᶜba.

Muslim astronomers from the eighth century onward concerned themselves with the determination of the qibla as a problem of mathematical geography. This activity involved the measurement of geographical coordinates and the computation of the direction of one locality from another by procedures of geometry or trigonometry. The qibla at any locality was defined as the direction of Mecca along the great-circle on the terrestrial sphere.

Muslims inherited the Greek tradition of mathematical geography, together with Ptolemy's lists of localities and their latitudes and longitudes. By the early ninth century observations were conducted in order to measure the coordinates of Mecca and Baghdad as accurately as possible, with the express intention of computing the qibla at Baghdad. Indeed, the need to determine the qibla in different localities inspired much of the most sophisticated activity of the Muslim geographers (see below).

Once the geographical data are available, a mathematical procedure is necessary to determine the qibla. The earliest Muslim astronomers who considered this problem developed a series of approximate solutions, all adequate for most practical purposes, but in the early ninth century, if not before, an accurate solution by solid trigonometry was formulated. The accurate formulae derived by the Muslim astronomers from the ninth century onward are impressive, and are mathematically equivalent to the modern formula. Muslim astronomers also compiled a series of tables displaying the qibla for each degree of latitude and longitude difference from Mecca, based on both approximate and exact formulae, the first of these being prepared in Baghdad in the ninth century.

Over the centuries, numerous Muslim scientists discussed the qibla problem, presenting solutions by spherical trigonometry, or reducing the three-dimensional situation to two dimensions and solving it by geometry or plane trigonometry. They also formulated solutions using calculating devices. But one of the finest medieval mathematical solutions to the qibla problem was reached in fourteenth-century Damascus: a table by al-Khalīlī displays the qibla for each degree of latitude from 10° to 56° and each degree of longitude from 1° to 60° east or west of Mecca, with entries correctly computed according to the accurate formula. This splendid table (rediscovered only in the early 1970s) was not widely known in later Muslim scientific circles. *Muwaqqits* of later centuries wrote treatises about the determination of the qibla but did not mention this Syrian table. By the fourteenth century the correct values of the qibla of each major city had long been established (correct, that is, for the medieval coordinates used in the calculations). Simple qibla-indicators fitted with a magnetic compass and a gazetteer of localities and qiblas became common, and the modern variety represents a continuation of this tradition.

Some of the most important Muslim contributions to mathematical geography are to be found in a series of treatises by the early eleventh-century scientist al-Bīrūnī. In one treatise he set out to determine for his patron the qibla at Ghazna (in what is now Afghanistan), first establishing the necessary geographical coordinates and then calculating the qibla by different procedures. Since 1989 three Persian qibla-indicators, made in Isfahan about 1675, have became available for study. They bear a cartographic grid so devised that one can read the direction and distance to Mecca directly. Mecca is at the center of the grid and one has only to lay the diametrical rule over any city marked on the map (between Spain and China, Europe and the Yemen) to read off the qibla on a circular scale around the grid and the distance on the diametral rule. The origin of this remarkable device is still under investigation; but the underlying mathematics is described in two treatises on conic sections, one from tenth-century Baghdad and the other from eleventh-century Isfahan. The tradition behind the Isfahan world maps represents the most sophisticated contribution to mathematical geography known between Antiquity and the Renaissance.

The alignment of medieval mosques reflects the fact that the astronomers were not always consulted on their orientation. But now that we know from textual sources which directions were used as a qibla in each major locality, we cannot only better understand the mosque orientations but also recognize numerous cities in the Islamic world that can be said to be qibla-oriented. In some, such as Taza in Morocco and Khiva in Central Asia, the orientation of the main mosque dominates the orientation of the entire city. In the case of Cairo various parts of the city and its suburbs are oriented in three different qiblas. The new Fatimid city of al-Qāhira, founded in the tenth century, faces winter sunset, which was the qibla of the Companions of the Prophet who erected the first mosque in Egypt in nearby Fustat some three centuries previously. The later Mamluk "City of the Dead" faces the qibla of the astronomers. The predominant orientation of architecture in the suburb of al-Qarāfa is toward the south, another popular qibla. The splendid Mamluk mosques and madrasas built along the main thoroughfare of the old Fatimid city are aligned externally with the street plan, and internally with the qibla of the astronomers: one can observe the varying thickness of the walls when standing in front of the windows inside the mosque overlooking the street outside. This is an area of the history of urban development in the Islamic world which has only recently been studied for the first time, not least because, prior to the discovery of the textual evidence, it was by no means clear which directions were used as qiblas; even if a qibla at variance from the true qibla was clearly popular, it was not known why. The first accurate longitude values of localities in the Islamic world become available only with the systematic scientific cartographic surveys of the eighteenth and nineteenth centuries. Thus most of the accurately computed qiblas of the medieval astronomers could be judged as being in error by a few degrees anyway.

Other Applications of Science to Daily Life

The Islamic laws of inheritance, based on prescriptions in the *Qurʾān*, are complicated, and their application involves some skill in arithmetic. Both legal scholars and certain mathematicians wrote on this subject, but only two or three simple works by legalists have been studied and until recently no research of consequence had been conducted on the large number of available sources. There is also a vast corpus of literature on weights, measures, and arithmetical techniques.

Muslims also developed geometric designs for the decoration of religious architecture and also secular artifacts. The acceptability of such ornamentation is discussed by various legal scholars, but their writings have yet to be properly studied. Only two Muslim mathematicians are known to have included remarks on geometric design in their writings, a fact which confirms the suspicion that this was an art passed down amongst the practitioners. Some years ago a manuscript of an artisan's manual with guidelines for generating numerous patterns is now published.

The legal scholars of medieval Islam used methods for regulating the calendar and prayer times and for finding the sacred direction which were simple and adequate for practical purposes. Their ingenuity in coping with differences of opinion never lost sight of the basic purpose of Quranic and Prophetic injunctions. Some of the greatest of the Muslim scientists dealt with the calendar, prayer times, and the qibla, and in these areas, as in others, their mathematical creativity and their quest for greater accuracy was impressive. In later centuries (after the thirteenth), competent astronomers were appointed to the staffs of major mosques in order to advise on these specific subjects. But the solutions developed by Muslim scientists were invariably too complicated for widespread application in the medieval milieu. Although the scholars of the sacred law and the scientists proposed different solutions for the same individual problem, there are few records of serious discord between the two groups in the medieval sources. The legal scholars criticized mathematical astronomy mainly insofar as it was used by some as the handmaiden of astrology, which was an anathema to them. The scientists seldom spoke out against the simple procedures adopted by the legal scholars.

See also: ►Astronomy, ►Calendars, ►*Qibla* and Islamic Prayer Times, ►Astrolabe, ►Quadrant, ►al-Khalīlī, ►Ibn Yūnus, ►al-Khwārizmī, ►Ottoman science, ►al-Bīrūnī, ►Maps and Mapmaking, ►Geometry, ►Weights and Measures

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Religion and Science in Islam II: What Scientists Said About Religion and What Islam Said About Science

Anton M. Heinen

The interaction between religious life and scientific enterprise in the culture that evolved under the impact of Islam is one of the predominating themes in today's discussions and writings of Muslims all over the world. It has continued to be such ever since the beginning of the last century, when European forces, with their newly developed technological means, extended their rule over large areas with Muslim populations until then concerned only with the traditional values of their preindustrial communities. Today's revivalist Muslim leaders, themselves often engineers or trained scientists and not theologians, fight for a new society based on a harmonious practice of Islam and science. Or governments build mosques with technological showpieces (e.g., minarets with laser beams as indicators of the *qibla*, the direction of Mecca, as recently in Morocco), and museums and universities dedicated to the "Islamic sciences". The scientific achievements of the West are considered to be the inheritance of great Muslim sages of the Middle Ages. Thus modern technology cannot be a dangerous evil because it belonged to the Muslims first. But it has been alienated by the West, truncated from its heart, which is the recognition of Allāh, the Creator of all beings. This was the view of the influential leader of the Muslim Brothers, Sayyid Qutb (1906–1966). Although he was executed under Nasser's government in Egypt in 1966, his brief sermon on *This Faith, Islam* is still representative of some sections of opinion in the Muslim community.

Observers from the outside world, where the dispute between religion and science has largely turned into a relic of the past, if it does not lead into ethical discussions about the effects of scientific and technological progress on human values, find it difficult to do justice to this preoccupation of their Muslim neighbors, which they usually interpret in analogy to apparently similar ideologies in their own realm, such as fundamentalism in America's "Bible Belt". However, the religious as well as the scientific realities involved differ greatly on both sides. Instead, the insights of the history of science as well as that of religion should be drawn upon when the relationship between the two fields is to be treated objectively. As the history of science has brought to light a whole spectrum of changing methods and conceptualizations that over the centuries have been interpreted as "science", so also "religion" has been described by its historians as being practiced variously by just about every people, culture, time, or even individual. Generalizations about the religious factor in human activities, in the West always identified with dogmatic teachings, are just as false as those about an unhistorically monolithic science, but even more widespread. The surprisingly bitter reaction to the attack of some European powers and individuals will be more readily understood if the interaction of science and Islamic religion, from the outset centered on increasing knowledge, is rightly appreciated.

The case of scientific technology probably was chosen as a favored battlefield because the Western critics, proudly flying the flag of enlightenment, had previously used it as a weapon against the Islamic religion. Thus, cultural and technological back wardness became a religious issue for Muslim intellectuals. Curiously enough, it was the philosophical and scientific work of Ibn Rushd (Latin Averroes, 1126–1198), who as "the Commentator" (namely of Aristotle) had been accepted as master by the European scholars throughout the Middle Ages, which stood in the center of this modern attack on Islam. That he had not been able to influence his co-religionists in the Islamic world to the same extent as the Jewish and Christian schoolmen in Europe was the main reason that Islam in the last century was made responsible for the worst obstruction against scientific progress. The main exponent for this attack was Ernest Renan's *L'Islam et la science*, written in 1883; the Arabic writings of Faraḥ Anṭūn in the journal *Al-Jāmiʿa* (Cairo, 1902–1903), easily accessible for Egyptian intellectuals, made this attack on Islam even more effective. From then on, the relationship between science and religion, both seen in the crystallized and almost ahistorical notions of that time, was turned into the most crucial question for any global view of Islam in human history. The question was raised on more general grounds: "Why did the Muslims fall back, while the others made progress?" The more general and fundamental questions have stood in the foreground; the more particular ones, e.g., the Islamic position *vis-à-vis* alchemy, astrology, geocentric vs. heliocentric astronomy, or such consequential medical questions as anatomical dissections, preventive measures against epidemics, abortion, birth control, etc., have been strangely pushed into the background, although numerous treatises over the centuries have been written on them.

In defense, the beginnings of the spread of scientific activity in Islamic culture, and then its high period, were chiefly taken for reference, not the obvious stagnation in the later Middle Ages. The latter phenomenon has hardly been studied, and almost no convincing explanations have ever been proposed. But it is revealing that no responsibility for such an intrusion into scientific development has been assigned to the Islamic religious authorities, as has been the case of the Inquisition trials in Christian countries.

But, in confrontation with medieval historians centered on Europe, it was not easy to reclaim the scientific heritage for the Muslims, for this heritage was primarily seen as that of the ancient Greeks whose works had been translated into Arabic. And since these works, some centuries later, were again translated from Arabic into Latin, the Arabs apparently were assigned the humble role of transmitters only, like the merchants in an import and export business. For Renan, the cultural role of Islam was actually limited to the preservation of ancient culture for and transmission to Europe, where it would be revived. That such translations from pre-Islamic Hellenistic culture involved a heavy indebtedness was not denied by Arab historians. However, in their view this ancient heritage was integrated into an already established Islamic society. As it is today, with more sources to judge by, the roots of the scientific movement in Islam itself are more generally recognized as having exerted a stimulating influence on the introduction of the more complete scientific heritage of pre-Islamic cultures: the *Qurʾān* and its exegesis, jurisprudence, philology, etc.

The first line of defense was taken up by such rationalist reformers as Shaykh Muḥammad ʿAbduh (1849–1905). He argued that Quranic religion was in no way opposed to, but on the contrary totally in harmony with science. The guidelines of his argument were taken from the apologetic discussions about the necessity of miracles as testimonials for the true prophet: miracles supposedly revealed the divine nature of Jesus, the Son of God, while the Prophet Muḥammad had only referred to the factual evidence of the Arabic *Qurʾān* in support of his divine message. (Miracles like the splitting of the Moon by the Prophet, as they were described in popular literature, were apparently not considered in this argumentation of modernist theology.) That the fact of revelation, divine speech entering the limits of creation, or the *Qurʾān* as an inimitable revealed book, were proposed by the Prophet as the decisive miracle, or that creation and recreation after death were described as miracles permeating the whole of human existence, all these truly "miraculous" events apparently were not considered to interfere with the course of nature.

Unfortunately, ʿAbduh's apologetic argumentation was later exaggerated by his disciple Rashīd Riḍā (1865–1935) who claimed science for Islam. In his commentary of the revealed book, all knowledge was traced to the *Qurʾān*, even modern technological and medical inventions. For example, the Arabic *Jinn* were identified with the microbes of contemporary medicine. But progress soon let such hasty identifications appear outdated, and today this unhealthy spirit of "Islamization" is much less prevalent.

More common, and truer to the revealed Quranic texts, is the derivation of an original Muslim science from the so-called "sign-verses," i.e., those verses that prescribe the inquiry into such signs in creation as the sun, moon, stars, earth, and sea, life in all its forms, in fact whatever enters the realm of human experience. Corresponding texts can be found in the works of Muslim scientists throughout Islamic history, in the *Taḥdīd nihāyāt al-amākin* (The Determination of the Coordinates of Positions for the Correction of Distances Between Cities) of the mathematician and astronomer al-Bīrūnī (973–1051), in the *Faṣl al-maqāl* (On the Harmony of Religion and Philosophy) of the philosopher Ibn Rushd (1126–1198), or the interviews of the living Nobel prize winner Abdus Salam. Such an inquiry, as should be noted against a frequent misunderstanding of Western scholars, was not to lead to higher developed proofs for the existence of God, for it would be contrary to the faith of Islam that such proofs should be needed. But Muslims of all times have interpreted the Quranic counsels of "considering the wonders of creation" as the most effective promotion of scientific research. The results were not predetermined; not even the existence of the Creator was imposed as the logical consequence of a binding argument. But the faithful scientist was to find himself placed in the more overwhelming presence of a personally approachable God Almighty. The inner spiritual motivations for an Islamic science, not the passing discoveries, were of the greatest significance.

How far along the way of an open and progressive science a Muslim scholar could be led by the sign-passages of the *Qurʾān* is best illustrated by Ibn Rushd's treatise *Faṣl al-maqāl*. Even though he was a high functionary of Islamic law at the court of the strict Almohad administration, Ibn Rushd wrote this work as a legal defense of objective and universalist scholarship. Beginning from the Quranic injunctions to respond with thought and inquiry to the wonders of creation, he gradually moved on to the defense of gradual progress beyond incomplete scientific results, relying in the process on the heritage of pre- and non-Islamic sages. Hence, the great lawyer could even accept preliminary results, teachings known to include errors. To tolerate such partially erroneous theories, while always proceeding toward deeper insights, was for him a basic consequence of the human condition. While not denying prophetic revelation as the source of the Islamic religious movement, Ibn Rushd with this open system may be said to have reached the highest peak of the Islamic scientific worldview.

It cannot be surprising that natural research on the background of the Quranic finding of the Creator, whose inner nature is above all human speculation, in the signs he had placed for humanity into his creation, has sometimes been understood along Pantheistic lines. Knowledge did seem to acquire a higher character for salvation, or even a certain participation in the unitarian nature of the One God. Influential theologians like al-Ghazālī (1058–1111), but also leading scientists up to Abdus Salam in present times, insisted on Allāh's personal nature as Creator. Scientific disciplines, therefore, were to be used only for specific human purposes, and no one but God himself granted his highest blissful knowledge to the faithful who had clung to the fulfillment of his revealed will. Since God himself as Creator was also the author of all instruction, the growth of knowledge and the production of new inventions were not really possible for man restricted to his own created capacities.

But, as heir to a tradition of scholars who already had worked at filling a still Hellenistic science with Islamic spirit, al-Ghazālī also proposed the method of *Tafakkur*, a kind of meditation on the various phenomena of creation, which could lead to greater insights and more extensive knowledge, under the constant guidance of the Almighty. Such a method may have been at the root of the widespread mysticism of nature in Islam. As S. H. Nasr has observed, some of the greatest scientists in Islam (e.g., Quṭb al-Dīn al-Shīrāzī, AD 1236–1311) are known to have practiced Sūfism as well. But *Tafakkur* also presents a corrective for the unitarian view of Islamic science described above, Muslim thinkers asserted God's unity in all spheres of reality, thus reducing the multiplicity of created phenomena into a forced monism. The contrary can also be said, because by always keeping the spiritual goal of *taʿẓīm Allāh* (Magnification of God) in mind, the Muslim researcher, instead of closing it, would instead turn more and more leaves of Allāh's grand book of nature. The linguistic particularity of the Arabic language, always concentrating on individuality (*shawādhdh*), naturally could enforce this tendency.

It has become a standard argument that Islam needed such sciences as astronomy, mathematics, and geography for ritual obligations like the pilgrimage to Mecca, the establishment of the *qibla* (direction to Mecca) of new mosques, or even any prayer according to the traditional prescriptions. But some scholars feel this point should not be overstressed: even a legal authority like Abū Hanīfa (d. 767) warned that spatial orientation was not essential for the submission of the worshipper to the Creator, and numerous religious leaders maintained a quite relaxed attitude when confronted with greater mathematical exactness in the setting of the *qibla*. On the other hand, quite simple devices were sufficient for these needs. The number of treatises on the mathematical problems of the *qibla* are not necessarily in proportion to its importance for the Muslim community.

Of greater significance, and easily demonstrable, is the promotion of mathematical works by the theological principles of Islamic law. As the mathematician and astronomer in the Biblical tradition was encouraged by the saying that God had created the whole world with numbers (Wisdom 11,20), so the Muslim was convinced that the divine lawgiver had left nothing to the arbitrary decisions of sinful mankind, not even the shares of inheritance to be distributed among the members of a family: "…the male shall receive the portion of two females…" (Sūra 4, 175 ff). The natural consequence was the discovery and perfecting of algebraic rules which future lawyers had to learn for the administration of bequests; in other words, some mathematical instruction even entered legal schools usually blamed for having marginalized the rational and natural sciences. There it achieved full recognition as the respectable "science of shares" (*ʿilm al-farāʾid*).

The most characteristic and generally applied argument in support of orthodoxy and orthopraxis in Islamic intellectual history has certainly been the principle of *Sunna*. With carefully examined traditional reports it had to be established that questionable teachings or practices were sanctioned by words or actions/omissions of the Prophet himself or his Companions, or, in the case of Shiite Islam, the Imams. As this had already been done for the concepts and arguments of the theologians and jurists, the procedure did not stop at science, where it would seem to have been singularly inappropriate. Thus one of the most copied treatises of the Middle Ages, an indicator of its popularity, was the *al-Hayʾa al-sanīya fī al-hayʾa al-sunnīya* by al-Suyūṭī (1445–1505), a cosmographical work totally made up of well-attested traditional fragments of early theories.

The apparently simplistic view that truth can only be what has been taught or practiced by respected members of the Muslim community, testified to by an interrupted chain of trustworthy witnesses, may have been grounded in the deeper conviction that all values are sanctioned by the harmony with the laws of a well-established community. Scientific progress cannot be judged good and sane if it does not fit into the proven structures of a justice-oriented society or a healthy environment. In Islam this social order and the harmony with a God-created nature are directly derived from religion; hence, their demands on the work of the scientists belong to the religious, not the ethical or secular, realm.

Jurisprudence, no doubt, has been the most important discipline in the intellectual formation of the Muslims throughout their history. Some historians, considering the numerical superiority of law teachers and their students at the colleges and universities in Muslim lands, have blamed the lawyers for having pushed the sciences to the margins of academic institutions. On the other hand, hardly any other religious community has been so deeply formed by the ideal of realizing all its vital functions according to the principles of justice. The work of the scientists has not remained unaffected by this ideal. Thus long before Simon Stevin in his *Weeghconst* (Theoretical Statics, 1586) prepared the "democratization of science", which eventually gave it a special measure of vitality in Western nations, his Arab predecessor al-Khāzinī (fl. first half of the thirteenth century) had published in the *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom) a remarkable memorandum on science's being rooted in an all-encompassing justice. This is, however, an aspect of the interaction of science and faith in Islam which has hardly been studied, in spite of its significance for the appropriation of technology by widely spread popular organizations, guilds, and Sūfi brotherhoods, or the stagnation up to modern times.

See also: ►Religion and Science I, ►*Qibla* and Islamic Prayer Times, ►Ibn Rushd, ►*Hayʿa*, ►al-Suyūṭī, ►al-Khāzinī, ►Science as a Western Phenomenon

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Religion and Science in the Native Americas

Åke Hultkrantz

If science may be said to be concerned with "observation, description, definition, classification, measurement, experimentation, generalization, explanation, prediction, evaluation, and control of the world," as it is in the *International Encyclopedia of the Social Sciences*, it is easy to conclude that all these practices have occurred among American Indians, mostly within a religious and mythological perspective. Some scholars presuppose that American Indians have lived in a natural–supernatural continuum where the distinction between this and the other world (however we care to define it) practically falls down. Others, including this author, are under the impression that the indigenous people postulated two experimental worlds, the natural world around them in everyday life, and the mysterious world of myth and religion which occasionally breaks into the natural world, for instance in dreams and rituals. In the long run this mysterious (supernatural) world seems to constitute the real, true world; at least some religious Native thinkers believe this is the case. It is not impossible that many Indian visionaries believed this without verbalizing their beliefs.

In any case, Indian observations and explanations have, in their own thinking, been linked to religious evaluations. Everyday reality was mostly experienced from a profane point of view where experiences followed each other in a foreseen way. Where this was not the case, or uncertain courses of events and unknown places are met, the other dimension is resorted to. Since the latter dimension is the most difficult to understand, and rules humankind's life, the interpreters of that world, medicine men, shamans and priests, and artisans that catch symbols and spiritual realities, are more important than experts on the everyday world. We can state that in Native America the range of spiritual experts has been much wider than that of technological experts.

The anthropologist Paul Radin has shown that there exists what he calls "two general types of temperament" among, in particular, American Indians: "the man of action and the thinker, the type which lives fairly exclusively on what might be called a motor level and the type that demands explanations and derives pleasure from some form of speculative thinking." It is characteristic that in order to describe the thinkers and their accomplishments he turns to the specialists on religion (and then a bit arbitrarily joins "historians," i.e., mythological raconteurs, with such specialists of experimental religion as medicine men and shamans). American Indians are on the whole not skeptics, since dreams, hallucinations, and traditions of visits to the other world by eminent spiritualists give strength to their religious beliefs. Collective rituals give these beliefs a realistic stamp. Only when different religions collide and a relativism of values ensues do religious brooding, skepticism, and indifference take over. There is thus little space for other than religiomythical incitements in penetrating the marginal recesses of the empirical world.

The dominance of religious thinking in what science today would call secular matters is obvious in the fields of cosmology and medicine. There are two great world pictures in America. One is certainly the older one, with Paleolithic–Mesolithic origins and connections with the hunting tribes in the Old World. It depicts a Universe where the world pillar or the world tree forms the axis which connects heaven and earth. It is often said that this pole or tree is situated in the middle of the world; its roots are fixed in the underworld and nourished by subterranean rivers or a well. Its top reaches the sky that rests on it. Sometimes the world column stretches through several skies until it reaches the highest sky. Symbols of the different species of animals living on different levels are supposed to dwell on the tree: lowest down snakes or fishes, on the earth level deer and buffalo, highest up birds like eagles and falcons. Some tribes relate that unborn souls inhabit the crown of the world tree. Other tribes believe that the world tree, that often has a forked top, is identical to the Milky Way which is "the backbone of the sky" and the road taken by the souls to the hereafter. The world has also formed the passageway downward for the gods when they cared to visit the ground and upward for the shamans when in their séances their souls went to the supernatural world to receive information of the gods (and, in some cases, to release a diseased person's captured soul from the realm of the dead). The world tree is ritually modeled in the middle pole of ceremonial structures, such as the Plains Indian Sun Dance hall, which is itself a ritual reproduction of the cosmos. The Sun Dance ceremony is a repetition of the cosmic creation.

The world tree expresses an inclination for a heavenly world. American high culture supplants the tree or pillar symbol with a temple mound, mostly a pyramid. On the top of this pyramid the gods have their habitats (read: statues), and many pyramids enclose the bodies of deceased princes. The sacred temple areas in Mexican pre-Columbian cities are modeled after the supposed heavenly geography.

The other world picture which has been distributed in agricultural areas has its parallels in the agrarian civilizations of the Old World. In this case the attention on the supernatural world is, at least partly, directed downward, to the underworld. Here is the place from which man, like the plants, once in mythic time came up, often climbing on a reed. Myths even talk of four successive underworlds, one darker than the other, or qualified through different colors. Inundating waters or other difficulties started the evacuation. Myths tell us that valuable animals, like the buffalo in North America, also came up from the nether world. Men and animals appeared from a grotto which ever since has been said to be the center of the world. After death the living beings returned to the underworld, like the plant returns to it when it withers. The underworld realm of the dead is mostly the place to which shamans send out their soul to retrieve the lost soul of a sick patient. Some divinities, be it the lord-lady of the dead or the spirits of vegetation, may be found in the underworld.

These world pictures are supposed to be stable, as when the Lenape (Delaware Indian) Supreme Being with his hand holds the upper part of the world pole.

However, in earthquake areas this is not the case. According to anthropologist Lowell J. Bean, the Cahuilla of Southern California believed

> that all matter was subject to unpredictable change… For example, dramatic changes in topography are vividly and frequently recalled…This instability was true from the beginning. Creation of the earth and life itself was fraught with indecision, mistakes, and conflicts of power between the creator brothers.

This is a neat example of how environmental changes are referred to mythical incidents.

Also in another topic, medicine and medical practice, religion outbids what we might consider a more “scientific” approach. Certainly, there is, even behind supernatural gestures, the beginning of a systematic and naturalist treatment of sick persons in a simple hunting milieu. The herbalists who supply herbs, cobwebs, sap, or leaves for wounds, or handle internal medicine for the patient, follow what they have learnt or what their own experiences have taught them. Observation and practice over the years thus guided their use of natural medicine, and today’s science of laboratory medicine can sometimes corroborate the positive medical properties of these medicines. If anything the choice of useful medicaments points out the scientific endeavors of American Indians.

However, there are other doctors as well, and their curing is considered more important. Medicine men and shamans invoke supernatural powers in order to deliver the sick from a serious disease (or a disease which they comprehend as serious). Gods and spirits are then thought to be the active medical powers, and the disease itself may be a demoniac being. In other words, the more serious the disease is, the more frequently supernatural powers have to be invoked. Of course, even simple herbalist methods may be accompanied by religious blessings.

Such a continuum between this world and the other world may, superficially seen, seem to make the distinction between them invalid, but this is not so. American Indians have had recourse to systems which would not satisfy Western logic; their logic is often created from the needs of the situation. In religion, completely reciprocally exclusive belief chains may be resorted to, depending on the situation. In the same manner, Indians may interpret phenomena as derived from this world or the other world, but also, in single cases, see a continuous line between them.

As a further example of such thinking the hierarchy of biological masters may be mentioned. In many places in both Americas animals and plants are supposed to be controlled by masters who rule over them and own them. These masters may be animals of some sort, or supernatural beings. The Mataco in Argentina and Bolivia believe that herbs and trees are subordinated to their “owners,” certain animals and birds. Thus, the wild red pepper is owned by the red-eyed dove. The dove in its turn obeys a lord of the forest who is also the lord of honey. We learn that the latter is a supernatural being, whereas the dove is a natural bird. In this connection it should be pointed out that in many places, scholars have observed a folk classification of natural plants and animals. Indian tribes have constructed taxonomies with a series of hierarchical levels. In these cases it seems that only natural species have been segregated. It is another matter when Plains Indian medicine men arrange their guardian spirits, which appear in animal disguise, in an order according to their efficiency: they are ranked as spirits, not as animals, and may be included in a hierarchy. It is a remarkable fact that this hierarchical thinking occurs in societies which are otherwise characterized by their equality.

We have seen how the world picture, or the view of the Universe, is arranged according to religiomythical models in original Native American thought. In addition to what was said above it can be noted that stars and planets are also included in these models. The sun and moon may be understood as divinities or symbols of divinities; the sun is often a manifestation of the Supreme Being, the moon a manifestation of Mother Earth, or the god (goddess) of vegetation. The planets and stars incarnate other supernatural beings, often the culture hero and hunting spirits. The Blackfoot and other tribes tell myths according to which the main actors are transformed into well-known stars when their adventures have finished. Among the Pawnee all dominant gods are stars, the chief one among them being the high god Tirawa who is identified as the North star. Thus, the stars are supposed to be living, spiritual beings, something which is also demonstrated in their movements over the sky. Such a portrait of the star charter is the presupposition of astrology. In the classical antiquity of the Old World some supreme power, or fate, ruled the star movements; in America, the prime movers could be the stars themselves, or some power behind the stars. In both worlds omens and policies were dictated by these powers, and thus what some call a pseudoscience, astrology, took form to find out the nature of these dictates.

Among the high civilizations, such as the Maya of Southern Mexico and Guatemala, parts of the clergy made observations of the sky for astrological purposes. It has been said that in Mesoamerica and South America people tracked the positions of the stars in order to know how they themselves should behave, when they should plant, and when they should perform sacrifices, whereas in North America the signs from the heaven were an aid to good living, not frightening information. This distinction is probably too exaggerated. In North America there was great fear when, during eclipses of the sun or the moon, the celestial body was supposed to be swallowed up by some monster.

Astrology has, all over the world, paved the way for astronomy; this is also true in North and South America. The great annual festivals, the fertility ceremonies, and other occasions for ritual celebrations could begin when star constellations were favorable. The Tapirape Indians of the Amazonian forest know that when the Pleiades disappear in the west the rainy season is over. The prehistoric northern Plains Indians constructed medicine wheels on mountain tops (or, if there were no mountains in the area, on the open plains) which archeologists and astronomers interpret as calendar monuments, used for the determination of the summer solstice. For instance, the famous Medicine Wheel on the ridge of the Bighorn Mountains in Wyoming has the form of a wheel with a central cairn united with the peripheral stone ring through 28 spokes of stone. Other cairns are situated close to the periphery. From one of the latter cairns one can perceive the sun over the central cairn on Midsummer's Day. There are reasons to assume that the structure also had cultic functions. Its ground plan mirrors the world picture with the world pillar in the middle of the world, as was described earlier. Among other things, the 28 spokes correspond to the 28 roof poles of the Sun Dance lodge. This might also correspond to the 28 lunar mansions in Chinese, Islamic, and Indian astronomy.

In the matter of astronomical calculations the Maya were the masters. In order to arrive at exact computations they developed mathematics, used multiplication tables, and calculated the days of the year. With these means the Maya priest-astronomers managed to bring the Venus cycle into relation with the year, and they were also able to construct a table for predicting solar eclipses (although the latter were not always visible in the Maya area). Such eclipses were considered to be dangerous. The foreknowledge of the times they would appear made it possible for the priests to take action to help the threatened human beings.

Thus it appears that the beginning of science was motivated by its use for religious and ritual purposes. The Maya scholar, Eric Thompson, has this to say about the Maya intellectual achievements:

> It is remarkable that the intellectual successes of the Maya were not (from our point of view) practical; they were the outcome of spiritual needs. The Maya astronomers strove for knowledge, not as an end in itself, but as a means of controlling fate, a kind of astrology. There was, he felt, an orderliness in the heavens to which the gods conformed; once that was learned, he could predict the future through exact knowledge of which gods held sway at any given time, and influence it by knowing when and whom to propitiate.

It is also possible that the Maya writing with its multivalent hieroglyphs was first developed to serve sacerdotal ends. In any case, during the Classic Period, the Maya texts deal with astronomy, the connections between stars and gods, and associated ceremonies.

We could of course argue that there was in aboriginal America an appreciation of knowledge and learning that had no religious causation; but it can be scarcely understood as a scientific ambition. Skills in technology, and inventions (Inca road building, Maya corbelled vaults, Mexican wheel toys, etc.), rarely deserve this designation either. Inuit coast maps are a wonder of precision and may pass for art. Truly profane science was not part of the American Indian world.

See also: ►Eclipses, ►Astronomy, ►Medicine, ►Medicine Wheels, ►Mathematics, ►Magic and Science, ►Medicine in Native North America

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Rice Fields Reclamation in Southern India

K. T. Rammohan

Backwaters are large water bodies that are receptacles of rivers but contain saline water as they are connected to the sea. The Vembanad backwater system in far southern India covers an area of over 21,000 ha, measures 96.5 km in length, and is 3 to 8 m deep. Designated as a Ramsar site in 2002, the Vembanad is the largest estuarine system on India's western coast and as a transitional ecotone between land and sea, offers protection to innumerable living organisms, including clams and waterfowl (Nair 2003). Population expansion and economic pressures of commercial agriculture and tourism, however, have put pressure on the backwater causing it to considerably dwindle over time (Narayanan 2003).

While reclamation of Vembanad backwater for habitation and cultivation has a history that dates back many centuries, the scale of operation was small until the nineteenth century. From this period, Travancore was rapidly drafted into the world economy as a source of varied goods: coffee, tea, coconut oil, coir, and later rubber. It was crucial for the export economy to be price-competitive in the international market. Export production was labour intensive. To keep prices low, wages had to be kept low. This in turn required keeping food prices under check. However, the demand for rice was rising and its supply was falling. Besides normal demographic expansion, the immigrant workforce in the plantations marked new demand. The relocation of agricultural workers to coir weaving factories in the coastal urban centres also possibly raised the demand for rice. Earlier, in the countryside, their food comprised some rice and a large share of tubers. In the town, lacking access to tubers that were not a marketed commodity, people substituted rice. As demand for rice rose, its supply fell. This was mainly due to the decline of hill cultivation of rice consequent to the setting up of plantations (Rammohan 1996).

The princely government of Travancore sought to address the growing mismatch between supply and demand of rice in three ways: import of rice from Bengal, Burma, and Siam; propagation of cassava as a rice substitute; and encouraging the creation of new rice lands by reclaiming the Vembanad backwater. Large-scale reclamation began towards the late nineteenth century, with the princely government granting short-term exemption from tax on reclaimed lands and extending loans at concessional rates to the cultivators. Even with cheap and servile labour, reclamation was expensive. Usually one person was given permission, but he carried out reclamation by forming partnerships with a few others. Networking was mostly confined within a caste or community or among castes and communities of similar social status. Nayars and Christians, jointly and severally, floated most of the partnerships. Lower castes and communities lacking financial resources and influence in government could not undertake reclamation. Workers of Pulaya and Paraya castes, considered 'untouchable' by their higher caste landlords, did most of the work. The technology of reclamation also is indebted to these castes, especially Pulayas, who had long resorted to reclaiming shallow backwaters for cultivation, as they owned no land themselves.

Reclamation occurred during the summer when water level in the lake dipped. It involved two major operations: building a circular dyke (outer main dyke or ring dyke or *mata*) to enclose the backwater area proposed to be reclaimed and draining water out from the enclosed area. Dykes had to be built where water was 8 to 10 ft deep. This involved several stages. First, coconut palm trunk piles in two parallel lines were driven into the bed of the backwater area to be reclaimed. These were fenced with bamboo screens on either side. The space enclosed by the bamboo screens was then tightly packed with clay, sand and brushwood. Clay had to be lifted from the lakebed at a depth of 10 to 12 feet and transported by country boats to the site. The dyke-enclosed area was then drained by using an array of waterwheels of different sizes, mounted one upon the other, operated day and night. After draining the area, usual agricultural operations could be commenced. With high water levels surrounding the field and the lake being prone to tides, constant vigil had to be maintained against any breach in the dyke. Land and water management was central to cultivation. All operations, including ploughing, sowing, weeding and harvesting, were dependent on timing and any delay could ruin the crop.

Rice cultivation in reclaimed lands was highly labour-intensive and its success depended on the availability of a captive workforce round the clock. Male workers built and maintained the dykes, and ploughed the field; the rest of the operations were mostly done by women. These workers were initially slaves and their masters were mostly members of upper castes like Brahmins and Nayars and communities like Syrian Christians. From the mid-nineteenth century, with the abolition of slavery, they were partially liberated but were still attached to the masters and their land. As land changed hands they had new masters. Some of them were settled in thatched mud huts in the master's homestead so that their services could be had anytime in the day or night. Others were settled on or near the dyke so that they could keep vigil over the dyke in times of heavy rains and act immediately if a breach occurred. The ring dykes demarcated individual fields while most fields were protected by outer dykes, built and maintained jointly by the farmers.

During the early years of reclamation, water was drained by using waterwheels made of wood. With the introduction of mechanical pump sets towards the end of the nineteenth century reclamation activity received a further boost. While earlier, only small blocks of 40–60 acres used to be reclaimed, large blocks of hundreds of acres could now be reclaimed. Over 5,000 acres were newly reclaimed. The first pump sets that were introduced during the late nineteenth century were worked by producer gas and those introduced in the early decades of the twentieth century were run by kerosene or diesel. A British engineering firm based in Cochin, Geo Brunton Company, boat builders and operators of steamboats, introduced the first pump sets. The company hired these out to farmers. The company's men, many of them Anglo-Indians, operated the pump sets. With increase in demand, new suppliers like Marshall Sons and Company of Edinburgh operating through its branch at Madras also entered the scene (Rammohan 1996).

Agricultural operations in the reclaimed tracts began in January or February. The field was ploughed using bullocks or oxen as draught animals. The soil of the reclaimed backwater was acidic and to neutralise it, lime was applied. The field was then flooded by opening the sluices in the dyke. The field remained submerged throughout the south western monsoon (June to August). By August when the water receded the field was again ploughed. This was a difficult operation as the worker had to wade through waist-deep and muddy water with the draught bullock or buffalo. Following this, the outer dykes were repaired and waterwheels set up at different points. The wheel was mounted vertically on a horizontal axle. The wheels were of different sizes; the number of spokes was usually in multiples of 6 and ranged from 6 to 36. To drain large areas an array of waterwheels, arranged in ascending order of size was used. The wheels were operated by gangs ranging from 8 to 10 workers, who perched themselves on bamboo scaffolding and pedalled the water away. This was hard labour and work was carried out in four shifts. The workers ascertained the time by looking at the sun, moon and stars. Alternatively, a half shell of coconut with a fine hole pierced at its bottom was used like an hourglass with water substituting for sand. The shell was placed in water and when water entering from below filled it entirely it was reckoned as a unit of time. Drainage operations were conducted for many fields at a time. As water levels receded, the inner dykes and irrigation channels were repaired. The soil was then raked with a harrow, weeded and worked into a soft puddle. Water was then let into the field up to knee-depth. Sowing was done in October or November after the monsoon subsided. Seeds, sprouted in screw-pine bags, were broadcast in water. The field was then completely drained and kept dry for a week. Water was then let in, and when seedlings were about a month old, some transplanting was done to reduce the unevenness resulting from broadcast sowing. The field was completely drained after transplanting and manure – cow dung, green leaves, hay, and ash – applied. Pesticides were not used. The most common pest was a worm. As water level in the field rose, the worm crawled up and positioned itself on the edge of the leaf-blade. The worms were swept away into a basket using a stick or a broom. Water was let into the field at regular intervals till the harvest, which occurred in February or March. The ear heads were garnered with sickles and threshed with feet. The grain was winnowed and sun-dried on the threshing floor and conveyed to the granaries in country canoes. The grain was boiled, sun-dried and pounded by hand into rice. In certain parts of reclaimed areas, a deep-water variety of rice was cultivated. Its ear heads floated on the surface of water and were harvested from the canoes (Pillai and Panikar 1965; Tharamangalam 1981).

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Road Networks in Ancient Native America

Rubén G. Mendoza, Gretchen W. Jordan

Pre-Columbian road networks in ancient America – specifically, the Southwestern United States, Mesoamerica, and Peru – provide a point of departure for exploring current issues in the study of non-Western technology. It should be noted that other major road networks have been documented for the Mississippian complex of eastern North America, Casas Grandes in Chihuahua, Mexico, and the Maya sacbe road networks of the Maya lowlands of Mesoamerica. These networks are currently the subject of ongoing investigations.

The three primary road networks of concern here are those of the North American Chaco Anasazi or Ancestral Pueblo of west-central New Mexico, Mesoamerican road networks centered on La Quemada and Xochicalco, Mexico, and the Inca system of Peruvian South America. These networks vary in scale, with the La Quemada complex representing a highly integrated, valley-wide network, dating to the period between AD 700 and 900. The Chaco network covers a circuit of over 300 linear miles of ground-verified constructed road segments and features spanning the period from AD 920 to 1140. The Inca road network was expanded in a vigorous campaign to integrate all pre-existing road segments in the period between AD 1438 and 1532. This system incorporates over 2,000 linear miles of roads into the single most massive archaeological feature in the Americas (Hyslop 1984).

The American Southwest

The formalized road network of Chaco Canyon, New Mexico, connects the canyon core with peripheral pueblo communities lying at relatively great distances from the core area. Over 500 miles of roads are indicated through the analysis of aerial photographs; however ground survey data are as yet incomplete, leaving unresolved the question of continuity in the network. The sociopolitical complexity of the Anasazi of the San Juan Basin is closely tied to the problem of road network continuity (Vivian 1990). If the road network was contiguous throughout, this would support the contention that Chaco served an administrative function as the center of a regional system extending from Southwestern Colorado to Southeastern Utah, into Western Arizona and Northwestern New Mexico. Lack of continuity in the road network indicates a less integrated system, and a more autonomous character for the outlying communities.

Functional aspects of the Chaco road system are as yet unclear. Functional considerations center on the nature and control of goods transported as well as with the degree of interaction between core and peripheral communities. Proposed interpretations include (a) a defensive role for outlying pueblos, (b) protection of trade routes, (c) ceremonial functions, (d) political administration, and (e) the transport of subsistence-related goods. It has also been suggested that outlying pueblos served as rural sustaining communities directly affiliated with representative groups of the canyon core (Kincaid 1983).

Chacoan road construction exhibits several characteristic features. Most notable is the absolute linearity of the roads, despite potential topographic obstacles. The great North Road deviates less than one degree from its northerly course in over 46 km. Masonry road elements such as flanking walls, or curbs, ramps, and raised roadbeds also characterize the system. Several architectural features are associated with road segments. These range from simple cairns and shrines to residential room-blocks and Great House communities with Great Kiva ceremonial structures. Stylistically uniform, these features and structures employ Bonito-style construction of core-veneer masonry and massive walls.

There are no historical data available describing the Chacoan road system. To date, all interpretations have been based on archaeological research and remote sensing techniques. Gordon Vivian pioneered this research in 1948. From 1971 to 1977, the Remote Sensing Project of the Chaco Center – in conjunction with the National Park Service and the University of New Mexico – undertook investigations of the Chacoan road network. Their efforts focused on the use of ground verification studies for the extensive mapping of road alignments appearing in aerial photographs. From 1980 to 1983 the New Mexico Bureau of Land Management undertook a comprehensive effort to document the road network by means of ground verification (Kincaid 1983).

Mesoamerica

Studies pertaining to Mesoamerican road networks are relatively recent, and most such studies have emphasized ground verification and mapping. The sites of Casas Grandes, La Quemada, Xochicalco, Teotihuacan, and the Maya lowlands have been the subject of most surveys to date, while the Tarascan and Sonoran regions have been the subject of the most recent surveys. The road networks of these regions provide a glimpse into both the Late Classic, and the Protohistoric developments of the fourteenth through sixteenth centuries AD (Mendoza 2001).

The area of La Quemada, Zacatecas, lies within a semiarid region of Mesoamerica's Northern Frontier. This area is dominated by a series of hill-fort centers, each of which is characterized by the presence of civic-ceremonial precincts, agricultural terraces, and secondary centers with related defensive features. An extensive intra-regional network of roads connected the primary centers of La Quemada and Los Pilarillos with secondary centers, and in turn, isolated mound groups, isolated platforms, defensive positions or fortifications, and agricultural terraces. This system, by contrast with that of Chaco Canyon, served to integrate communities within a tightly constricted area. Road segments linking the La Quemada road network with regions beyond the valley have yet to be fully mapped or verified.

The specific road-related features identified with La Quemada include (a) formal causeways or other elevated road segments; (b) road segments terminating at elevated platforms; (c) causeways of between 5 and 7 m to 12 and 14 m in width with road-bed elevations of between 30 and 40 cm; (d) causeways that extend to wide, low platforms and stairways with precipitous descents down steep escarpments; (e) parallel road and canal or other irrigation segments; and finally (f) where the larger causeways are concerned, such roads are identified with defensive positions. At La Quemada, the aforementioned features are taken to represent a sociopolitical pattern geared to militarism or related defense activity (Trombold 1991b).

Where the road networks of the Mesoamerican Epiclassic era (ca. AD 650–900) are concerned, the central Mexican city-state of Xochicalco, Morelos, provides a salient example. The site of Xochicalco, like its La Quemada contemporary, is situated in a strategically located acropolis-centered hill-fort locality. Most of the road segments identified with Xochicalco emanate from the hill-fort to other centers within the valley below, and as such, Xochicalco provides a characteristic example of roads as symbols of power, prestige, and levels of regional integration. In other words, this position holds that Mesoamerican road networks function primarily as mechanisms for social integration or as symbols of the power and prestige of social or religious elites (Hirth 1991). The scale and magnitude of construction activity invested in the road systems of Mesoamerica have led some scholars to speculate that such roads were less functional and more ceremonial in character. Monumental construction and related public works are taken as indicators of political power, and thereby elite command of critical resources (such as slaves and construction personnel) in the valley during the pre-Columbian era (Trombold 1991a).

Mesoamerican economic systems, by virtue of the nonexistence of draft animals, and thereby, wheeled vehicles, were limited to human burden bearers. Despite this limitation, such systems were every bit as formal as those of other Old and New World polities. Primitivist interpretations of New World economies have unnecessarily minimized the perceived scale of economic formations in Mesoamerica and the New World despite available ethnohistorical data. The extent and magnitude of investment in road construction, and scale of integration made evident by the contiguity in the system, is again a key indicator of the types of sociopolitical formations that once prevailed in Mesoamerica. The Aztec era provides only a hint at what prior civilizations engaged in the way of road network investment in construction and maintenance, and by any account, the investment was substantial and culturally significant. Robert Santley's recent projection of road networks for the Basin of Mexico presents us with a system that was highly integrated and equally complex (Santley 1991).

The utility of a formalized – organized, linear, weatherproof – road network over which to maintain the movement of goods and services was critical to trade and exchange in Mesoamerica. Like the ancient informal paths that preceded them, formalized roads served to guide and expedite the movement of goods and services on both an intra- and inter-regional scale.

A typology of Aztec era roads was recorded by Fray Bernardino de Sahagun, the sixteenth century Franciscan cleric who documented such aspects of postconquest central Mexican culture (Sahagun 1963). Of the seven types of roads identified by Bernardino de Sahagun the ochpantli and oquetzalli road types have been isolated as representative of the Xochicalco road types. The first term pertains to the "main road" and the second to the "royal road" networks of the Aztec era. The well groomed roads of Xochicalco are interpreted as the royal road type. This interpretation is based on the monumental nature of the associated architecture (primarily defensive in character), the cut-stone pavements, and the relatively large width of the roadbed itself. In addition, archaeologist Kenneth Hirth distinguishes between "road" and "thoroughfare." Roads are "transportation arteries at the regional level which connect two or more spatially separated sites"; thoroughfares are "streets and other communication corridors which organize space and/or direct traffic flow within the community" (Hirth 1991). The fragmentary nature of the data precludes a region-wide economic and social interpretation of the Xochicalco network.

The Xochicalco road network exhibits a number of distinct architectural characteristics, including:

a. Stone-surfaced intra-site rough-cut mosaic pavements or roadbeds of 3–5 m widths
b. Intra-site masonry ramps
c. Parallel platforms flanking key road segments or thoroughfares leading into the site core area
d. Roads which bisect massive rampart walls with narrow gateways in order to access intra-site thoroughfares
e. Intra-site pavements or roadbeds edged with cut-stone masonry blocks
f. Stucco used along flanking masonry edging in the intra-site sectors
g. Intra-site pavements made flush with surfaces traversed and modified with ramps – both smooth and stepped
h. Lateral masonry walls flanking intra-site pavements
i. Access causeways along circuits of defensive ditches or moats
j. Evidence for the use of a probable wooden bridge spanning a defensive moat adjacent to Cerro de la Bodega

Transport architecture extending beyond the site perimeter consists of less formal construction techniques in addition to significantly less evidence of overall integration with the site core of Xochicalco.

Recent studies provide indications of a massive road network that connected the Classic period center of Teotihuacan with an ancient trade corridor linking that site with the Puebla Basin, and by extension, the Mexican Gulf lowlands. Unlike the more defensive character of the La Quemada and Xochicalco road networks, the Teotihuacan corridor linking Teotihuacan with a whole host of ancient mercantile centers in the Mesoamerican highlands and Gulf coastal plain served a key transport function for the movement of goods and services provisioned and sought by Teotihuacan.

The road-associated settlement hierarchy of the Teotihuacan Corridor, as well as the recent identification of specific features of transport network architecture along the Teotihuacan Corridor, is currently under study. Additional features of Mesoamerican transport network architecture include (a) causeways – such as the Street of the Dead – measuring some 40 m in width; (b) the presence of Momoztli structures, or elevated platforms or shrines (often laden with trade offerings) situated at the crux of important crossroads along the corridor; (c) an approximate inter-site road width of 24 m, and 60 cm depth, for sites located on the Teotihuacan Corridor; (d) spur roads that connect road-associated settlements with the principal arteries of the Teotihuacan Corridor and with other key nodal points or market centers; (e) related architectural styles and construction along the course of the transport network; (f) roughly equidistant spacing of road-associated settlements at 8–9 km intervals for specific Teotihuacan related centers; and (g) stepped ramps, road shrines, crossroads, and attendant roadbed linearity. The overall network is dendritic in structure, in that the main road connects with primary centers, which are in turn connected to a constellation of secondary centers sharing affinities with key terminals along the Teotihuacan Corridor.

Peru

The most intensively studied ancient road system of South America is that of the Inca Empire, extending over a vast area from Ecuador to Chile, from the coastal deserts to the Andean highlands, into the Bolivian forests. This network included some 20,000 miles of roadways and encompassed 40,000 miles at the point of European contact. This road system constitutes “South America’s largest contiguous archaeological remain,” and provides valuable insights into the organization and technology that are hallmarks of the Inca state (Hyslop 1984).

In contemplating the vastness of this road network, one is struck by the enormity of the Inca achievement. First, there is the effectiveness of the political infrastructure that organized and mobilized a labor force specialized in the building and maintenance of roadways. Second, the Inca were exceptionally efficient in their use of resources, both natural and human. Pre-existing roadways were frequently incorporated into the Inca network. Inca engineers did not seek to modify natural topography to any great extent unless required to do so in order to achieve safe passage. Where road modifications were concerned, locally available materials were utilized and work was performed by locally organized labor pools under the supervision of a road administrator. Third, the Inca brought to bear a vast body of technical knowledge and expertise, accumulated over the course of centuries among the diverse ethnic groups of the empire. Finally, the efficiency of the road network insured that Inca rulers could maintain communication with – and thereby, the integration of – every corner of the empire.

Four primary state roads divided the empire into cosmologically defined quadrants (Urton 1981). The sacred geography associated with road networks reflected the Inca preoccupation with cosmology defined *vis-á-vis* extant social divisions. Cuzco, the political and administrative center of the Inca state, was linked via these sacred paths to the most ancient shrines and temples. Roadways not only defined the partitioning of sacred space, they also served as linkages in a massive transport and communication network.

Road characteristics varied considerably in terms of construction methods and the extent of labor investment. Construction methods varied with the highly fractured and variable topography of the region, and as such, a single road might include both road segments with very complex architectural features and evidence for intensive labor investment, and simple unpaved or earthen pathways. Ultimately, road construction varied with localized conditions, topographic obstacles, available materials and labor, and the importance of the specific road segment to ceremonial and ritual activities.

Coastal routes varied from simple “pole-roads” to broad thoroughfares with stone or adobe sidewalls. Pole-roads were paths marked by linear arrangements of wooden posts placed at intervals. High-altitude roads on nonagricultural lands were, by contrast, engineered for durability in order to withstand harsh climatic conditions. Such roads incorporated elaborate stone curbs, retaining walls, and paving. These later constructions are among the best-preserved roads in evidence for the Andes. Roads traversing agricultural fields are characterized by very high sidewalls – of 1 or 2 m in height – designed to protect crops from travelers or livestock such as llamas and alpacas. Such walls were likewise built of stone or adobe. Agricultural roads were relatively narrow so as to minimize their impact on the availability and productivity of arable lands.

Where roads crossed wet plains or slopes, stone paving was used to preserve the roadbed. If flooding was unavoidable, the road was constructed on an elevated surface or causeway. Inca causeways were of rubble-core construction, with or without stone retaining walls. In those instances where existing slopes were less than 10° off horizontal, the Inca used a combination of stone or rock-cut ramps, stairways, or switchbacks in order to buffer ascent and descent. Depending on the steepness of the existing slope, structures ranged from a single retaining wall to a series of walls and benches built on the downhill side of the slope, and intended to serve as secondary retaining features.

Bridges are among the most spectacular structures engineered by the Inca. While sixteenth century European construction employed the principle of the arch in bridge construction, the Inca were able to span greater distances through a variety of engineering principles and techniques. Early Spanish explorers marveled at the sight of Inca suspension bridges which were unknown in Europe. Though made of woven and braided fiber coils, these suspended structures supported considerable pedestrian traffic, in addition to European horses and carts of the conquest period. Other types of spans built by the Inca included floating bridges supported by pontoons of reed bundles, wooden bridges manufactured from logs placed over stone abutments (with or without cantilevers), and a variety of stone bridges. Culverts were stone-lined troughs left open, or capped, if necessary for safe passage. Somewhat wider rivers were spanned by stone columns placed adjacent to one another, thereby forming "multicell" culverts which supported the overlying roadbed. Some stone bridges employed cantilevered abutments supporting very large stone pavers. Finally, natural rock formations were utilized as bridged areas where available.

An integral component of Inca era road networks was the *tambo* system. Tambos were multiuse structures or facilities maintained by the Inca state but administered locally. Hyslop estimates that between 1,000 and 2,000 of these facilities were in use throughout the Inca empire. Tambos exhibit considerable variation in size, ranging from sites with a few isolated structures to large administrative centers representing a multitude of activity areas. Storage and lodging constitute the primary uses for which tambos were employed. Storage structures included silos, corrals, and adjoining rooms. Lodging in tambo facilities was temporary, and intended either for travelers or as permanent residence for local administrators. Tambos were also employed in the processing of raw materials, military and ceremonial activities, local administration, and craft production. Tambos were equidistantly spaced on any given route at intervals representing a day's travel time. According to recent Inca road surveys, tambos were spaced at intervals that average between 15 and 25 km. The combined tambo system and vast complex of roadways formed a critical component of the state's infrastructure. This highly efficient transport and communication network supported the state's practical needs for efficient military mobilization, colonization, economic maintenance, and administration. In addition, the complex network of roads supported the ideological needs of the Inca hierarchy, providing a highly visible set of linkages between the people and the state.

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Rockets in Ancient Korea

Chae Yeon-Seok

The development of Korean rockets as tactical weapons began in the late fourteenth century. According to *Koryo Sa* (The History of the Koryo Dynasty) and *Cho Son Wang Cho Silok* (The Historical Records of the Choson Dynasty), King Wu (1377–1389) of the Koryo dynasty (918–1392) ordered the establishment of the Hwa-tong-do-gam (General Bureau of

Gunpowder Artillery) in 1377 on the recommendation of Choi, Mu-Son (1325–1395). Commissioned temporarily at the height of Japanese piracy, the Bureau was charged with administering the manufacture of gunpowder and firearms.

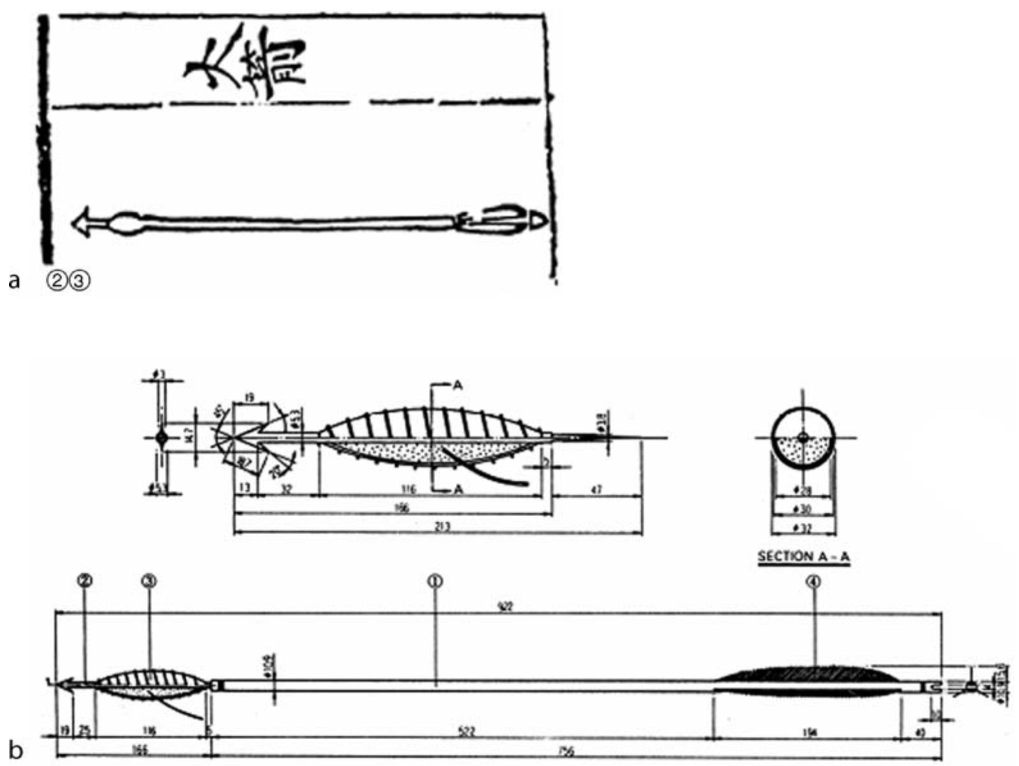
Choi, Mu-Son produced a variety of gunpowder and firearms in the newly commissioned Bureau. Fire arrows, called *Haw-Jon*, manufactured at Hwa-tong-do-gam between 1377 and 1391 near the end of Koryo Dynasty were not, unlike some Chinese counterparts, rocket-propelled arrows but exclusively incendiary arrows. They were shot with a bow. Figure 1a illustrates the fire arrow as described in *Kuk Cho Ore Sorye* (Introductory Remarks on National Rituals/Formalities of National Functions) of the Chosun Dynasty (1392–1910) published in 1474. Figure 1b shows a drawing of fire arrows in metric units converted from the Korean measurement system in which one *chuck* corresponds to 312.4 mm, one *chun* to 31.2 mm, one *pun* to 3.1 mm and one *le* to 0.3 mm.

Unfortunately there is no direct documentary evidence attesting that firearms manufactured at Hwa-tong-do-gam involved rocket-propelled firearms. However, *Kuk Cho Ore Sorye* contains illustrations of rocket-propelled firearms called *Sin-Gi-Jeon*. Moreover, *Hwa Po Sik Un Hae* (Korean Annotation of Gunpowder and Firearms Method, 1635) makes reference to the identity of the propellant cases of *Sin-Gi-Jeon* and *Ju-Hwa* (running fire), a term used for rocket-propelled arrows of the Koryo Dynasty. It is inferred from these historical records that the *Ju-Hwa* manufactured at Hwa-tong-do-gam was the first Korean rocket.

According to *Kuk Cho Ore Sorye*, the arrow shaft of the Ju-Hwa is made of a bamboo stick, and the arrowhead is iron. The tail fins of the arrow are feathers. Although there is neither a direct nor detailed description attesting that *Ju-Hwa* was rocket-propelled, that may be inferred from other historical records. *Choson Wang Cho Silok* records King Sejong speaking to an official PyeongAn, in HamGil province:

> Running-fire is very efficient and incomparable because it can be fired easily using a quiver by a mounted soldier. It is detrimental to the enemy; its loud noise and shape instill fear and incite surrender. Once used at night, its exhaust flame lightens the fields and shakes the enemy's spirits.
> When used where the enemy is lying in ambush, its flame and smoke cause the enemy to disclose themselves for fear. Running-fire does not fly straight and it spends more powder and requires more precaution than cannon.

"Its loud noise and shape," implies a propulsive device which produces thrust by ejecting combustion gases



Rockets in Ancient Korea. Fig. 1 Drawings of *Hwa-Jeon* (a) Fire arrow (*Ju-Hwa*). Drawing from *Kuk Cho Ore Sorye* 1474). (b) Fire arrow (*Hwa-Jeon*). Drawing in metric units (from Chae 1981). ①: arrow shaft, ②: arrowhead, ③: black powder, ④: fins.

Rockets in Ancient Korea. Table 1 Powder charge of rockets and cannons in fifteenth century Korea

Rockets		Cannon and guns	
Name	**Powder weight**	**Name**	**Powder weight**
Large running fire	2,628 g	Chun Ja Chong Tong (General cannon)	870 g
Medium running fire	41.4 g	Dae Wan Gu (Large motor)	870 g

and thus produces the loud noise. "Once used at night, its flame lightens the field," excludes the possibility that *Ju-Hwa* was a cannon or rifle as it produced "flame and smoke" during flight. In addition, the motion of ancient rockets does not generally follow a straight line because it depends on stabilizing sticks made of bamboo with an exhaust hole in the powder charge in the propellant case. Most of the weight of a solid-propellant rocket is due to the propellant. *Ju-Hwa* "spends more powder" than a gun or cannon as it continues to eject combustion gas in flight.

According to *Hwa Po Sick Eon Hae*, the medium running fire was charged with 41.4 g of black powder. Extrapolating the weights of small and large running fires from the weight of the medium-sized running fire and proscribed volumes of propellant cases of the small and large running fire, the weight of small and large running fire is given by 12 and 2,628 g, respectively. The weight of black powder for a large running fire is significantly larger than that of the largest cannon used in fifteenth century Korea with the black powder weight of 870 g (Table 1).

Korean Rockets of the Fifteenth Century

The reign of King Se Jong (1418–1450) of the Choson dynasty marked a turning point in the development of firearms, moving beyond the imitation of Chinese models and creating a distinctive Korean model. In the 30th year (1448) of the reign of King Se Jong the details and manufacturing methods of firearms and ready-to-launch munitions were compiled, illustrated and published in the *Chong Tong Deong Rok* (Reproduced Records of Firearms and Gunpowder). No copy of *Chong Tong Deong Rok* had survived, but part of it is in *Kuk Cho Ore Sorye.*

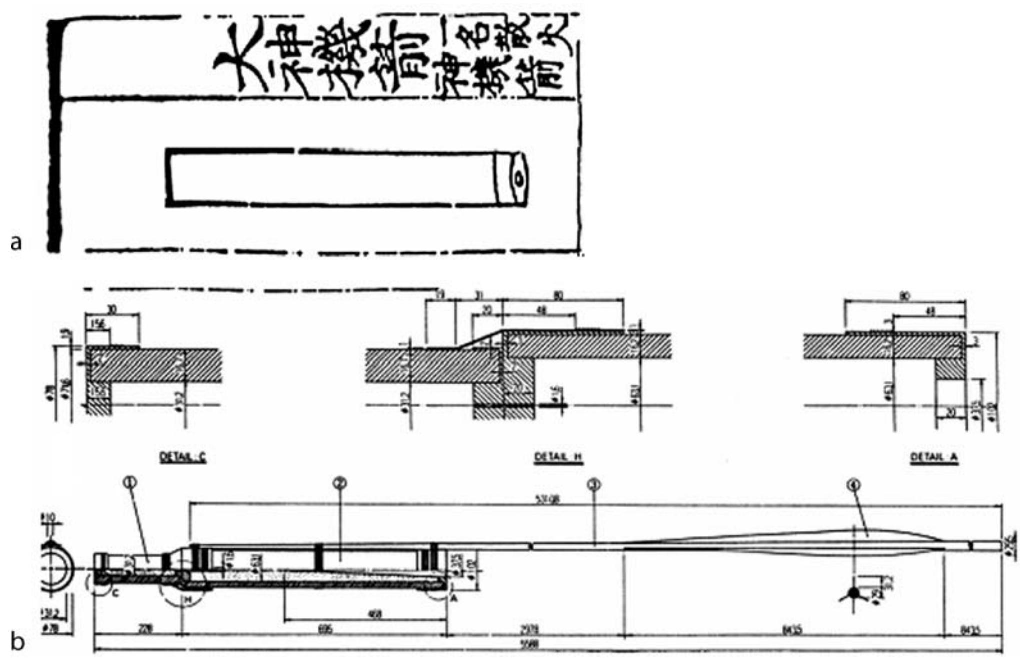
According to *Hwa Po Sik Eon Hae*, three types of rocket-propelled arrows were in wide use in their mature form by the 29th year (1447) of King Se Jong's reign: large, medium, and small running fires. In *Choson Wang Cho Silok*, such firearms are no longer mentioned by those names after 1448 and onward, but instead a new set of names of firearms begins to appear, namely *Sin-Gi-Jeon*, literally meaning "magical machine arrow." However, the specifications and manufacturing methods of the medium-sized *Sin-Gi-Jeon* described in *Hwa Po Sik Eon Hae* are identical to those for the *Ju-Hwa*. Thus, it is inferred that the *Sin-Gi-Jeon* was based on the *Ju-Hwa* and developed further to include versions of various sizes: small (*So*), medium (*Chung*), large (*Dae*), and multiple bomblets magical machine arrows.

Dae-Sin-Gi-Jeon (Large Magical Machine Arrow)

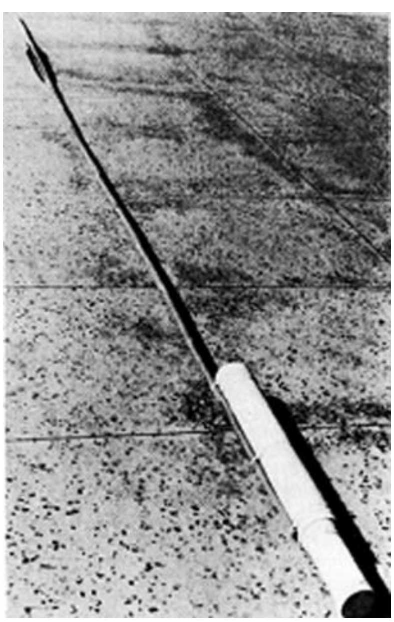
Figure 2 shows a drawing of the *Dae-Sin-Gi-Jeon* (large magical machine arrow) in the *Kuk Cho Ore Sorye,* and a drawing reproduced in metric units. The propellant case filled with black powder is a cylindrical tube made of paper. It is 695 mm long, 17.8 mm thick, and the internal diameter is 63.1 mm. Both ends of the propellant case were sealed with paper several times and attached to the front end of the bamboo shaft by strings. At the bottom end of the propellant case, opposite the warhead, a hole was made to allow exhaust fumes to exit. The bamboo shaft is 5.3 m long with the cross-sectional diameter increasing from 10 mm at the front to 29.5 mm at the rear. At the rear of the bamboo shaft three feathers were evenly distributed in between. The "Firearms Illustration" in *Kuk Cho Ore Sorye* records that they are bird feathers. However, there is no feather of size 30 mm × 840 mm, and it is reasonable to conjecture that they were made of leather, considering that arrows fired from a cannon at that time were equipped with feathers made of leather.

An explosive tube is mounted on the front end of the propellant case. A detonating fuse extends from the explosive tube through a hole made on the surfaces of the explosive tube and the propellant case into the propellant case. Such an arrangement enabled the explosives to detonate during or near the end of the flight to the target. The overall length of the *Dae-Shin-Gi-Jeon*, including the explosive tube, reached 5.6 m. *Dae-Sin-Gi-Jeon* was primarily used to launch an offensive on enemies across the Aprok river at its estuary from Eui-Ju City. Considering the width of the estuary, the *Dae-Sin-Gi-Jeon is* surmised to range from 1.5 to 2 km.

The *San-Hwa-Shin-Gi-Jeon* (Fire scattering magical machine arrow), an application of *Dae-Sin-Gi-Jeon*, was also used. Instead of employing the explosive tube of *Dae-Sin-Gi-Jeon*, the front part of the propellant case was occupied by a bundle of paper explosives called *So-Bal-Hwa* (small fire burner) connected by a detonating fuse. *San-Hwa-Sin-Gi-Jeon* was designed to disperse paper explosives ignited when they were near the target.



Rockets in Ancient Korea. Fig. 2 Large magical machine arrow (a) Propellant case from *Kuk Cho Ore Sorye*, 1474. (b) Drawing in metric units. ①: warhead, ②: propellant case, ③: bamboo, ④: fins.



Rockets in Ancient Korea. Fig. 3 Image of large magical machine arrow.

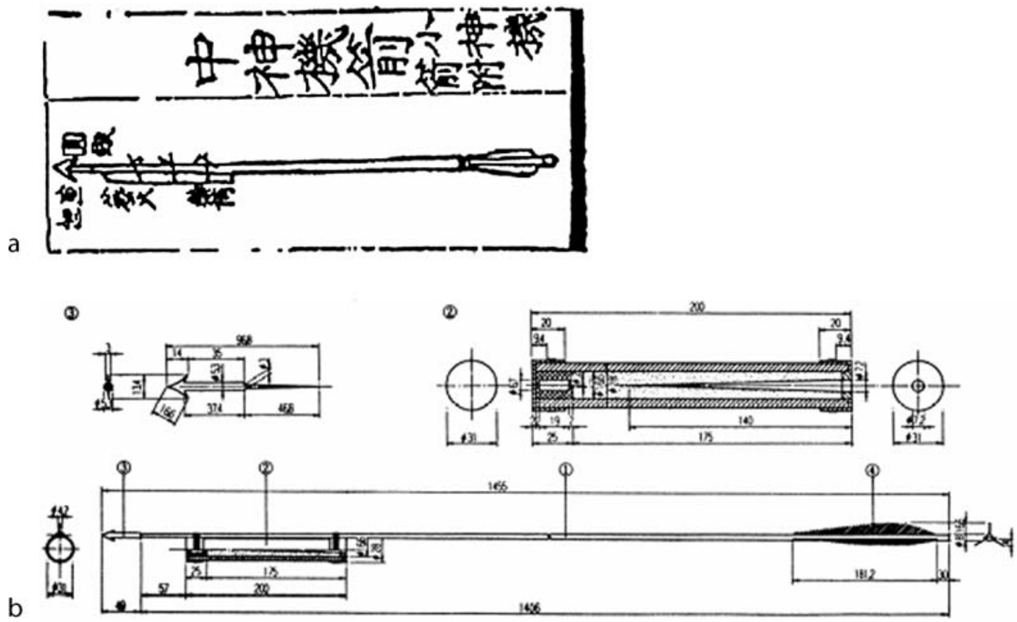
Dae-Sin-Gi-Jeon is the largest rocket ever made employing explosive cases made of paper, and a reproduced version is shown in Fig. 3. It was 350 years later that rockets of comparable size were manufactured elsewhere; in 1805 William Congreve of England produced 6-pound rocket with a propellant case 550 mm long, a diameter of 110 mm and an overall length including stabilizing sticks of 4.3 m.

Medium and Small Magical Machine Arrow (Chung- & So-Sin-Gi-Jeon)

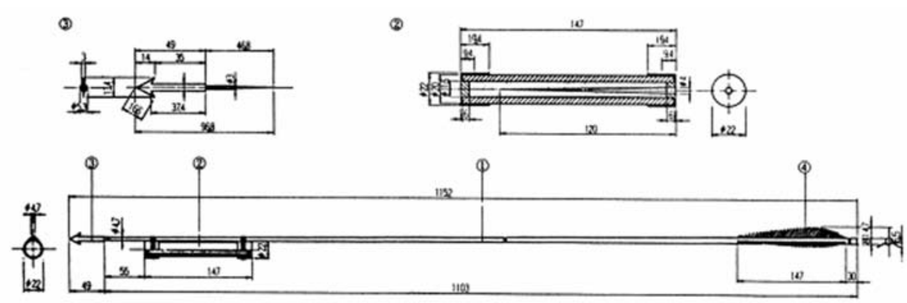
The *Chung-Sin-Gi-Jeon* (medium magical machine arrow) has a 1.4 m long bamboo shaft with a 200 mm long propellant case attached to the front. An arrowhead weighing 5.5 g is fixed at the front end of the *Chung-Sin-Gi-Jeon*, and at the rear end are attached 17.8 cm long bird feathers. There is no mention on the range of *Chung-Sin-Gi-Jeon*, but it is estimated to range from 150 to 200 m.

A detailed drawing showing the internal structure of the medium magical machine arrow is reproduced in Fig. 4. The lower part of the propellant case is bound with twine as in the large magical machine arrow. The propellant case is charged with powder up to the height of 175 mm leaving an empty space with a corresponding height of 25 mm. A small explosive tube (*so-bal-hwa-tong*) 56.2 mm long, 47.8 mm in circumference, 4.4 mm thick and 6.9 mm in internal diameter is inserted into the propellant case. The length from the end of the cylindrical case to the attachment twine is 6.3 mm, and the diameter of the nozzle is 2.2 mm. Finally, the powder in the propellant case of the medium magical machine arrow was connected with fuses.

The *So-Sin-Gi-Jeon* (small magical machine arrow) is the smallest version of the series as shown in Fig. 5.



Rockets in Ancient Korea. Fig. 4 Medium magical machine arrow. (a) Drawing from *Kuk Cho Ore Sorye*, 1474. Drawing in metric units. ①: warhead, ②: propellant case, ③: bamboo, ④: fins.



Rockets in Ancient Korea. Fig. 5 Drawing of small magical machine arrow in metric units.

Its propellant case, 15 cm long with a cross-sectional diameter of 15 cm, is attached to the front of a 100 cm-long bamboo shaft. At the rear end bird feathers are attached. The diameter of the exhaust hole installed in the propellant case is 4 mm, and the range is estimated to be about 200 m. Figure 6 shows pairs of reproduced running fire, and small and medium magical machine arrows reproduced in 1979.

Multiple Bomblets Magical Machine Arrow (San-Hwa-Sin-Gi-Jeon)

The multiple bomblets magical arrow is similar to the large magical machine arrow in size, but it differs in the warhead system. A propellant case serves as a warhead instead of an explosive tube.

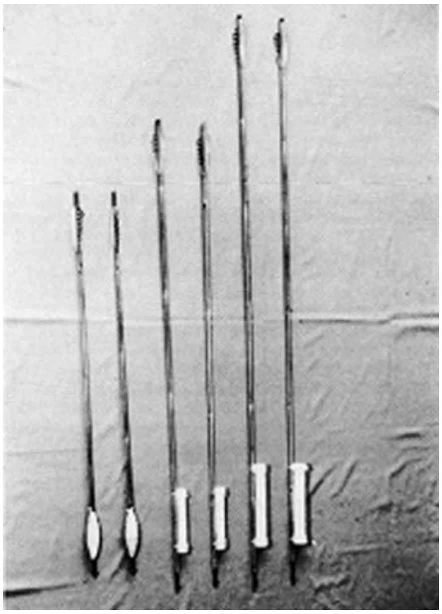
The detailed internal structure of the propellant case and explosive system of the multiple bomblets magical machine arrow is shown in Fig. 7. The lower part of the propellant case was bound with twine as in the large magical machine arrow. The propellant case was charged with powder up to the height of 579.5 mm, leaving an empty space corresponding to the height of 115.6 mm. Several layers of paper were attached to the top surface of the powder. Several land fire tubes (*Ji-Hwa-Tong*) attached to small explosive tubes (*So-Bal-Hwa-Tong*) were placed on the top of the propellant case with their fuses attached to the propellant charge.

The "Firearms illustration" section of the *Kuk Cho Ore Sorye* provides detailed explanations on manufacturing arrows, including charging propellant cases. A long, coned-shaped awl was inserted through the hole in the bottom of the propellant case. Then a small quantity of powder was spread and hardened with an empty cylindrical iron stick with its external diameter equal to the internal diameter of the propellant case.

Rocket Launch Device: Hwa-Cha (Fire Cart) and Launch Pad

The structure of the launch pads for rockets is relatively simple, since it primarily serves the function of providing a direction to the target. Even now, launch pads of rocket cannons retain such simplicity, resembling a piece of a chimney.

During the reign of King Moon Jong (1450–1452), proper launch pads were developed for the *Sin-Gi-Jeon*. King Moon Jong himself was interested in the development of firearms. When he was a crown prince he assumed some responsibility at the Bureau of Weapons. He also played a pivotal role in developing a *Hwa-Cha* (fire cart). *Hwa-Cha* could be loaded either with a launch pad capable of launching 100 *Sin-Gi Jeon* in sequence or with a gun tube pad capable of launching 200 *Se-Jeon* (bullets). Figure 8 shows a drawing of the fire cart in *Kuk Cho Ore Sorye* and a drawing reproduced in metric units.

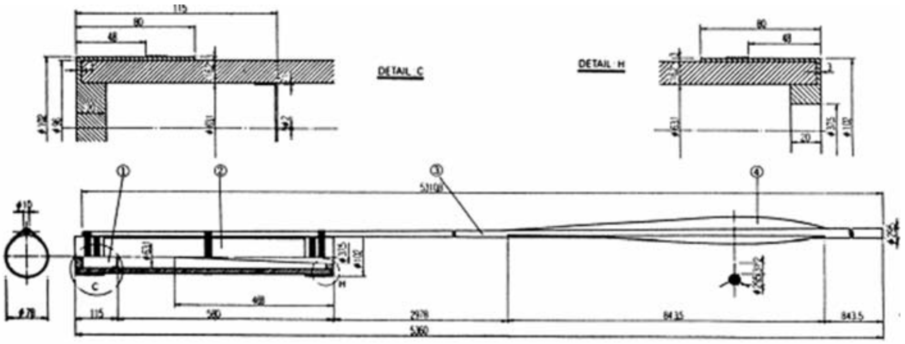


Rockets in Ancient Korea. Fig. 6 Pairs of running fire and small and medium magical machine arrows.

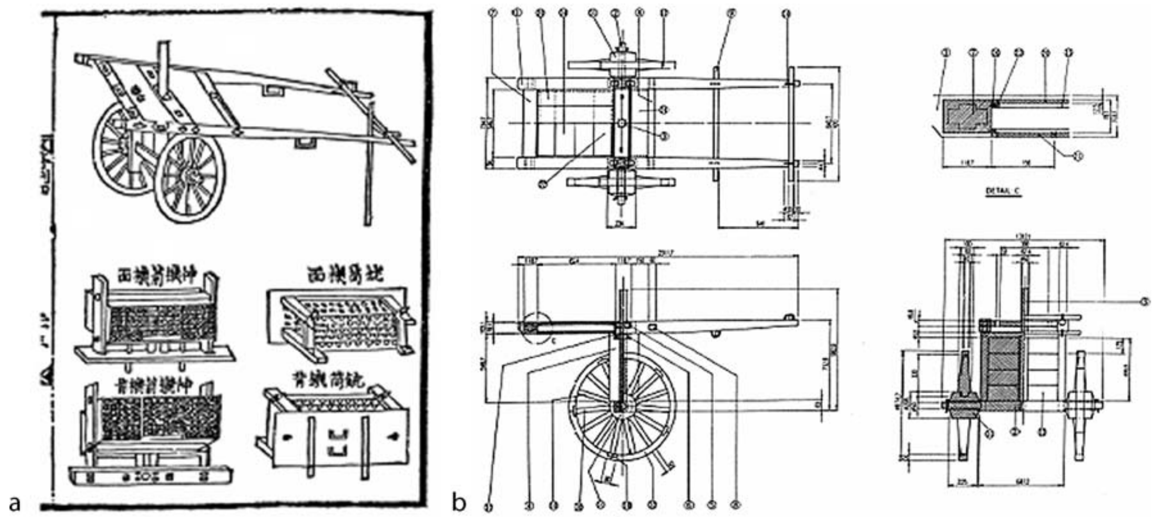
The most notable feature of the *Hwa-Cha* is that the inclination of the launch pad was variable. The general feature of carts up to the reign of King Se Jong was to load a launch pad on the axle of the wheel. However, the car invented during the reign of King Moon Jong employed a column on and in the middle of the axle of the wheel, which enabled the launch pad to be inclined up to 40°. The first *Hwa-Cha* was dispatched in 1,451, and in the same year 700 additional carts were soon dispatched to strategic coastal regions and fortresses. During peace time *Hwa-Cha* served as wagons.

The diameter of the wheel is 874.7 mm. The hub is made of wood, 225 mm wide and 206.2 mm in diameter. Each wheel has 15 spokes. The spindle on which the wheels revolve is made of wood, 1,312.1 mm long, and consists of three parts: a middle square pillar and two end columns which are inserted into two wheels. Two wide posts are set up at both ends of the top side of the middle square pillar. A small post is set up at the center of the square pillar. Thin wooden boards are attached between each wide post. Two yokes are set up at both ends of the wide posts. An upper center crossbar is placed between the ends of both wide posts. It has a hole in the center for the small post. A rear crossbar is attached at the rear of (four-cornered part) of both yokes. Several thin wooden crossbars are attached between the rear crossbar and the upper center crossbar. This forms a wooden box to hide some arms. Its length and width are 624.8 and 515.5 mm.

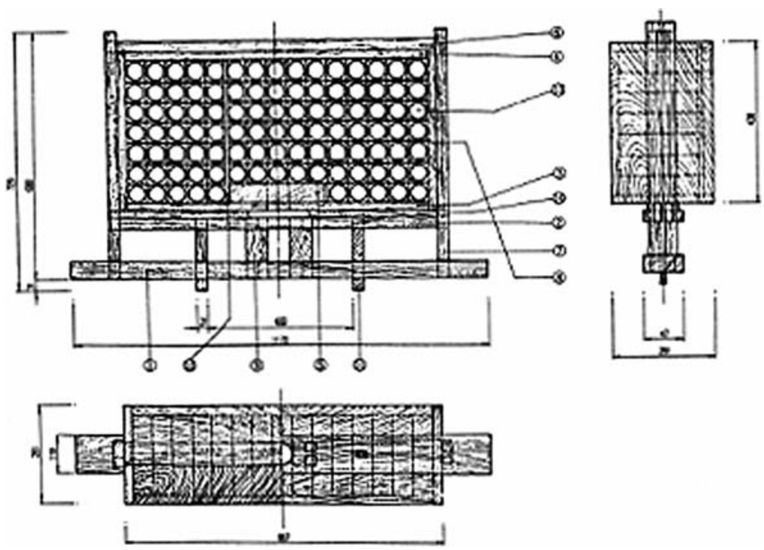
Four U-shaped nails are driven into the front and middle of the column part of the yokes to insert rods, which are used to pull the fire cart. Two men could draw the cart on level ground, but it would require another man pushing from behind going uphill, and two more men had to push the cart when it was going up a steep hill.



Rockets in Ancient Korea. Fig. 7 Drawing of multiple bomblets magical machine arrow in metric units. ①: warhead, ②: propellant case, ③: bamboo, ④: fins.



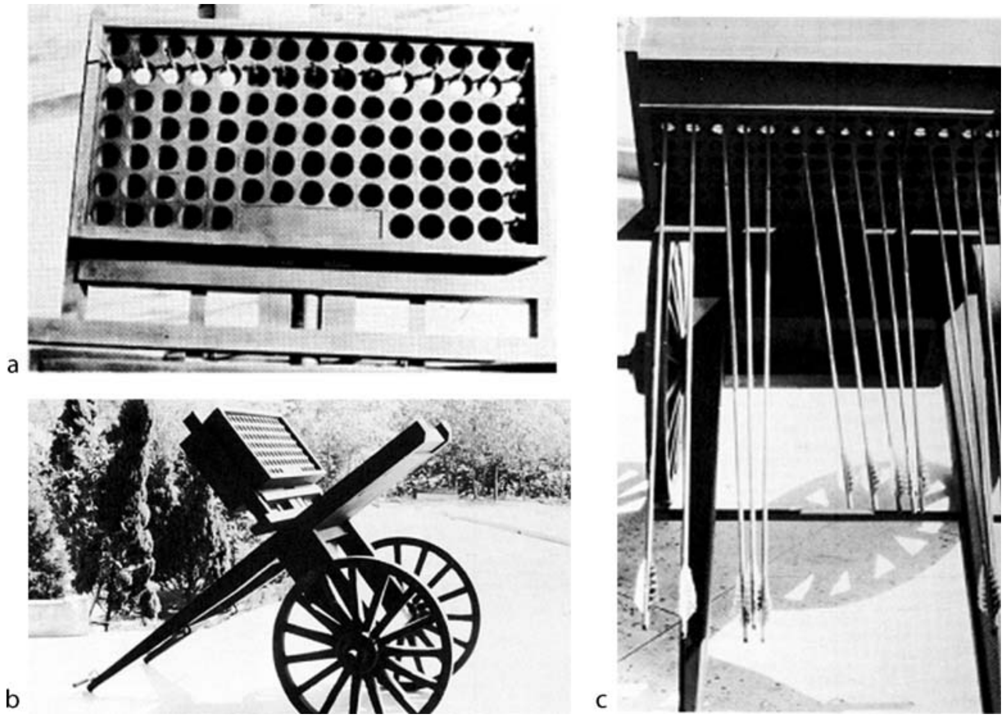
Rockets in Ancient Korea. Fig. 8 *Hwa-Cha* (Fire cart) (a) Drawing from *Kuk Cho Ore Sorye*, 1474. (b) Drawing in metric units. ①: yoke, ②: axletree, ③: small post, ④: wide post, ⑤: upper center crossbar, ⑥: lower center crossbar, ⑦: rear crossbar, ⑧: front crossbar, ⑨: rod, ⑩⑬⑰⑲⑳㉒㉔: thin wooden beam; ⑱: U-shaped nail.



Rockets in Ancient Korea. Fig. 9 Drawing of magical machine arrow launcher in metric units. ①: first crossboard, ②: second crossboard, ③/④: top/bottom wide boards, ⑤: rectangular block of wood, ⑥: third crossboard, ⑦: column, ⑧: side wide board, ⑨: small square column, ⑩: detailed board, ⑪: assistant column; ⑫: thin column; ⑬: cylindrical-hole-wood-block.

Figure 9 shows a drawing of the launch pad for magical machine arrows based on the descriptions in *Kuk Cho Ore Sorye*. It consists of a rectangular box containing blocks with 100 cylindrical holes and a supporting mechanism. They are comprised of seven rows of blocks. The end of each block is pierced with a wire and both ends of the wire are attached to the external surfaces of the side boards of the rectangular box. The supporting mechanism houses the rectangular box and consists of a set of columns and crossboards. The first crossboard is 1,171.6 mm long, 109.3 mm wide, and 47 mm thick. It has a 62.4 mm diameter hole in the center into which the small post of the fire cart is inserted. The main body of the launcher is supported by two columns, small square columns, and assistance columns.

The design of the fire cart and the magical machine arrow launcher enabled the cart body to be raised above the axle by short pillars to regulate the angle from 0° to 43°. The magical machine arrow launcher when fully



Rockets in Ancient Korea. Fig. 10 Fire cart and magical machine arrow launcher (Hangju Fortress Museum, Korea). (a) Magical-machine-arrow-launcher with medium and small magical machine arrows. (b) Fire cart equipped with a launch pad.

loaded could launch 100 medium or small magical machine arrows in groups of 15 at a time. According to the *Moon-Jong-Silok*, 700 fire carts were built in Korea in 1451. Figure 10 shows a version of a fire cart and launch pad loaded with small and medium magical machine arrows reproduced in 1979.

The first Korean rocket manufactured in Hwa-tong-do-gam between 1377 and 1389 provided the technological heritage for forthcoming rockets called *Sin-Gi-Jeon*. *Kuk Cho Ore Sorye* served as a technical manual for manufacture and operation of the rockets. While the large *Sin-Gi-Jeon* is the largest rocket ever made amongst those employing a propellant case made of paper in the fifteenth century, the use of the unit of length "le" corresponding to 0.3 mm demonstrates that *Sin-Gi-Jeons* were manufactured with a considerable level of precision. Historical records attest that 33,000 or so running fires and magical machine arrows were maintained in Korea by 1447, and dispatched for action with the fire cart from 1451. These weapons are believed to have served as powerful weapons for raiding Chinese and Japanese bandits.

Unfortunately, neither the *Sin-Gi-Jeon* nor the fire cart survives, primarily because they were made of wood and paper. In order to verify the technical feasibility of drawings and manufacturing methods in *Kuk Cho Ore Sorye*, small and medium *Sin-Gi-Jeons* were reconstructed together with their fire carts and launch pads for a flight test at the Daejeon Exposition

Rockets in Ancient Korea. Fig. 11 Flight test of small and medium *Sin-Gi-Jeon* at Daejeon Expo 93.

in 1993. Figure 11 depicts the moment of the flight test of 100 small and medium *Sin-Gi-Jeons* in 1993. The *Sin-Gi-Jeons* traveled between 100 and 200 m in distance. The successful test cleared the obscurity surrounding the rockets which had arisen from the fact that there were no remaining models; it demonstrated that they were nearly flawless in terms of design and function.

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Rockets in China

Pan Jixing

Traditionally, a rocket is a flying device launched by direct-reaction using a solid black powder of high-nitrate composition. The appearance of rockets signified a revolution in the development of firearms. All modern rockets were gradually developed on the basis of traditional ones. In Ancient China the rocket was generally called *huojian* (fire-arrow) which sometimes meant incendiary arrow and sometimes rocket. Both of them were invented in China. It is necessary to differentiate one from the other. From 968, the classical fire-arrow was sent by low-nitrate gunpowder in paste form from a bow or crossbow. It was thus an incendiary arrow, although it was the earliest gunpowder weapon. Since the beginning of the twelfth century solid gunpowder of high-nitrate composition and fuses were made and used for making fireworks and firecrackers. Some of them were directional devices, such as the *di laoshu* (earth-rat), *qihuo* (flying fire), and others. This provided a necessary premise for making rockets. During 1127–1234 the invention and military use of rockets were perfected in China on the basis of fireworks technology. There were two types of early rockets having different names.

The so-called *pili pao* (thunder-bolt missile) used in the Battle of Caishi between the Song and Jin was actually the earliest rocket-propelled bomb in the world. It was an enlarged *ertijiao* (double-bang firecracker) and was made according to the principle of *qihuo* (flying fire) used by the Song people in an earlier time. The *fei huojiang* (flying fire-lance) used in the Battle of Kaifeng between the Jin and Mongols in 1232 was an ordinary rocket for setting things on fire. Its rocket tube made of paper was fastened to the point of a lance or an arrow. During the thirteenth to fourteenth centuries the Song, Jin, and Mongol troops all used improved rockets to fight with each other. They even used the reaction weapon abroad. For instance, single rockets and multiple rocket-launchers with a common fuse were used by the Mongols in the Battle of Leignitz in Poland in 1241, known as the "Chinese dragon belching fire" in the West. Winged rockets must have been made in about 1300, since it was described in the *Huolong Jing* (Fire-Dragon Manual, ca. 1350).

In the Ming dynasty (1368–1644) rocketry entered a new epoch. Two-stage rockets were designed and made at the beginning of the fourteenth century. There were various kinds of different rockets from single ordinary ones to multiple rocket-launchers and wheelbarrows, as well as winged rockets and rocket-propelled bombs. Their range reached 200–500 paces (330–825 m). There was a special rocket troop in the Ming army and rocket weapons were used as standing weapons by land and naval forces and cavalry troops. It is interesting that a Chinese military officer, Wan Hu (fl. 1440–1495), built a flight device made of 47 big rockets for a flight experiment. He was the first in history to try to use rockets for flight as a means of transportation. All of these ancient achievements in the field of rocket technology can be found in the military work entitled *Wubei Zhi* (Treatise on Armament Technology) written by Mao Yuanyi (ca. 1570–1637) in 1621. After rocket technology was perfected in China it was spread to other parts of the world. It went first to the Arab world in 1240–1260, then to Europe in 1260–1270. The term *rochetta* first appeared in Italian literature in 1330. In the eighteenth century rockets were popular in some major European countries. Rockets arrived in other Asian countries in the same time during the Mongol-Yuan period, first in Vietnam and Korea, then in India and Southeast Asia.

In 1805 the British military officer William Congreve (1772–1825) developed modern rockets made of iron tubes with black powder, which had a range of 2,300 m. But after the mid-nineteenth century rocketry ceased to develop, because modern cannons seemed to be more powerful and effective. Since the beginning of the twentieth century rockets have been given more attention and studied carefully. As a result, various new types of rockets have been developed and used, especially since World War II. Joseph Needham says:

> In this day and age, when man and vehicles have landed on the moon and when the exploration of outer space by means of rocket-propelled craft is opening before mankind, it is hardly necessary to expatiate upon what the Chinese started when they first made rockets fly.

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Rockets in India

RODDAM NARASIMHA

Fire arrows (*agni-bāṇa*), shot with the energy of a taut bow-string were used in India and other civilizations for thousands of years. Rockets are different in that they are self-propelled. It is widely agreed that the first recorded use of rockets comes from China in the eleventh century CE. The invention travelled rapidly (presumably through the Mongols) to Europe, where it was first mentioned in 1258 CE and was experimented with and used up to the fifteenth century. The Moghuls in India also used it during the late fifteenth and early sixteenth centuries. However rockets fell into disuse with the increasing accuracy and power of artillery.

The re-emergence of the rocket as a significant military weapon during the eighteenth century in the princely state of Mysore in South India is a fascinating little episode in the history of technology in India, with an interesting sequel in nineteenth century Britain and Europe. Haidar Ali, a bold officer in the army of the Raja of Mysore, and his son Tipu Sultan, used the rocket frequently in various battles in South India, including the four "Anglo-Mysore Wars" fought in the second half of the eighteenth century (Haidar's father had already commanded 50 rocketmen for the Nawab of Arcot, another South Indian prince). The interest in the events of the late eighteenth century arises from two facts: the balance of industrial power began to shift from Asia to Europe in that period, and interesting accounts have been left behind by European observers.

The rockets used by the Mysoreans consisted of a metal cylinder ("casing") containing the combustion powder ("propellant"), which was tied to a long bamboo pole or sword that provided the required stability to the missile. It bears a strong resemblance to the much smaller "rocket" that is a part of the fireworks that are still commonly seen during the Indian festival of lights, Deepavali. Two specimens preserved in the Royal Artillery Museum, Woolwich Arsenal in England have these dimensions:

Casing 58 mm outer diameter – 254 mm long, tied with strips of hide to a straight 1.02 m long sword blade.

Casing 37 mm outer diameter – 198 mm long, tied with strips of hide to a bamboo pole 1.9 m long.

These rockets had a higher thrust and range than anything in use at that time in Europe, as confirmed by later tests in England. The range is often quoted as about 1,000 yards. There are however other accounts that speak of rockets that generally weighed 3.5 kg, tied to 3 m bamboo poles, and with a range of up to 2.4 km; this was by European standards an outstanding performance for the time.

The superior performance of these rockets cannot be attributed to the propellant, which was a standard material like gunpowder. There was nothing unusual about the aerodynamics either; it turns out that their superiority lay in the material employed for the casing. The casing was a metal cylinder made of hammered soft iron. Although it was crude, it represented a considerable advance over earlier technology, as European rockets of the time had combustion chambers made of some kind of pasteboard. For example, Geissler in Germany used wood, covered with sailcloth soaked in hot glue. The use of iron (which at that time was generally of much better quality in India than in Europe), increased bursting pressures, which permitted the propellant to be packed to greater densities; this is what gave the rockets their outstanding performance.

There was at that time a regular Rocket Corps in Tipu's Mysore Army with a strength of about 5,000, with several units of rather more than a hundred men each. There are accounts that mention the skill of the Mysorean operators in giving the rockets an elevation that depended on the varying dimensions of the cylinder and distance to the attack target. Furthermore, the rockets could be launched rapidly using a wheeled cart with three or more rocket ramps.

The first account we have of the use of these rockets is in the Battle of Pollilur, fought on 10 September 1780 during the Second Anglo-Mysore War near a small village about 180 km east of Bangalore. Haidar and Tipu achieved a famous victory in this battle, and it is widely held that a strong contributory cause was that one of the British ammunition tumbrels was set on fire by the Mysore rockets, a scene that is celebrated in a famous mural that can be seen at the summer palace in Tipu's capital Sri-ranga-pattana. Writing about this war, Sir Alfred Lyall, a British historian of the early twentieth century, remarked that, as a consequence of this defeat, "The fortunes of the English in India had fallen to their lowest water-mark."

A celebrated victim of such a rocket attack was Colonel Arthur Wellesley (later Duke of Wellington and the hero of Waterloo), who suffered a traumatic encounter with rockets in a mango grove just outside Sri-ranga-pattana in 1799. From these and other accounts it is clear that the British were caught off guard by the Indians' use of rockets, which at the least caused great fear and confusion. They started developing their own rockets in the early years of the nineteenth century. The programme began when several Indian rocket cases were collected and returned to Britain for analysis. Further development was chiefly the work of Col. (later Sir) William Congreve, who tested the biggest skyrockets then available in London. Their range was found to be about 500–600 yards, less than half that of the Mysore rockets. He then developed his own, using the facilities of the Royal Laboratory at Woolwich Arsenal.

Congreve used these rockets during the Napoleonic wars and in several engagements during the Anglo-American War of 1812, sometimes with little and on other occasions with great effect. They were still rather unreliable and inaccurate, but had greater range than cannons and could even be fired from rowboats. It was a spectacular but unsuccessful attack on Fort McHenry that led to the reference to "the rockets' red glare" in the US national anthem, which began as a patriotic song composed by Francis Scott Key, who was witness to the attack.

One major reason for interest in this episode is that it occurred during a time of global transition in geopolitics, economics, and technology. Clearly, even in the late eighteenth century there were several Indian products technologically superior to Western equivalents, and both sides recognized this. But the British effort that followed had the sophistication of research and development today. Scientific principles were applied, designs made, products developed and tested, and all of this was carefully documented – a process alien to Indians of that time. The Indian rockets were well made but not standardized, being the creation of traditional artisans.

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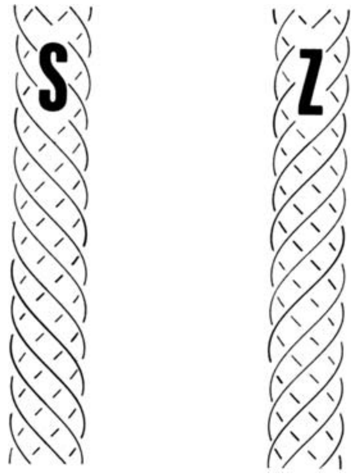
Rope and Knots in Ancient Egypt

Willeke Wendrich

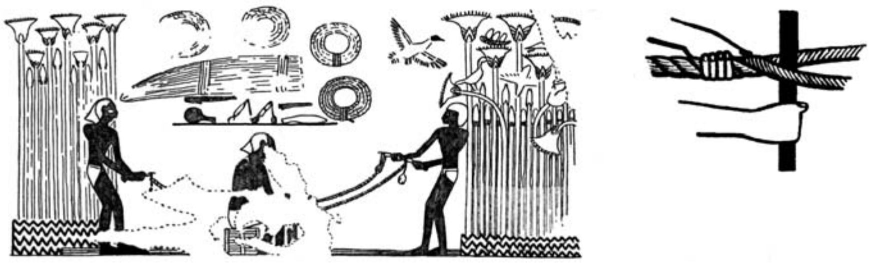
From securing a ship, to tying cattle to a post, building shelters and curing headaches, rope and string were a multipurpose commodity in ancient Egypt. The technology to make rope and string is presumably one of the oldest, predating stone working. Due to the perishable materials used for rope, no extant examples have survived in Egypt until the predynastic period. The material used most widely for the production of rope was papyrus (*Cyperus papyrus*) and other sedges of the *Cyperus* family. For large ropes, the entire stem was used, while smaller string was made of the rind of papyrus stems. The production of papyrus sheets for writing required the thick triangular stems to be peeled and sliced. The peelings made a strong raw material from which extremely fine string could be made. Many examples of such string were found in archaeological contexts, for instance in cordage from the Giza Plateau, in the rubbish tips of the building phases of Khufu's pyramid (ca. 2600 BCE). Its popularity continued into the New Kingdom. At the workmen's village of Amarna (ca. 1350 BCE) remains of a papyrus amphora carrying net were excavated (Wendrich 1989: 182–5).

Cordage was made in a large variety of ways. The fibers were spun or twisted in either S or Z direction (see Fig. 1). Two or three strands were plied to form the string, usually twisted in the opposite direction of the orientation of the strands. Two or three strings might be twisted into a cable. Again the orientation was usually the opposite of the twist direction of the ply.

The production of yarn or fine string followed three steps: (1) spinning and splicing (adding short prespun lengths by twisting the fibers in the same direction as the spin) using a spindle whorl; (2) plying in the opposite direction, and (3) cabling in the same orientation as the spin. This type of string was usually made of flax and had a diameter of approximately 0.5–2 mm for the spun and spliced yarn, 1–3 mm for the plied string, and 2–5 mm for a cable. Flax was typically spun and spliced in S direction, then Z-plied and S-cabled (Kemp and Vogelsang-Eastwood 2002: 75–6).



Rope and Knots in Ancient Egypt. Fig. 1 S and Z orientation of spinning, plying, or cabling.



Rope and Knots in Ancient Egypt. Fig. 2 Representation of rope making, using weights in the tomb of Nefer, Saqqara. To the right: detail of the action of the man seated in the middle.

Producing string of other materials was often done in one phase. Grass string, for instance, was spun and plied in one movement of the hands, the opposite direction of spin (usually z) and ply (usually S) locking the string immediately and preventing it from unraveling (Wendrich 1999: 298–300). Materials for which this technique was used were tall hard grasses (*Desmostachya bipinnata* and *Imperata cylindrica*), leaf and leaf sheath fibre of the date palm (*Phoenix dactylifera*), leaf of the doam palm (*Hyphaene thebaica*) and probably also papyrus peel. The result of this hand-rolling technique was a string consisting of two yarns, usually 'spun' in Z-direction and plied in S-direction (sZ_2 string). A third plying strand (sZ_3 string) was added separately, by doubling the end of one of fiber bundles and working back along the string. For ropes, the entire length of string was folded double and twisted into a cable ($sZ_2[S]_2$ rope).

Papyrus rope, however, was usually not cabled. The enormous ropes used in shipping consisted of multiple strands of complete papyrus culms [stems] twisted together. Such giant plied ropes were built of up to 15 thick strands of papyrus culms, each with a diameter of approximately 30 mm, resulting in a thick rope of 160 mm in diameter. We have few depictions of rope making, for instance in the tomb of Nefer at Saqqara (Fig. 2), dating to the Fifth Kingdom, ca. 2465–2323 BCE. This seems to be a more industrial approach than the hand-rolling method, which could typically be done by anybody at anytime, whenever a piece of string was needed. The use of swinging weights to make long lengths of rope was most probably needed to twist complete papyrus stems. Presumably the stems were first dried, then soaked (to render them pliable again), twisted into rope and left to dry, so that the twist would settle into a strong plied rope. Toward the Greco-Roman period, grass, papyrus, and doam palm leaf string became less ubiquitous and the material that was used most often was the leaf sheath fiber of the date palm. This hard brown fiber did not need much preparation. Soaking in water for half a day would soften the fibrous sheets enough to enable them to be worked into small bundles or tufts, which were then used to make a very hard red-brown string or rope. This material was also worked in the hand-rolling method.

Knots and knotting are part of understanding the use of rope. In all periods of ancient Egyptian history, from at least the predynastic period onward, standard knots such as the overhand knot, the reef knot (also known as square knot), and the netting knot were known and widely used. Studying everyday objects from refuse dumps, clarifies that then, as now, certain people were better versed in the art of knotting than others. The occurrence of a considerable percentage of 'granny knots,' faulty reef knots, testifies to that effect (Wendrich 1999).

Depictions of knots and knotting on Egyptian monuments had a very specific meaning. The hieroglyph for 'protection' (ancient Egyptian *shen*) represented a rope ring, which surrounded what needed to be protected. The *cartouche,* (French for 'bullet') was the protective oval inscribed around the name of the Pharaoh. It represented an elongated rope oval tied at the base.

Knotting had a particularly important protective function in Ancient Egypt. The *tit* amulet, also known as the "Isis knot" represented a looped knot with four ends hanging down. The *tit*, often made of the red semiprecious stone jasper, is thought to be either the girdle of the goddess Isis, or a tampon, with the function of protecting pregnant women from a miscarriage (Wendrich 2006). A more symbolic interpretation should be given to the quite common depiction of two nameless Nile gods, or the gods Horus and Seth, knotting the lotus and the papyrus (or the lily), symbols for Upper and Lower Egypt respectively, around a trachea with lungs. This was the hieroglyph for the verb *semaa* and the knotting of a reef knot around this hieroglyphic sign symbolizes the unification of the Nile Valley and the Delta, the two lands that together formed Egypt. In ancient religious texts, such as the Pyramid Texts, the Coffin Texts, and the Book of the Dead, several references were made to knotting. In all cases this seemed to be a protective action, in keeping with the important protective function of knots in medical and magical texts. This forms a stark contrast with terms used for 'binding,' or 'fettering,' which were used in funerary contexts to describe serious dangers to the deceased. The mummy wrappings were literally considered fetters that prevented the dead from functioning in the afterlife. The action of knotting, however, was related to encircling, the protective embrace, and the guarantee of the integrity of body and *ba*.[1]

[1] The *ba*, a concept often translated as 'soul,' is an integral part of a person. The *ba* is depicted as a bird with a human head and is the free-ranging part of a human being. When a person dies, the body is entombed, but the *ba* can exit the tomb, to return each night to the body.

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Ṣāᶜid al-Andalusī

SEMA'AN I. SALEM

Abū al-Qāsim Ṣāᶜid ibn Abū al-Walīd ibn ᶜAbd al-Raḥmān ibn ᶜUthmān al-Taghlibi, better known as Ṣāᶜid al-Andalusī or Qāḍi Ṣāᶜid, was born in Almeria in southern Spain in AD 1029. He was a philologist, natural philosopher, and historian as well as judge. As his name indicates, he was a member of the tribe of Taghlib, one of the largest tribes of Arabia. When the Arabs invaded Spain in AD 711, members of this tribe entered the country and prospered there.

Ṣāᶜid was born into a well-to-do family, whose members spent much of their time and wealth in the quest of knowledge and education. His father occupied a highly respected position in the city of Cordoba, and his grandfather, ᶜAbd al-Raḥmān, was a judge in Sidonia, Spain. After receiving his early education in Cordoba, Ṣāᶜid toured Muslim Spain to further his education. For the same reason, at the age of 17, he moved to the city of Toledo.

Like most young Arab students, Ṣāᶜid studied law, Islamic religion, Arabic language, and Arabic literature. Later in life, he specialized in the study of mathematics and observational astronomy. Among his most famous teachers were al-Fātiḥ Muḥammad ibn Yūsuf (d. AD 1059), Abū Walīd al-Waqshī (d. AD 1059), and Ibn Idris al-Tajibī, who taught him mathematics and astronomy.

Early in the eleventh century, Cordoba ceased to be the principal intellectual center of Spain, and the capital cities of the *Mulūk al-Ṭawā'if* (party-kings) tried to capture its former glory. One such city was Toledo, the capital of the princedom of Banū al-Nūn. When Ṣāᶜid entered Toledo, it was governed by Yaḥyā ibn Dhi al-Nūn (r. AD 1037–1074) and extended his kingdom to include Valencia and most of the eastern parts of Andalusia. During his reign, Toledo became an important literary and intellectual center. In addition to several authorities in Islamic sciences, Yaḥyā's court had several good mathematicians, well-known astronomers and astrologers, several men of medicine, poets, and geometers.

The number of eminent scholars, poets, and philosophers in a ruler's court was one of the status symbols of the time. Probably for that reason, Yaḥyā invited Ṣāᶜid into his court and appointed him a judge (*qāḍi*).

Several of Ṣāᶜid's students later became accomplished scholars. Among them was ᶜAbd al-Bāqi ibn Baryal, who was in part responsible for the style and language of some of Ṣāᶜid's writing. There was also the outstanding astronomer and mathematician Abū Isḥaq al-Zarqali (Arzaquiel) who, with the assistance and the guidance of his mentor, constructed the famed Toledan Tables. These astronomical tables, which were accurate calendars, were translated into Latin by Gerard of Cremona, and became the basis for the Marseilles Tables.

Ṣāᶜid wrote several manuscripts on a variety of subjects. All of his works except for *Ṭabaqāt al-ʾUmam* (Book of the Categories of Nations) are lost. He mentioned in *Ṭabaqāt al-ʾUmam* that he wrote a document on observational astronomy, one on the history of nations, and another on their religions. He may have written a manuscript on the history of Andalusia and one on the history of Islam. *Ṭabaqāt al-ʾUmam* is an authoritative source and a precise reference that identifies the natural philosophers of Muslim Spain.

Ṣāᶜid died in July, AD 1070. Ibn Yaḥyā al-Ḥadidī, the most illustrious dignitary in the court of Ibn Dhi al-Nūn, read his official obituary.

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Ṣadr al-Sharīᶜah

AHMAD DALLAL

Ṣadr al-Sharīᶜah al-Thanī, ᶜUbayd Allāh ibn Masᶜūd (fl. Bukhārā, d. 747 AH/AD 1347), was a scholar and astronomer of the fourteenth century.

He belonged to a family of famous religious scholars; his great–great–grandfather, Ṣadr al-Sharīʿah al-Awwal, was referred to as the second Abū Ḥanīfa in recognition of his rank among the legal scholars of his time. Ṣadr al-Sharīʿah, moreover, was himself a traditional religious scholar: he wrote on the subjects of *Ḥanafī* positive law, principles of jurisprudence, Arabic grammar, rhetoric, theology, legal stipulations and contracts, and *Ḥadīth* (the spoken Traditions attributed to the prophet Muḥammed). In addition, he wrote a three-volume encyclopedic treatise, *Taʿdīl al-ʿUlūm* (The Adjustment of Sciences). The first of the three books is on logic, and the second is on theology (*kalām*). The questions discussed in these two books were not unfamiliar to theologians of the time, and it seems quite probable that a jurist would be informed in such areas of research. What is uncommon, however, is Ṣadr al-Sharīʿah's competence in astronomy, which he demonstrates in the third book of the above work.

This last section entitled *Kitāb Taʿdīl Hay'at al-Aflāk* (The Adjustment of the Configuration of the Celestial Spheres) was finished in the year 747 AH (AD 1347) shortly before the death of its author. The motive for writing it, as expressed by the author in the beginning of the book, was to resolve the problems of the longitudinal motion of the moon and the other planets, as well as the latitude motion. The resulting work is indeed a revision of the astronomical tradition from within its own existing framework. In this Ṣadr al-Sharīʿah was obviously driven by the momentum of the revisionist tradition of the thirteenth-century Maragha school, which aimed at reforming Ptolemaic astronomy.

Ṣadr al-Sharīʿah was especially influenced by two sources: the *Tadhkira* of Naṣīr al-Dīn al-Ṭusī (d. AD 1274) and the *Tuhfa* of Quṭb al-Dīn al-Shīrāzī (d. AD 1311). Ṣadr al-Sharīʿah proposed to review critically the planetary models of his two predecessors, and in the course of this revision he proposed his own alternative configurations. The models which he purported to examine and replace were for (1) the longitudinal motion of the moon, (2) the longitudinal motion of the superior planets, (3) the longitudinal motion of Mercury, and (4) the motions in latitude. The mathematical mechanisms utilized by Ṣadr al-Sharīʿah to solve the problems of these models were not new, but his ingenuity lay in bringing some of these different mechanisms together. In three of the above cases he succeeded in producing new models, and in at least two of these the resulting configurations seemed to resolve the theoretical problems of earlier models, while predicting the planetary positions in accordance with the Ptolemaic observations.

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Salt

S. A. M. Adshead

Salt, its production, distribution and consumption, was an important element in the economies of all ancient societies and played a significant role in their societies, politics, and culture. This article falls into two parts. First, the principal methods of producing salt before 1800 will be analyzed. Second, the particular methods in use in the four primary civilizations of Western Eurasia (excluding Europe itself), East Asia, sub-Saharan Africa and pre-Columbian America will be outlined, together with their characteristic means of distribution and levels of consumption.

Salt exists in nature in two forms. First, there is actual salt. This takes the form of rock deposits from evaporated seas which can be quarried or mined, spontaneous evaporation at the edge of the sea or saline lakes, and incrustation on the surface of saline soil, both of which may be collected. Second, there is potential salt. This takes the form principally of brine from the sea, lakes, springs or wells, but also of saline earth and the plants growing in it. From potential salt, actual salt can be made by a variety of techniques. In most non-Western cultures these techniques were more important as a source of salt than quarries, mines or collection. Evaporation of brine, whether from the sea, lakes, springs or wells, or artificially prepared from saline rock, earth or plants, accounted for 90% of all salt consumed before 1800. Brine could be made to yield salt in two ways. It could be boiled over an artificial fire and fueled in various ways: what the Chinese called *chien*. Or it could be evaporated naturally by the power of the sun and wind: what the Chinese called *shai*. Artificial boiling and natural evaporation produced different kinds of salt. Quicker, *chien* produced a small-crystal salt, or, if prolonged, cake salt. Slower, *shai* produced a large-crystal salt. Each method had subvarieties whose differences varied the cost, color, consistency, purity, and cleanliness of the salt produced.

Subvarieties of artificial boiling may be classified according to the fuel used. Wood was commonest, but reeds, natural gas, coal, and oil shale were also used. Fuel was the chief item of cost and its availability the principal constraint. The amount required depended on the salinity of the brine. To reduce it, brine salinity was frequently intensified either by preliminary exposure to sun and wind or by filtration through saline sand, earth or ash. Since artificial boiling was everywhere an older method than natural evaporation, it may have been this preliminary exposure which provided the idea of using sun and wind to effect the whole process.

Subvarieties of natural evaporation may be classified according to the number and function of the basins used. First, there was single basin evaporation. Here, brine was run into a single basin, or battery of basins, and allowed to evaporate completely. Salt made in this way, however, was gritty, deliquescent, and possibly injurious to health, because the sodium chloride would be contaminated by the calcium and magnesium compounds contained in most brines and especially in sea water. Next, there was successive basin evaporation. Here, brine was run through a series of basins for catchment, condensation, and crystallization. In this way, sodium chloride could be separated from the calcium and magnesium compounds through the different sedimentation rates of these chemicals. Thus the calcium compounds settled in the condensers, while salt was removed from the crystallizers before it could be contaminated by the magnesium compounds in the mother liquor which was then drawn off. By this triple process, a much purer sodium chloride was obtained. The process could be tuned to give different degrees of cleanliness and size of crystal by varying the frequency of harvest and the ratio of condensers to crystallizers. The more frequent the harvest, the more likely the adherence of the floor of the crystallizer to the salt, so the dirtier the product. The higher the ratio of condensers to crystallizers, the longer the process, so the bigger the crystals. The choice of frequency and ratio depended on cost, especially of land, convenience to the producer, climate, and consumer preference as to the kind of salt. Salt was a sophisticated industry.

Salt has been sought since the first agriculturalists found a vegetable diet bland and insipid compared to meat and fish. It was sought too for its supposed medicinal effects on the internal parasites with which early agriculturalists were endemically affected. Finally, as the "general of foods", it was sought to create flavor, cuisine, and social distance. Salt was an adjunct of civilization. Although the body does require a minimum intake, the quantity is small and satisfied by normal diet, so that salt deficiency is rare in humans.

Most human consumption is in excess of physiological need. Culture, not nature, called for salt. It traveled by whatever form of transport was cheapest for bulk goods, which in premodernity meant by water, where available, rather than by land.

In the Ancient Near East and in its successor the Central Islamic lands, natural salt in the form of rock, spontaneous evaporation and incrustation was widely distributed. Salt never became big business and consumption was high. When Muslims moved beyond their homeland, however, they experienced a shortage of salt. The expansion of Islam to the Mediterranean, North Africa, India, and Indonesia was therefore accompanied by the introduction of new techniques of salt production. In particular, Islam diffused the Chinese technique, invented around AD 500, of successive basin solar cum wind evaporation. That the technique was diffused rather than independently invented in a number of places is indicated by the presence everywhere initially of the original Chinese condensers to crystallizers ratio, itself functionally unnecessary and in some circumstances dysfunctional.

In China itself, before AD 500, salt had been acquired either, in the northwest, by the collection of natural deposit, or, in the southeast, by boiling of marine brine (*chien*). Initially *shai* was regarded as inferior to *chien*. Indeed, in the Mongol period it was temporarily abandoned in its original site. In the long run, however, its absence of fuel costs, plus a number of technical improvements, gave it complete victory over *chien*, save in Szechwan which enjoyed the advantage of natural gas and more saline brine. In India too, though the mines of the Salt Range continued to operate, successive basin solar evaporation became the chief form of production: principally at the Sambhar Lake and on the west coast, but subsidiarily, with technical modifications, in Tamil Nadu. Bengal long remained a center of *chien*, till its industry was overwhelmed by imports from Britain and the Red Sea, the latter being a *shai* center.

In pre-Columbian America and in sub-Saharan Africa, production remained limited and consumption low until the coming of the Europeans to the first and of Islam to the second. Some Matto Grosso Indians neither produced nor consumed salt (the same is true of the Maori in New Zealand). Elsewhere in America, supply was by collection, boiling, or single basin evaporation, though one archaeological site has raised the possibility of an independent Maya invention of the successive basin technique. In Africa, supply was similar, though the Saharan quarries and mines may have been developed before the coming of Islam. The greatest consumers of salt were the Islamic world and China. Despite the development of marine based salines at its extremities, Islam supplied itself mainly by land, using camels for transportation. China supplied itself mainly by water, by junk. There, because sources of supply, chiefly on the coast, were relatively few, salt did become big business. Indeed, until it was supplanted in the eighteenth century by textiles, it was the chief component of the premodern Chinese economy.

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Salt in China

Hans Ulrich Vogel

In premodern China, hundreds of terms for different kinds of salt existed which were distinguished according to place of origin, type of deposit, method of production, shape, physical appearance and properties, taste, color, translucence, use, and function within the salt monopoly system. An important and authoritative scientific explanation for the existence of various salt deposits was provided by the *Shujing*. There, in the chapter "Hong fan," saltiness (*xian*) is related to the phase of Water, which by soaking and descending becomes salty. Another important explanation referred to cosmogonical thinking, stating that the clear and light (i.e., underground currents of sweet water and water of rivers and lakes) are to be found above, while the heavy and turbid (i.e., underground brine and sea water) below.

The economically and fiscally most important types of salt were, in descending order, sea salt (*haiyan*), lake salt (*chiyan*), well salt (*jingyan*), earth salt (*jianyan* or *tuyan*), and rock salt (*yayan*). In the late imperial period, sea salt accounted for more than 80% of the empire-wide production. The percentages for lake salt and well salt were about 12 and 6%, respectively. The shares of earth and rock salt are quantitatively negligible.

The Chinese salt production sector reflects typical features of the history of production techniques in China. The far greatest amounts of salt, that is sea, lake, earth, and rock salt, were produced with the help of rather simple and old-established production techniques, which in many cases required a high input of human labor. Manpower also played an important role in well salt production, but, because of the use of deep-drilling methods and exploitation of natural gas resources, this sector contained a revolutionary technological potential. Finally, we can observe that, sometimes, sophisticated production techniques were abandoned, like the method of basin solar evaporation at the salt lake of Xiezhou in Hedong (Shanxi) during the thirteenth to the sixteenth centuries.

Several partly overlapping stages of development may be observed in the production of sea salt. Early sources mention that salt was produced by boiling seawater. It is, however, far from clear whether this statement refers to the rather uneconomic process of boiling seawater directly down or whether prior to boiling a concentrated brine had been prepared. Probably both methods coexisted.

The first written account of the production of concentrated brine comes from the late ninth century. A hollow was dug, covered with wood and bamboo twigs. Sands enriched in salt were heaped up over the hollow and were then leached out by the invading flood. The concentrated brine dripped into the hollow and was tested with grains of cooked rice which floated or descended according to the degree of salinity. Finally, the brine was boiled to salt in iron pans, or pans made out of woven bamboo strips and coated with a layer of clamshell lime. This became the basic method of sea salt production in China. Improvements were added in later ages. For instance, besides sand, ashes were used which were spread out on specially prepared fields, artificially sprinkled from time to time, and exposed to the sun, thus raising their content of salt particles. In this way, the amount of brine and its salinity could be increased. The sophisticated and labor-intensive process of later ages is fully described and illustrated in the *Aobo tu* of 1334 (see Fig. 1).

The production of sea salt by solar evaporation (*shai yan*) began probably in the late Song period. The term *shai yan* is, however, ambiguous. It may either denote the production of salt in successive solar evaporation basins, making use of the fact that common salt would crystallize *after* the precipitation in the condensers of the calcium salts contained in the brine and *before* the precipitation of the magnesium compounds. Or it may be connected with the traditional leaching process, in which the last step in the production process, the boiling of enriched brine, was simply replaced by solar evaporation. The latter technique may be considered a transitional step in the slow shift from the original method of boiling brine to the production of salt in successive solar evaporation basins. This transitional method had probably already begun in the late Song period. A special form developed in parts of eastern Zhejiang where from the late eighteenth century onward the enriched brine was exposed to the sun in portable wooden trays.

While Adshead (1990, 1992) thinks that successive basin solar evaporation of sea salt first appeared in Changlu (Hebei) in 1522 at the latest, and then spread to Huaibei (1550), Shandung (1570), Fujian (1575) and other places, Liu (1988) is of the opinion that it was not adopted at the sea coast before the middle or late sixteenth century. Moreover, there is clear evidence that Fujian was prior to Changlu which took over the method of successive basins from Fujian perhaps in the middle or late sixteenth century (Bai 1988; Lin 1992). From the seventeenth century onward the method of solar evaporation in successive basins gradually replaced the traditional methods of preparing enriched brine for the final crystallization either with the help of fire or solar heat. Generally speaking, either method of solar evaporation resulted in economies of fuel and manpower.

The use of solar evaporation basin methods, however, did not originate at the sea coast, but at the salt lake of Xiezhou in southern Shanxi. In the beginning of Chinese culture, this lake must have been an important and contested source of salt supply. First, salters extracted naturally and spontaneously produced salt, a process which had always been considered an auspicious and divine phenomenon. In the late fifth or early sixth century at the latest artificial solar evaporation basins emerged. For both methods of harvesting (see Fig. 2), the warm southern wind of the summer months was a decisive factor in bringing about crystallization. Salt production in basins was conceived basically as a kind of agricultural process which is suggested by the use of terms like “fields,” “parterres,” “ditches,” “raised paths,” and “sowing salt.” From the late thirteenth to the late sixteenth century, however, solar evaporation basins were given up, and probably only naturally and spontaneously produced salt was extracted. Political reasons were partly responsible

Salt in China. Fig. 1 Sea salt production from the *Aobo tu* of 1334, with the title “Carrying the ashes and pouring them into the leaching basin.”

Salt in China. Fig. 2 The two methods of harvesting salt at the salt lake of Xiezhou, as shown in the *Zhenghe* pharmacopoeia of 1249.

for this, because the method of solar evaporation basins was closely associated with the saline's corvée [a form of unpaid labor required by a lord] system. Solar evaporation basins were reintroduced in the late sixteenth century. A perennial problem was the protection of the salt lake's brine reservoir from intruding fresh water floods caused by inundating rivers. Dikes and spillover areas were constructed for this purpose. One of these inundations silted up the lake's brine reservoir in 1757, so that thereafter wells and pits were constructed for getting brine.

Whether single basin or successive basin solar evaporation was carried out at Xiezhou is debatable. Successive basin solar evaporation was explicitly described for the first time in the early eighteenth century. Educated guesses about the actual date of invention or adoption of successive basin solar evaporation at Lake Xie, however, vary greatly. It is said to have been either the fifth or sixth century (Adshead 1992), the eleventh century (Chai 1993) or the late sixteenth century (Vogel et al., forthcoming).

The production of well salt in Sichuan province can be divided roughly into two periods. From the third century BCE to the eleventh century AD shaft wells were dug for exploiting the underground brine deposits. Recent research has shown that deep drilling was invented in the 1040s, thus inaugurating the era of deep drilled wells from the middle of the eleventh century up to the twentieth century. Salt produced by privately run deep drilled wells was cheaper and of better quality than that offered by the state managed shaft wells. The new type of well was drilled with a heavy iron bit which was fastened to a cable made out of bamboo strips notched together. The cable was attached to the drilling frame's lever beam. By jumping up and down the lever beam the drill was lifted and dropped, thus crushing the rock down in the well and creating a hole with a diameter of only about 13 cm. The upper part of the finished well was tubed with large bamboo stalks. From the late sixteenth century onward it was also provided with a foundation of stone rings, and large tubes made out of wood were used. Slurry and brine were lifted with a bamboo tube which was equipped with a leather valve at its lower end. When entering the brine, the valve opened inward, and it closed under the pressure of the brine when the tube was lifted.

Salt in China. Fig. 3 A Sichuan salt well, as depicted in the Sichuan salt gazetteer of 1882.

A great number of utensils were invented to remove obstructions that occurred during the process of drilling and brine hoisting. Deep drilling, hoisting, and repair operations developed in the course of time. This development was characterized by the use of heavier drill bits, more solid drilling frames, higher hoisting rigs, and larger hoisting tubes and hoisting drums, driven by up to four buffaloes. While in the mid-eleventh century a depth of about 200 m may have been sometimes reached, wells of the mid-eighteenth century may have been more than 500 m deep. And in 1835, the Xinghai well of Furong (*Ziliu jing*) measured more than 1,000 m. The nineteenth-century Furong wells (see Fig. 3) were much more successful than their predecessors in the tapping of subterranean brine and natural gas deposits.

Earth salt was produced in northern Shanxi and eastern Hebei in a way similar to producing sea salt, that is by leaching earth containing salt particles and by boiling down the resulting brine. The exploitation of rock salt was reported from Gansu and Shaanxi, where a kind of red-colored salt was collected in rocky caves.

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Salt in India

S. D. Gomkale

As India is one of the oldest civilizations, it is no wonder that salt was produced in ancient India and that one finds its mention in ancient scriptures. The salt industry flourished as a cottage industry for centuries. The word for salt is *Lāvaṇa* in Sanskrit. A passage from *Arthaṣāstra*, a book dealing with the history of the Mauryan period (300 BCE), says that salt manufacture was even at that distant date supervised by a state official named Lavanadhyaksa and the business was carried out under a system of license granted on the payment of fixed fees or part of the output. This tradition, handed down from Hindu kings of old, is even now followed with variations by the Government of India through its Salt Department. The history of many countries shows connections with salt; in India salt was used by Mahatma Gandhi as a tool to win independence, when he completed his famous 400-km march to the sea at Dandi on 6th April 1930. The development of the Indian salt industry will now be briefly examined in two periods, pre- and post-independence.

Salt was prepared in ancient times and until British rule from sources like seawater, subsoil and lake saline water, rock salt deposits, and water extracts of saline soils (particularly in Uttar Pradesh) mainly by solar evaporation. If required, artificial evaporation was resorted to. The salt was produced in the coastal regions of Bengal, Bombay, Madras and the Rann of Kutch and in the inland regions of Rajasthan, Uttar Pradesh, and Central India from saline brines of lakes and as rock salt in Punjab. The salt industry provided a source of revenue to the rulers in the respective regions, and it received protection and encouragement from them. However, the industry faced a sort of setback and discouragement from the British rulers who not only raised the taxes and levies as early as 1768 but also later started importing salt around 1835–1836 from European countries, Aden, and other places. The salt industry in Bengal province first felt the impact of the British policy which then affected the salt industry not only in other parts of their empire but also in Goa, which was under Portugese rule. The quantity of salt imported, mainly in Bengal, in the pre-independence period ranged between 0.4 and 0.6 million tons annually.

However, the British rulers reconsidered their drastic policies around 1930–1931, which helped to revive the Indian salt industry, and salt production picked up. Changes and improvements in salt production methods, particularly from sea water, based on scientific principles were brought about by an Indian chemical engineer, Kapilram Vakil. Before establishing India's first large scale marine salt farm at Mithapur in 1927 with the support of the Maharaja of Baroda, he had earlier (1919–1920) studied in detail the status of the salt industry in the eastern states of Bengal and Orissa. Thus production of salt in large salt works established on the basis of scientific knowledge began in India before independence.

After Independence, the majority of rock salt producing areas went to Pakistan. Salt is now mainly produced from sea water, subsoil brines, and inland lake brines. India exports salt; the imports are around 8,000–15,000 tons per year in recent years and it is mostly as rock salt from Pakistan.

Efforts have to be made to improve the quality of salt produced from both sea water and subsoil brines in the field itself, and this is one of the challenges faced by the Indian salt industry. The industry is highly labor intensive and thus has a low output. It is necessary to upgrade the technologies, adopt mechanization, and improve transportation, loading, and port facilities. This is another challenge to be tackled by the Indian salt industry, an ancient industry that must adapt to changing times.

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Salt Production in Mesoamerica

Eduardo Williams

Common salt, or sodium chloride, has always been a strategic resource of primary importance. In pre-Hispanic Mesoamerica salt was used mainly for human consumption, as the native diet (consisting mainly of plants such as maize, beans, chili peppers, and squash) had little chloride and sodium (Williams 2003). Chloride is essential for digestion and respiration, and without sodium our organism would be unable to transport nutrients or oxygen or transmit nerve impulses. Throughout the world, once human beings began cultivating crops, they began looking for salt to add to their diet (Kurlansky 2002: 6–9).

In the preindustrial world, sodium chloride had several important uses apart from its role in the diet, particularly as preservative of animal flesh, as a mordant for fixing textile dyes, as a medium of exchange, and as a principal component in the preparation of soaps and cleansing agents (Parsons 1994: 280).

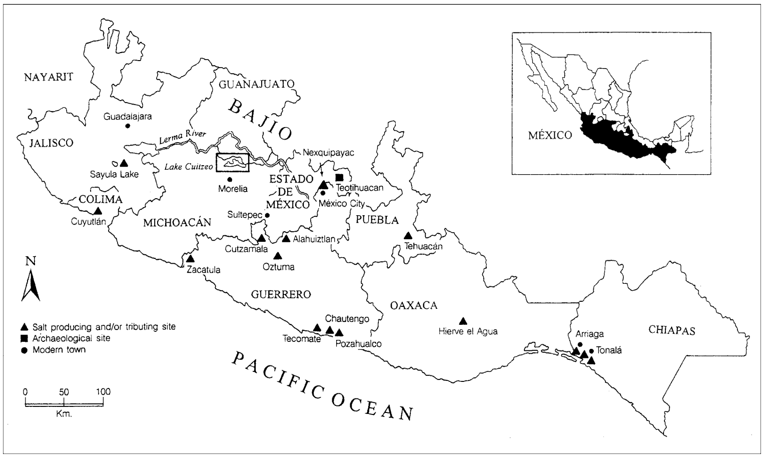
An ancient technology where salt was very important was textile dyeing. There may have been a direct functional link between saltmakers and cloth dyers in Mesoamerica; saline solutions have been commonly used as mordants by traditional cloth dyers in several parts of the world to fix dyed colors in textiles (Parsons 2001: 241). In fact, salt's important role in the Mesoamerican economy can be indirectly gauged by the huge number of dyed textiles that circulated through commerce and tribute. Among the Aztecs, for example, cotton cloth had many uses. Cloth was used for clothing, bedding, bags, awnings, decorative hangings, battle armor, adornment for statues of the gods, and shrouds for the dead (Smith 1998: 91). Cotton textiles served as items of exchange, as well as currency in the markets; they were exchanged as gifts among the nobility, and formed the dominant item of tribute payment at all levels (Smith 1998: 91).

Imperial tribute received by the Aztec state every year included 128,000 mantles or capes, 19,200 garments, and 665 warrior costumes. Most of these items were woven with dyed cotton thread, and the amount of salt used in the dyeing process must have been very high indeed. To this we should add the 4,000 "salt loaves" paid to the Aztecs by several tributary provinces every year (Smith 1998: Table 7.2).

Throughout Mesoamerica, salt was one of the most important items of trade and tribute. Access to major natural sources and control of long-distance salt trade was a fundamental factor in the formation of states. Among the Maya, for instance, many ancient trade routes had one or two key resources, whose exchange was the stimulus for the origin and growth of commerce. One of these resources was salt and to a lesser degree cotton, obsidian, and jade (Andrews 1983: 134).

The Tarascans of west Mexico expanded their empire from their homeland in central Michoacan (Fig. 1) toward the Lake Cuitzeo basin in the east, the Sayula Lake in the west, and the Pacific coast of Michoacán and Colima to secure many strategic resources such as salt, obsidian, copper, gold, and silver, which were lacking in the empire's heartland (Pollard 1993; Williams 2003).

Mesoamerican salt sources can be broken down into three types: saline inland lakes, highland springs, and coastal estuaries (Kepecs 2003: 126). The methods used to extract salt in pre-Hispanic times consisted of boiling brine, leaching brine through salt-laden earths, and solar evaporation. These processes often were combined (Kepecs 2003: 127). Salt itself is usually not preserved in the archaeological record. The archaeological



Salt Production in Mesoamerica. Fig. 1 Map showing salt-producing sites in central-western Mesoamerica (© Eduardo Williams).

markers or material remains linked to saltmaking with native techniques consist of (1) pottery vessels (which were used and discarded in great quantities at salt production sites); (2) shallow solar evaporation ponds made of sand and lime; (3) canals for taking the water from the springs to the production sites; and (4) mounds of leached, discarded earth (Williams 2003).

Salt production and trade played a fundamental role in Mesoamerican culture from the earliest times. By 1200 BCE, Olmec merchants from the Gulf of Mexico penetrated highland and Pacific coastal Guatemala, Oaxaca, and central Mexico in their quest for salt and various other strategic resources such as obsidian, jade, serpentine, iron ores, basalt, cacao, marine shells, animal pelts, and exotic bird feathers. Olmec traders actively engaged in salt extraction and trade along the Gulf coast in the Formative (Diehl 2004: 128). During this same period in Oaxaca saltmaking was restricted to villages near saline springs. As early as 1300 BCE some salt-making areas were visited briefly, but no houses were built. During the Middle Formative (ca. 900–300 BCE), the production of salt by boiling brackish spring water in pottery jars was a common activity. Saltmaking was probably one of Formative Mesoamerica's most widespread regional specializations (Flannery and Winter 1976: 39–40).

What follows is a brief discussion of pre-Hispanic saltmaking in several areas of Mesoamerica. This discussion is based on archaeological, ethnohistorical, and ethnographic data (for a detailed discussion, see Williams 2003).

The Basin of Mexico

Parsons (1994, 2001) studied saltmaking at San Cristóbal Nexquipayac, a small village on the northeastern shore of Lake Texcoco, central Mexico. According to Parsons, saltmaking at Nexquipayac involves six basic sequential steps:

1. collecting the soils whose salts are to be leached
2. mixing the soils in the correct manner
3. filtering the water through the soil mixture in order to leach out the salts and concentrate them in a brine solution. A conical pit excavated in the workshop to a depth of 40–50 cm and 90–100 cm in diameter was used for this
4. boiling the brine to obtain crystalline salt
5. drying the crystalline salt and
6. selling the dried salt (Parsons 1994: 263, 269, 2001).

The Sayula Basin, Jalisco

The initial process used to extract salts in the Sayula basin must have been the leaching of saline sediments. The leaching process consisted of "washing" and filtering saline earth with fresh water; the result was a salt-laden liquid or brine. This stage of production required various types of installations. The producers built a filter sustained by a wooden fork, composed of a rectangular base of sticks on which sedge, fodder, and sand were placed. The resulting brine was collected in a circular pan (Valdez et al. 1996: 179).

Following the extraction process, it was necessary to reduce the collected brine through natural or induced evaporation to achieve the final product – salt. Although salt production carried out until recently in the Sayula basin relied on solar evaporation, the historical texts always refer to fire reduction in ceramic vessels (Valdez et al. 1996: 179; Liot 2000).

Cuyutlán, Colima

In pre-Hispanic times, the most common salt-making technique in coastal Colima was by boiling the brine.

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When seawater or water from saline wells was not used, it was necessary first to obtain water with a high saline content, or brine, through several processes of leaching and washing of saline soils; later the resulting brine was boiled to evaporate the water. Both processes, filtering and evaporation, were carried out using clay pots. This method was effective, but not too practical when attempting to produce large volumes of salt. As demand increased, new technologies were developed. Toward the end of the sixteenth century filters were first introduced in Colima. These consisted of wooden platforms with woven branches or sticks supporting several layers of filtering substances. A similar device is still used in Cuyutlán, Colima (Reyes 1995: 152, 154).

Lake Cuitzeo basin, Michoacán

There are several thermal springs in the eastern end of Lake Cuitzeo, whose water, which has a high mineral content, is used for the production of salt. Each salt-producing unit (known as *finca*) consists of two or more *estiladeras* (Fig. 2), wooden structures that are used as filters to separate the salt from the earth by leaching. In every *finca* there are several *canoas* (wooden troughs, manufactured like dugout canoes; Fig. 3), where the brine that has been filtered in the *estiladera* is evaporated by the sun. Each *finca* has an area of some 50 m^2 where salt-bearing soils are extracted and mixed. There is also a network of canals that bring water from the springs to the *fincas*, with a depth of ca. 50–80 cm, and several meters in length (Williams 1999).

The tools used by the saltmakers are quite simple: shovels, hoes, and picks to excavate the soil, wheelbarrows to take it to the *estiladera*, buckets to take the water to the *canoas*. The tools used in the past, however, were quite different: a type of sack made of jute fiber was used to carry the earth, and clay vessels were used to carry the water within the *finca*.

Salt Production in Mesoamerica. Fig. 2 This device, known as *estiladera,* is used for filtering the water from the springs through salty soil to obtain brine by leaching (© Eduardo Williams).

The salt-making process can be divided into four stages: (1) soils are extracted, mixed, and prepared; (2) brine is obtained by leaching the earth in the *estiladera*; (3) brine is evaporated by the sun in the *canoas* and salt is collected; (4) the finished product is packed and sold.

Although the tools and permanent fixtures used today for making salt in the study area are not the same that were employed during the early colonial era, much less in pre-Hispanic times, the basic process for saltmaking still used in this area is in many ways similar to the one described in the sixteenth century *Relaciones Geográficas*. Both ancient and modern saltmaking requires extracting the soil, mixing two or more types of earth, adding water, leaching and evaporation (Williams 1999). Saltmaking in coastal Michoacán is similar to what has been described earlier (Williams 2002; see Figs. 4–6).

Coastal Guerrero

The process known as *tapeite* in coastal Guerrero, still used in sites such as Tecomate, Chautengo, and Pozahualco, consists of leaching salt from soils where saltwater marshes dry up during the dry season. The

Salt Production in Mesoamerica. Fig. 3 The *canoas* are shallow troughs made with dugout pine trunks, used in the solar evaporation of brine. Note the crystallized salt on the right, the liquid brine on the left (© Eduardo Williams).

Salt Production in Mesoamerica. Fig. 4 Filtering device known as *tapeixtle*, used on the coast of Michoacán for leaching estuary water to produce brine (© Eduardo Williams).

Salt Production in Mesoamerica. Fig. 5 Shallow pools made of sand and lime, known as *eras.* They are used in the solar evaporation of the brine. The *tapeixtle* is in the background, covered by palm fronds (© Eduardo Williams).

Salt Production in Mesoamerica. Fig. 6 Harvesting the crystallized salt from the *era,* coastal Michoacan (© Eduardo Williams).

saltmakers carefully break up the thin upper crust of earth and carry it to their saltworks, where they deposit it in a large filter known as *tapeite,* which is constructed on a raised base of wooden or cane slats covered with palm or tough grass. Adobe sides create a rectangular basin lined with coarse sand and a second layer of fine, sifted sand. Brackish groundwater is drawn from a shallow well dug next to the *tapeite* and poured over the saline earth. After seeping through the filter, the water is channeled into a plaster-lined holding tank. The concentrated brine is poured into the solar drying pans, where it evaporates to leave white granular salt crystals (Good 1995: 2).

The Maya Area

Salt was a regional necessity everywhere in Mesoamerica, yet the white salt of Yucatán was also a bulk luxury, traded far beyond the regional level. Flowing from international trading centers to regional markets in foreign territories, it augmented regional supplies as a product of superior quality (Kepecs 2003: 129). The pre-Hispanic Maya obtained salt from several sources, the most abundant ones being the coastal saltworks. The primary source of salt in pre-Hispanic Mesoamerica was coastal Yucatán, where salt was obtained through solar evaporation. Archaeological evidence shows that Yucatecan saltworks were active from the Late Formative (ca. 300 BCE–AD 300). In colonial times salt production in Yucatán was approximately 20,000 tons per year, enough to satiate the needs of several thousand people, or the whole of the Maya Lowlands through history (Andrews 1997: 40). Salt was scarce in the southern Maya lowlands of Guatemala and Belize. It was imported in bulk from the north coast of Yucatán, although recent fieldwork has documented closer sources of salt than those of the north coast (McKillop 2002).

A method for making salt which is still found in a few sites near the Chiapas coast is the one known as *tapesco*. It involves leaching marsh soil with estuary water which is then evaporated in small solar pans. The *tapesco* salt-making operation takes place mainly during the dry season (from January to May or June). The soil to be leached is raked up and placed on raised wooden structures known as *tapescos*, the bottom part of which consists of a three-layered filter made of thin sticks covered with grass reeds, which in turn are covered by a thin layer of sand. Salt water is drawn from small shallow wells and poured over the soil in the *tapesco*, thus leaching the soil. After passing through the filter the water collects in a mud-lined pan beneath the *tapesco.* The brine is then placed in a series of small shallow solar evaporation pans, where evaporation takes place anywhere from 4 to 6 days, depending on available sunlight (Andrews 1983: 62–3).

Veracruz

During the Early Formative (ca. 1200–900 BCE) in El Salado, Veracruz, solar evaporation in pottery trays was

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the primary method of salt production. This method was supplemented by some saltmaking involving boiling brine. During the late Classic (ca. AD 600–900) brine reduction involved a two-step process whereby salt content in the brine was first increased by boiling in pots; this brine was later reduced to loaves by boiling over fire in shallow ceramic basins (Santley 2004).

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Samūˤīl ibn ˤAbbās (al-Maghribī)

E. Ruth Harvey

Samūˤīl (or Samau'al) ibn ˤAbbās, also called Abū Nasr Samūˤīl ibn Yahyā ibn ˤAbbās, was a Jew whose father's family origins were in Fez in Morocco. Samūˤīl is often called al-Maghribī, "the westerner," but he spent his life in Iraq, Syria, Kurdistan, and Azerbaijan, and died in Maragha in about 1175 (570 AH). He was famous as a mathematician and physician, and left a number of works on both subjects. In 1163 he underwent a conversion to Islam and subsequently wrote a polemical treatise against the Jews; in an autobiographical appendage to this work he provided a very interesting account of his careful upbringing, extensive education, and the dreams which prompted his conversion. Samūˤīl practiced medicine at Baghdad (where he wrote some of his works) and Maragha (where he served a number of local princes and important personages).

The early Arab biographers ascribe many works to Samūˤīl, but not all of these are extant. Steinschneider and Brockelmann list 17 treatises, some of which are works not mentioned by the biographers but which are ascribed to Samūˤīl in manuscript; some attributions are doubtful.

The only extant medical treatise attributed to Samūˤīl is an elaborate work on sex and gynecology entitled *Nuzhat al ashāh fī muˀāsharat al-ahbāb* (The Entertainment of Friends and the Dealings of Lovers), often referred to in catalogs as *De Coitu*. Works of this kind are not infrequent in the Arabian medical tradition; Samūˤīl's treatise was written for the ruler of Hisn Kayfa, Muḥammad ibn Qara Arslan, and was famous enough to have survived in a number of widely scattered manuscripts; it has never been printed. An account of the work may be found in Leclerc. It contains two books. The first deals with sex, both homosexual and heterosexual, sexual desire, diet, and hygiene; it contains an account of the physical and moral characteristics of women from different countries. The second book deals with such topics as impotence, aphrodisiacs, conception, sterility, and female ailments. There are manuscripts in Paris, Berlin, the Escorial, I eipzig, and Istanbul. The Berlin catalog lists (in Arabic) all the chapter headings of the *Nuzhat*.

Some of the treatises on mathematical subjects ascribed to Samūˤīl by the early biographers are no longer extant, but copies of his *al-Tabsira fīˀ ilm al-ḥisāb* (Introduction to Arithmetic) survive. Both Leiden and Oxford have manuscript copies of a work entitled *Fī kashfˀawar al munajjimin* (On the Errors of Astronomers), in which Samūˤīl defends the idea of scientific progress, citing an arithmetical work of his own, *Al-bahir*, as an example of an advance on ancient mathematics. Brockelmann says that a manuscript of a work entitled *Al-bahir fīʾilm al-ḥisāb* attributed to Samūʿīl exists in Istanbul; perhaps this is the one referred to in *Errors of the Astronomers*. Another work on arithmetic, *Al-mujiz al-mardawi fī al-ḥisāb*, also exists in a single manuscript in Istanbul.

The Arabic text of Samūʿīl's polemic against Judaism, *Ifhām al-Yahūd* (Silencing the Jews), together with his autobiogrphical addition, has been edited and translated into English by Perlmann, who provides in his introduction the best account of Samūʿīl and his works. Perlmann points out that the work *Al-Ajwiba alfakhira raddan ʾan il-milla al-kafira* ascribed to Samūʿīl by Brockelmann derives from Samūʿīl's work but is not by him. Another polemical work against the Jews, the *Contra Judeos* of Samuel Marochitanus which was translated from Arabic into Latin in 1339, has often been ascribed to Samūʿīl ibn Abbas; it contrasts Judaism unfavorably with Christianity, not Islam, and is clearly the work of another author.

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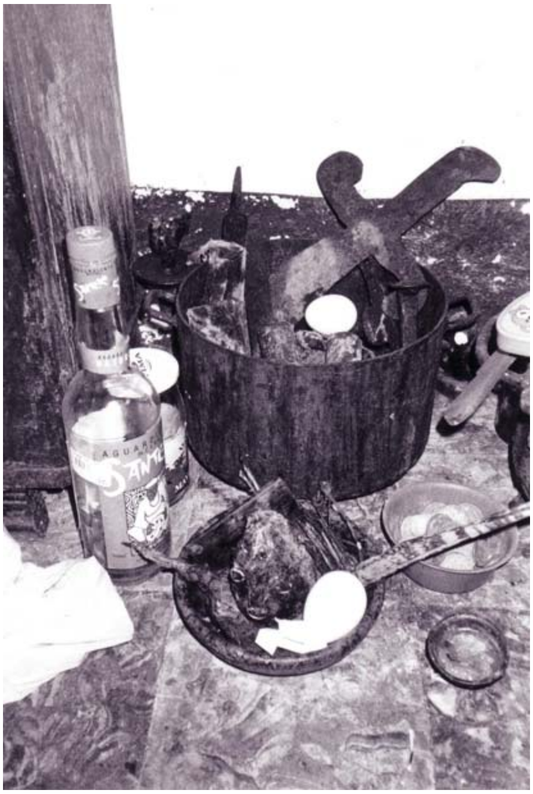
Santería

Johan Wedel

Santería has its roots in the slave trade when a large number of slaves were taken from Africa to Cuba. Many were from the Yoruba people, who now live in southwestern Nigeria. The Yoruba, well known for their artistic traditions, urban lifestyle, and a well-developed division of labor, brought with them a belief in their divinities, *orishas*. In Cuba, the orishas merged with the saints of the Roman Catholic Church, which, in turn, led to the creation of santería, "the way of the saints" (Thompson 1983; Brandon 1993; Lawal 1996; Matibag 1996; Thomas 1997; Wedel 2004).

Only a handful of the more widely recognized orishas survived the Middle Passage. As the divinities acquired their Catholic equivalents, they became to be known as *Santos* –saints. Oshún, for example, the orisha of freshwater, acquired a Catholic equivalent in the form of Virgen de la Caridad del Cobre. Shangó, the manly warrior who represents thunder, lightning, and fire, found a counterpart in the Catholic saint Santa Barbara. Apart from these two popular divinities, some of the most prominent orishas/santos include: Eleggua, messenger and guardian of crossroads; Ogún, lord of war and iron; Obatalá, father and lord of peace and purity; Yemayá, mother and ruler of the seven seas; and Oyá, female warrior, guardian of the cemetery, who is associated with strong winds.

The actions and adventures of the divinities appear in the many santería myths (*patakies*), which, in turn, are related to various kinds of divination systems (Martínez Furé 1979; Valdés Garriz 1997; Pérez Medina 1998). In one myth, the supreme god Olodumare-Olofi first



Santería. Fig. 1 Eleggua, guardian of crossroads, is represented by a "head" of cement with eyes and mouth made of cowrie shells while Ogún, lord of iron, is represented by a cauldron with iron tools. (Photo by Johan Wedel).

Santería. Fig. 2 When sacrifice is performed, ashé, divine force, is released. The santería objects are then covered with feathers from sacrificed fowls in order to "cool" the "hot" blood. (Photo by Johan Wedel).

Santería. Fig. 3 Sacrifice of a goat during an Afro-Cuban quasi-religious ceremony in the street Callejon de Hamell, Central Havana. (Photo by Johan Wedel).

created the universe and then distributed his *ashé*, life force, to the orishas/santos. As humans develop their relationship with the divinities through rituals and sacrifices, they benefit from the ashé that came from the high god Olodumare.

In Cuba today, as well as in other Latin American countries and in the United States, people frequently turn to santería for all kinds of problems. Illness, however, is a particularly common reason for consulting a priest (see also Sandoval 1979, Pasquali 1994; Sandoval 1995; Jones et al. 2001; Wedel 2004). Using divination, the priest will relate the client's problems to the santería mythology and a number of proverbs. The priest (*santero* or *santera*) uses cowrie shells when divining with the dilogún divination system, while the high priest (*babalao*) uses a chain made of coconut shell or tortoise shell when divining with the Ifá system (Bascom 1952, 1980; Mason 1993; Matibag 1997; Valdés Garriz 1997; Wedel 2004). It takes many years of training to become a skilled diviner. A babalao is considered "mature" after working and divining for 16 years (Wedel 2004: 92).

Once the priest has identified the client's condition through divination, spiritual cleansing, offerings, sacrifices, and minor rituals are commonly suggested. Santería priests usually have extensive knowledge of a multitude of herbs and plants, and some of these may also be recommended (Marks 1987; Brandon 1991; Cabrera 1993; Wedel 2004). In the case of an illness, clients are often told to pay a visit to a physician. From the perspective of santería, however, it is not sufficient to try just to cure the affliction; the underlying reasons for the problem must also be identified. The priest will also explain why a person has been struck by ill health and may attribute the problem to a lack of ashé, to afflicting spirits, to disturbed social relations and sorcery, or to the client's lifestyle (Wedel 2004).

In santería, it is recognized that both physical and mental illnesses are frequently related to disturbed social relations and these are expressed in terms of sorcery (cf. Stoller and Olkes 1987; cf. Geschiere 1997). An envious neighbor or family member, for example, might be said to have performed sorcery on the client (although the priest seldom reveals the name of the evildoer). The client may then be advised to break up a relationship, move to another house, change jobs, or avoid certain persons in order to become well. An affliction may also be caused by a spirit or divinity who wants the person to change his way of life and become a practicing priest (Wedel 2004).

When divination discloses a serious illness and it is established that medical treatment will not be adequate, initiation may be recommended. This was expressed by a Cuban babalao who also works as a physician, who said: "We do this when modern medicine can do no more, when you reach the limits of science" (Wedel 2004: 121). A similar opinion was articulated by

Santería. Fig. 4 Osain is the lord of herbs and plants. He is represented by a calabash with powerful, secret herbs, which is hung from the ceiling. If a menstruating woman comes into contact with the calabash, it will lose its power. (Photo by Johan Wedel).

Santería. Fig. 5 Afro-Cuban objects arranged by the artist Salvador Gonzalez at Callejon de Hamell, Central Havana. (Photo by Johan Wedel).

another babalao: "We religious people say that sometimes a person has to attend *el brujo blanco* [the "white sorcerer"] who is the [biomedical] doctor. Sometimes he has to attend *el brujo Yoruba* [the "Yoruba sorcerer"], who is the santero or babalao" (121).

Initiation into santería, which also may take place for reasons other than illness, is a "rebirth", a gradual process designed to change a person's experience and transform the whole lifeworld of the devotee (cf. Turner 1969, 1986; cf. Willis 1999; Wedel 2004). The "newborn" builds a beautiful altar for his/her personal divinities (Flores-Peña and Evanchuk 1994; Brown 1996, 2003), and is kept in isolation for seven days, while a godmother or godfather feeds and cares for them. The initiate is also given *omiero*, a mixture of secret herbs said to contain large quantities of ashé (Brandon 1991).

During the initiation, which is largely secret and closed to the noninitiated, a divinity will be "placed in the head" of the initiate. This orisha/santo, who is said to be the "father" or "mother" of the initiate, will then offer its protection for the rest of the initiate's life. The initiation also involves a complex divination session, including ritual cleansing, animal sacrifices, offerings to the dead ancestors, and dancing to the sacred santería drums. During the drum ceremony, the divinity may "descend" into the body of the novice, who may experience possession trance (cf. Goodman 1988, 1990; cf. Turner 1992; Murphy 1993, 1994; cf. Willis 1999; Wedel 2004).

For one year after the initiation, everyone will address the initiate as iyabó. He/she is close to the divine world of the santos/orishas and must obey certain rules, such as wearing white clothes and not visiting cemeteries. The initiate will also acquire new social relations and become a "sister" or "brother" to others who have been initiated by the same godmother or godfather. Through initiation, an intimate relationship between humans and the world of the orishas/santos is created, and the initiate develops a new understanding of what has caused the affliction and how to avoid problems in the future.

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Śatānanda

K. V. Sarma

Śatānanda, son of Śaṅkara and author of the popular astronomical manual *Bhāsvatī*, was a resident of Puruṣottamapurī, the modern city of Puri, in Orissa. The *Bhāsvatī* was written in the Śaka year 1021, AD 1099. The epochal constants are also given for Puri, instead of for Ujjain as is normal in astronomical manuals. In 82 pithy verses distributed in eight chapters, the *Bhāsvatī* sets out the several computations required for preparing the daily almanac. There is a traditional statement that eclipses computed according to the *Bhāsvatī* would be exact. Towards the beginning of the work, the author avers that he was composing the work on the basis of the (Old) *Sūryasiddhānta* condensed by Varāhamihira in his *Pañcasiddhāntikā*. There is also a pun in the word *Bhāsvatī*, based on the above, since *bhāsvān* means *Sūrya* (Sun). There is a pun on the word *Śatānanda* as well; the literal meaning of the word is "one who revels in hundreds," and in this work the author used the centismal system for commencing the epochal position and specified several of the multipliers and divisors in computation in terms of hundreds. There are several recensions of the work and some manuscripts add an *Uttara-Bhāsvatī*.

Śatānanda introduced certain other innovations in his work. For the computation of Mean planets, he took not the *Ahar-gaṇa* (number of elapsed days), but the *Varṣa-gaṇa* (number of elapsed years). As the commencement of the year, he did not take the Mean *Meṣādi* (Aries ingress), but the True *Meṣādi*, which is advantageous in certain aspects. Another specialty of Śatānanda's is that, as mentioned above, he adopted the centismal system for commencing epochal positions and for specifying multipliers and divisors. The positions of the sun and the moon are stated in terms of *nakṣatras* (constellations) and not in *rāśis*, which is normally the case in texts of this type. Then again, Śatānanda took AD 528 as the zero precession year and the rate of precession as 1 min per annum.

The popularity of Śatānanda's work in North and Northeast India is attested to by the presence of a large number of manuscripts of *Bhāsvatī* in these regions and by the fact that most of his commentators hail from there. Some of the principal commentators are Aniruddha (*Śiśubodhinī*, 1495), Mādhava (*Mādhavī*, 1525), Acyuta (*Ratnamālā*, ca. 1530), Kuvera Miśra (*Ṭīkā*, 1685), Rāmakṛṣṇa (*Tattvaprakāśikā*, 1739), and Yogindra (1742).

See also: ►Varāhamihira, ►*Sūryasīddhānta*, ►Lunar Mansions, ►Precession of the Equinoxes, ►Astronomy in India

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Science as a Western Phenomenon

Roshdi Rashed

Philosophers, historians, and sociologists of science all accept as a basic postulate that science is essentially Western. This postulate is still conditioning contemporary scientific ideologies. This article analyzes the characteristics, history, and validity of this doctrine by means of a confrontation with one of the non-Western scientific contributions: science written in Arabic.

Classical science is essentially European, and its origins are directly traceable to Greek philosophy and science; this tenet has survived intact through numerous conflicts of interpretation over the last two centuries. Almost without exception, the philosophers accepted it. Kant, as well as Comte, the neo-Kantians as well as the neopositivists, Hegel as well as Husserl, the Hegelians and the phenomenologists as well as the Marxists, all acknowledge this postulate as the basis of their interpretations of Classical Modernity. Even until our time, the names of Bacon, Descartes, and Galileo (sometimes omitting the first, and sometimes adding a number of others) are cited as so many markers on the road to a revolutionary return to Greek science and philosophy. This return was understood by all to be both the search for a model and the rediscovery of an ideal. One might impute this unanimity to the philosophers' zeal to pass beyond the immediate data of history, to their wish for radical insight, or to their effort to seize what Husserl describes as "the original phenomenon (*Urphänomen*) which characterizes Europe from the spiritual point of view." One would expect that the position taken by those who have stuck more closely with the facts of the history of science would be quite different, but such is not the case. This same postulate is adopted by the historians of science as a point of departure for their work, and especially for their interpretations. Whether they interpret the advent of classical science as the product of a break with the Middle Ages, whether they defend the thesis of continuity without breaking or cutting, or whether they adopt an eclectic position, the majority of historians agree in accepting this postulate more or less implicitly.

Today, in spite of the works of many scholars on the history of Arabic and Chinese science, in spite of the wide representation of non-Western scientists in *Dictionary of Scientific Biography*, the works of the historians rest on an identical fundamental concept: in its modernity as well as in its historical context, classical science is a work of European man alone. Furthermore, it is essentially the means by which this branch of humanity is defined. Occasionally the existence of a certain practical science in other cultures might be acknowledged; nevertheless, it rests outside history, or is integrated into it only to the extent of its contributions to the essentially European sciences. These are only technical supplements which do not modify the intellectual configuration or the spirit of the latter in any way. The image given of Arabic science constitutes an excellent illustration of this approach. Essentially it consists of a conservatory of the Greek patrimony, transmitted intact or enriched by technical innovation to the legitimate heirs of ancient science. In all cases, scientific activity outside Europe is badly integrated into the history of the sciences; rather, it is the object of an ethnography of science whose translation into university study is nothing more than Orientalism.

The effects of this doctrine are not limited to the domain of science, its history, and its philosophy. It is at the center of the debate between modernism and tradition. As was the case in eighteenth-century Europe, we find, in certain Mediterranean and Asian countries of today, that science (which is qualified as European) is identified with modernism. Our purpose here is not to redress wrongs, nor to oppose to that science qualified as European an alleged Eastern science. It is simply a matter of understanding the significance of the European determination of the concept of classical science, grasping the reasons for it and measuring its importance.

We shall begin by sketching the history of this view of European science and then estimate its effects. We shall limit ourselves to posing the problem and advancing several hypotheses, and we also add these two restrictions: the only non-European science considered is one which was produced by various cultures, by scholars of different beliefs and religions, all of whom wrote their science principally, if not exclusively, in Arabic. As for the tenets of the history of the sciences, we shall most often cite those of the French historians.

The concept of a European science is already present in the works of the historians and philosophers of the eighteenth century. In the debate of the Ancients and the Moderns, scholars and philosophers referred to science to define modernity where one combines reason and experience. Historical induction intended to give its concrete determinations to this dogmatic debate, so as to render the superiority of the Moderns indisputable. But the West was already being identified as Europe, and "Oriental wisdom" was already counterpoised against the natural philosophy of the post-Newtonian West, such as we find in Montesquieu's *Persian Letters* (1721).

Classical science is European and Western only to the degree that it represents a stage in the continuous and regular development of humanity. The *Discours Préliminaire* of Abbé Bossut in Diderot's *Encyclopédie Méthodique* offers an illustration of this concept. Dividing the history of the progress of the exact sciences into three periods, this tableau allows conjecture, alleged facts, and facts to intermingle. Its initial postulate is that "…all of the eminent peoples of the ancient world liked and cultivated mathematics. The most distinguished among them are the Chaldeans, the Egyptians, the Chinese, the Indians, the Greeks, the Romans, the Arabs, etc… in modern times, the western nations of Europe." Classical science is European and Western because, writes Abbé Bossut, "…the progress made by the western nations of Europe in the sciences from the sixteenth century to our times utterly effaces those of other peoples."

The concept of Western science changed in nature and extent at the turn of the nineteenth century. With what Edgar Quinet called the "Oriental Renaissance", the conceptualization was completed in its anthropological dimension in the last century. This Oriental Renaissance ended by discrediting science in the East.

If it is true that the eighteenth-century concept still survived here and there, from the first years of the nineteenth century the materials and ideas of Oriental studies contributed the most to the makeup of the historical themes of the different philosophies. In Germany as well as in France, the philosophers adopted Oriental studies for diverse reasons in accordance with an identical representation: the East and the West do not oppose each other as geographical, but as historical positivities; this opposition is not limited to a period of history, but goes back to the essence of each term. In this regard, *Lessons on the History of Philosophy* and other works of Hegel can be invoked. Also at this time, as is shown by the French Restoration philosophers, the themes of the "call of the East" and the "return to the Orient" appear, which translate as a reaction against science, and more generally, against Rationalism. But it is with the advent and growth of the German philological school that the notion of science as a Western phenomenon was regarded as having been endowed with the scientific, and no longer purely philosophical, support which had been lacking until then.

This influence also extended into mythological and religious studies. For example, Friedrich von Schlegel distinguishes two classes of language: the flexional Indo-European languages, and others. The former are "noble," the latter less perfect. Sanskrit, and consequently, German, considered the closest to it, is "…a systematic language and perfect from its conception"; it is "…the language of a people not composed of brutes, but of clear intelligence." There is nothing surprising in this; with the advent of the German school we are already in the realm of classifying mentalities. From now on everything is in place for effecting the passage from the history of languages to history through languages.

The comparative study of religions and myths is developed around the middle of the century by A. Kuhn and Max Müller in particular. The classification of mentalities is perfected. It is from the basis of these tenets and dating from this period that one of the most important efforts to establish the notion of science as Western and European in an allegedly scientific manner is elaborated. This project achieves its full extent in France in the work of Ernest Renan.

For Renan, civilization is divided between Aryans and Semites; the historian only has to evaluate their contributions in a differential and comparative manner. The notion of race would constitute the foundation of historiography. By race, one meant the whole of the "…aptitudes and instincts which are recognizable solely through linguistics and the history of religions." In the last analysis, it is for reasons attributable to the Semitic languages rather than the Semites themselves that they did not and could not have either philosophy or science. "The Semitic race," writes Renan, "is distinguished almost exclusively by its negative traits: it has neither mythology, epic poetry, science, philosophy, fiction, plastic arts nor civil life." The Aryans, whatever their origin, define the West and Europe at one and the same time. Arabic science is, "…a reflection of Greece, combined with Persian and Indian influences."

The historians of science borrowed not only their representation of the Western essence of science from this tradition, but also some of their methods for describing and commenting on the evolution of science. Thus, they applied themselves to discovering the concepts and methods of science and to following their genesis and propagation through philological analyses of the terms and on the basis of the texts at their disposal. Like the historian of myths or of religion, the historian of the sciences must be a philologist as well. In France, the situation is such that philosophers borrow Renan's interpretation and, often, even his terminology. Even though this brand of anthropology has already been abandoned by historians, they nevertheless preserve and propagate a series of inferences engendered by it. These can be enumerated as follows:

1. Just as science in the East did not leave any consequential traces in Greek science, Arabic science has not left any traces of consequence in classical science. In both cases, the discontinuity was such that the present could no longer recognize itself in its abandoned past.
2. Science subsequent to that of the Greeks is strictly dependent upon it. According to Duhem, "…Arabic science only reproduced the teachings that it received from Greek science." In a general fashion, Tannery reminds us that the more one examines the Hindu and Arabic scholars, "…the more they appear dependent upon the Greeks…(and)…quite inferior to their predecessors in all respects."
3. Whereas Western science addresses itself to theoretical fundaments, Oriental science, even in its Arabic period, is defined essentially by its practical aims.
4. The distinctive mark of Western science is its conformity to rigorous standards; in contrast, Oriental science in general, and Arabic science in particular, lets itself be carried away by empirical rules and methods of calculation, neglecting to verify the soundness of each step on its path. The case of Diophantus illustrates this idea perfectly: as a mathematician, said Tannery, "…Diophantus is hardly Greek." But when he compares the *Arithmetics* of Diophantus to Arabic algebra, Tannery writes that the latter "…in no way rises above the level achieved by Diophantus."
5. The introduction of experimental norms which, according to historians, totally distinguishes Hellenistic science from classical science, is solely the achievement of Western science.

Thus it is to Western science alone that we owe both the concept and experimentation. We are not going to oppose this ideology to another. We propose simply to confront some of these elements with the facts of the history of science, beginning with algebra and concluding with the crucial problem of the relationships between mathematics and experimentation.

Algebra

As with the other Arabic sciences, algebra had practical aims, a flair for calculation, and an absence of rigorous standards. It is precisely this that allowed Tannery to make his statement. Bourbaki took this as his authorization to exclude the Arabic period when he retraced the evolution of algebra. The historical writings of the modern mathematician Dieudonné are significant; between the Greek prehistory of algebraic geometry and Descartes, he finds only a void, which, far from being frightening, is ideologically reassuring. Some historians cite al-Khwārizmī, his definition of algebra and his solution of the quadratic equation, but it is generally to reduce Arabic algebra to its initiator. This restriction misconstrues the history of algebra, which in actuality does not show a simple extension of the work of al-Khwārizmī in the West, but an attempt at theoretical and technical overtaking of his achievements. Moreover, this overtaking is not the result of a number of individual works, but the outcome of genuine traditions. The first of these traditions had conceived the particular project of arithmetizing the algebra inherited from al-Khwārizmī and his immediate successors. The second one, in order to surmount the obstacle of the solution by radicals of third and fourth degree equations, formulated in its initial stage a geometric theory of equations, subsequently to change viewpoint and study known curves by means of their equations. In other words, this tradition engaged itself explicitly in the first research in algebraic geometry.

As we have said, the first tradition had proposed arithmetizing the inherited algebra. This theoretical program was inaugurated at the end of the tenth century by al-Karajī, and is thus summarized by one of his successors, al-Samaw'al (d. 1176): "to operate on unknowns as the arithmeticians work on known quantities."

The execution is organized into two complementary stages. The first is to apply the operations of elementary arithmetic to algebraic expressions systematically; the second is to consider algebraic expressions independently from that which they can represent so as to be able to apply them to operations which, up to that point, had been restricted to numbers. Nevertheless, a program is defined not only by its theoretical aims, but also by the technical difficulties which it must confront and resolve. One of the most important of these was the extension of abstract algebraic calculation. At this stage, the mathematicians of the eleventh and twelfth centuries obtained some results which unjustly are attributed to the mathematicians of the fifteenth and sixteenth centuries. Among these are the extension of the idea of an algebraic power to its inverse after defining the power of zero in a clear fashion, the rule of signs in all its general aspects, the formula of binomials and the tables of coefficients, the algebra of polynomials, and above all, the algorithm of division, and the approximation of whole fractions by elements of the algebra of polynomials.

In a second period, the algebraists intended to apply this same extension of algebraic calculation to irrational algebraic expressions. Al-Karajī questioned how to operate by means of multiplication, division, addition, subtraction, and extraction of roots on irrational quantities. To answer this question the mathematicians gave, for the first time, an algebraic interpretation of the theory contained in Book X of the *Elements*. This book was regarded by Pappus, as well as by Ibn al-Haytham much later, as a geometry book, because of the traditional fundamental separation between continuous and discontinuous magnitudes. With the school of al-Karajī, a better understanding of the structure of real algebraic numbers is achieved.

In addition, the works of this algebraic tradition opened the route to new research on the theory of numbers and numerical analysis. An examination of numerical analysis, for example, reveals that after renewing algebra through arithmetic, the mathematicians of the eleventh and twelfth centuries also effected a return movement to arithmetic to search for an applied extension of the new algebra. It is true that the arithmeticians who preceded the algebraists of the eleventh and twelfth centuries extracted square and cube roots, and had formulas of approximation for the same powers. But, lacking an abstract algebraic calculation, they could generalize neither their results, their methods, nor their algorithms. With the new algebra, the generalization of algebraic calculation became a constituent of numerical analysis which, until then, had only been a sum of procedures, if not prescriptions. It is in the course of this double movement which is established between algebra and arithmetic that the mathematicians of the eleventh and twelfth centuries achieved results which are still wrongly attributed to the mathematicians of the fifteenth and sixteenth centuries. This is the case with the method attributed to Viète for the resolution of numerical equations, the method ascribed to Ruffini-Horner, the general methods of approximation, in particular that which D. T. Whiteside designates by the name of al-Kāshī-Newton, and finally, the theory of decimal fractions. In addition to methods, which were to be reiterative and capable of leading in a recursive manner to approximations, the mathematicians of the eleventh and twelfth centuries also formulated new procedures of demonstration such as complete induction.

We have just seen that the concept of polynomials is among those elaborated by the algebraist arithmeticians from the end of the tenth century. This tradition of algebra as the "arithmetic of unknowns", to use the expression of the time, opened the road toward another algebraic tradition which was initiated by ʿUmar al-Khayyām (eleventh century), and renewed at the end of the twelfth century by Sharaf al-Dīn al-Ṭūsī. While the former formulated a geometric theory of equations for the first time, the latter left his mark on the beginnings of algebraic geometry.

The immediate predecessors to al-Khayyām, such as al-Bīrūnī, al-Māhānī, and Abū al-Jūd, had already been able, in contrast to the Alexandrian mathematicians and precisely because of the concept of the polynomial, to treat the problems of solids in terms of third degree equations. But al-Khayyām was the first to address these unpondered questions: can one reduce the problems of straight lines, planes, and solids to equations of a corresponding degree, on the one hand, and on the other, reorder the group of third degree equations to seek, in the absence of a solution by factoring, solutions which can be reached through means of the intersection of auxiliary curves? To answer these questions, al-Khayyām is led to formulate the geometric theory of equations of a third or lesser degree. His successor, al-Ṭūsī, did not delay in changing perspective; far from adhering to geometric figures, he thought in terms of functional relations and studied curves by means of equations. Even if al-Ṭūsī still solved equations by means of auxiliary curves, in each case the intersection of the curves is demonstrated algebraicly by means of their equations. This is important, since the systematic use of these proofs introduces into the practice instruments which were already available to the mathematical analysts of the tenth century: affine transformations, the study of the maxima of algebraic expressions, and with the aid of what will later be regarded as derivatives, the study of the upper bounds and lower bounds of roots. It is in the course of these studies and in applying these methods that al-Ṭūsī grasps the importance of the discriminant of the cubic equation and gives the so-called Cardan formula just as it is found in the *Ars Magna*. Finally, without enlarging any further on the results which were obtained, we can say that both on the level of results as well as that of style, we find al-Khayyām and al-Ṭūsī fully in the field allegedly pioneered by Descartes.

If we exclude these traditions and justify this exclusion by invoking the practical and computational aims of the Arab mathematicians and an absence of rigorous standards of proof in their work, we can say that the history of classical algebra is the work of the Renaissance.

Among the mathematical disciplines, algebra is not a unique case. To varying degrees, trigonometry, geometry, and infinitesimal determinations are likewise illustrative of the preceding analysis. In a more general sense, optics, statistics, mathematical geography, and astronomy are also no exception. Recent works in the history of astronomy render Tannery's understanding of the Arab astronomers and the interpretations which he gives of them manifestly outmoded, if not erroneous. But since we assigned ourselves the task of examining the doctrine of the Western nature of classical science, we shall restrict our discussion to an essential component of this doctrine, experimentation.

Experimentation

In fact, is not the cleavage between the two periods of Western science, the Greek period and the Renaissance, often marked by the introduction of experimental norms? Undoubtedly the general agreement of the philosophers, historians, and sociologists of science stops here; the divergences become apparent as soon as they attempt to define the meaning, the implications, and the origins of these experimental norms. The origins are linked in one case to the current of Augustinian-Platonism, in another to the Christian tradition, and particularly to the dogma of Incarnation, in a third case to the engineers of the Renaissance, in a fourth to the *Novum Organum* of Francis Bacon, and finally, in a fifth, to Gilbert, Harvey, Kepler, and Galileo. Some of these attitudes superimpose upon one another, become entangled or contradictory, but they all converge on one point: the occidental nature of the new norms.

Nevertheless, as early as the nineteenth century, historians and philosophers such as Alexander von Humboldt in Germany and Cournot in France diverge from this predominating position to attribute to the Arab period the origins of experimentation. It is difficult to analyze the origins or the beginnings of experimentation correctly, since no study has been made of the interrelations of the different traditions and the different themes to which the concept of experimentation has been applied. Perhaps it would be in writing such a history, especially a history of the term itself, that one could give an accounting of the multiplicity of uses and ambiguities of the concept. For this analysis two histories are needed: the history of the relationship between art and science and that of the links between mathematics and physics.

With the history of the relationship between science and art, we are in a position to understand when, why, and how it became accepted that knowledge can emanate from demonstrations and from the rules of practice at the same time, and that a body of knowledge possesses the stature of a science while, at the same time, it is conceived in its possibilities of practical realization with an external purpose. The traditional opposition between science and art seems likely to be the work of the intellectual currents of the Arabic period. Certainly one fact is striking: whether we are dealing with Muslim traditionalists, rationalist theologians, scholars of different fields, or even philosophers of the Hellenistic tradition such as al-Kindī or al-Fārābī, all contribute to the weakening of the traditional differentiation between science and art. In other respects, this general trait is at the origin of the opinion of some historians regarding the practical spirit and realistic imagination of the Arab scholars. Knowledge is accepted as scientific without its conforming either to the Aristotelian or to the Euclidean scheme. This new concept of the stature of science promoted the dignity of scientific understanding of disciplines which traditionally were confined to the domain of art, such as alchemy, medicine, pharmacology, music, or lexicography. Whatever might be the importance of this concept, it could only lead to an extension of empirical research and to a diffuse notion of experimentation. One does witness the multiplication and systematic use of empirical procedures: the classifications of the botanists and the linguists, the control experiments of the doctors and alchemists, and the clinical observations and comparative diagnostics of the physicians. But it was not until new links were established between mathematics and physics that such a diffuse notion of experimentation acquired the dimension that determines it, a regular and systematic component of the proof. Primarily it is in Ibn al-Haytham's work in the field of optics where the emergence of this new dimension can be perceived.

With Ibn al-Haytham the break is established with optics as the geometry of vision or light. Experimentation had indeed become a category of the proof. The successors of Ibn al-Haytham, such as al-Fārisī, adopted experimental norms in their optical research, such as that performed on the rainbow. What did Ibn al-Haytham understand by experimentation? We will find in his work as many meanings of this word and as many functions served by experimentation as there are links between mathematics and physics. A thorough look at his texts indicates that the term and its derivatives belong to several superimposed systems, and are not likely to be discerned through simple philological analysis. But if attention is fixed on the content rather than the lexical form, one can distinguish several types of relationships between mathematics and physics which allow one to spot the corresponding functions of the idea of experimentation. In fact, the links between mathematics and physics are established in several ways; even if they are not specifically treated by Ibn al-Haytham, they underlie his work and are amenable to analysis.

As for the field of geometric optics, which was reformed by Ibn al-Haytham himself, the only link between mathematics and physics is a similarity of structures. Owing to his definition of a light ray, Ibn al-Haytham was able to formulate his theory on the phenomena of propagation, including the important phenomenon of diffusion, so that they relate perfectly to geometry. Then several experiments were devised to assure technical verification of the propositions. Experiments were designed to prove the laws and rules of geometrical optics. The work of Ibn al-Haytham attests to two important facts which are often insufficiently stressed: first of all, some of his experiments were not simply designed to verify qualitative assertions, but also to obtain quantitative results; in the second place, the apparatus devised by Ibn al-Haytham, which was quite varied and complex, is not limited to that of the astronomers.

In physical optics one encounters another type of relationship between mathematics and physics and therefore a second meaning of experimentation. Without opting for an atomistic theory, Ibn al-Haytham states that light, or as he writes, "the smallest of the lights", is a material thing, external to vision, which moves in time, changes its velocity according to its medium, follows the easiest path, and diminishes in its intensity depending on its distance from its source. Mathematics is introduced into physical optics at this stage by means of analogies established between the systems of movement of a heavy body and those of the reflection and refraction of light. This previous mathematical treatment of the concepts of physics permitted them to be transferred to an experimental plane. Although this situation on the experimental level might be somewhat approximate in nature, it nevertheless furnishes a level of existence to ideas which are syntactically structured, but semantically indeterminate, such as Ibn al-Haytham's scheme of the movements of a projectile.

A third type of experimentation, which was not practiced by Ibn al-Haytham himself but was made possible by his own reform and his discoveries in optics, appears at the beginning of the fourteenth century in the work of his successor al-Fārisī. The links established between mathematics and physics aim to construct a model and to reduce by geometric means the propagation of light in a natural object to its propagation in an artificial object. The problem is to define for propagation, between the natural and the artificial object, some analogical correspondences which were genuinely certain of mathematical status. For example, they built a model of a massive glass sphere filled with water to explain the rainbow. In this case, experimentation serves the function of simulating the physical conditions of a phenomenon that can be studied neither directly nor completely. The three types of experimentation studied all reveal themselves both as a means of verification and as furnishing a plane of material existence to ideas which are syntactically structured. In the three cases, the scientist must realize an object physically in order to handle it conceptually. Thus, in the most elementary example of rectilinear propagation, Ibn al-Haytham does not consider any arbitrarily chosen opening of a black box, but rather specific ones, in accordance with specific geometric relationships, in order to realize as precisely as possible his concept of a ray.

To recapitulate several points:

1. The tenet of the Western nature of classical science which was launched in the eighteenth-century owes to the Orientalism of the nineteenth century the image that we now recognize.
2. On the one hand, the opposition between East and the West underlies the critique of science and rationalism in general; on the other, it excludes the scientific production of the East from the history of science both *de facto* and *de jure*. An absence of rigor is invoked, as well as the computational attributes and the practical aims of science written in Arabic, to justify this effective debarment from the history of science.
3. This tenet reveals a disdain for the data of history as well as a creative capacity for ideological interpretation, which are admitted as evidence for ideas that raise many more problems than they solve. Thus we have the notion of a Scientific Renaissance, when in several disciplines everything indicates that there was merely a reactivation. These pieces of pseudoevidence quickly become conceptual bases for a philosophy or sociology of science, as well as the departure point for theoretical elaborations in the history of science.

We must ask ourselves if the moment has not arrived to abandon this characterization of classical science and its still lively traces in the writing of history, to restore to the profession of the historian of science the objectivity required of it, to ban the clandestine importation and diffusion of uncontrolled ideologies, to refrain from all reductionist tendencies which favor similarities at the expense of differences, and to be wary of miraculous events in history. The neutrality of the historian is not an a priori ethical value; it can only be the product of patient work which will not be duped by the myths which the East and West have engendered. Above all, it is necessary to cast out the periodization everywhere admitted in the history of science. The term used for classical algebra or classical optics, for example, will integrate the works which extended from the tenth to the seventeenth centuries. Consequently, it will realign not only the idea of the classical sciences, but also that of medieval science. The classical sciences will then reveal themselves as the product of the Mediterranean which was the hub of exchanges among all civilizations of the ancient world. Only then will the historian of science be able to enlighten the debate over modernism and tradition.

Science as a Western Phenomenon: Postscript

The 26 years since the publication of the original French edition of the text above has been a very fertile period for the study of the history of Islamic science. Indeed, we have witnessed an unprecedented rebirth of this discipline. Texts have been written and translated, new collections have appeared, and specialized reviews and journals have been published. These have offered historians the possibility of developing and comparing their research findings with facts. The task remains huge, and we are only at the beginning, but at least this new growth of information puts to rest the argument of ignorance.

With all this new information, one would have expected historians and philosophers to rectify the impressions and ideas they had inherited from the nineteenth century. One would have thought that the doctrine of Western science which we have described and analyzed here would have disappeared along with the props on which that doctrine was based. Indeed we were beginning to see a growing tendency to break with this doctrine and its implications. Then, for reasons which are extraneous to science and its history, images of Islamic society – if not of Islam itself – arose, according to which it was seen as irrational and intolerant and thus a society foreign to science. The aging doctrine was naturally given new life because of these images. How is it possible, under these conditions, to reconcile such an image of Islamic society with scientific results obtained from the heart of that same society? It was enough to back up the preceding doctrine with another, the doctrine of double marginality: with regard to the society which saw the development of science, and with regard to the history of the sciences. Thus, one could still write in 1992, "We must remember that at an advanced level the foreign sciences had never found a stable institutional home in Islam," or "Greek learning never found a secure institutional home in Islam, as it was eventually to do in the universities of medieval Christendom" (Lindberg 1992). As for the second marginality, we have already described how it works. Thus, we are back where we started and the doctrine of the Westernness of science is saved. Undoubtedly, these ideological views are beginning to give way, weakened by new research findings. And even if they are still capable of slowing down the acceptance of facts, it is not widespread, and it certainly will not last much longer.

See also: ►Western Dominance, ►Ibn al-Haytham, ►ʿUmar al-Khayyām

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Science East and West

Dhruv Raina

The social shaping of representations of non-western astronomy and mathematics in eighteenth- and nineteenth-century European scholarship has been of recent scholarly interest from the perspective of the politics of knowledge (Charette 1995; Raina 1999). My own concern has been to focus upon Indian astronomy and mathematics in the French Enlightenment and post-Enlightenment historiography. In dialogue with Said's *Orientalism*, this exploration has sought to examine whether the history of mathematics (the least likely case) is also inscribed within the frame of European colonial adventure and enterprise, as happened in the arts, literature, and social sciences (Assayag et al. 1997). In the study of the French Enlightenment I had qualified the Saidian thesis by suggesting that the so-called "European tradition" was fractured along national lines (Raina 1999). The present project is to focus upon British Indology[1] and its relationship with the corpus of French scholarship that preceded it. More specifically, the article attempts to ascertain when the first texts of Indian astronomy were translated into a European language, and by whom, and it elaborates upon how the Indian tradition of mathematics came to be constructed as one that was devoid of the idea of proof. While this characterization acquired stability in the nineteenth century, the construction itself was prefigured in the eighteenth century. In other words, it is suggested that historians of science mobilized the ideas of proofs or demonstrations as a criterion for demarcating different mathematical traditions.

Edward Said's thesis links the production of knowledge about the Orient with the exercise of colonial power (Said 1978). Does this thesis envelope the landscape of European writing on India? The thesis needs qualification from a number of points of view, for the landscape in Said's view is envisioned as monolithic and homogeneous. The eighteenth century has been considered the formative period for the emergence of the discourse on colonialism, but this discourse was not yet "monolithic or univocal." European writing on India comprised a network of "intersecting and contending discourses," and was preoccupied with a wide range of questions on authority (Teltscher 1995: 2). The representations of India in this writing are naturally very "diverse, shifting, historically contingent, complex, and competitive." The texts themselves are shaped often by "national and religious rivalries, domestic concerns," and the cognitive or intellectual cultures of the respective interlocutors (Teltscher 1995: 2; Raina 1999; Jami 1995). Critical studies on oriental scholarship have sought to situate these texts in national and religious contexts and to identify the elements they share (Županov 1993; Inden 1990). It has been argued that until the eighteenth century it was possible to speak of a European tradition of writing about India that differentiated into several national traditions by the middle of the eighteenth century. The birth of a specifically British tradition is put around 1765 when the East India Company was granted rights to collect land revenues and administer civil justice in Bengal (Teltscher 1995: 3). With the founding of the Asiatic Society British writing on India especially from the 1780s onward was marked by the impulse of British writers to "foreground the textual nature of their activity" (Teltscher 1995: 6).

European writing on India following the discovery of the sea route has been categorized into three distinct genres. The first comprises writing relating to travel, trade and the exploits of European powers on Indian soil. This writing was limited to the activities of Europeans in India; wherein an exotic India was presented to the West, and which either projected European superiority or criticized European institutions. But there was little elaboration of the philosophical or religious literature of India or its history (Kejariwal 1988: 14). The missionaries in India in the seventeenth and eighteenth century provided a second set of accounts. This writing itself is internally differentiated. On the one hand, we have letters recording the progress of missionary activity in India. On the other, Jesuit missionaries resident in India were studying Indian philosophy, religion, and culture. It may even be suggested that they were the first Europeans to be acquainted with Indian languages (Kejariwal 1988: 15). And finally, there is the scholarly writing on India. The French missionaries who came to India in the late seventeenth century were the first to have spoken of India's scientific past. French Indology, according to Filliozat, emerged in the early decades of the eighteenth century, when the King's librarian requested Étienne Fourmont, of the Collège Royale, to draw up a list of works of note from India and Indo-China, to be purchased for the King's library. By 1739, a catalogue of Sanskrit works had been prepared, and copies of Vedas, epics, philosophical and linguistic texts, and dictionaries had been procured (Filliozat 1955: 1–3). Curiously enough there were very few, if any, scientific texts that were included in the cargo to the King's library (Raina 1999). The first generation of Indianistes was possibly preoccupied with studying the speculations of the Indians, their philosophy, and the "niveau de connaisances scientifques" (Filliozat 1954). The Jesuit astronomers were the first to study the Indian astronomical systems that Filliozat considers

[1] Indology refers to the study of India. It is the study of cultural aspects such as religions, philosophies, art, and architecture, as well as spiritual and social aspects.

"the first scientific or even cultural achievements of India studied by Europeans" (Filliozat 1957). Kejariwal goes so far to suggest that the "history of French Orientalism is also the history of the rediscovery of ancient Indian astronomy in the modern period" (Kejariwal 1988: 17). The latter point needs some nuancing.

In any case, these accounts were constantly contrasting India with Europe, "through explicit analogy or through implied difference." A fruitful approach into this archive of scientific texts and not just literary or religious texts is to pay attention to moments "which unsettle the confident moments of cultural description," to trace those "competing and fluctuating logics of similarity and difference," that characterize the early discourse of India (Teltscher 1995: 14). In examining these mathematical texts, it is essential to be alert to those moments and descriptions of mathematical results and procedures encountered within Sanskrit texts that were not accompanied by demonstrations or proof or exegesis. Thus the British mathematician and geologist John Playfair in introducing Indian astronomy to an English-speaking audience wrote:

> The astronomy of India is confined to one branch of the science. It gives no theory, nor even any description of the celestial phenomena, but satisfies itself with the calculation of certain changes in the heavens…The Brahmin…obtains his result with wonderful certainty and expedition; but having little knowledge of the principles on which his rules are founded, and no anxiety to be better informed, he is perfectly satisfied, if, as it usually happens, the commencement and duration of the eclipse answer, within a few minutes, to his prediction (Playfair 1790).

There are three core ideas that are evident in this passage, and that run constantly throughout the construction of Indian astronomy and mathematics. Inasmuch as Indian astronomy is a science it differs from modern astronomy in that it (a) lacks a theoretical basis, (b) does not provide a description of celestial phenomena, and (c) is not methodologically reflective ("little knowledge of the principles on which his rules are founded"). On account of the predictive accuracy of the astronomy it merits being a science, and the Indian astronomers are concerned no more with it than in this instrumental context.

The Origins of British Indology and the History of Indian Mathematics

British studies on Indian astronomy and mathematics may be said to lie at the conjuncture of two different historiographies: the French historiography of Indian astronomy and British studies on Indian society and culture. Consequently, British historiography of the sciences of India draws upon these sources and develops not unexpectedly in different directions. Without stretching a point too far it could be added that British Indology on the sciences of India commences with the pioneering work of John Zephaniah Holwell (1711–1798). Holwell came to India as a surgeon's mate in 1732 and was Governor of Bengal for a couple of months in 1760. To historians of science he is best known for his *An Account of the Manner of Inoculating for the Smallpox in the East Indies* (1767). The relevant issue here is not Holwell's article, but the different point of view he adopted for studying the traditions, cultures, and sciences of India. This strayed from the central precepts of Jesuit historiography (Murr 1986). While insisting as the Jesuits did on the antiquity of the Indian people and their literature, he proposed that this antiquity was not reconcilable with the "Christian view of History" (Holwell, quoted in Kejariwal 1988: 19). Misidentifying his account from earlier European scholarship that he considered "defective, fallacious, and unsatisfactory," Holwell proposed instead a philological approach to the "sublime rational source and foundation" of what to the Western eye appeared preposterous superstition founded on irrationality (Kejariwal 1988: 19). It is not germane here to establish whether Holwell could be considered the inaugurator of this approach; but this view was shared by a number of British scholars who founded the Asiatic Society.

One of the earliest British Indologists to speak of the distinctive tradition of Indian algebra was Rueben Burrow. The prior French tradition of the history of science had been preoccupied with the origins of Indian astronomy. Burrow centered the question about the origins of Indian algebra and arithmetic. This will become evident further ahead. That Burrow shared the same viewpoint as Holwell is evident in his "Hints concerning the Observatory at Benaras" (1783):

> Notwithstanding the prejudices of the Europeans of the last century in favour of their own abilities, some of the first members of the royal society were sufficiently enlightened to consider the East Indies and China & c, as new worlds of science that remained undiscovered…had they not too hastily concluded that to be lost, which nothing but the prejudice of ignorance and obstinacy, had prevented being found, we might at this time (be) in possession of the most finished productions of Asia as well as Europe; the sciences might, in consequence, have been carried to a much higher degree of perfection with us than they are at present; and the elegance and superiority of the Asiatic models might have prevented the neglect and depravity of geometry, and that inundation of Algebraic barbarism which has ever since the time of Descartes, both vitiated taste, and overrun the

> publications, of most of the philosophical societies in Europe (Burrow 1783: 94–95).

It is evident from the above that beyond the aesthetic of the search for the marvelous, the encounter with other non-European scientific traditions was encouraged by the ideological impulse to advance the frontiers of knowledge. In that sense Burrow's philosophy of science resonated with that of the Enlightenment thinkers. As far as the history of astronomy is concerned, this project was quite consistent with historical astronomy being pursued in China and India since the late seventeenth century (Han 1995; Raina 1999). The most striking feature of the above passage is that the Indian tradition for Burrow is not characterized as algebraic or geometric. In fact, at this point the characterization is the very reverse of the late nineteenth-century one. Modern European mathematics since Descartes had been overwhelmed by "algebraic barbarism." An exposure to Asiatic models would then have prevented the neglect of geometry that marked contemporary sciences. The relevant concern here is that "until the end of the eighteenth century the British Indologists still entertained the hope that they would discover Indian geometrical texts that would unveil to them the foundations of an Indian geometrical tradition." Thus Playfair would in 1792 pose six questions to the researchers of the Asiatic Society, the first of which was: "Are any books to be found among the Hindus, which treat professedly of Geometry?" (Playfair 1792: 151). For one it could be said that the question that the geometry of the Hindus could have a different basis from the Greek ones is implied by the "professedly" in the question. That this is what Playfair meant might be inferred from his elaboration upon the question he posed:

> I am led to propose this question, by having observed, not only that the whole of the Indian Astronomy is a system constructed with great geometrical skill, but that the trigonometrical rules given in the translation from the *Surya Siddhānta*, with which Mr. Davis has obliged the world, point out some very curious theorems, which must have been know to the author of that ancient book (Playfair 1792: 151).

The rule according to which the "trigonometrical canon" of Indian astronomy is constructed according to Playfair, is based on a theorem:

> If there be three arches of a circle in arithmetical progression, the sum of the sines of the two extreme arches is to twice the sine of the middle arch as the cosine of common difference of the arches to the radius of the circle (Playfair 1979: 152).

Although the theorem was not known to Europe before Viète, the method was employed by the Indian astronomers for constructing trigonometrical tables, and was based on a simpler procedure of calculating sines and arches than through the use of methods that were based on extracting square roots (Playfair 1798: 152). The immediate task for Playfair appears to have been to identify those mathematical works where the theorem on which the trigonometrical rule employed in astronomy is first laid out. This brings us back to Burrow's concern with the origins of Indian mathematics.

Where Are the Geometrical Texts, or Is the Tradition Algebraic?

In the eighteenth century it would be possible to differentiate between the efforts of the British Indologists and that of their French counterparts studying Indian astronomy and mathematics on two counts. Methodologically speaking, while the British Indologists were busy underlining the textual nature of their enterprise, the French astronomers–savants relied a great deal on protoethnographic descriptions of the mathematical and astronomical practices of India. Second, the histories of Indian astronomy of Bailly (1787) and Le Gentil (1781) are preoccupied with astronomical literature and the origins of Indian astronomy.

Even Montucla (1799) relies extensively upon the sources employed by Le Gentil and Bailly and draws inferences concerning Indian mathematics from them. The British Indological tradition on the other hand, engages with specific texts and from the astronomical rules presented there makes a claim that these rules must be based on a mathematical system. They subsequently proceeded to discover mathematical texts. Their focus thus shifts from the origins of astronomy to the origins of Indian mathematics, in particular Indian algebra and arithmetic.

What were the rules encountered and what were the claims made?

Rueben Burrow, a British official in Bengal, was probably amongst the earliest of the British Indologists to engage with the textual tradition of Indian mathematics, although this search was prompted through his exposure to and study of astronomy, including Indian astronomy. This does not mean that these texts did not relate in any way to the histories of Le Gentil and Bailly. Actually, the texts of the former provided an initial viewpoint to interpret the differences between the two traditions. Burrow, like Bailly, entertained a wild hypothesis concerning the origins of the sciences, but this never seemed to have been noticed as much as Bailly's antediluvian hypothesis. Consequently, for Burrow the study of the procedures employed by Indian astronomers in calculating eclipses would advance the progress of modern astronomy as well: "…and the more so as our methods of calculation are excessively tedious and intricate" (Burrow 1783: 101). The sentiment echoes that of Le Gentil and Bailly, and it is certain that he was acquainted with the work of Le Gentil (Burrow 1783: 116), although it is not possible to say the same of Bailly's *Traité*. This fascination with the computational procedures employed in astronomy led Burrow to infer in 1783 the existence of an advanced algebraic tradition:

> It is also generally reported that the Brahmins calculate their eclipses, not by astronomical tables as we do, but by rules…If they (the rules) be as exact as ours, …it is a proof that they must have carried algebraic computation to a very extraordinary pitch, and have well understood the doctrine of "continued fractions", in order to have found those periodical approximations… (Burrow 1783: 101).

The rules for computing eclipses employed by the Brahmins were not only different, but their complexity varied with the requisite degree of exactness:

> …which entirely agrees with the approximation deduced from algebraic formulae and implies an intimate acquaintance with the Newtonian doctrine of series…and therefore it is not impossible for the Brahmins to have understood Algebra better than we do (Burrow 1783: 101).

This was to become the central point from which in subsequent papers Burrow would build his argument for the existence of an advanced algebra among the Indians. One of the first histories of Indian algebra was authored by Burrow and was entitled "On Early History of Algebra" (Burrow 1810), and was possibly published posthumously. The paper emphasized the originality and importance of algebra among the Hindus and contained extracts that were translated from the *Bījagaṇita* and *Līlāvatī*. These extracts were translations into English from Persian translations of the original Sanskrit texts. If we were to go by his own admission in an earlier paper (Burrow 1790), these extracts were translated in 1784, but he deferred publishing them until a full text was obtained. But he prizes the moment "when no European but myself…even suspected that the Hindoos had any algebra" (Burrow 1790: 115). The rationale provided for the existence of treatises on algebra in India in this paper is based on the knowledge of the binomial theorem among the Indians and is the same as that suggested in the earlier paper. Many of the approximations used in astronomy were "deduced from infinite series; or at least have the appearance of it" (Burrow 1790: 115). These included finding the sine from the arc and determining the angles of a right-angled triangle given the hypotenuse and sides without recourse to a table of sines, etc.

The urgency of the moment was then to discover those texts before they perished. Burrow thus emphasized the need for the collection of available astronomical and mathematical texts that until then had not been the focus of attention of the French Académiciens. The idea that the existing tradition was probably algebraic was being insinuated:

> That many of their books are depraved and lost is evident, because there is now not a single book of geometrical elements to be met with; and yet that they had elements not long ago, and apparently more extensive than those of Euclid is obvious from some of their works of no great antiquity (Burrow 1790: 115).

And while Burrow promised to publish translations of *Līlāvatī* and the *Bījagaṇita*, the promise was not fulfilled possibly during his life. Inspired by Burrow's research, Colebrooke embarked on a study of Sanskrit in order to probe some of the issues raised more deeply.

But the just-mentioned paper by Burrow contains a very brief demonstration of the knowledge of the binomial theorem in the Indian tradition, which unlike Newton's understanding was limited to whole numbers alone. Burrow first offers a translation from Persian of the problem:

> A Raja's palace had eight doors, now these doors may either be opened by one at a time, or by two at a time, and by three at a time; and so on through the whole, until at last all are opened together: it is required to tell the number of times that this can be done (Burrow 1790: 118).

Setting out the procedure for resolving it follows the statement of the problem. Write down the number of doors by decreasing from eight to unity. Just under these numbers write down the numbers in the reverse order.

8	7	6	5	4	3	2	1
1	2	3	4	5	6	7	8

Step 1. The number of times the door can be opened one at a time is obtained by dividing the first number 8, by the number under it, the quotient being 8.

Step 2. To obtain the number of times that two different doors may be opened, multiply the quotient 8 by the next number 7, and divide the product by 2 beneath it, the result being 28.

Step 3. To obtain the number of times three different doors may be opened, multiply 28 by the next number 6, and divide the product by 3, and the quotient is 56.

And so on.

"The sum of all the different times is 255" (Burrow 1790: 119). This setting out of the procedure, Burrow calls a "demonstration" and insists that it should be "evident" to mathematicians when inspecting the coefficients of a general equation. So to Burrow goes

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the credit for providing the first glimpses into the Indian algebraic tradition.

It was left to Samuel Davis to publish the first full-fledged translation and analysis of an Indian scientific work from the Sanskrit into a European language. This was a translation of the *Sūryasiddhānta* (Davis 1789). This translation was based on the reading of an original version of the text procured by Sir Robert Chambers in 1788. Davis encountered a number of obscure technical terms and had to rely upon a *teeka* or commentary procured by Jonathan Duncan (Davis 1789). In fact, if you examine the structure of Davis' paper, it appears as a *teeka* on the *Sūryasiddhānta*, with passages translated from the text and Davis' explanation intercalated between the translated passages. Most British Indologists who worked on Indian astronomy toward the last decades of the eighteenth century were familiar with two canonical European accounts, that of Bailly and Le Gentil.

Without referring to either, Davis begins by contesting the portrait of Indian astronomy and astronomers projected by Le Gentil and Bailly,[2] without naming either of them. The first idea that he rejected was that this astronomical tradition was disfigured over the years by idolatry and that the gems of Indian astronomy had been irretrievably lost over the centuries, in the absence of a textual tradition. The second idea was that the Brahmins had shrouded their astronomy in mystery such that it was impossible to arrive at a cogent account of it. Further, they loathed sharing their ideas with others. Davis set out to show that:

> …numerous treatises in Sanskrit on astronomy are procurable, and that the Brahmins are willing to explain them…I can further venture to declare that, from the experience I have had, that Sanskrit books in the science are more easily translated than almost any others, when once the technical terms are understood: the subject of them *admitting neither of metaphysical reasoning nor of metaphor*, but being delivered in plain terms *and generally illustrated with examples in practice* (Davis 1790: 175) (emphasis added).

The British Indologists were departing from the reading of Académiciens grounded in Jesuit protoethnography, by textually locating their work. This textual grounding would revise the portrait of the French savants (Table 1). A hundred years later in a review of the history of the history of Indian astronomy Burgess was to write: "Mr. Davis' paper, however, was the first analysis of an original Hindu astronomical treatise, and was a model of what such an essay ought to be" (Burgess 1893: 730–731). It appears then, as has been argued elsewhere, that the French savants in India were unable to establish trust with their Indian interlocutors, in total contrast to the first generation of British Indologists such as William Jones (Raj 2001). Two papers of William Jones followed closely on the heels of Davis' papers and a cursory glance at them reveals that they mutually respected and supported each other's enterprise. And yet they both were in agreement with Bailly's thesis of the independent origins of the Indian zodiac, differing very strongly with Montucla on this count:

> I engage to support an opinion (which the learned and industrious M. Montucla seems to treat with extreme contempt) that the Indian division of the zodiac was not borrowed from the Greeks or Arabs, but having been known in this country from time immemorial and being the same in part with other nations of the old Hindu race… (Jones 1790).

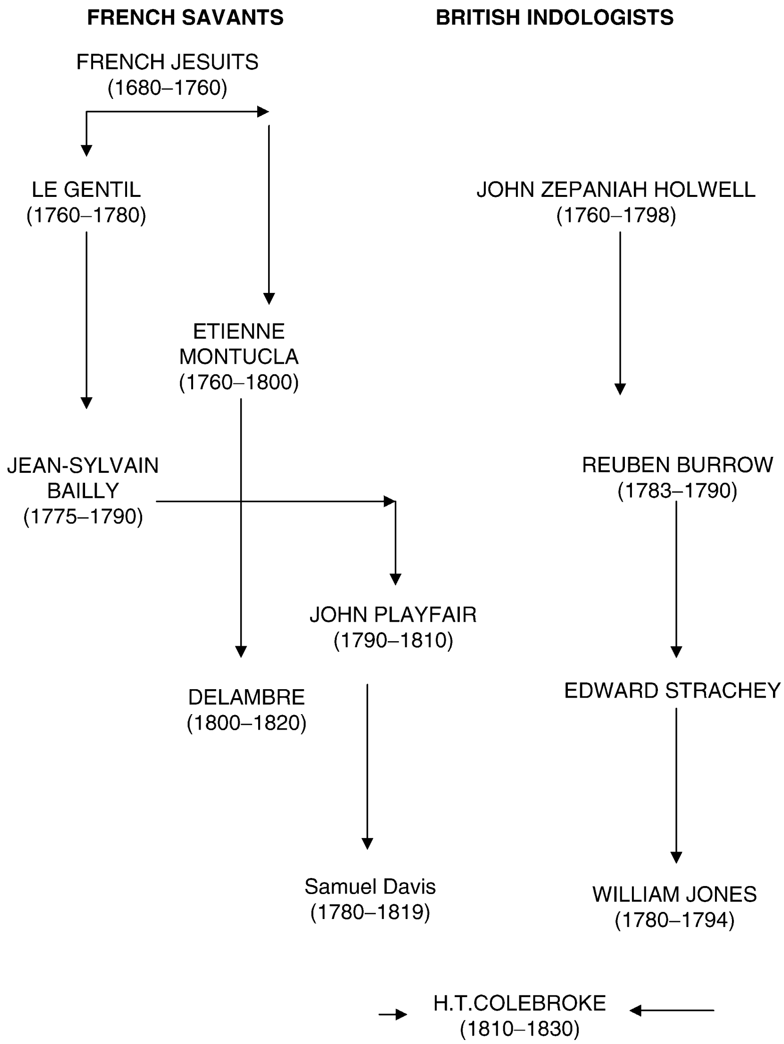
But then they were also gradually transforming and refining the portrait Bailly had left behind. Thus Jones recognized that in Davis' translation resided the hope that it would "convince M. Bailly that it is very possible for an European to translate and explain the Surya Siddhānta" (Jones 1790a).

John Playfair's Program and Colebrooke's Recovery of Indian Algebraic Texts

As far as the history of Indian astronomy and mathematics is concerned I have tried to argue that the French Jesuits of the seventeenth and eighteenth century are the inaugurators of a tradition, which was to inspire the histories of Le Gentil and Jean-Sylvain Bailly (Raina 1999). As has been argued elsewhere, it was Bailly's history that inspired the work of the British mathematician John Playfair and provided a stimulus to subsequent generations of British Indologists writing on Indian mathematics; although they were to disagree with the details of Bailly's *Histoire*, adding some nuance here and digressing from it in another context (Raina 2001). The antediluvian hypothesis proposed by Bailly was the source of both fascination and controversy, and was the outcome of his attempt to juxtapose observations of ancient Indian astronomy with astronomical theory of his day; from which he went on to draw the inference that ancient Indian astronomy was the

[2] More than Bailly and Le Gentil, Davis was refuting Sonnerat's constructions of Indian astronomy: "my present intention, which is to give a general account only of the method by which the Hindus compute eclipses, and thereby to show, that a late French author was too hasty in asserting generally that they determine by set forms, couched in enigmatical verses & C.'. So far are they from deserving the reproach of ignorance, which Mons. Sonnerat has implied, that on inquiry, I believe the Hindu science of astronomy will be found as well known now as it ever was among them, although perhaps, not so generally, by reason of the little encouragement men of science at present meet with…" (Davis 1789: 177). Evidently, Sonnerat, unlike Davis, could not enter the world of the Hindu astronomers on account of his inability to abandon a hermeneutic of suspicion.

Science East and West. Table 1 French savants and British Indologists



source of Greek astronomy (Bailly 1775). However, this reading was located within Jesuit historiography that sought to accommodate Indian history within the Christian conception of history (Raina 2003).

Bailly’s work was introduced to English-speaking readers through an article authored by the mathematician and geologist John Playfair (1748–1819), entitled “Remarks on the Astronomy of the Brahmins” published in the *Transactions of the Royal Society of Edinburgh* in 1789 (Playfair 1790). The article draws extensively upon the *Mémoires* of Le Gentil (Le Gentil 1785) published by the Académie des Sciences, Paris and Bailly’s *Astronomie Indienne* (Bailly 1785). This article of Playfair’s was of prime importance for Indologists working on the history of Indian astronomy for the next four decades, despite the fact that it was inspired by the work of such “un vulgariser.”

Just in and around the time Bailly’s *Traité* appeared, the important tradition of British Indology was beginning to crystallize. Marsden and Bentley were the first to contest Bailly’s assumptions and calculations. This opened the floodgates of criticism in France. Playfair jumped into the controversy attacking Bailly’s critics for their amateurism and for daring to question Bailly’s superior abilities. One of the early papers of the legendary William Jones was dedicated to defending Bailly’s thesis concerning the origins of the Hindu zodiac. Playfair’s central contribution resided in reappropriating Bailly’s *Traité* in the light of the contributions of Davis and Burrow and proposing a set of tasks that could well be considered a research program for the Asiatic Society. These included (a) to search for and publish works on Hindu geometry; (b) to procure any books on arithmetic and going by Burrow's article on the binomial theorem amongst the Indians to ascertain those arithmetical concerns whose trace is not to be found among the Greeks; (c) to complete the translation of the *Sūryasiddhānta* as initiated by Samuel Davis; (d) to compile a catalogue raisonné, with a scholarly account of books on Indian astronomy; (e) to examine the heavens with a Hindu astronomer in order to determine their stars and constellations; and (f) to obtain descriptions and drawings of astronomical buildings and instruments found in India (Playfair 1792: 152–155).

Bailly had stirred a hornet's nest in his time by suggesting that the origins of astronomy were in India, albeit this astronomy was inherited by the Indians from an even more ancient people. Burrow's paper did the same with the origins of algebra. It is at this time difficult to separate the discussion on the history of astronomy from the history of algebra; for both the Académiciens and the Indologists often turn to the history of astronomy to evoke computational procedures that were analyzed mathematically. This program of the recovery of the mathematical literature from the astronomical literature was taken up by Colebrooke, who may be seen as providing translations from the Sanskrit into English of the first texts supposedly dedicated solely to algebra and arithmetic. I say supposedly because portions of some of the texts that Colebrooke's discovers for the English-speaking world were essentially the mathematical sections of larger astronomical canons of the Indian tradition.

A brief recapitulation is required before we proceed to the translations of Colebrooke, for his work certainly marks a departure in the study of the history of Indian mathematics. The objective of this study thus far has been to examine the textual legacy that leads up to the translations of Colebrooke. Stated briefly, two main historiographic currents in the eighteenth century oriented the study of the history of the mathematics and astronomy of India. The first approach was that pursued by the Jesuit savants in India, who were observing the astronomical and computational procedures circulating among Indian astronomers. Their audience did not merely comprise the devout back in France, but the Académiciens and astronomers, two of whom transcribed these proto-ethnographic accounts into a history of Indian astronomy. Administrator-scholars, who studied texts, collated fragments of texts, and published translations with critical editions and commentaries, while indebted to the first, pursued another approach. In the late eighteenth century, Sanskrit commentaries and canonized astronomical or mathematical works were considered the key to obscure technical terms and texts. What needs to be examined is whether by the late nineteenth century, commentaries shared the same destiny as some of the Vedic texts. For it has been pointed out that by the second half of the nineteenth century some Sanskritists belittled, marginalized, and removed "explicit references to the intermediary process of transmission and exegesis of texts without which they would not have had access to them" (Vidal 1997: 25). The status of proofs in the Indian tradition is related to how these commentaries on mathematical texts were read.

The point needs some reaffirmation, since both Colebrooke and Davis who worked with commentaries of canonized astronomical and mathematical texts, respectively, do mention the existence of demonstrations and rules in the texts they discuss. In Colebrooke's introduction to his *Algebra with Arithmetic and Mensuration, from the Sanscrit of Brahmegupta and Bhascara*, there are four terms of concern to us here, namely, demonstration, rule, proof, and analysis that come up often, but it is only the last of these that Colebrooke clarifies. Noted by its absence in the title is the term "geometry," as a systematized science; on the contrary, the translation does allude to mensuration as discussed in the books he translates. The crucial problematic for Colebrooke was, as with Burrow before him, to determine the origins of Indian algebra. Inspired,

	Trope of forgetting	Trope of disfigurement	Historiography
Jesuit savants	The Brahmins had forgotten the original true Noahic religion from which they had descended and fallen into idolatry	The religion of the Brahmins had been disfigured over the centuries as they had tumbled into idolatry and superstition	Jesuit historiography of India
Astronomer savants of the French Enlightenment	The Brahmins had forgotten the intelligence of the astronomical methods that had been their legacy from an ancient people	The Brahmins had disfigured the core of an ancient science that they had inherited from an ancient people	Enlightenment historiography of astronomy

Taken from Raina (2003).

as it were, by the textual exemplars of Davis and Burrow, and guided by the research program John Playfair had drawn up for the researchers of the Asiatic Society, Colebrooke highlighted the pathway to his own work:

> In the history of mathematical science, it has long been a question to whom the invention of algebraic analysis is due, among what people, in what region was it devised, by whom was it cultivated and promoted, or by whose labours was it reduced *to form and system* (Colebrooke 1817: 121) (emphasis added).

The subsequent narrative focuses upon establishing that "the imperfect algebra of the Greeks," that had through the efforts of Diophantus advanced no further than solving equations with one unknown, was transmitted to India. The Indian algebraists, through their ingenuity, advanced this "slender idea" to the state of a "well-arranged science" (Colebrooke 1817: 145–146). In his reading, Colebrooke shares a fundamental historiographic principle, disputed by current scholarship, with Burrow, one that enjoyed currency among historians of mathematics into the twentieth century. In this historiographic frame,

> …the Arabs themselves scarcely pretend to the discovery of Algebra. *They were not in general inventors but scholars*, during the short period of their successful culture of the sciences (Colebrooke 1817: 121) (emphasis added).

The science of "algebraic analysis," a term Colebrooke would later expand upon, existed in India before the Arabs transmitted it to modern Europe (Colebrooke 1817: 121). The evidence for these claims resided in the translations of the *Bījagaṇita* and *Līlāvatī* of Bhāskarācārya,[3] as well as Brahmagupta's (Colebrooke: "Brahmegupta") *Gaṇitadhyāya* and *Kuṭṭakadhyāya* (Colebrooke: "Cuttacadhyaya"), the last two as their name suggests were the mathematical sections of Brahmagupta's *Brāhmasphuṭasiddhānta*. Without focusing too much on the antiquity of these texts, Colebrooke saw his oeuvre as disclosing that the

> …*modes of analysis*, and in particular, *general methods for the solution of indeterminate problems* both of the first and second degrees, are taught in the Vija-Gaṇita, and those for the first degree repeated in the Līlāvatī, which were unknown to the mathematicians of the west until invented anew in the last two centuries by algebraists of France and England (Colebrooke 1817: 124) (emphasis added).

The terrain of historical studies on Indian mathematics was being transformed into a polemical one, with Colebrooke surreptitiously introducing categories that the French Indologists had denied the Indian tradition: typically for the first time he speaks of "modes of analysis," or the "general methods for the solution of indeterminate problems." The historians of astronomy had previously advanced the idea that the Indians had no idea of the generalizability of the methods they employed. In the absence of such generalizability, how could it have been possible to extend the idea of generalized methods dedicated to solving classes of problems in order to extract the different "modes of analysis"? The intention here is not to paint Colebrooke's construction as the diametrical opposite of that of the French historians of science that provided a context to his effort. On the contrary, Colebrooke's project is naturally marked by a deep ambivalence. The ambivalence arises from the fact that he attempted to draw the characterization of Indian mathematics away from the binary typologies of the history of science that were already set in place. The lack of mathematical authority amongst the network of the British Indologists served as major handicap and deterred his ability to create a new vocabulary. This also explains why John Playfair was so important to the Indological enterprise. He was a mathematician of repute who conferred the Indological accounts with authority.

However, Colebrooke begins by pointing out that Āryabhaṭa was the first of the Indian authors known to have treated of algebra. Possibly a contemporary of Diophantus, the issue was important for drawing an arrow of transmission from Alexandria to India or vice versa. Colebrooke leaves the issue of the invention of algebra open by suggesting that it was Āryabhaṭa who developed it to the high level[4] that it attained in India; this science he called an "analysis" (Colebrooke 1817: 130). It is here for the first time that a portion of the Indian mathematical tradition is referred to as analysis, and it is important to get to the sense in which he employs the term. Thus it is noticed that the use of a notation and algorithms is crucial to this algebraic practice. Colebrooke then proceeds to elaborate upon the idea and takes note of the procedures not merely for denoting positive or negative quantities or the unknowns but of manipulating the symbols employed (Colebrooke 1817: 131–132). An important feature of this algebra is that all the terms of an equation do not have to be set up as positive quantities; there is no rule requiring that all the negative quantities be restored to

[3] I have given here the contemporary English spellings of the names of Sanskrit books and scholars. Colebrooke himself spelled the *Bijagaṇita* as *Vija-Gaṇita* and *Bhāskarācārya* as *Bhascara Acharya*.

[4] The high level of attainment was ascribed to the ability of the Indian algebraists to solve equations involving several unknowns and of possessing a general method of solving indeterminate equations of the first degree (Colebrooke 1817: 130).

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the positive state. The procedure is to operate an equal subtraction "…(*samasodhana*) for the difference of like terms." This operation is compared with the *muqabalah* employed by the Arab algebraists (Colebrooke 1817: 135). The presence of this "analytic art" among the Indians was apparent from the canvas of their mathematics.

This included the arithmetic of surd roots, the cognizance that when a finite quantity was divided by zero the quotient was infinite, an acquaintance with the procedure for solving second-degree equations and "touching upon" higher orders, solving some of these equations by reducing them to the quadratic form, of possessing a general solution of indeterminate equations in the first degree. And finally, Colebrooke finds in the *Brāhmasphuṭasiddhānta* §18:29–49; and *Bījagaṇita*: §75–99; a method for obtaining a "multitude" of solutions to second-degree equations starting from a single solution that is plugged in. It was left to Lagrange to show that problems of this class would have solutions that are whole numbers (Colebrooke 1817: 135–136). The analytic art of the Indians or algebraic analysis is then for Colebrooke: "…calculation attended with the manifestation of its principles." This is manifest in the Indian mathematical texts being discussed since they intimate to the reader a "*method aided by devices*, among which symbols and literal signs are conspicuous" (Colebrooke 1817: 141). In this sense Indian algebra bears an affinity with D'Alembert's conception of analysis as the "method of resolving mathematical problems by reducing them to equations" (Colebrooke 1817: 141). Delambre and Biot would subject these views of Colebrooke to trenchant criticism, but that is another subject (Raina 1999). The issue at stake here is that Colebrooke had insinuated the idea that Indian mathematics was not lacking in methodological reflection or generality, a feature that had hitherto been denied.

Did this algebraic analysis provide for demonstrations or proofs of its rules or procedures? Citing specific sutras from the *Brāhmasphuṭasiddhānta*, the *Bījagaṇita* and the *Līlāvatī*, Colebrooke moves to a characterization of Indian algebra, just as Diophantus is evoked to characterize early Greek algebra. Thus, we are informed that these Indian algebraists applied algebraic methods both in astronomy and geometry, and in turn, geometric methods were applied to "the demonstration of algebraic rules." Obviously, Colebrooke was construing the visual demonstrative procedures employed by Bhāskara as exemplifying geometrical demonstration. Further, he goes on to state that:

> In short, they cultivated Algebra much more, and with greater success than geometry; as is evident in the comparatively low state of their knowledge in the one, and the high pitch of their attainments in the other (Colebrooke 1817: 136).

This passage came to be quoted so often in subsequent histories of science, and in the writings of mathematicians[5] as evidence of the algebraic nature of Indian mathematics. The power of its imagery resides in its ability to draw the boundary between different civilizational styles of mathematics. In this contrast between Western and Indian mathematics it could be suggested that Colebrooke's qualification concerning the "comparatively low" state of one and "high pitch" of the other was lost sight off, and the contrast between the two traditions came to be subsequently accentuated.

This leads me to conjecture that Colebrooke's translation is a watershed in the occidental understanding of the history of Indian mathematics on a second count as well; this is that it inadvertently certified the boundary line drawn between Indian algebra and Greek geometry. This was not Colebrooke's intention at all, but a consequence of the comparative method he had adopted. Colebrooke's particular comparative method consisted in displaying where India's specific contributions to mathematics resided, and he always contrasted these contributions with the Greek and Arab traditions of mathematics.[6] This attempt to accentuate the contrast certainly revealed the differences, but with the loss of the context of the contrast, it was first transformed into a caricature and then stabilized as a characterization. The boundary lines had however been marked out before Colebrooke's time.[7]

Thus there are four specific areas in which "Hindu Algebra appears particularly distinguished from the Greek" (Colebrooke 1817: 137). Some of these have been mentioned above. The additional one that has not been mentioned concerns the application of algebra to "astronomical investigation and geometrical demonstration." In the process the Indian algebraists, Colebrooke suggests developed portions of mathematics that were reinvented recently. This last statement of his prompted a very severe reaction. He then takes up three instances, which he considers "anticipations of modern discoveries" from the texts he discusses and lays out their procedures of demonstration. There is nothing in the subsequent portion of the introduction to suggest that he did not consider these as demonstrations.

[5] The nineteenth-century British mathematician Augustus De Morgan, a self-proclaimed aficionado of Indian mathematics, wrote a preface to the book of an Indian mathematician punctuated with apercus from Colebrooke's introduction. The introduction in fact provides him the ground to legitimate the work of the Indian mathematician for a British readership (Raina and Habib 1992).

[6] Going by his text alone, he appears to have been totally oblivious of Chinese mathematics.

[7] This passage reminds me of the simplistic manner in which Marx's "religion is the opium of the masses" is read out of context.

On reading of the early responses from a French savant to the work of Colebrooke, it is possible to discern that Delambre for one uses a very fine comb in rebutting several of the points taken up by Colebrooke. While Colebrooke himself does not draw a very fine distinction between the use of the term "proof" and "demonstration" in his reading, he does distinguish between algebra and analysis, and as mentioned earlier, he specifies wherein the Indian tradition could be characterized as an algebraic analysis. A study of the reception of Colebrooke's translations of the works on Indian arithmetic and algebra is a matter for a separate study. The curious question to be examined by such a study is that despite its canonical status in Western scholarship on the history of Indian mathematics and algebra, neither Colebrooke nor Davis ever insinuated that it was a tradition devoid of proof or demonstration. And yet, as the historiography of nineteenth-century Oriental mathematics evolved, a theory of the absence of proof would become one of its salient elements. One of the factors responsible for the strong criticism of Colebrooke's work at the time was that it might have been provoked by Colebrooke's method of taking up those demonstrations from Indian mathematics for which equivalents existed in eighteenth-century European mathematics. This would have vitiated both the claims of novelty and originality, both very important features of the new sciences. Second, until the end of the eighteenth century these Indologists still believed that they could discover the origins of an Indian geometry, and the later work of the French Indologist G. Thibaut may be seen to be in continuity with this tradition. But by the end of the nineteenth century the binary typologies of the history of mathematics, that portrayed the West as geometric and the East as algebraic, were well in place in the standard picture.

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Science in China

HO PENG YOKE

Scholars in the past found it difficult to focus their attention on Chinese science because in traditional China knowledge did not come under the same groupings as in the West. For example the Chinese pharmacopoeias included knowledge on natural history; the official dynastic histories, some Daoist writings, and the works of some great poets contain information on astronomy and alchemy, and compendia on military science mention meteorology and firearms together with magic and divination. It is true that there are some Chinese monographs on science and technology, such as the *Tiangong kaiwu* (Exploitations of the Work of Nature) and the *Jiuzhang suanshu* (Mathematical Manual of the Nine Sections). Nevertheless knowledge of traditional Chinese science exists mainly in the official dynastic histories, the compendia (*leishu*), the gazetteers, religious works like the *Daozang* (Daoist *Tripitaka*), the numerous book collections (*congshu*), and the general literature.

In sixteenth-century Europe, Francis Bacon (1561–1626), Jean Fernal (1497–1558), and Jerome Cardano (1501–1576) all made reference to three great inventions, namely the compass, the art of printing, and gunpowder. In the minds of many there was only some vague connection between China and these three inventions. Indeed, prior to the middle of the twentieth century the history of Chinese science received little attention both from inside and outside China. It gained recognition in the middle of the twentieth century when Joseph Needham launched his monumental work, *Science and Civilisation in China*. Needham did not pioneer the study of the history of Chinese science. Sinologists and scientists before him had written on acoustics, alchemy, architecture, astronomy, gunpowder, hydraulics, mathematics, and medicine in traditional China. However, Needham demonstrated the originality of many Chinese discoveries and inventions, including the "three great inventions" of Renaissance Europe, and made Chinese science a new discipline of study. Modern scholarship and recent archaeological discoveries have increased our understanding of Chinese science and helped in the reappraisal of some old interpretations.

Excavations carried out first at Anyang between 1928 and 1937 and again after 1950, followed by those done at Zhengzhou in Henan province, substantiated the existence of the Shang dynasty (sixteenth–eleventh centuries BCE) and brought to light many bronze artifacts, foundry sites, and proto-porcelain wares. At the ruins in Anyang the remains of the capital of the last Shang kings were found. This later period of the Shang dynasty is known as Yin (fourteenth–eleventh centuries BCE). Besides bronze artifacts, archaeologists uncovered gold, jade, pottery, and shell objects, wooden artifacts with traces of lacquer, traces of silk fabric, and even a chariot. The most important find, however, was the oracle bones, which were carapaces of a specie of tortoise or shoulder blades of buffaloes that bear inscriptions written by the people of Yin for divination purposes. They contain records of eclipses and novae, as well as names of stars and asterisms. They also show that the Yin people were already using a lunisolar calendar with 12 moons or lunar months in one year. Each month consisted of either 29 or 30 days each, and every 2 or 3 years there was one extra month, known as the intercalary month, added to the year. The numerals in the oracle bones were the earliest known

Chinese numerals until the discovery of the inscriptions on the pottery at the ruins of Banpo, which dated back to about the year 3000 BCE. From the oracle bone numerals we know that the Yin people were already using a decimal system. We also find that the Yin people already had some knowledge of irrigation, agriculture, sericulture, and wine-making. For example, for tooth decay they used a character that included the character for "worms," suggesting that they had made an effort to attribute the problem to a cause. Chinese archaeologists have been quite active in recent years trying to re-establish the Xia dynasty. According to their tradition this dynasty existed for four centuries immediately before Shang, which itself lasted six centuries. Erlitou in Henan province, where bronze vessels dating back to the year 1700 BCE were recovered in 1971, is one of the more promising sites where they hope to discover epigraphical evidence to confirm the existence of that ancient dynasty.

Bronze vessels and pottery are some of the works of art characteristic of the Chinese. Shang bronzes show that the technique of bronze casting had already reached an advanced level. It was also in Shang China that the earliest proto-porcelain ware was discovered. It took the form of a wine container (*cun*), made of kaolin clay, with a yellowish green glaze on the surface about the mouth and a translucent deep green glaze on the inner and outer surfaces. The Western Zhou period (eleventh cenrury – 771 BCE) produced beautiful bronze vessels with inscriptions and proto-porcelain wares, some of which can be seen in many museums today.

In the Spring-and-Autumn period (722–481 BCE) two early texts, which Confucius (551–479 BCE) himself referred to, namely the *Shujing* (Book of Documents) and the *Shijing* (Book of Odes), were written. Both contain astronomical material from about the tenth to the fifth century BCE. The earliest sighting of Halley's comet in the year 613 BCE is recorded in the *Chunqiu* (Spring-and-Autumn Annals), which also contains references to solar and lunar eclipses, meteor streams, and other comets. The *Zhouli* (Records on the Rites of Zhou) informs us that the Zhou kings employed star clerks to observe astronomical and meteorological phenomena and to make astrological prognostications therefrom. The earliest star catalog is said to have been made by a court astronomer Wu Xian, of whom little is known. Two other catalogs were produced by Gan De and Shi Shen between 370 BCE and 270 BCE. The three original catalogs have long been lost. Some fragments claimed to be from the originals are quoted in many old astronomical writings. In the early fourth century Chen Zhuo (fl. ca. 310) constructed a star map supposedly based on such information.

Two weapons with iron plates taken from meteorite sources and dating back to the Western Zhou period were discovered in 1949. In 1976 a steel weapon of the sixth century BCE was excavated in Changsha, Hunan province, showing that by then China had already entered the Iron Age. Subsequently more iron artifacts of the fifth century BCE were found in Jiangsu and Henan provinces. It is interesting that although Europe knew about iron earlier, the Chinese came to know about the making of cast iron not later than the fifth century BCE, soon after iron was known to them. Another interesting technology developed by the Chinese of about that period is the breast-strap harness seen on the horses among the terra cotta warriors guarding the tomb of Qin Shihuangdi in Xian. Showing good understanding of the horse, this method was far superior to the throat-and-girth harness of the Roman chariot adopted in Europe in the early days. Some time between the years 600 and 1,000 the breast-strap technique went to Europe and evolved into the modern harness.

Between the sixth and the fourth centuries BCE the "Hundred Schools of Philosophical Teachings" flourished in China. Some of these schools played an important role in the development of science and technology in China. The philosopher Mozi (b. ca. 479 BCE) is remembered for his techniques of defense and for his knowledge of mechanics and optics embodied in his *Mojing* (The Canon of Mozi). Confucius is said to have edited the *Yijing* (Book of Changes), which contains one of the most subtle and influential methods of Chinese divination. In the past, especially in China, it was difficult to draw a sharp line of demarcation between science and divination. These two subjects were included within the term *shuxue* (mathematics). The writings of the Daoist philosophers and the Naturalists exerted a great influence on early Chinese science, and indeed they provided a set of natural laws that was supposed to be "universal", even more so than what modern scientists believe. Indeed the attempt to be too universal made it difficult for science in traditional China to separate itself from philosophy and to develop into modern science. The greatest name among the Naturalists was Zou Yan (fl. ca. 300 BCE) who lived in the eastern seaboard state of Qi (in modern Hebei province). He was the greatest exponent of the *yin* and *yang* theory and that of the *wuxing* in ancient China.

Traditional Chinese science was based on the philosophy of Harmony of Nature, in which heaven (*tian*), earth (*di*), and human beings (*ren*) were all mutually related. Attempts were made to develop a philosophy to explain everything – from astronomy to astrology, from mathematics to fortune-telling, from alchemy to magic, from philosophy to ethics, from politics to fine arts, and from medicine to music – in a common concept based on *qi*. The word *qi* has a wide range of meanings, which cannot be adequately covered by a single term in translation. Its modern meaning includes "air", "gas", "vapor", "steam", "weather", "trend", "demeanor", "manner", "temper", and a sort of life-giving force, reminding us of the Greek concepts of *pneuma* and *psyche*, the Hindu idea of *prāṇa*, and what modern scientists call "matter-energy".

From *qi* the two opposite and yet complementary cosmological forces *yin* and *yang* and the five *xings* were derived. *Yin* conveys the idea of darkness, the shady part of a mountain, coldness, cloudiness, rain, anything that is feminine, and so on. *Yang*, on the other hand, refers to brightness, the sunny side of a mountain, warmth, clear sky, sunshine, anything that is masculine, etc. The term *wuxing* was generally translated as "Five Elements". This gave rise to some confusion. When the Jesuits rendered the Four Elements of the ancient Greeks into Chinese they used the term *siyuan*, (four *yuans*), but when they translated the Chinese term *wuxing* they called it Five Elements. Unlike the Greek Elements (earth, air, fire, and water), the Chinese *xing*'s were not stationary but were in a state of constant motion rather than rest. They are Fire, Water, Wood, Metal, and Earth. There is an order of production or generation in which Fire produces Earth, Earth produces Metal, Metal produces Water, Water produces Wood, and Wood produces Fire. Then there is an order of conquest or destruction in which Fire conquers Metal, Metal conquers Wood, Wood conquers Earth, Earth conquers Water, and Water conquers Fire. In Chinese medicine for example, the *Huangdi neijing* divides different parts of the body into *yin* and *yang* and associates them with the five *xings*. For example, the heart, the small intestines and the tongue are associated with Fire, the kidneys and the ears with Water, the gall-bladder and the eyes with Wood, the lungs, the large intestines and the nose with Metal, and the stomach, the spleen and the mouth with Earth. The foundation of health, tranquility, and well-being rests on the perfect equilibrium and harmony of the two cosmological forces *yin* and *yang*, which continually ebb and flow. Everything is produced by union and perishes by decomposition. From the two orders of mutual production and mutual conquest the Chinese derived two principles, namely the "principle of control" and the "principle of masking". Any of the five *xings* that conquers another *xing* is controlled by the *xing* that conquers it. For example, Fire conquers Metal, but the process is controlled by Water. Any *xing* that conquers another *xing* is masked by a *xing* that produces the conquered *xing*, i.e., Fire conquers Metal, but Earth masks the effect.

Then comes the system of the *Yijing* (Book of Changes) with its 64 hexagrams said to be derived from the theory of *yin* and *yang* and that of the *wuxing*, although the system was sometimes used to support those two theories instead. Traditionally the origin of the system traced back to the eleventh century BCE when the sage father of the founder of the Zhou dynasty got inspiration from two mystical diagrams, the *Hetu* (River Diagram) and the *Luoshu* (*Luo* Chart). These two diagrams supposedly held the secrets of *yin* and *yang* as well as the *wuxing*. In the *Yijing* heaven and earth, thus *yang* and *yin*, originated from *Dao*. This term probably refers to natural order in this context but is opened to a broad range of diverse interpretations. The system of the *Yijing* was mainly employed for the purpose of divination. Besides divination it also found its use in the "explanation" of scientific phenomena, such as in astronomy and alchemy.

In traditional Chinese thought, divination and mathematics were inseparable. The word *shuxue*, the modern term for mathematics, was only first used in the modern sense in the last century when Li Shanlan (1811–1882) translated Western mathematical works into Chinese. Before then the same term in traditional China referred not only to divination and mathematics but also to astronomy and music. One is reminded of the word mathematics as defined by Boethius (480–524) to include arithmetic, geometry, astronomy, and music, which became the *quadrivium* in medieval Europe. In the eyes of traditional Chinese mathematicians, such as Liu Hui (fl. 263) and Qin Jiushao (1202–1262), divination was the loftiest form of *shuxue* while mathematics (in its modern sense) was only its common form. *Shu* was something that could be predicted by calculations, whether by means recognized by modern scholars as mathematics, such as finding the unknown number in a mathematical equation, or predicting rain in weather forecasts and telling the future using the system of the *Yijing*.

Buddhism and Daoism gradually gained ground over the Confucianists after Han China in the third century. A revival of learning during the time of Song China (960–1279) saw the neo-Confucianists attempting to cover science, particularly cosmology, within their schools of philosophy. The most celebrated among them was Zhu Xi (1130–1200), who sought to explain everything, both natural and human, with *li* (Nature's pattern), *qi*, and *shu*, while Zhang Zai (1020–1077) applied the concept of *qi* to explain natural phenomena and moral issues. Then there was the *xiangshu* (numbers of the symbols of the *Yijing*) school that focused its attention on the elucidation, verification, and application of the system of the *Yijing*. The most famous member of the school was Shao Yong (1011–1077), who used the system to explain natural phenomena and human affairs and to work out past and future events. His new order of the 64 hexagrams was shown by Leibniz (1646–1716) to be similar to the arrangements using the binary notation. Although Zhu Xi's philosophy was adopted as state orthodoxy, it does not imply that it met no opposition. For example, a contemporary, Lu Xiangshan (1139–1192) developed the neo-Confucian school of Idealism or of the Mind, which was later further developed by the Ming philosopher Wang Shouren (1472–1529), who had a large following.

The earliest text on Chinese astronomy and mathematics is the *Zhoubi suanjing* (Mathematical Manual of Zhoubi), which Christopher Cullen showed recently to be a compilation of the first century. In 1973 many important discoveries were made in the excavation of a Western Han (206 BCE–AD 9) tomb in Mawangdui, Hunan province. They included a manuscript recording the ephemerides of Jupiter, Saturn, and Venus between the years 246 BCE and 177 BCE and a silk manuscript illustrating comets in various shapes. Astronomical instruments such as bronze clepsydrae and bronze sundials have also been discovered in other excavations.

The Commentary to the *Jiuzhang suanshu* (Nine Chapters on Mathematical Arts) by Liu Hui (fl. 263) was the most influential text in the history of Chinese mathematics. In 1983 the *Suanshushu* manuscript (Mathematics Book), written on bamboo strips, was discovered in an ancient tomb dating back to the second century BCE at an excavation carried out in Hubei province. A preliminary study shows some similarities between this manuscript and the *Jiuzhang suanshu*. Liu Hui also wrote another, but much shorter text, the *Haidao suanjing* (Sea Island Mathematical Manual), using the right-angled triangle to measure distance and height. Before the time of Liu Hui, around the year AD 190, Xu Yue wrote his *Shushu jiyi* (Recording Omitted Items in Mathematics). Between AD 280 and 473 the *Sunzi suanjing* (Mathematical Manual of Sunzi) appeared. Of all the problems it contains, the one that has aroused most attention among modern scholars is that of the Remainder Theorem. The problem is to find a number, which when divided by three leaves a remainder two, when divided by five leaves a remainder three, and when divided by seven leaves a remainder two. The required answer is 23. Actually this problem involves three indefinite simultaneous linear equations of one unknown, and there is an infinite number of answers of which the required answer is the smallest. Historians of mathematics study this purely as a case of the Remainder Theorem. However, a more important application of this problem was recently revealed. It was found to be the method adopted by Chinese astronomers up to the eighth century to calculate and construct new calendars.

Several other mathematical texts were written in the following three centuries. One must note the evaluation of the ratio of the circumference to the diameter of a circle made by Zu Congzhi (429–500) and his son Zu Keng. They gave three different values, of which the most accurate was $3.1415925 < \pi < 3.1415926$. The method used by Zu Congzhi was described in his book, the *Zuishu*, which unfortunately is already lost. Chinese mathematics reached its golden age of development in the twelfth and the thirteenth centuries. During the twelfth century, mathematicians like Liu Yi and others could solve cubic equations numerically. Their writings are no longer extant, but fortunately we have the works of four great thirteenth-century mathematicians, namely Qin Jiushao, Li Zhi (1192–1279), Yang Hui (fl. 1261–1275), and Zhu Shijie (fl. ca. 1280–1303). The study of numerical solutions of equations of higher degrees is yet another of the characteristics of Chinese mathematics. Li Zhi also had a great influence in the development of mathematics in Japan.

The Chinese emperor regarded calendar-making as one of his duties that came with the mandate bestowed upon him from Heaven. The Chinese calendar took into account the apparent cycle of the sun and the cycle of the moon, both of which cannot be expressed in an exact number of days. The astronomer responsible for constructing a lunisolar calendar had to make accurate observations of the sun, the moon, and the planets, but however accurate his observations, his calendar would eventually, in just a matter of decades, go out of step with observations. In 1972 archeologists working at the site of a Han tomb at Linyi in modern Shandong province, discovered a calendar for the year 134 BCE. Throughout the history of China no less than one hundred calendars had been constructed, not to mention other unofficial calendars sometimes used in certain regions. The most renowned among the Chinese calendars were the *Dayanli* calendar completed by the Tang Tantric monk Yixing (683–727) in 727 and the *Shoushili* calendar prepared under the Mongols by Guo Shoujing(1231–1316) in 1280. They used the method of differences in mathematics to make their calculations. Accurate and new astronomical observations had to be made for the purpose of calendar making. New astronomical instruments were constructed for this purpose. Yixing, for example had to construct his own armillary sphere. The Song dynasty (960–1279) is remembered for the several large armillary spheres made for this purpose. The most famous was that made by Su Song (1020–1101). It was an armillary sphere driven by a water wheel using the principle of escapement.

In the early stages medicine and magic were indistinguishable from each other, as both were practiced by the shamans (*wu*). Shamans and doctors were together referred to as *wuyi* (shamans and doctors). During the Spring-and-Autumn Period (722–480 BCE) there were signs that physicians and shamans had already parted company. There was the celebrated physician Qin Yueren, better known as Bian Que (fl. 501 BCE), who was the counterpart of Hippocrates (465–370 BCE) in China. He was already acquainted with the four important diagnostic procedures used in Chinese medicine: observing external signs (*wang*), listening to sounds (*wen*), asking the patient's history (*wen*), and feeling the pulse (*qie*). These are sometimes referred to as looking, listening, asking, and touching. The earliest Chinese medical writing known to us until recently is the *Huangdi neijing* (The Yellow Emperor's Manual of Corporeal Medicine). Consisting of two parts, the book appears to have been written by several earlier unknown authors but took its final form during the second century BCE. Between the winter of 1973 and the spring of 1974 some valuable medical writings were discovered during the excavations at Mawangdui near the city of Changsha in modem Hunan province. The tomb where these writings were found dated back to the year 168 BCE and hence the medical writings concerned must have belonged to an earlier date. These are the two most ancient Chinese medical writings extant.

The earliest Chinese pharmacopoeia that we have is the *Shennong bencaojing* (Pharmacopoeia of the Heavenly Husbandman). We do not know its exact authorship and neither are we certain about when it was written, although the date could not be later than the second century. It sets a tradition followed by a long series of succeeding pharmacopoeias over a period of more than a thousand years. It mentions the *yin* or *yang* property and the indications of each medicinal substance, noting that some combinations of two or more of them are either beneficial or counterindicative. It divides all the 365 items of medicine that it contains into three categories. Those in the first category have the efficacy of nourishing or prolonging life; those in the second are, as a rule, nontoxic and can be used to restore the constitution of the patient; and those in the third are usually toxic or have side effects. The last category is used for combating diseases. Thus the *Shennong bencaojing* catered to the needs of both the physicians and the aspirants of longevity.

While the physicians had parted company with the shamans, some of the latter devoted their attention to prolonging the human life span. Some of the substances they ingested, such as mercuric sulfide, mica, licorice, and asparagus, are listed in the *Shennong bencaojing* pharmacopoeia. The search for the way to physical immortality probably began in China at least 2,500 years before our time. It is recorded that in the Warring States Period (480–221 BCE) someone presented an elixir to the prince Jingxiang wang in the State of Qu. Some modern writers attribute the first practice of alchemy in China to Zou Yan. Later on the story of the elixir told by the shamans got the fancy of the emperor Qin Shihuangdi, who made several attempts to procure an elixir for himself so that he could live and rule his empire to eternity. Another patron of the shamans was the emperor Han Wudi, who reigned about 133 BCE. It was then that the shamans talked about making gold as the first step toward the elixir. At about the same time, Liu An, the Prince of Huainan, compiled, with the help of a group of shamans and alchemists retained by him, the *Huainan wanbishu* (The Ten Thousand Infallible Arts of the Prince of Huainan). Tradition says that this book dealt mainly with alchemy, especially the making of gold, but unfortunately we no longer have the complete text, and the fragments of the book now left are only concerned with magic. In the following century Liu Xiang, who was said to have inherited this book, was commissioned by the emperor to make gold for the Treasury. His failure landed him in prison.

The earliest Daoist alchemical treatise that is still extant today was written by the alchemist Wei Boyang in the second century AD. Entitled *Cantongqi* (The Kinship of the Three), the text is very obscure, containing a number of alchemical terms with "hidden" meanings. The use of the system of the *Yijing* (Book of Changes) has contributed directly to the obscurity of the text of the *Cantongqi*. Alchemy gained popularity following the work of Wei Boyang. During the fourth century Ge Hong wrote his *Baopuzi neipian* (The Esoteric Chapters of the Solidarity Master), showing the great advancement made in alchemy since the time of Wei Boyang. Ge Hong was at the same time an accomplished physician. Other famous physicians who were also great alchemists after Ge Hong were Tao Hongjing (456–536), Sun Simo (?581–?682), and his disciple Meng Shen (621–718). For the next eight hundred years or so after Ge Hong, alchemy continued to flourish and many alchemical works were written. Most of these works are lost; those that survived are included in the present version of the *Daozang* (Daoist *Tripitaka*), a collection of 1464 Daoist works, only a small fraction of which deal with the subject of alchemy.

In many of their experiments the Chinese alchemists used the process of sublimation and of distillation. They often made use of the reaction-vessel, called *yaofu*. Many of the elixir recipes contained toxic ingredients such as mercury, arsenic, and lead. Hence such elixirs would be quite poisonous. Quite a number of Chinese emperors showed great interest in the elixir and some of them unwittingly perished. For example, the Jin emperor Aidi died in his very prime, aged only 25, as a result of his attempt to avoid growing old. The emperor Wenxuandi of Northern Qi, on the other hand, exercised more caution. When presented with the elixir he decided that the most opportune moment to test it would be on his death bed. At least three Tang emperors died as a result of taking the elixir. Political motives might be behind the early demise of some Chinese emperors, but the alchemists responsible were quickly punished for their failure. With the evidence so efficiently destroyed the full case is difficult to investigate.

There were probably many charlatans among the alchemists, who, when their elixirs brought about the early demise of unfortunate emperors, managed to escape before it became too late. However, there were also alchemists sincerely interested in their work who believed in the elixirs they made. So strong was their faith that many alchemists must themselves have fallen martyr to their own beliefs, or become victims to mistakes in following the obscure and contorted instructions of their predecessors. The most experienced or industrious experimenters were often the most enthusiastic believers, and in the end the surest victims. In this respect the elixir mania must have acted as an inhibiting factor to the progress of chemical knowledge in China.

Many Chinese alchemists were aware of the toxicity of their products. Some tried to neutralize the poison; some recommended only symptomatic treatment; some believed that the ill effects were only side effects associated with the elixir and as such should be completely ignored; some turned to the vegetable kingdom to look for suitable ingredients; and some turned away from the material elixir and practiced "physiological alchemy" (*neidan*) following a regime of meditation and breathing exercise. By the ninth century alchemy in China had already seen its best days. The alchemists gradually relied more and more on the vegetable kingdom for their raw material. Hence there was an alchemical work that included the term *bencao* (pharmacopoeia) in its title, namely the *Waidan bencao* (Pharmacopoeia of Operative Alchemy) by Cui Fang (fl. eleventh century). After the turn of the fourteenth century several books on elixir plants made their appearance. The Chinese alchemists seemed to have gone round one full circle back to the days of the ancient shamans. Alchemy merged again with the tradition of Chinese medicine set by the *Shennong bencaojing* pharmacopoeia.

Hence traditional Chinese medicine and alchemy arose from the same source. At first the shamans practiced both magic and medicine. About the sixth century BCE medicine and magic took different courses. Some shamans developed the art of prolonging human life and reached the conclusion that one had to make gold by artificial means as a first step to physical immortality. That was the beginning of alchemy. Alchemy maintained a close link with medicine, dealing only with different aspects of human life. Quite a number of alchemists were at the same time famous physicians, as in the case of Ge Hong, Tao Hongjing and Sun Simo. A preliminary study shows a close connection between alchemy and Chinese medicine in the similarities between the basic principles used in medical and elixir prescriptions. Medicine and alchemy borrowed from each other. For example, alchemical works are liberally quoted in the more important pharmacopoeias of later time such as in the *Bencao gangmu* (the Great Pharmacopoeia) written in 1596. Although the Chinese alchemists did not succeed in their quest for the elixir of immortality, they played a part as the iatrochemist in Chinese medicine. Another by-product of their experiments was that they stumbled upon gunpowder when some of them caused an accident when they did not exercise sufficient caution in using saltpeter and sulfur, allowing some carbon impurities to get in from the charcoal or wood that they used as fuel.

There was early intercultural transmission of scientific and technological knowledge between China and her neighbors, especially west Asia, before the Christian era. Buddhism first came to China in the second century. Scientific knowledge followed the wakes of missionary and pilgrimage activities. During the eighth century Indian monks and calendar experts, Nestorians, Arab merchants, Korean and Japanese students, and others lived together in the Tang capital Changan (modern Xian) which had a population estimated to be over one million. Mutual exchange of knowledge was inevitable. Muslim astronomers found employment in the astronomical bureau in thirteenth-century China and some Chinese astronomers could have been sent by Hulagu Khan to work in the observatory in Maragha under its director Naṣir al-Dīn al-Ṭūsī (1201–1273). The Renaissance in Europe was influenced in no small measure by Arabic and Indian learning, but Europe also acquired knowledge of Chinese science and technology through the Arabs and the invasion of the Mongols during the thirteenth century. Since the seventeenth century science in Europe has advanced by leaps and bounds while Chinese traditional science remained in a state of stagnation. Toward the end of the sixteenth century the Jesuits arrived in China, using science as a tool to promote their mission. Science from Europe, particularly mathematics and astronomy, demonstrated its superiority to traditional science. In the latter half of the nineteenth century modern science came to China from Europe and North America, and by the twentieth century China had joined the world in the common enterprise of modern science.

See also: ►*Yinyang*, ►Astronomy, ►Metallurgy, ►Calendars, ►Armillary Sphere, ►Alchemy, ►Ethnobotany, ►Medicine, ►East and West, ►Magic and Science

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Science in Japan

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The history of Japanese science, technology, and medicine is divided into two distinctly different periods, traditional and modern, the dividing line being the late nineteenth century when Japan started wholesale Westernization. Since the subject matter of modern Japanese development is not much different from Western development, this article deals only with the traditional and transitional periods.

The Traditional Period

The written history of Japan started approximately in the sixth century when Chinese writing, culture, and institutions were brought in by Korean immigrants. Technical professions began in Japan with the immigration of Korean experts in the sixth to eighth centuries. The immigrants slowly settled into Japanese society, and the Chinese view of nature gradually began to take root in Japan. Thus, traditional Japanese science, technology, and medicine are basically a ramification of Chinese paradigms. In the following, we shall elucidate the points of Japanese deviation from the Chinese prototype.

Whereas the Western world of learning had an integral structure of trivium, quadrivium, scientia, or Wissenschaft, the corresponding Chinese world of learning was thoroughly structured with Confucian classics at the center of a structured bureaucracy. Scientific subjects were of peripheral importance, with mathematics and calligraphy being necessary for the civil service examination system, and astronomy, medicine, and architecture being fields with their own branch offices in the bureaucracy. The small replica of the Chinese world of learning and bureaucracy was created during the eighth century in Japan.

In principle, the Japanese Astronomical Bureau was a miniature reproduction of the Chinese bureaucracy, but a closer look reveals significant remodeling to meet local requirements. While in China the astronomical organizations that computed the ephemerides and observed celestial phenomena had important astronomical bureaux, in Japan all of these activities were subsumed under the single *Yinyang* Board, the name of which indicates a clear priority for divination. After that time, the Japanese *Yinyang* art developed into a complex of divination techniques.

Given a Chinese manual of calendrical science from which to determine basic parameters and computational procedures, there was little that local talent or preference could add. On the other hand, when unforeseen and ominous celestial phenomena were observed they had to be interpreted without delay. Thus in astrology the Japanese were thrown upon their own resources, and the practical application of imported knowledge was valued over basic theory.

It was not the regularities of the eternal truths of mathematical astronomy but the unforeseeable omens of the astrologers that attracted attention in Japan. Whereas abstraction and involved theoretical argument were by no means rare in Chinese science, they were vastly less important in Japan.

As the Chinese influence became less noticeable from the tenth century on, the bureaucracy also diminished in strength. Throughout the medieval period, it was in family businesses rather than the government bureaucracy where those with talent enough to pass civil service examinations were employed. Kinship ties returned to their former importance.

Because they were separated from the Asian continent, the Japanese were not totally overwhelmed by Chinese influence. Japanese society was much less bureaucratic than that of China or Korea, and as a result was more able to respond to the incoming intellectual flux. The Japanese received Chinese influence selectively to meet local needs.

Meanwhile, Buddhism reached Japan from India by way of China and Korea. Although enthusiasm for Buddhism waned somewhat in China and Korea, the Japanese have retained it throughout history. In medieval times, Buddhist monks competed with official astronomers in predicting eclipses by use of their *Fu-tian* calendar. In the paradigmatic treatise of Japanese divination art, *Sukuyōkyō*, excerpts from classics of Tantric Buddhism were mixed side by side with Chinese Daoist texts. In Japanese medical classics, certain Buddhist recipes were mixed and preserved. This reflects Japanese intellectual pluralism.

The Platonic conviction that eternal patterns underlie the flux of nature is so central to the Western tradition that it might seem that no science is possible without it. Nevertheless, although Chinese science assumed that regularities were there for the finding they believed that the ultimate texture of reality was too subtle to be fully measured or comprehended by empirical investigation. The Japanese paid even less attention to the general while showing an even keener curiosity about the particular and the evanescent.

This attitude may be seen in the career of Shibukawa Harumi (1639–1715), the first official astronomer to the Japanese Shogun. In the preface to his early treatise *Shunju jutsureki* (Discussions on the Calendar Reflected in the Spring and Autumn Annals, the oldest Chinese chronicle), he stated that astronomers had rigidly maintained that when Confucius dated the events in his *Annals of the Spring and Autumn Era* he made conventional use of the current calendar with little care for its astronomical meaning, so that the dates were not very reliable. "This error is due to the Chinese commitment to mathematical astronomy, so that they do not admit that extraordinary events happened in the heavens. Extraordinary phenomena do in fact take place in the heavens. We should therefore not doubt the authenticity of [Confucius'] sacred writing brush."

Once admitting, as Shibukawa did, that regular motion was too limited an assumption, one could easily conceive such notions as that astronomical parameters could vary from century to century. In the official Chinese calendar in the thirteenth century and earlier, the discrepancy between ancient records and recent observations was explained by a secular variation in tropical year length. Shibukawa revived this variation in the Japanese calendar, and Asada Goryu (1734–1799) extended it to other basic parameters to account for Western as well as Eastern observations then available to him.

The variation terms used in Japanese astronomy were too large to survive empirical testing, and were eventually discarded. It is, however, noteworthy that their cosmological outlook was so flexible that they accepted the notion that all astronomical parameters were subject to change and the whole universe was changeable, while in the West the Aristotelian notion of an unalterable universe was followed rigorously, and irregular motions in the sky were inconceivable.

In early Chinese history, higher mathematics was always associated with calendrical science, in terms of solving indeterminate equations for ascertaining the time of grand conjunction. In Japan, interest in mathematics was also raised in connection with calendrical science in the seventeenth century, and was soon developed as mathematical puzzles to be enjoyed by hobbyists, in the same way as there were enthusiasts of flower arrangement and the tea ceremony. This form of Japanese mathematics called *wasan* was mostly viewed as a popular art. It was not considered a scholarly activity.

I shall not attempt a conceptually rigorous definition of scholarship and hobby here, but merely note that scholarship is usually thought to have some public function while hobbies are regarded as private indulgences which may or may not have significant social value. While art does not require legitimation, scholarship does, and there has to be some basis on which to differentiate one from the other. Some kind of legitimation was found to be necessary for mathematicians and one way of doing so was to invite Confucian scholars to write prefaces to their books, in effect borrowing Confucianism's prestige.

The Japanese mathematicians were generally socially marginal curiosity seekers. During the Tokugawa period, mathematics was not formally recognized by the government. The Tokugawa mathematical tradition existed entirely in the private sector and had no official support. Whenever scholars demand legitimacy from society, they display a sense of mission which reinforces their commitment. This sense of mission is associated with the rise of professions, but the Japanese mathematicians cannot be called professionals.

With the use of mathematical rods, Chinese mathematics developed quite sophisticated algebraic formulae. Building on the Chinese tradition, a significant development was made by Japanese mathematicians to develop numerical algebra into symbolic algebra by writing on paper and making it possible to obtain a more general treatment. Curiously enough, the formulae of *wasan* resemble modern algebraic formulae but they are written vertically. However, due to stylistic differences, there was no intercourse between Japanese and Western developments in mathematics.

Wasan mathematics developed a unique custom in the formative period consisting of the posting of mathematical problems called *idai* (bequeathed questions). A mathematician would post scores of problems of several kinds at the end of a book and then publish it. Another mathematician would post answers to these problems and present his own in the same manner. According to convention, yet a third mathematician would post answers to these problems and issue his own in relay fashion. This mechanism of *idai* caused a chain reaction and greatly stimulated the formation of *wasan* groups. The tradition began with 12 problems from the *Shinpen Jinkoki* published in 1641. A succession of mathematical lineages soon developed and reached their peak during the life of Seki Kowa (Takakazu). Practically all of the important problems in the history of *wasan* date from the period above.

Another feature of *wasan* development was the *sangaku* (mathematical tablet) form that came in the later phase. These tablets included both problems and answers and were dedicated at shrines. The best mathematicians made their accomplishments known through books, but it was largely the custom of *sangaku* which supported the activities of the *wasan* enthusiasts. That *wasan* was a hobby which cost money to pursue is best shown by the elegant diagrams which embellished such work. In fact, the offering of *sangaku* had a strong attraction as it showed a desire to keep their work on more or less permanent view.

Chinese natural philosophy developed certain abstract concepts in ancient times. The *qi* concept, one of the basic ideas which appeared in the *Huangdii Neijing* (The Yellow Emperor's Internal Classic), the earliest Chinese medical compilation, is today interpreted as something akin to energy which is imponderable but permeates and circulates in the macro- as well as the microcosmos. When the *qi* concept was introduced into Japan, medical doctors tended to interpret it as materialistic, unable to comprehend such a highly abstract concept of imponderable energy. Given the difficulty of understanding the subtleties of Chinese philosophical speculation, the Japanese physicians adopted a more simplistic, pragmatic, and empirical approach.

For instance, certain tumors and internal swellings were thought to be stagnated or congealed *qi*. Indeed, the seventeenth-century Japanese physician, Goto Gonzan, attempted to explain the cause of all medical disorders by stagnation of this kind.

Traditional Chinese medicine was concerned primarily with function and only secondarily with tissues and organs. Internal disorders were never local in Chinese medicine. The major physiological and pathological theory was to regulate energy flow internally and externally between the micro- and macrocosmos, so that holistic diagnoses could be applied. They depended heavily on pulse diagnosis as the indication of energy flow. More materialistic Japanese physicians such as Yoshimasu Todo (1701–1773), however, developed stomach and abdomen diagnosis by touching the location of disease, rejecting the traditional pulse diagnosis. Yoshimasu, the foremost figure of the radically critical school, declared that the *qi* of the universe had nothing to do with medicine. This group was prepared to take a position much closer to that of the solidists in the West than had been possible in Japan at an earlier time. Functional analysis lost its importance, and the physical organs could be studied for their own sake. This was nothing less than a gestalt change.

In accordance with the extension of the materialistic inclination of Japanese physicians, they were interested in anatomy and found that Western schema were a great deal more accurate than the Chinese anatomical charts. In mathematical astronomy and calendrical science, Western superiority in accuracy was quickly recognized. In medicine, there is good reason to doubt that there was any difference in therapeutic efficacy before the late nineteenth century. It is above all in the comparison of anatomical charts that the strength of Western medicine would be apparent.

In the second half of the eighteenth century, Sugita Genpaku took up the study of anatomy because it seemed the most tangible, and therefore the most comprehensible, part of Dutch medicine. Following the solidist breakthrough, Sugita's successors in medicine studied physics and chemistry and opened up the world of modern science. The Copernican influence was minor by comparison, because the Japanese cosmos had not been defined by religious authority. The impact of anatomy challenged the energetic and functional commitments not only of medicine but also of natural philosophy. Its effect was bound to be revolutionary.

The learned treatises of the Chinese and Japanese medical traditions lacked terminology not only for brain function but also for mental processes. It was only later scholars with considerable knowledge of Western anatomy, such as Sugita Genpaku, who could abandon the Chinese tradition entirely and display as much anatomical interest in the brain as in the viscera.

Materia medica and natural history books were brought first from China and later from Holland. The first thing for a Japanese natural historian to do was to identify local species with imported Chinese books. This identification work endowed Japanese scholars with new insights into comparative study. While the original Chinese texts were intended for the collection of medicinal herbs for pharmaceutical purposes, the Japanese developed this study into a natural history of visual observations for identification.

In feudal Japan, all occupations were hereditary. The post of official astronomer to the Shogun was created to recognize the personal achievement of Shibukawa Harumi, and was passed down to his descendants. It had no significance beyond the technical, and thus was of no interest to the generalists. Those who held technical posts of this kind, such as medical doctors and Confucian scholars, were from the beginning separate from the general samurai bureaucracy.

When the official astronomer and his subordinates were compiling the ephemerides, Confucian scholars were not consulted. The astronomers had inherited the tradition through their family line since medieval times. At the time of a calendar reform, once every hundred years for a Chinese-type lunisolar calendar, the descendants were usually incapable of innovative work, but able to perform the routine calculations necessary for the distribution of the yearly calendar according to a given formula. In most such cases, talented astronomers in the private sector were appointed to the post of official astronomer. Beginning with Shibukawa Harumi, the number of such hereditary official astronomers amounted to seven families toward the end of Shogunate rule.

Often professionals were encouraged to adopt talented young boys rather than their own sons. Under the rules of samurai society in the Tokugawa period, only the first son was entitled to inherit the family stipend. Later born sons were adopted by other sonless samurai families or left to find ways of obtaining their livelihood themselves. For either, they had to show their ability by studying hard. These younger sons would provide Japan with a pool of talented professionals.

In Japan, there was no social or political reason for a single philosophical orthodoxy. Although nominally based on the centralized Chinese model, Japanese feudal society remained multifocal, consisting of the Shogunate and a hundred fiefs. Thus freedom to choose between several paradigms seems to have been as desirable as the search for a unitary principle was in China.

In China and Korea, the official character of science and learning was rigidly maintained by adherence to the civil service examination system. The Japanese imitated the Chinese bureaucracy for only a short time in the seventh and eighth centuries, and subsequently this failed to take root in Japanese society. It was only in the last quarter of the nineteenth century with the establishment of a modern government system that a centralized bureaucracy complete with civil service examinations emerged. During the Tokugawa period, it was centralized feudalism, in which the Tokugawa government had overwhelming power but in which each fief government was able to maintain a degree of autonomy by having their own independent schools, bureaucracy, and policies, in competition with other fiefs.

The Tokugawa Shogunate wanted to instigate centralized civil and medical service examinations but was unable to impose such a system on the fief governments. As a result, there was no rigidly maintained state orthodoxy of science and learning, although the exclusion of Christian tenets was executed with considerable harshness. In short, the Japanese have enjoyed the merits of multiculturalism. It is not the kind of multiculturalism which involves the peaceful coexistence of different races in one society but rather signifies the acceptance of different cultures by largely one single group.

Science and learning had been substantially privatized and able to respond to imported foreign ideas by the late eighteenth and early nineteenth centuries. Even during the semiseclusion period under the Tokugawa Shogunate, the activity of Dutch learning was practiced by city intellectuals, medical doctors, and merchants in the private sector. Only after the Western threat of invasion became substantially felt in the nineteenth century, particularly after the news of the Opium War and the arrival of Commodore Perry's gunboats in 1853, did the knowledge of Western learning become the business of the public sector. Samurai became interested in Western military technology, finally overthrowing the feudal government and replacing it with a centralized state.

From the seventeenth century onward, when Western knowledge began to exert claims of its own against the backdrop of Chinese learning, Japanese thinkers were critically attentive. As soon as they were convinced that European technical knowledge was superior, the Japanese switched to the new paradigm with remarkable speed. They quickly modified their attitudes and oriented themselves toward achieving certain desirable goals that had been reached in the West. For the Chinese, the encounter with European ideas was traumatic; to accept them was to reject traditional values, and to reject them would leave them with no defense against dismemberment by Western powers. For the Japanese it was merely the appearance of another paradigm to be accepted in their eclectic manner. The Japanese were flexible enough to accept the Western paradigm without strong resistance.

The Transitional Period

Let us now turn to the occupational support groups who successively played a leading role in the introduction of Western science to Japan.

Astronomers and Interpreters

The adoption of Western "barbarian" astronomy in the seventeenth century by the Chinese dismayed conservative elements in Japan. However, it did not promote the desire in others for a similar change in the Japanese calendar, which was modeled on that of the ancient Chinese. As has been mentioned, the eighth Shogun Yoshimune and his court astronomers recognized the superiority of Western over Chinese astronomy, but astronomers were primarily government bureaucrats or technicians whose scope remained limited to their assigned duties of drawing up the official calendar. Their interest in Western science was limited to the precision of astronomical data and methods of calculation, and they made no attempt to jeopardize their hereditary posts by entertaining revolutionary paradigms such as were developing in Europe at that time.

Professional interpreters at Nagasaki were the most well versed in the Dutch language, through which they must have become acquainted with the concepts of Western science. But again, they were also hereditary government officials who remained within the boundaries of their duty of faithful translation and nothing more. Neither official astronomers nor interpreters published their work for general audiences.

Independent Scholars and Physicians

From the late eighteenth century on, a sizeable number of Dutch books containing the term *Natuurkunde* (study of nature) found their way into the country and aroused the interest of various independent scholars in the private sector who set about translating them, although their foreign language skills were much inferior to those of the Nagasaki interpreters. The majority of these "Dutch scholars", as they came to be called, were avant-garde physicians who were primarily freelancers, with no strict subordinative links to the governing elite or subsequent interest in maintaining an existing *status quo*.

Thus they were not inhibited in stepping out of their line of work and were free to extend their interests to anything Western except perhaps the Christian doctrine. Astronomy was the first area in which people sensed that the West was superior, but the notion that the West was superior in other fields of scientific endeavor first spread among these independent physicians.

As they inched their way through Dutch texts, they realized that Western science was more than a variant of the natural history line of their own tradition. As they saw it, its essence could be translated as *kyuri* (literally, investigating the principles of things, a new Confucian term, or "natural philosophy", being a systematic and fundamental investigation and consideration of the nature of things). Thus, although at first there was no clearly established tradition for the term, *kyuri* was later to become the most common, and given the vocabulary of the period, it was an informative translation. In recognizing an enquiry into principles at the bottom of such traditional practical studies as medicine and calendar-making, in becoming aware, i.e., of natural philosophy or physics, they also grasped the hierarchical structure of modern science, from basic to applied. Above and beyond the culturally bound achievements of Western science, they seemed to have sensed that it contained a revolutionary paradigm, since the belief in underlying laws in Nature which could be formulated was weak in Japanese traditional thought. This was in marked contrast to the official astronomers who looked upon science as something that could be handled at the technical level and assigned it only a supplementary role.

The physicians recognized the importance of physics and chemistry as the basis of medical work, and several founded schools for the teaching of Western medicine. Their students, during their apprenticeship and internship days, moved from one school to another in major medical centers like Nagasaki, Osaka, Kyoto, and Edo (Tokyo), and played a role of diffusing knowledge of Western culture as well as medicine. While some physicians remained in the practice of medicine, others turned to the teaching of the Dutch language and even the discussion of international knowledge and politics and also founded schools for such. Thus, the cultural influence of the physicians was more considerable than that of the astronomers who limited their activities to the translation of technical works.

But these support groups were by no means adequate preparation for the reception of contemporary science. The Dutch scholars were still only amateur supporters of uninstitutionalized paradigms, comparable in this respect to gentleman members of the Royal Society. Their schools were few and regarded on the whole as avant-garde. Had they flourished in the seventeenth and eighteenth centuries their work might have had greater consequences. By the mid-nineteenth century, however, modern science in the West had entered the systematically structured world of the university and reached new advanced levels. Reception of learning that was now systematically pursued in Europe within the structures of the university required the creation of an institutional system. It had to be met not by self-taught amateurs but with professional scientists who had received a modern systematic education. These early scholars were not aware of the institutionalized aspect of Western science up until the mid-nineteenth century, remaining bookish translators of the *kyuri*, paradigmatic aspect of Western science.

Samurai

The Opium War between the Chinese and Western colonialists created concern among the samurai cognoscenti, but Commodore Perry's visit to Japan in 1853 and the subsequent threat of war caused all samurai to realize that the Westerners' science was needed for national defense. As a result, young samurai flocked to the schools of Western learning established by physicians. As they were traditionally the ruling class, and in time of war the warriors, it was natural that samurai interest in Western science and technology training was based on more real and pressing needs than reception of and support for particular scholarly paradigms.

First, they tried to learn the Western art of manufacturing firearms, but soon realized that it was impossible to catch up and compete with Western forces by a crash project of manufacturing cannons. They could purchase hardware, but what was really needed was the software of Western military training and tactics. Moreover, the acquisition of Western military discipline was one of the contributing factors in the overthrow of the ruling Tokugawa family by anti-Tokugawa samurai and the subsequent establishment of the Meiji government in 1868. The samurai recognition of Western science was therefore political rather than cultural.

After the revolution, convinced that Western scientific learning was essential, the ruling class set out to disseminate their conviction through the establishment of an educational infrastructure. With Meiji effort and initiative, modern science was fully assimilated in a wholesale introduction through governmental institutions rather than a piecemeal cultural infiltration, as in the previous era, and modern scientific and technological professions became the artificial creation of the new Western-oriented government.

The main practitioners of these new professions were former samurai. In the past they had received hereditary family stipends in exchange for their loyalty to the feudal powers, the Shogunate or local feudatories. But in the 1870s, efforts were made by the Meiji government to curtail the inherited family stipends of the samurai class as a step toward social modernization. While other classes, farmers, artisans, and merchants, could continue to be engaged in their inherited vocations, samurai completely lost their guaranteed source of income. Consequently, they had to find new ways of living independently. Since the samurai could not compete with other classes in the fields of traditional occupations like agriculture and medicine, science and technology was one of these new fields into which jobless samurai were attracted and invited. Almost all of the early graduates of the engineering colleges were samurai. Even as late as 1890, the percentages of Imperial University samurai graduates in engineering and science were 86 and 80, respectively.

Thus, Japanese modern science and technology professions were, in the beginning of their formation, very much "samurai-spirited." The samurai were the class long accustomed by mental habit to think in terms of public affairs and by behavior patterns to play the game of public office. Unlike the European pattern in which science and technology training was one experience of the rising bourgeoisie, the new Japanese scientific and technological professions in the last quarter of the nineteenth century were dominated by the proud old samurai class, comprising the top 5% of the total population.

Table 1 summarizes the sequence of support groups' thrust toward Westernization in Japan.

In the first stage, Western science was confined merely to technical knowledge by technicians in the government sector. In the second, Western knowledge in the form of its revolutionary paradigms was garnered by vanguard physicians but they were alienated from the central power structure. Only in the third stage was Western science fully admitted into the power structure, and after the Meiji Restoration, through institutionalization, it was recognized as a most legitimate study for the youth of the samurai class.

The modernist samurai leadership soon established a policy of Westernization in which the establishment of Western-style educational institutions occupied a central position. During the 1870s and 1880s greater emphasis was placed on science and technology in the Japanese educational curriculum, from elementary school to university level, than in any other nation. For instance, mathematics and science occupied about one-third of the school curriculum at the lower grades (first 4 years) and two-thirds at the upper grades of the 8-year elementary education, though due to the shortage of qualified teachers available, it is somewhat questionable to what extent these ideal plans were put into practice. At the tertiary level too, the emphasis on science and technology was evident in the high percentages of graduates in scientific disciplines of Tokyo University (85% in the 1880s). In Europe in the nineteenth century, the voluntary activities of scientific or professional societies usually preceded their inclusion into the university curriculum. In the case of Meiji Japan, however, and as is generally the case when a foreign discipline is artificially transplanted under state sponsorship, this process was reversed. Tokyo University was established as an indispensable part of the modern technocratic bureaucracy. Graduates in science and technology were mostly samurai descendants who were accustomed to working in the public sector and inspired in technocratic policy-making, rather than by engineering apprenticeship of the traditional artisan class. They were adaptable in "public science" initiated by the government, which was indispensable for the operation of a modern state, in areas such as geographical and geological surveys, weights and measures, meteorological observations, sanitation, printing, telegraph and telephone system, military works, railways, and surveys of national resources.

In addition, the government participated in private entrepreneurial activities, constructed and managed pilot plants, and guided and subsidized new kinds of industries. Their enterprises were, however, from the beginning exposed to financial risk. Many of the projects of the Ministry of Technology eventually proved to be too far ahead of their times, as they intended to introduce the technology of an industrialized society into a preindustrial environment. For instance, their railway construction and textile mill enterprises were economically unsuccessful at the time.

Some of the samurai experiments in the public sector were successfully transferred into the private sector, where they were transformed to the market-oriented "private science" of the traditional artisan,

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Science in Japan. Table 1 The sequence of support groups' thrust toward Westernization in Japan

Occupation	Astronomers and interpreters	Physicians	Samurai
Leading century period	Eighteenth century	Late eighteenth to early nineteenth century	Mid-nineteenth century
Interest	Technical	Cultural	Political
Status	Technicians	Freelancers	Planners and administrators
Role	Referees of superiority	Diffusion and popularization	Institutionalization

such as Toyota Sakichi, the founder of Toyota Motors. The privatization of science phase was finally completed after World War II.

See also: ►Seki Kowa, ►Shibukawa Harumi, ►Environment and Nature, ►Astronomy, ►*Yinyang*, ►Computation: Chinese Counting Rods, ►Asada Goryu, ►Divination in China, ►Mathematics in Japan

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Science in Korea

Jeon Sang-Woon

Korea is a nation with 5,000 years of history. Located on the periphery of East Asian civilization, it was greatly influenced by China. However, Koreans have developed a culture and tradition independent from that of the Chinese. At the same time, the history of Korean science can be regarded as a branch or an adaptation of Chinese traditional sciences, although, in most cases, Chinese sciences and technology were not adopted in their original form.

Korea had its own unique Paleolithic Age some 500,000 years ago. Some of the tools of the Paleolithic Age found in Korea are not found in any other parts of East Asia. The Korean people of the Neolithic Age differed from the Chinese people in that they belonged to what is often called the northern race. Unlike the lineage from the Paleolithic Age, the lineage from the Neolithic Age has continued to survive down to the formation of the Korean people. Elements of the Neolithic Age combined with each other and then with elements of the Bronze Age in the formation of the Korean people.

The highly developed Bronze Age culture in Korea around the year 1000 BCE was influenced by a northern culture that was different from the Chinese scientific one. Chinese science and technology were adopted on the basis of an indigenous technological tradition. Koreans have always attempted to reshape Chinese technology whenever it was introduced into Korea to make it uniquely Korean and to develop new technology.

Typical examples of this kind of endeavor are found in the bronze sword and mirror. The lute-shaped bronze sword and Korean-style sword and the bronze mirror which has a thick lined design with two knobs, and the thin lined mirror, are uniquely Korean bronze instruments. These instruments reveal unique design and casting skills indicating the highly developed state of bronze-making technology. This technology in Korea has a different lineage from that of the Chinese. This is found in the chemical make-up of the bronze instruments themselves. Even the earliest bronzes found in Korea there are alloys of zinc and bronze.

Koreans demonstrated a special creativity by developing an advanced skill in bronze production and alloy making. Bronze makers in Korea used both mud molds and stone molds to produce bronze items. Stone molds, which are frequently found in Korea, are very seldom discovered in China.

Casting technology utilizing stone molds led to the development of a unique iron ax casting system that developed from the third century BCE in Korea. In this period iron axes were produced in massive quantities by using stone molds. It is a commonly held belief that the Iron Age in Korea started in the fifth to fourth centuries BCE with the introduction of Chinese iron culture. The mass production of iron axes can be explained as the creation of a new technology, which would not have been possible if there had not been an autonomous tradition of iron technology in Korea.

The development in iron-casting technology brought about a dramatic increase in agricultural production on the basis of the mass production of farm instruments. Iron ingots of the late Iron Age found in the southern regions of the Korean peninsula are unique symbols of power and wealth. Iron ingots developed by Koreans spread to Japan, setting in motion the development of an iron culture there.

The widespread use of iron brought about new kinds of earthenware. Kaya culture (or Kimhae culture) of the region produced hardened quality earthenware produced through the combination of the technology of the indigenous people of the area (who were known for their designs which lacked ideogrammatic characters) and Chinese ashen-earthenware skills.

Other regions on the Korean peninsula, such as Koguryo, Paekche, and Silla, were also developing a technological culture. The people of Koguryo, Silla, and Paekche each constructed their tombs in unique ways. The painters of the Koguryo tombs painted their walls with individual and powerful lines and colors. The many kinds of pure gold objects discovered in kings' tombs, with their distinctive designs and refined inscriptions, testify to what seems to have been a highly refined manufacturing technology.

Besides those kinds of technical cultural traditions, several examples of scientific inquiry are known to have been written in the Three Kingdoms period (first century BCE–seventh century AD). Among the most outstanding are the developments in astronomy and medicine. Records indicate that Koguryo had maps of stars in the sky inscribed on stones, and a special astronomic observatory. The paintings of the stars found in a mural of Koguryo support this likelihood. Paekche also had astronomical observatories, and special calendrical specialists were appointed in the sixth century.

The Ch'omsongdae observatory in Kyongju is symbolic of the astronomical enterprise of the Three Kingdom period of Korea. Ch'omsongdae, a stone brick edifice, built in AD 647, is the oldest surviving astronomical observatory. The delicate aesthetic lines that characterize Ch'omsongdae are a symbol of the Korean sense of beauty. Records of astronomic observations dating from the Silla period are indications of very active institutionalized astronomical observation in that period. Astronomers in Silla learned calendrical studies from the Chinese, but were not content with just learning or copying from them. They endeavored to develop their own kind of astronomy. Ch'omsongdae is a valuable part of the heritage of their efforts.

Although actual records of medical prescriptions for long life and for the curing of diseases are scanty, they enable us to picture the systematic herbal medicine practiced in the period.

The period of Unified Silla is best represented by the great quantity of surviving remnants and records. Korea achieved a high level of creative development in science and technology in this period.

The Sokkuram grotto and the Darani scripture, among others, are representative of the achievements of Silla science and technology. The grotto, the most highly regarded edifice left by the craftsmen of Silla in the eighth century, is seen as the highest point in traditional architecture because of its geometric design and daring construction skills. There is no doubt that the Sokkuram grotto was a copy of a rock cave temple in China. However, while the Chinese edifice was built into a natural rock cave, the Sokkuram grotto is an artificial stone cave created on the basis of a harmony of various compositions including circles, spheres, triangles, hexagons, and octagons.

Silla master craftsmen also produced a number of beautiful bells. They successfully combined ancient Chinese bells and tinkle-bells in creating a unique Silla style. A special feature of the Silla bells is found in the dragon shaped hooks for hanging them. Historical records assert that Silla's craftsmen produced an alloy of bronze combined with copper, tin, and lead for a better sound. This was found to be true in a chemical analysis. The Chinese naturalist, Li Shizhen, wrote in his *Bencao Gangmu* that "Persian bronze is good for making mirrors and Silla bronze for making bells." The bell preserved in the Kyongju National Museum was made in 771. It has a height of 3.3 m. Its solemnity and the arrangement of its design patterns are typical of Silla bells.

Master craftsmen of Silla began developing wood print type in the early part of the eighth century. The scroll of Darani scripture found in 1966 was assessed to be a wood type print on white hammered paper produced between 705 and 751. This makes it the oldest surviving printed material in the world. On the basis of surviving evidence, this would prove that printing technology was invented in Korea prior to its development in China. Whatever the merits of this claim are, the fact that Silla technology had developed, in the eighth century, to the level of producing wood type print, is a significant demonstration of its technology. It indicates that the gap between the level of technology in China and Silla was not very wide.

The science and technology of Koryo developed on the basis of the achievements of the sciences and technology in Silla. They were also greatly influenced by the Sung and Yuan dynasties in China, and there are signs of the indirect influence of Islamic scientific and technological culture. The representative achievements of science and technology in Koryo are the development of wood block printing, the invention of bronze type printing technology, and the development of Koryo celadon.

Wood block printing in Koryo developed as a result of the aristocratic interest in print copies of calligraphy in pine wood blocks. It was also stimulated by a religious motivation. Buddhist scripts were made into wood type in order to draw on the power of Buddha in the struggle against the Mongol invasion. Eighty Thousand Scriptures, the world's largest and oldest surviving wood block printing set known, was also produced out of this motivation. The printing of the Eighty Thousand Scriptures is regarded as the highest level of technology in wood block printing.

The invention of a bronze type printing system was created from a totally different motivation. Koryo, having less demand for books than China, could not maintain the enormous amount of wood blocks, time, and labor to produce a variety of kinds of books. Bronze type was invented as a solution to this problem.

Ceramic type printing was invented by Bi Sheng in the China of the eleventh century. However, a metal type printing system was not established even by the fourteenth-century because of the difficulties in casting and the ink and paper needed for metal type printing. However, all these were possible with the science and technology available in Koryo. There, craftsmen knew of the technique of producing sand molds to make bronze print type, and were already producing oil ink suitable for printing with metal type and good quality paper. Because of this, the master craftsmen of Koryo were able to invent bronze type from wood type.

The central element in making bronze type was making sand molds. This was one of the greatest contributions in the development of printing technology. It may have been developed from the accumulated knowledge from production of various bronze vessels and casting of the grand bells.

The craftsmen of Koryo were successful in developing their skills for making celadon. They also adopted the inlaying method, which until that time had only been used in metal ornament making, for celadon making. This illustrates that, while Koryo celadon skills were adopted from Sung China they were never a simple copying of the Sung products.

Astronomy and herbal medicine were also two of the central pillars of science in Koryo as in the previous dynasties. Koryo scientists also developed geography. Major efforts in astronomy in the Koryo period were in observational astronomy and in calendar making. Official records of astronomical observations contain records of observation over 475 years. Among the records, there is a record of 132 occasions of an eclipse of the sun. This is on a par with the astronomic records of Islamic astronomers. There are also notable observations of sunspots.

A systematic foundation of herbal medicine in Korea was established from the sixth to the seventh centuries at the height of the Three Kingdom period. It came as a combination of traditional medicinal prescriptions and the influence of medical theories from China. A system was developed for utilizing herbs found in Korea. *Bencao jingjizhu* (The Shennong Pharmacopoeia with Collected Annotations) written by Dao Hungzhing contains 11 medicinal herbs that originate form Korea. And *Ishimpō* (Tamba no Yasayori's Collected Prescriptions), a famous medicinal book in tenth century Japan, contains various quotations of prescriptions from medical texts from Paekche and Silla. By the ninth century, 22 kinds of medicinal herbs originating in Korea were recorded in the medicinal texts used in China and Japan. A national medical school was established in the tenth century, and national examinations for medical practitioners were introduced. In the twelfth and thirteenth centuries, Sung medical science was introduced into Korea, while native prescriptions of local medicines emerged in Koryo in the form of three volumes entitled *Hyangyak kuguppang* (First-aid Measures with Local Medicines). This represented the first medical text describing herbal medicinal practice in the Koryo period.

In the early period of the Choson dynasty, efforts to create an independent culture brought about a forceful development of science and technology. In 1402, King Taejong proceeded with the development of bronze type print despite strong opposition from high ranking government officials. However, the books printed with the newly developed type (*kemi*) were not of better quality than the books printed with wood type. Furthermore, it resulted in lower efficiency in printing one kind of book, and it did not bring about any improvements in cost and labor productivity. It was a low efficiency technology. However, this project provided the basis for greater improvements when the succeeding king adopted it as a state-funded program. As a result Choson type printing developed to a state of perfection.

Achievements in science and technology reached their highest point during the King Sejong period, which is regarded as the golden age of Korean traditional science. The invention of the rain gauge is one of its achievements. Rain measuring instruments and watermarks were developed between 1441 and 1442, enabling the scientific measurement of rainfall. The invention of a cylindrical rain gauge resulted from efforts to obtain a precise measure. As a result the scientists in the court of King Sejong were able to develop a scientific method for the quantitative measurement of natural phenomena. Government officials maintained the measurement and recording of rainfall throughout the country, utilizing a highly systematic method, for over 400 years.

New astronomical observatories were built during the reign of King Sejong. The great equatorial torquetrum observation platform built in Kyongbok Palace contains a torquetrum, armillary clock, armillary sphere, gnomon, direction markers, an automatic striking clepsydra, a jade clepsydra, and various other kinds of sundials. In order to construct these astronomical observatories, which took 7 years to complete, King Sejong sent mathematicians, astronomers, and technicians to China to study astronomical observational instruments. Scientists designed an astronomical instrument that was modeled on the Guo Shoujing system of the Yuan dynasty in China. However, major aspects of the instrument were modified to reflect Korean characteristics. The astronomical observatory built through such a process was the largest of its kind and among the best equipped in the fifteenth century.

Astronomers of the King Sejong period developed an independent calendar on the basis of their observations and calculations. The publication of the calculation of the motions of the seven governors, the inner and outer parts (*Ch 'ilchongsan Naep 'yon* and *Ch 'ilchongsan Oep 'yon*), is the product of such efforts. The outer part is regarded as one of the most authoritative texts written in Chinese characters on Islamic astronomy and calendar science.

The scientific achievements of the King Sejong period were found in all fields of endeavor. Koryo celadon was developed into Punch'ong ware by early Choson craftsmen to produce unique Choson celadons that differed in style and quality from Koryo celadons. A blue and white porcelain was first imported from China during the King Sejong period and began to be produced in Korea from the middle of the fifteenth century. However the geometric shape and design of the porcelain were entirely different from the Chinese originals.

Military technology also developed unique characteristics in the early period of Choson. The development of

Choson style firearms and turtle ships are representative examples. Firearms began to be used widely from the late Koryo period after introduction of the skill from China. However, by the King Sejong period, firearms production in Choson had abandoned a great many of the Chinese features leading to the development of unique firearms. By totally recasting the firearms, which were improved to strengthen the national system, the Choson court, they were modified and standardized until they had their own style.

There were also notable achievements in geography. The map of the world drawn by Choson geographers in 1402, while based on some of the central maps in China, was a more complete one. Although it did not overcome the Chinese world view, it contained a depiction of Europe and Africa and the Far East which can be said to make a true world map with the most up-to-date geographical knowledge.

In the King Sejong period, actual national measurements were undertaken to produce a complete map of the country.

The map of Choson produced in the fifteenth century, currently preserved in Japan, is a map of the highest quality in comparison with others produced in the same period. Geographical scientists in the King Sejong period endeavored, in addition to making maps from thorough field surveys and study of literature, to do proper geographic work that included national and provincial maps.

The field of medicine experienced a total systematization and concentration of Korean herbal medicine and Oriental medicine. Study of local medicinal herbs was collated into a basic foundation for herbal medicine in Korea. It was developed into a comprehensive system for prescription. The *Hyangyak chipsongbang* (Great Collection of Native Korean Prescriptions), in which a total of 703 Korean native medicines were included, was completed in 1433. Concurrent with these efforts was the editing and publishing of *Uibang yuch 'ui* (Classified Collection of Medicinal Prescriptions). This was a medical encyclopedia, completed in 1445, which incorporated 153 different Korean and Chinese texts, and was regarded as one of the greatest medical texts of the fifteenth century. Also, the *Tongui pogam* (Precious Mirror of Eastern Medicine) was completed from 1556 to 1610 by Hochun.

Agricultural technology also experienced great development in the King Sejong period. Much of the agricultural technology in Korea until this period was based on Chinese agricultural texts. However, they could not provide appropriate guidelines for farming in Korea. To provide these, an agricultural technology text, *Nongsa chiksol* (Theories and Practice of Farming), was edited and published in 1429. This book surveyed the various farming methods in different fields and summarized the most developed and practical methods. This book contributed greatly to the improvement in agriculture in Choson and became the basic farming textbook.

However, Korean traditional sciences suffered a series of ruptures along with their creative development. A number of foreign invasions which decimated the entire territory disrupted the creative tradition in Korean scientific endeavors. The history of Korean sciences and technology is at the same time a history of these efforts. The introduction of Western science and the efforts to systematize the traditional sciences and technologies by "Sirhak" scholars from the seventeenth to the eighteenth centuries is just one example. These scholars advocated practical learning (*sirhak*) under the slogan *silsa kusi* (verification of truth on the basis of factual studies), and accepted some of the little European science that came their way. They thus began what might have become a scientific reformation because they were influenced by modern science and technology in Europe through Qing China, where the same kind of movement had been going on for some time, partly as a reaction to mystical tendencies in late Confucian philosophy. Sirhak scholars pioneered new frontiers in scientific and technological theory and scientific philosophy. However, their efforts were frustrated because of the onset of another round of invasions.

See also: ►Maps and Mapmaking in Korea, ►Eclipses, ►Mathematics in Korea, ►Ceramics

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Science of the Native Americans

Ubiratan D'ambrosio

It is commonly accepted practice to refer to the peoples and cultures established in the territory now called the Americas as Native Americans. When the expedition of Christopher Columbus reached the Caribbean Islands in 1492, they called the inhabitants "Indians." This is because of the Spaniards' mistaken view that they had arrived in Asia. Although Columbus himself never realized that he had reached another continent and kept referring to the lands as "Cipango," soon the conquerors realized that they were indeed in a continent as far from Asia as from Europe and dealing with a completely different culture. However, the early chroniclers used the denomination "West Indies" and up to now all the peoples and the cultures native to these newly encountered lands are called Indians.

The denomination "America" also came as the consequence of a fortuitous event. The navigator Amerigo Vespucci, who had visited and described practically the entire coast of the newly found lands, was consulted by German Cartographer Martin Waldseemüller, when he was writing the treatise *Cosmographiae Introductio*, a sort of revised version of Ptolemy's *Geography.* The cartographer, without a name for the new territories added to the original maps, coined the name "Americas" to honor the man who helped them to place these additions to the old maps. This vast amount of land stretched from about the North Pole to the South Pole, between Europe and Asia, roughly in the middle of the waters surrounding the known world. The peoples and cultures of this territory reached by Columbus, strangers to the conception of the world prevailing in the fifteenth century, are mostly referred to as "American Indians." The name Native Americans is not widely used.

The original occupation of the Americas (North, Central, and South) is uncertain. The colonizers have claimed, an obvious political assertion, that the peoples in the Americas were immigrants who arrived from Asia through a glaciation of the Bering Strait no more than 20,000 years ago. Some theories claiming that these peoples are autochthonous were advanced in the early twentieth century, but they were disclaimed on the basis of a lack of scientific support. The best known of these theories is from the Argentinean anthropologist Florentino Ameghino (1854–1911). These claims recur frequently. The theory of a common origin for all of mankind, coming from the heights of Eastern Africa, is the most accepted version for the origin of humans in the Americas. They arrived in migratory fluxes through the Bering Strait, which does not exclude the possibility of ocean access, both through the Atlantic and the Pacific. There is mounting evidence of the presence of humans in these lands since 70000 BCE, but this evidence is very controversial. The most accepted versions place early findings of *Homo sapiens* at about 40000 BCE, without the presence of early hominids.

There is a considerable amount of material relating the impressions of the first Europeans who arrived in the Americas. The first one, the journal of Columbus, is a most important one, but others have also told of the enormous impression made by these peoples and lands on the Europeans. The chroniclers of the conquest reveal their surprise and failure in understanding such different cultures.

Most of the attempts to interpret scientific knowledge in the Americas prior to the arrival of Europeans are limited to a description of what was seen. Buildings, roads, agricultural fields, and artifacts are always listed as evidence of knowledge. Their meaning and cultural context are problematic. An example is the *quipu*, a collection of colored strings with knots, taken as a form of abacus. We now understand these are a very elaborate form of register, both qualitative and quantitative. Also, the wheel appears frequently in pre-Columbian cultures but without the uses so well known in the history of Europe and Asia.

There is a reasonable amount of literature on science and technology in the Americas in the pre-Columbian era written by anthropologists and psychologists. To relate this to the work of historians and philosophers of science and technology is an important step toward a broader understanding of the nature of science and technology and their places in societies. This asks for a clear recognition of the dynamic character of knowledge: from its generation through its organization, both intellectual and social, and through its diffusion. Although these aspects are studied in disciplines such as cognition, epistemology, history, politics, and education, it is practically impossible to understand and explain knowledge in such a fragmented way. This is an important step toward recognizing different modes of thought which lead to different forms of science, which we may call ethnosciences.

Research on the status of knowledge in the Americas in the pre-Columbian period uses methodological instruments and an intellectual posture of classifying it according to accepted, European, views of science. The underlying epistemology is dictated by current scholarship. Thus, research focuses on ethnoastronomy, ethnobotany, ethnochemistry, and so on. The "ethno" prefix stands for "the astronomy of the Aztecs," for example. This reductionist approach does not take into account the meaning of "astronomy" for the Aztecs. This is true for every science. A special situation occurs in the recognition of an ethnomethodology in different cultures. Researchers in this field rely on ethnography, the use of direct observation and extended field research. This produces a naturalistic description of peoples and their culture, uncovering codes, symbols, and categories of analysis which these peoples use to conceptualize, explain, understand, and interpret reality. The generation of these instruments is the essence of studies in cognition and culture. We are thus led to look into the history of science in a broader context, so as to incorporate other possible forms of knowledge, interpretation, and explanation, to deal with nature and natural phenomena.

Generation of knowledge goes on in different environmental settings, according to a multiplicity of stimuli. Practices are created by individuals in response to their immediate needs, motivation, and curiosity, and thus generated, they are intellectually organized as knowledge. A communication system of codes and symbols allows this knowledge to be transmitted informally throughout society and socially organized before it is diffused through education. Its growth into more and deeper knowledge is now a response to further needs and curiosity. These new responses (the *hows* and the *whys*) are incorporated in the pool of common knowledge which keeps a group of individuals together and operational. This is usually called culture.

Cultural forms, such as language, eating and drinking preferences, musical and bodily expression, mathematical practices, religious feelings, familial hierarchy and structure, dressing and behavior patterns, are thus diversified. A larger community is partitioned into several smaller ones, from individuals and their immediate kin to communities and societies, each with distinct cultural variants. The multiplicity of cultural factors is essentially responsible for the dynamic process of the production of new forms of thought and of more sophisticated expressions of the ingenuity of individuals and societies in satisfying their needs of survival and of transcendence. This is the process we call cultural dynamics.

A theory of culture is thus the result of analyzing the intellectual evolution of humankind, focusing on the search for different practices and intellectual tools for explaining, understanding, learning about and managing their natural and sociocultural environment. In "explaining, understanding, learning about and managing," we recognize the Greek root *mathema.* And a natural and sociocultural environment is well expressed by the prefix *ethno.* Thus we have coined the word ethnomathematics to describe the mathematical practices of the day-to-day lives of preliterate cultures. In a broader sense, ethnomathematics is a research program in the history and philosophy of mathematics, with pedagogical implications.

Much has been said about the universality of knowledge, in particular of scientific knowledge. This concept of universality becomes harder to sustain as recent research shows evidence of practices, such as health care and tool use, which are typically scientific, and methodological practices, such as observing, counting, ordering, sorting, measuring, and weighing, all performed in distinctive ways in different cultural environments. This has encouraged further studies on the evolution of scientific concepts and practices within a cultural and anthropological framework. We feel this has been done only to a very limited, and we might say very timid, extent. Indeed, universality of knowledge, more specifically of scientific knowledge, is a fabrication of the colonial ideology.

A new historiography reestablishing authentic universality is needed. There is some agreement about this in several areas of knowledge, but the history of science seems to be immune to this movement. Indeed, the tone of some reviews of recent books and papers in the history of science, in particular mathematics, focusing on this form of redeeming cultural history or proposing a non-Eurocentric view, is discouraging and, sometimes, contemptuous. It is well recognized that the best strategy for hegemony is the suppression of historicity of the subordinates. Here is an example from the history of science: the first nonreligious book published in the New World was Juan Diez Freyle's treatise dealing with the arithmetic of the Aztecs in 1557. Less than a century later, this book had lost its appeal and became completely lost, along with pre-Columbian arithmetic. Freyle's book was ignored and replaced by the arithmetic of the Spaniards.

The suppression of the history of a people involves the removal of all traces of structured knowledge, labeling all forms of knowledge as "popular wisdom," superstition, and folklore.

Early Cultures in the Americas

The early cultures in the Americas are distinct, according to broad ranges of latitude. The peoples in the icy northern regions developed into a culture generally known as Inuit, or Eskimos. Those in the fertile northern prairies and woods of what is the now the United States and Canada, ranging from the Pacific to the Atlantic, were identified under the generic name of "Indians," organized into several distinct nations. Those in the more desert regions neighboring the Rio Grande were distinct nations with a distinguishable urban organization and rather unique architectural forms. South of the Rio Grande, in the highlands of Mexico and Central and South America there are peoples with cultural styles of a rather different nature. These peoples are now called Aztecs in the region around what is now called the Ciudad de Mexico, Mayas in the Central American jungles, mainly southern Mexico and Guatemala, and Incas, spread throughout the mountainous region called the Andes, from the northern part of South America to the northern part of Chile. Aztecs, Mayas, and Incas are called the "high civilizations" of the Americas. In the "lower lands" – coastal areas, the Amazon Basin and subsidiary basins to the South, and much of the territory east of the Andes – other cultures flourished in a very different style. Apart from the high civilizations, and not mentioning those cultures north of the Rio Grande, we have to mention as best organized those located in the Island of Marajo (in the mouth of the Amazon River), with a considerably developed pottery, the agriculturalist Araucanians in the Southern part of South America, and the Guaranis, the latest major group to organize themselves in an agricultural economy, in central South America.

The Aztecs are distinguished by a monumental religious architecture, with abundant pyramids with precise designs to accommodate astronomical data. The Aztec Calendar reveals these achievements. Sculpture was at a level of sophistication comparable to civilizations in the Old World. Commerce was developed and practiced in large fairs. They used numbers and measures, but had no commerce by weight. The Aztecs were skilled workers in ceramics and in metals (gold, silver, copper, tin, and bronze). They had hieroglyphic writing, using colors which endure to the present day, literature, and a school system.

The Mayas had distinctive urbanization styles. Stone pyramids, temples, and palaces, decorated with very elaborate sculptures, were religious centers, and the population was spread in the surrounding jungles. These centers appear to have been temporary. One hypothesis is that they were abandoned as new ones became ready – another possibility is that the mobility was the result of destruction by wars. These peoples had a very advanced astronomy, with data comparable to those available to the Europeans. From the sixth century, they had developed the zero and positional number system, thus producing an advanced arithmetic. They also had a pictorial writing system which was not recognized as such by Europeans. Some early translators relied on reports of books and documents without recognizing this as reading.

Among the classics of their literature we have the elaborated description of the origins of the world and men, the *Popol Vuh*, a book written in the mid sixteenth century, in Central America. The book describes, simultaneously, the myths of origin, the history of kings and the peoples of the region, as well as the catastrophe of the Spanish conquest.

Also very important is the book of natural phenomena, the *Chilam Balam*. It describes a myth of origins, similar to the *Popol Vuh*, when gods of the underworld kept the universe captive. Also of great importance is the war drama *Rabinal Achi*, a piece showing the existence of a form of ritual theatre. It is typical of the post-Classical period of the Maya civilization, from the tenth to the fifteenth centuries. Maya cultures developed a series of artistic expressions which included dancing, theater, music, and literature.

The third high civilization, known as the Incas, took the name after their monarch. The Inca was the highest religious, civilian, and military authority. Although succession was by blood, the successor was not necessarily the eldest son. Like the Aztecs, the religion of the Incas was focused on the divinity of the Sun, and human sacrifices were common. The architecture of the Incas was of a varied nature. Visitors still marvel at what is called cyclopic architecture, buildings and palaces constructed using enormous stones, as in Machu Picchu, Peru.

The early history of these cultures reveals a great dispersion of nomadic groups, with an economy of hunters and collectors. In general, in all of the Americas, animal domestication was modest. In Mexico, turkeys were domesticated; in Peru the llama and the alpaca, as pack animals and for textiles, were also domesticated, as were dogs and some rodents. Some tribes farmed turtles, some bees and birds, mainly parakeets and parrots. Fish from the coasts of Peru were consumed in the high altitudes, transported, and preserved through a sophisticated system of utilization of natural ice.

Agriculture was much more developed. About 6000 BCE we see evidence of the domestication of plants, mainly in the northern region (north of Mexico and southeast United States), among them squash, cotton, and several species of beans. The important development of maize (*Zea mays*) opens up a new era in the development of agriculture and the settlement of people in larger regions, which characterizes the urbanization period. There is much controversy about when this occurred. A recent academic argument about the occurrence of maize in Panama, 5000 versus 3000 BCE, is more important for revealing the search for a new historiography for science and technology in pre-Columbian Americas than for the dating question itself.

Intensive Agriculture and Urbanization

Up to the beginning of the Christian era we see the formation of agricultural cultures. They developed different techniques, using fire, intensive irrigation, fertilization, and terrace agriculture. Agriculture was the main subsistence form and the determinant of the political struggles and the development of economy.

A special and unique type of building, characterized by yards built with stone walls, was recently located in the center of a village in La Puntilla, Peru. There are indications that these buildings, dating about 2,000 years ago, were for centralized work, and not for ceremonies. Other findings, such as finding manufactured products in domestic units, reveal an organized structure for distribution of the production, suggesting the existence of a dominant class controlling production. An intense craftsmanship, which included making andesite and obsidian tools, manufacturing ornaments of marine shells, weaving and spinning, and agricultural processing tasks are present. It is also notable that some of the raw material used in the crafts, as for example spondylus shells, are not local, but brought from distant lands, probably the coastline of Ecuador.

As we advance in time, around the second millennium AD we see the development of a variety of urban styles, the weaving of cotton and wool, pottery and ceramics, statuary, metallurgy, especially work in gold, ritual decoration, and architecture. We notice the development of several forms of pyramids, possibly evolving from the common funerary mounds, and other forms of religious architecture. Ceremonial dressing is varied, with feathers, plants, animals, painting, and bright colors. The period also reveals, probably as a consequence of the permanent struggle for land, the development of a variety of languages, with more than two thousand distinct languages or dialects. In the lower lands there is considerable development of agriculture, mainly manioc or cassava (*Manihoc utilissima*) and sweet potatoes (*Ipomoea batatas*).

There is also evidence of an intense coastal commerce. Indeed, navigation in the Pacific seems to be highly developed among the Andean cultures. There is recent evidence of Japanese arrivals in what is now Ecuador about 3000 BCE. Also, there is a possibility of commercial exchanges between China and South America in the first century AD, and contacts between Mexico and Africa in the first millennium are most probable. There are no doubts about the practice of considerably advanced navigation among the high civilizations.

There is much controversy about the development of a written/pictorial form of language. As mentioned above, recent findings reveal a written language among the Mayas. They also developed calculations, especially for astronomical and commercial purposes, with a sophisticated vigesimal (base 60) system. The register of historical and statistical data was rather sophisticated, as with the surprisingly powerful *quipus* among the Incas. Calculating devices, such as the *yupana*,[1] reveal theoretical approaches as yet not sufficiently studied. We are just beginning to recognize the formal knowledge – logic, mathematics, philosophy – possessed by these cultures.

Colonial discourse was absolutely biased in saying that the American peoples were not highly developed. Agriculture was developed in Asia in the eighth millennium BCE, while there is evidence that it was developed in Mexico only in the fifth millennium BCE. Ceramics and pottery are seen in Asia about 6000 BCE, while they appear in 3000 BCE in the northeast of South America. Proto-literacy is recognized in Mesopotamia about 3300 BCE, but in Mesoamerica only about 800 BCE. Urban cultures are seen in Egypt and Mesopotamia using writing and bronze about 2800 BCE, while limited writing and metallurgy are identified in urban complexes of Mexico and Peru only in the beginning of the Christian era.

What was going on in the centuries preceding the arrival of Columbus was a political process very similar to that which took place in Europe during the Middle Ages, when principalities and other smaller domains were uniting into larger organizations such as kingdoms and nations. The Spanish conquerors were able to take advantage of the local conflicts in destroying the emergent power elites and replacing them with the power of the conqueror, based on a well-balanced State/Church structure controlling the means of production. Although effective production was in the hands of natives, the conqueror assumed the role of the native monarchy in controlling the centralized system. Even now, production is, to a great extent, done by impoverished natives. A 1950 study showed that in Bolivia about four thousand native communities were responsible for about 25% of the agricultural production. The conqueror succeeded in deepening these conflicts. As a result, today different cultures, even different tribes, do not recognize their common history. In the lower lands, East of the Andes and the Amazon Basin and subsidiary basins in the South, and mainly in the Atlantic coast, the strategy was no different.

As we have said before, knowledge is generated as a permanent activity of human beings. It is carried out by individuals and groups of individuals in different environmental settings, according to a multiplicity of stimuli. Among the several stimuli, we have to consider cultural encounters and mutual exposition of different modes of thought. In the evolution of cultural forms subjected to mutual exposition, the possibilities are: first, an absolute domination of one form, either leaving the others in the state of latency or leading them to an eventual total elimination; and second, allowing coevolution, which eventually leads to new cultural forms. This second possibility occurs in systems which are tolerant of the different, of the stranger. Thus, our analysis of the formation of scientific knowledge and the development of technology among the civilizations of Latin America necessarily goes through an analysis of the occupation of territory and the development of means of production.

To conceptualize modes or styles of development is crucial for better understanding the evolution of native knowledge systems, in particular science, in the Americas. The Latin America Economic Commission of the United Nations proposed, in the 1960s, the conceptual basis for development. Development is understood as a strategy resulting from political agreement or group alliances, with the objective of reaching a common goal. Thus a model of development is the result of the power structure and of the social conflicts resulting of the prevalent forms of capital accumulation and distribution of richness. These are based on a complex of historical circumstances that go back to the conquest, colonial period and the early decades of independence. These internal and external conjunctures are in conflict with the values intrinsic to the cultures. To understand the native knowledge systems a new historiography is needed, anchored in the concept of models of development.

See also: ►Metallurgy, ►Animal Domestication, ►Astronomy, ►Mathematics, ►Writing among the Maya, ►*Quipu*, ►Ethnomathematics, ►Knowledge

[1] See ►http://www.quipus.it/english/Andean%20Calculators.pdf for a detailed discussion of Andean Calculators.

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Systems of the Incas, ►Aztec Science, ►Calendar, ►Weights and Measures, ►Stonemasonry

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Science of the Ottomans

Ekmeleddin Ihsanoglu

The term "Ottoman Science" covers the scientific activities in the Ottoman Empire which was spread over a vast geographical area.

These scientific activities comprise various scientific traditions, including the Islamic tradition inherited by the Ottoman Turks and carried on by the Arabs, who were part of the Empire; then came the traditions of the European people such as the Bosnians and Albanians who had converted to Islam, as well as those of different Christian peoples living in Anatolia and the Balkans, followed by the contributions of native Jewish scholars who emigrated to the Ottoman lands from Andalusia. The Ottoman world had the necessary grounds for the interaction of all these different traditions. The Empire held vast lands in Europe and, as a result of their contact with European science from the very early ages, the new scientific European tradition spread in these lands for the first time outside its own cultural environment where it originated.

The Ottoman Empire that was founded as a small principality at the turn of the fourteenth century gradually expanded into the lands of the Byzantine Empire both in Anatolia and the Balkans, while its sovereignty reached the Arab world after 1517. It became the most powerful state of the Islamic world covering a vast area extending from Central Europe to the Indian Ocean and persevered by keeping the balances of power with Europe. Following its defeat in First World War, the Ottoman Empire came to an end in 1923.

Ottoman science emerged and developed on the foundations of the scientific legacy and institutions of the pre-Ottoman Seljukid period in Anatolian cities and benefited from the activities of scholars who came from Egypt, Syria, Iran, and Turkistan, which were the most important scientific and cultural centers of the time. The Ottomans enriched the cultural and scientific life in the Islamic world by a new dynamism and the Islamic scientific tradition reached its zenith in the sixteenth century. Besides the old centers of Islamic civilization, new centers flourished such as Bursa, Edirne, Istanbul, Skopje, and Sarajevo. The heritage that developed during this period constitutes the cultural identity and scientific legacy of the present-day Turkey as well as several Middle Eastern, North African, and Balkan countries. This article aims to give an overview of the formation and development of Ottoman science in Anatolia and the scientific activities which later expanded from Istanbul, the capital of the Empire, to the Ottoman lands, with the exception of the scientific activities related to non-Muslims due to insufficient studies and researches at hand.

The Ottomans always searched for solutions to the intellectual and practical problems they encountered in Islamic culture and science. Since the early periods, their attitude toward European science and technology was a selective acceptance. After the scientific and industrial revolutions in Europe, there appeared a gap between the Ottomans and the Western world. However, the Ottomans began to make some selective transfers from Western science and gradually the scientific tradition began to change from "Islamic" to "Western." For this reason Ottoman science should be studied under two headings: Classical Islamic Tradition and Modern Western Tradition. Although it is difficult to separate the two traditions in the transition period in a clear cut way, the demarcation between the two traditions became more evident as their contacts became more frequent.

In the classical period, the *medrese* (in Arabic *madrasa* "college") was the source of education and science and the most important institution of learning in the Ottoman Empire. The Ottoman medreses continued their activity from the time of the foundation of the State until approximately the turn of the twentieth century. The basic structure of the medreses remained the same within the framework of the Islamic tradition, but in terms of organization they underwent several changes during the Ottoman period. Starting with the first medrese, established in 1331 in Iznik (Nicaea), all medreses had *waqfs* (charitable foundations) supporting their activities.

Besides the *ulemā* (scholars who were medrese graduates) that provided religious, scientific and educational services, the medreses also trained the personnel for administrative and bureaucratic posts and the courts. Those ulema who were members of the *ilmiye* (Muslim learned, cultural, and religious institution) also played an important role in every aspect of the social and official life. With the reign of Mehmed II (Fatih, known as the Conqueror, 1451–1481), the number of medreses increased considerably and they were graded to differentiate them from each other.

Shortly after Mehmed II conquered Istanbul in 1453, he built the Fatih complex (*Külliye*) (1463–1470) which comprised a mosque at the center with other units located around it, also colleges, one hospital, one *mektep* (primary school), one public kitchen, setting an example for similar institutions that were built by the succeeding sultans and high-ranking members of the ruling class. The structure of an integrated campus was represented by the *Sahn-ı Semān Medreses* (Eight Court Colleges) of the Fatih Complex that comprised sixteen adjacent medreses. Owing to the political stability and economic prosperity of the Conqueror's period, distinguished scholars and artists of the Islamic world assembled in the capital of the Empire. The Ottomans especially protected the Muslim and Jewish scientists fleeing from the persecution that followed the fall of Granada in 1492 and provided them with shelter in the Ottoman lands. Moreover, as the waqfs which were the financial sources of medreses grew rich, scientific and educational life developed further. Following the establishment of the eight court medreses by Mehmed II, the rational sciences comprising mathematics and astronomy, were included in the formal educational system.

The medrese graduates served as teachers, *qādīs*, *kazaskers* (chief judges) and chief *muftis.* Several physicians were trained and many patients were treated in the *daruşşifa* (hospital) of the Fatih Complex which was active until the middle of nineteenth century. It provided services to the society in the fields of religion, education, science, and health, as well as offering food to the needy in its public kitchens. As of the second half of nineteenth century, the Fatih Complex gradually became ineffective, its various units, namely the hospital, *tābhāne* (hospice), *muvakkithāne* (office of the timekeeper), caravanserai and the primary school stopped operating. Finally, after all the medreses were discontinued in the Republican Period in 1924, its colleges, too, were closed down. The mosque, however, continues its principal function from the time of its establishment until the present day.

The establishment of the Süleymaniye complex (*Külliye*) by Süleyman the Magnificent (1520–1566) in the sixteenth century marked the final stage in the development of the medrese system where, besides the conventional medreses, a specialized (Medical College) *Dārüttıb* was founded (1550–1557). Thus, for the first time in Ottoman history, in addition to the *şifahānes* (hospitals), an independent institution was established to provide medical education. The other specialized medreses established by the Ottomans were the *Dārülhadīs* and the *Dārülkurrā. Dārülhadīs* held the highest grade in the medrese hierarchy.

In addition to the medreses, there were institutions where medical sciences and astronomy were practiced and taught by the master–apprentice method. These were the șifahānes, the muvakkithānes and the office of the *müneccimbaşı* (chief astronomer of the sultan).

The institutions which provided health services and medical education were called *dārüşşifa*, *şifahāne*, or *bīmāristan.* The Seljukids had built *dārüşşifas* in the cities of Konya, Sivas, and Kayseri. Similarly, the Ottomans built several dārüşşifas in cities such as Bursa, Edirne, and Istanbul. Some Western sources mention that in Istanbul they were numerous in number in the sixteenth and seventeenth centuries, which is an indication of the importance attributed to them. The Ottoman dārüşşifas were not independent buildings but were constructed as part of the külliyes.

In the Ottoman palace administration, the müneccimbaşı was the head of the astronomers and this position was established sometime between late fifteenth and early sixteenth centuries. They were selected from among the ulemā who were medrese graduates. From sixteenth century onward, they were entrusted with the preparation of calendars, fasting timetables, and horoscopes for the palace and prominent statesmen. Until 1800, the calendars were made according to the *Zīj* (astronomical handbook) of Uluğ Bey (Ulugh Beg); after that, the *Zīj* of Jacques Cassini was used. The chief astronomer and sometimes a senior astronomer fixed the most propitious hour for important events such as imperial accessions, births, wedding ceremonies, the launching of ships, wars, etc., as well as lesser events. Moreover, the chief astronomers followed extraordinary events such as earthquakes and fires as well as astronomical occurrences such as the passage of comets, solar, and lunar eclipses and passed on the information to the palace with related interpretations. The observatory founded in Istanbul was administered by chief astronomer Taqī al-Dīn al-Rāsıd (d. 1585) who was the greatest astronomer of the period. Thirty-seven people held the post of chief astronomer until the end of the Empire in 1923. Muvakkithānes were also under the supervision of the müneccimbaşı.

The timekeepers' offices were public buildings located in the courtyards of mosques or *masjids* in almost every town. They were mostly built after the conquest of Istanbul and administered by the waqfs. *Muvakkits* were the officials that worked at the muvakkithānes and kept the time, specifically the prayer hours. The following major instruments were used in timekeeping: quadrant, astrolabe, sextant, octant, hourglass, sundial, mechanical clock, and chronometer. Depending on the level of the timekeepers' knowledge, the muvakkithānes also functioned as locations where astronomy was taught and simple observations were made.

The Ottoman scientific literature in the classical period was produced mainly within the milieu of the medrese. Scholars compiled several original works and translations in the fields of religious sciences, mathematics, astronomy, and medicine, besides a great number of text-books. These works were written in Arabic, Turkish, and Persian, the three languages called *elsine-i selāse* which were known by the Ottoman scholars. At the beginning, the literature was mostly written in Arabic, but from fifteenth century onward, Turkish was used more often. As of eighteenth century, the majority of scientific works were written in Turkish and upon the establishment of the first printing house in Istanbul in 1727, Ottoman Turkish became the most frequently used language in the transfer of modern sciences.

In recent years, on account of the increasing research and studies on the survey and cataloging of Ottoman scientific literature, our knowledge of Ottoman literature on astronomy, mathematics, and geography has been enriched to a great extent and many new aspects of scientific activities of the Ottoman period were revealed. The results of these studies also illustrate with complete clarity the intensity of scientific activities carried out by the Ottomans. The examination of this literature shows that a total of 582 authors produced 2,438 works on astronomy; 491 authors that we were able to establish produced 1,116 works on mathematics and 458 authors produced 825 works on geography.

Statistics show that the total number of astronomical works is more than the number of mathematical works. This situation stems from the fact that calendars specifically occupied an imported place in astronomy literature. A continuous increase is observed in the number of works in these three disciplines until the eighteenth century. The number of works attained their maximum in the eighteenth century and then started to decrease. As for mathematics, the total number of works continued to increase except for the eighteenth century. Works on mathematics, which recorded a major increase especially in the nineteenth century, attained the maximum in the twentieth century. There is also an increase in the total number of works on geography similar to that of mathematics. The rates of increase of the works in these three subjects are close to each other.

Bursalı Kadızāde-i Rūmī (d. 844 AH/AD 1440, also known as Qādī Zādeh al-Rūmī) made the first important contribution to the development of the Ottoman scientific tradition and literature. He was tutored in Anatolia and settled in Samarkand after he compiled his first work. Qādī Zādeh wrote *Sharh Mulakhkhas fi'l-Hay'a* (Commentary on the "Compendium on Astronomy") and *Sharh Ashkāl al-Ta'sīs* (Commentary on "The Fundamental Theorems" of Geometry) in Arabic and became the chief professor at the Samarkand medrese and the director of the observatory founded by Ulugh Beg (d. 853/1449) in Samarkand. He was also the coauthor of *Zīj-i Jurjāni* (The Astronomical Tables of Ulugh Beg) written in Persian. He simplified the calculation of the "sine of a one degree arc" in his work *Risāla fi Istikhrāj Jaybi Daraja Wāhida* (Treatise on the Calculation of the Sine of a One Degree Arc). Qādī Zādeh's two students from Turkistan, Ali Kuşçu (d. 879/1474) and Fathullāh al-Shirwānī (d. 891/1486), influenced the Ottoman science by disseminating the scientific legacy of the Timurid period in the Ottoman Empire. In the preface of his work *Sharh Ashkāl al-Ta'sīs*, Qādī Zādeh indicated that "the philosophers who ponder about the creation and the secrets of the universe, the jurists (*faqihs*) who give *fetvās* in religious matters, the officials who run the affairs of state, and the *qādis* who deal with judicial matters should know geometry." Thus, he emphasized the necessity of science in philosophical, religious, and worldly matters. This understanding reflects a general characteristic of Ottoman science in the classical period. In the period of modernization, however, the Western concept of man's domination of nature through science and technology was foreign to Ottoman scholars.

Other astronomy books of this period included *Urjuza fī Manāzil al-Qamar wa Tulu'ihā* (Verses on the Mansions of the Moon and their Rising) and *Manzuma fī Silk al-Nujūm* (Verses on the Orbits of the Stars) written in Arabic by 'Abd al-Wahhāb ibn Jamāl al-Dīn ibn Yūsuf al-Maridānī. Two books titled *Risāla fi'l-Taqwīm* (Treatise on the Calendar) and *Sī Fasl fi'l-Taqwīm* (Thirty Sections on the Calendar) by Nasīr al-Dīn al-Tūsī, the founder of the Marāgha school, were translated from Persian into Turkish. Ahmed i Dā'ī (d. ca. 825/1421) was the translator of the second work.

During this period, Egypt was another source for Ottoman science. Hacı Paşa (Celaleddin Hıdır) (d. 1413 or 1417), a well known physician of the time who was educated in Egypt, wrote two books in Arabic titled *Shifa' al-Asqām wa Dawā' al-ālām* (Treatment of Illnesses and the Remedy for Pains) and *Kitāb al-Ta'ālīm fi'l-Tibb* (Book on the Teaching of Medicine) which played an important role in the development of Ottoman medicine. He had many other works in Turkish and Arabic. The works written by Sabuncuoğlu Şerefeddin (d. ca. 1468) on the subject of medicine have an important place in the development of Ottoman medical literature. His first work in Turkish on surgery called *Jarrāhiyāt al-Khāniyya* is composed of the translation of a section on surgery from the general medical book *al-Tasrīf* by Abu'l-Qāsım Zahrāwī, the famous Andalusian physician and surgeon, and three additional sections that he wrote himself. The work, in addition to the classical Islamic medical knowledge, reflects the influence of Turkish–Mongolian and Far Eastern medicine as well as the author's own experiences. The influence of Sabuncuoğlu was observed outside the Ottoman borders, specifically in Safavid Iran. Miniature paintings that depict surgical operations are one of the most significant features of this work that attained great fame in the history of medicine.

Ottoman science developed further owing to the keen interest of Mehmed II and the educational institutions which he established after the conquest of Istanbul. Consequently, some brilliant scholars emerged in the fifteenth century and made original contributions to science in this period. Mehmed II patronized the Muslim scholars, meantime he instructed Georgios Amirutzes, the Greek scholar from Trabzon, and his son to translate Ptolemy's *Geography* into Arabic and to draw a map of the world. Patriarch Gennadious prepared a book on the Christian belief titled *I'tikādnāme* (The Book on Belief) for him; the works *Geographia* and *De re Militari* by Francesco Berlinghieri and Roberto Valtorio, respectively, were presented to him by the authors. The Sultan's interest in European culture had started while he was a *şehzāde* (prince) at the Manisa Palace in 1445 where Italian humanist Ciriaco d'Ancona and other Italians taught him Roman and European history. Mehmed II also encouraged the scholars of his time to produce works in their special fields. For example, Hocazâde and 'Alâ al-Dîn al-Tusî were both asked to compare Ghazali's *Tahâfut al-Falâsifa* (The Inconsistency of the Philosophers) which criticized the views of peripatetic philosophers regarding metaphysical matters and *Tahâfut al-Tahâfut* (The Inconsistency of the Inconsistency) written by Ibn Rushd as a response to Ghazali's work.

The most notable scientist of the Mehmed II period was Ali Kusçu, a representative of the Samarkand tradition. He wrote 12 works on mathematics and astronomy, among them his commentary on the *Zīj-i Uluğ Bey* in Persian. His two works in Persian, namely *Risāla fi'I- Hay'a* (Treatise on Astronomy) and *Risāla fi'l-Hisāb* (Treatise on Arithmetic) were taught in the Ottoman *medrese*s. He rewrote these two works in Arabic with some additions under new titles, *al-Fathiyya* (Commemoration of Conquest) and *al-Muhammadiyya* (The Book Dedicated to Sultan Muhammed), respectively. Another noteworthy scholar of the Sultan Bayezid II period (1481–1512) was Molla Lūtfi. He wrote a treatise about the classification of sciences titled *Mawdu'āt al-'Ulum* (Subjects of the Sciences) in Arabic and compiled a book on geometry titled *Tad'īf al-Madhbah* (Delos Problem) which was partly translated from Greek. Mīrīm Çelebi (d. 1525), a well-known astronomer and mathematician of this period and the grandson of both Ali Kuşçu and Qādī Zādeh, contributed to the establishment of the scientific traditions of mathematics and astronomy and was renowned for the commentary he wrote on the *Zīj* of Ulugh Beg.

Some Jewish scholars who found shelter in the Ottoman Empire after the fall of Granada in Spain, (1492) also contributed to the Ottoman scientific literature. Among them the medical and astronomical works in Arabic written by Ilya ibn Abram al-Yahudī, the Andalusian scholar who settled in Istanbul during the reign of Bayezid II and changed his Jewish name to 'Abd al-Salām al-Muhtadī al-Muhammadī (sixteenth century) after embracing Islam, are examples of such contributions. In a treatise which he wrote in Hebrew and later translated into Arabic in 1503, he introduced the instrument of his own invention called *al-Dābid,* and stated that it was superior to the *Dhāt al-halaq* (armillary sphere) invented by Ptolemy. This treatise illuminates an aspect of Ottoman scientific literature which is not much known. Scientific literature developed considerably in the period of Süleyman the Magnificent. We find two major mathematical books in Turkish titled *Jamāl al-Kuttāb wa Kamāl al-Hussāb* (Beauty of Scribes and Perfection of Accountants) and '*Umdat al-Hisāb* (Treatise on Arithmetic) by Nasuh al-Silāhī al-Matrāqī (d. 971/1564). His book in Turkish titled *Beyān-ı Menāzil-i Sefer-i Irakeyn* (Description of the Stopping Places of the Campaign to the Two Iraqs) related to geography, should also be mentioned. Musā ibn Hāmūn (d. 1554), another famous Jewish physicians of Andalusian descent who was Sultan Süleyman's physician, wrote the first Turkish book on dentistry. It was one of the earliest independent works on dentistry and was based on Greek, Islamic, and Uighur Turkish medical sources and in particular on Sabuncuoğlu Şerefeddin's works.

In the sixteenth century, important works on astronomy were written by the representatives of the Egypt-Damascus tradition of astronomy–mathematics. In 1570 Taqī al-Dīn al-Rāsıd came to Istanbul from Egypt, and in 1571 he was appointed müneccimbaşı by Sultan Selīm II (1566–1574). He combined the Egypt-Damascus and Samarkand traditions and wrote about thirty books in Arabic on mathematics, astronomy, mechanics, and medicine. Shortly after Sultan Murād III's (1574–1595) accession to the throne, he started the construction of the Istanbul observatory. This institution was conceived as one of the largest observatories in Islam and was comparable to Tycho Brahe's Uraienborg observatory built in 1576. There is a striking similarity between the instruments of Tycho Brahe and those of Taqī al-Dīn. In his astronomical tables called *Sidrātü Munteḥā'l Efkār* (The Lotus Tree of the Extremity of Thoughts), Taqī al-Dīn states that he started the observations in Istanbul in 1573 with 15 assistants. The observatory was demolished on 4 Dhu'l-Hijja 987 corresponding to 22 January 1580.

Therefore, it can be estimated that he carried out observations from 1573 until 1580.

Taqī al-Dīn invented new instruments that were added to those already in use for observations in the Islamic world. The instruments that he used were (1) armillary sphere, (2) mural quadrant, (3) azimuthal quadrant, (4) parallel ruler, (5) ruler-quadrant or wooden quadrant, (6) an instrument with two holes for the measurement of apparent diameters and eclipses, (7) *Dhāt al-awtār* an instrument with chords to determine the equinoxes, invented by Taqī al-Dīn to replace the equinoctial armillary, (8) *Mushabbaha bi l-manātiq*, another of his inventions, the nature and function of which is not clearly explained, (9) mechanical clock with a train of cogwheels, and (10) *sunaydi* ruler, apparently a special type of instrument of an auxiliary nature, the function of which was explained by Alaeddin el-Mansur. Taqī al-Dīn used a mechanical clock of his own make, as well as a wooden wall dial that he set up in the observatory. He described the clock with the words: "We built a mechanical clock with a dial showing the hours, minutes, and seconds and we divided every minute into 5 seconds." This was a more precise clock than those previously used and it was considered to be one of the significant inventions in the field of applied astronomy that was developed during the sixteenth century.

Taqī al-Dīn found a different method of calculation to determine the latitudes and longitudes of stars by using Venus and the two stars near the ecliptic, i.e., Aldebaran and Spica Virginis. He determined that the magnitude of the annual motion of the Sun's apogee was 63″. Considering that the value known today is 61″., the method he used appears to be more precise than the methods of Copernicus (24″.) and Tycho Brahe (45″.).

Starting with Ptolemy in the second century AD and continuing until Copernicus in the sixteenth century, the Western world used chords for measuring angles. For this reason, the calculation of the value of the chord of (1°) was an important matter for astronomers. Thus, while Copernicus used the method based on the calculation of the chord of (2°) that yielded an approximate value, Taqī al-Dīn used trigonometric functions such as the sine, cosine, tangent, and cotangent to measure the values of angles, in line with the tradition of Islamic astronomy. Inspired by Ulugh Beg, Taqī al-Dīn developed a different method for the calculation of the sine of (1°). Furthermore, he applied decimal fractions to astronomy and trigonometry which had been previously developed by Islamic mathematicians such as al-Uqlidīsī and al-Kashī; prepared sine and tangent tables accordingly and used them in his work titled *Jarīdat al-Durar wa Kharīdat al-Fikār.*

Ottoman scientific tradition reached its highest level in the sixteenth century, meanwhile the scholars began to follow the innovations that developed in Europe in a selective way. Within this framework, the Islamic world first came into contact with the Copernican astronomy around the middle of seventeenth century. The earliest work that was translated from European languages on this subject is the astronomical table by French astronomer Noel Duret (d. ca. 1650) called *Nouvelle Thèorie des Planétes* which was printed in Paris in 1635. Ottoman astronomer Tezkereci Köse Ibrahim Efendi of Szigetvâr translated this work in 1660 under the name of *Secencelü'l Eflak fî Gayeti'l İdrak* (Mirror of Revolving Spheres of Heaven on the Limits of Perception) which mentioned Copernicus' heliocentric system of the universe. The first reaction to this book came from the chief astronomer Mehmed Efendi who said: "Such presumptuousness is abundant among the Europeans." However, after learning its application from the translator and comparing it with the *Uluğ Bey Zic* (The Astronomical Tables of Uluğ Bey), he appreciated the work and awarded the translator. The initial reaction of the chief astronomer is a typical example of the cautious approach of the Ottomans who were sure of their own scientific tradition and acquisitions and did not immediately accept the scientific superiority of the West.

The basic concept of the perception of the new astronomy of Copernicus with "the sun at the center of the universe and the earth in motion" which created major disputes in Europe was not taken up as a subject for polemics; for the Ottoman astronomers there was no religious dogma against it. Until modern astronomy lessons were started at the new educational institutions established in the last quarter of the eighteenth century and the beginning of the nineteenth century, the majority of the works on astronomy translated from European languages were composed of astronomical tables.

The Ottomans needed the knowledge of geography in order to determine the borders of their continuously expanding territory and to establish control over the military and commercial activities in the Mediterranean, the Black Sea, the Red Sea, and the Indian Ocean. They made use of both the geographical works of classical Islam and works of European origin. By adding their own observations, Ottoman geographers produced original works as well. The first source of the Ottoman knowledge of geography is the Samarkand tradition of astronomy and geography.

From sixteenth century onward, noteworthy geographical works were produced by Pirī Reis. In 1511, Pirī Reis drew his first world map and presented it to Sultan Selim I in 1517. A section of this map is now kept at the Topkupi Museum in Istanbul. It was drawn on the basis of a number of Islamic and European maps including Columbus' map of America. This first Ottoman map which included preliminary information about the New World showed southwestern Europe, northwestern Africa, southeastern and Central America; it was a portolano, without the latitudes and longitudes but with lines delineating coasts and islands. Pirī Reis drew his second map and presented it to Süleyman the Magnificent in 1528. Only the part which showed the North Atlantic Ocean and the newly discovered areas of the time that comprises North and Central America is now extant. Pirī Reis also wrote the book *Kitāb-ı Bahriye* (Book of the Sea) in Turkish in 1521. In this work, he presented drawings and maps of the cities on the Mediterranean and Aegean coasts and gave extensive information about navigation and nautical astronomy. Admiral Seydi Ali Reis (d. 1562) was the author of the work titled *al-Muhīt* (The Ocean) in Turkish; he was a notable figure in maritime geography in his period. This work contains astronomical and geographical information necessary for long sea voyages and his own observations about the Indian Ocean.

Another work of the sixteenth century which contains information about the geographical discoveries and the New World is the book titled *Tārih-i Hind-i Garbi* (History of Western India). This anonymous work based on Spanish and Italian geographical sources was presented to Murād III in 1583. It is important in showing that the geographical discoveries of the West were known to the Ottomans. The work has three parts; the third part, which is the most important one comprising two thirds of the whole book, relates the adventures of Columbus, Balboa, Magellan, Cortes, and Pizarro within the 60 years that started with the voyage to America between 1492 and 1552.

In the seventeenth century, cartography was organized as a profession in the Ottoman Empire; 15 individuals were occupied with the art of surveying in eight locations in Istanbul.

With the sixteenth century, some European physicians arrived in the major Ottoman cities, mainly Istanbul. Meanwhile the spread of many infectious diseases of European origin brought new methods of treatment, preventive steps and ideas. The new medical doctrines of Paracelsus (d. 1541) and his followers, the theories, and applications of treatment with chemical substances which became widespread in Holland in the seventeenth century and the new iatrochemistry appeared in the Ottoman medical literature with the names of "tıbb-ı cedid" (modern medicine) and "tıbb-ı kimyevî" (chemical medicine). Salih b. Nasrullah b. Sellüm (d. 1670), one of the most famous followers of these developments, quoted many European sources in his work called *Nüzhetü'l Ebdan* (Pleasure of Bodies) and noted the compositions of their medicines. Furthermore, he translated Paracelsus' work on iatrochemistry from Latin into Arabic. In the same manner, el-İznikî (d. eighteenth century) also prepared his work called *Kitab-ı Künüz-i Hayat el İnsan Kavanin-i Etibba-ı Feylesofan* (The Book on the Treasury of the Life of Humans and the Laws of the Philosophers–Physicians) where he presented the old and the new medicine together by making use of the works of the European physicians along with Arabic, Persian and Ancient Greek sources. Ömer Sifaî (d. 1742) stated that he translated his work called *el-Cevher el-Ferid* from European languages into Turkish and the medicines in the book were taken from the books in Latin written by European physicians. Thus, in the Ottoman medical literature, the new medical knowledge and methods of European origin were quoted together with the traditional knowledge of medicine and methods until the beginning of the nineteenth century.

Ottoman medical literature carried both the classical Islamic and the European medical information until the beginning of the nineteenth century when Şānīzāde Atāullah (d. 1826) wrote his work titled *Hamse-i Şānīzāde* (Five Works of Şānīzade) composed of the following branches of medicine: anatomy, physiology, pathology, surgery, and pharmacology. These were based totally on modern European sources without any reference to traditional medicine.

The famous Ottoman scholar and bibliographer Kātip Çelebi (d. 1658), also known as Hacı Halife, was one of the first Muslim intellectuals to notice the gap between the levels of scientific development in Europe and the Ottoman world. Kātip Çelebi was able to approach analytically both to classical Islamic culture and modern Western culture. He wrote on a variety of subjects in Arabic and Turkish. In the field of history, he translated the *Chronik* of Johann Carion from Latin under the title of *Tārih-i Firengī Tercümesi* (Translation of European History) and compiled his *Ravnak al-Saltana* (Splendor of the Sultanate) on the basis of works by authors such as Johannes Zouaras, Nicestas Acominate, Nicephorus Gregoras, and the Athenian Laonikas Chalcondyle. In the field of geography, he translated the *Atlas Minor* of Mercator and Hondius under the title *Lawami'al-Nūr fi Zulmāt Atlas Minur* (Flashes of Light on the Darkness of Atlas Minor). Furthermore, in his work titled *Mīzān al-Haqq fī Ikhtiyār al-Ahaqq* (The Balance of Truth and the Choice of the Truest), Kātip Çelebi criticized the intellectual life of his period.

The Ottoman Empire was geographically a European country and had common borders with many states in the West. This had been influential in making it the first country outside the Western world where modern science and technology had spread. This proximity also provided the Ottomans with an awareness of the new explorations and inventions that appeared in Europe. The relationship, which was formed within a selective process of transfer, characterized the nature of the Ottomans' attitude vis a vis Western science and technology and their attitude toward the innovations developed in Europe. The adoption of these innovations by the Ottomans differed from those of the Russians, Chinese, and Japanese. Also, it did not conform to the theories of "central-peripheral" and "exploiter-exploited" interpretation of the spread of Western science outside its cultural environment. The attitudes of the Ottomans toward Western science and technology are better interpreted as "selective attitude adopted by a powerful Empire in response to the developments outside its own sphere and area of influence." The Ottomans started to transfer European technology, especially in the fields of firearms, cartography, and mining as of the fifteenth century. Furthermore, the Ottomans had the opportunity to become acquainted with the Renaissance astronomy and medicine through the Jewish scholars who took refuge in the Ottoman Empire. In spite of this, the Ottomans considered themselves to be superior to the Europeans, both spiritually and culturally, in addition to their military superiority. Furthermore, their feeling of sufficiency from the aspect of both the educational system and economy was the reason for their being selective in the transfer of science. It is obvious that the Ottomans, in their periods of progress, did not feel the need to follow the intellectual and scientific activities such as the "Renaissance" and the "Scientific Revolution" that emerged in the West. The following interpretation made by some modern historians that: "The Ottomans did not understand that such developments would constitute a danger for them in the future" is anachronistic. Since the Ottomans, along with the other societies that had deep-rooted civilizations, became aware of the unsurpassable progress made by the Europeans in science and technology after the effects of the Industrial Revolution. The military striking power of the Europeans that resulted from the "Industrial Revolution" grew to a great extent as compared to the past; their ability to reach swiftly to every corner of the world on land and sea by steam engine and their means to produce an unrivaled amount of goods for the world markets with the new industrial technology, established the crushing superiority of the Europeans.

In these periods the Ottomans required immediate transfers of science and technology to strengthen their military power. Thus, they established the imperial engineering schools at the end of the eighteenth century and the imperial medical school at the beginning of the nineteenth century. Major reforms known as the *Tanzimāt* (1839) led to a shift in the process of selective transfer to include civilian projects and objectives. In the second half of the nineteenth century individuals started to establish professional and learned associations similar to those in the West. These new corporate bodies which did not exist in the classical period, added a new dimension to Ottoman scientific life with their legal statute and work procedures.

The concepts and information related to both the East and the West appeared side by side in the Ottoman scientific literature in the eighteenth and early nineteenth centuries. An example is the presentation of the heliocentric and geocentric systems of the universe in the same work. It is possible to observe the same situation on the subject of medicine. In the eighteenth century, along with the transfer of the practical medical knowledge of Europe, the classical concepts such as the "ahlat-ı erbaa" (four humors) in physiology and traditional anatomy were still dominant.

The teachers at the Imperial School of Engineering that was established toward the end of the eighteenth century to teach modern sciences to the officers, began to prepare their textbooks by translating and adapting the works selected from among the textbooks which were taught at the military technical schools in the West. The first scientific publications that came out at the turn of the nineteenth century were the books prepared by the Chief Instructor of the Imperial School of Engineering, Hüseyin Rıfkı Tamānī (d. 1817). They were composed of compilations and translations on the subjects of astronomy, mathematics, and geography and were printed many times. These works were followed by 13 volumes comprising the compilations and translations based on the Western and especially French sources prepared by Ishak Efendi (d. 1836) who was Tamānī's student and later his successor as the chief instructor at the school of engineering. His most famous work is *Mecmu'a-i 'Ulūm-ı Riyāziye* (The Compendium of Mathematical Sciences). This four volume work occupies a special place, because it is the first wide scope attempt in the Ottoman world in the preparation of a textbook containing many modern scientific disciplines, among which are mathematics, physics, chemistry, astronomy, biology, botany, and mineralogy. Ishak Efendi had a significant role in finding Turkish equivalents for the new scientific terms and disseminating them to the other provinces outside Istanbul.

Obviously the Ottoman's perception of modern European scientific traditions lacked an overall approach although they followed it closely. It is also clear that their scientific activities concerning research and production of new knowledge and technology – despite various relevant examples – did not have priority in their planning. Research activities conducted by Ottoman scientists inside and outside the Empire, particularly in the European countries, did not reach the critical mass as compared to the contemporary Russian and Japanese examples.

During the classical period, the Ottoman scientists and scholars displayed a remarkable success in developing Islamic science and were able to make new contributions to the various branches of science. However, in the modernization period they were not able to show a parallel performance but were successful in developing the modern scientific terminology of universal Islamic character and the Ottoman Turkish language to a level that would enable them to express their modern scientific and scholarly knowledge on various disciplines. The cultural and scientific heritage of the Ottoman period constituted the scientific and cultural infrastructure of many states founded in the Balkans and the Middle East, with the Republic of Turkey in the lead, and formed the foundations of subsequent activities.

See also: ►Ulugh Beg, ►Zīj, ►Taqī al-Dīn, ►Pirī Reis, ►Maps and Mapmaking, ►Qādī Zādeh al-Rumī, ►Rationality

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Science and Spirit

NITIN TRASI

The word "spirit" is derived from the Latin *spirare*, to breathe, or *spiritus*, breath. The term "spiritual" is sometimes taken to mean matters concerning the supernatural or the occult. However, the true meaning of the word concerns matters pertaining to the spirit, the animating principle in man, as opposed to matters pertaining to the physical and material. Thus "spirituality" in Sanskrit is *adhyātma*; in Pali, it is *ajjhat*.

The true spiritual quest in the most rigorously scientific sense of the term would then mean research into consciousness itself. Although India has had its fair share of occultists and those interested in the paranormal, a significant contribution of India to the world, from ancient times down to the modern age, has been the remarkable research into the nature of consciousness. Right from the Vedic times, the seers of India have been interested in questions about life and its meaning and in consciousness itself. Who are we? Where do we come from? What is the nature of the consciousness that animates us? What is its source? Is there an unchangeable ultimate reality or first principle in life? What is the cause of human suffering, and what is its solution? These and other fundamental questions have engaged their attention. These men have conducted scientific research into consciousness, in which they have explored the mind and the inner world within man himself. They conducted thought experiments and delved deep into their own minds and thinking processes to seek out the basic truths about life, consciousness, and the universe.

S

Vedānta

The four *Vedas* are the most ancient sacred literature of India. They were probably composed over several centuries during the second millennium BCE. The early Vedic hymns contain extremely detailed poetical descriptions of nature, and speculations about the origin and nature of the universe. The *Ṛg-Veda* declares, "Who verily knows and who can here declare it, whence it [the universe] was born and whence comes this creation?" (Nikhilananda 1997). And before this creation? "There was neither existence nor nonexistence then, neither air nor the sky beyond…neither death nor immortality, night nor day…darkness was concealed in darkness there!" (*Ṛg Veda*, III.129.1–3).

Deities symbolized the different forces of nature, but even in these early hymns, there is an awareness of the unity of these deities. "They speak of Indra, Mitra, Varuṇa, Agni, [names of deities]…the One Reality the sages call by many names." (*Ṛg Veda*, I.164.46, *Atharva Veda*, IX.10.28). "In That all this unites, from That all this emerges. The all-pervading One is the warp and woof of all created things." (*Yajur Veda*; *Vājasneya Saṁhitā*, 40.1).

Though the earlier parts of the *Vedas* (the *Karma-kānda*, the ritualistic section) dealt more with means to derive health, wealth, and material prosperity, later on the approach changed, as it was realized that these benefits were all transitory and subject to corruption with time. It is in these latter parts (the *Jñānakānda*, the knowledge section) that the *Vedas* really begin to deal with the question of lasting peace and happiness and the nature of consciousness itself. The concluding portions of the *Vedas* are called the *Vedānta* (*anta*: end, essence) and include the treatises called the *Upaniṣads,* which date back to the last millennium BCE. There are 108 *Upaniṣads*, of which 11 are considered the most important.

The Knower

In the *Upaniṣads*, the approach is highly introspective, and a critically important distinction is made between the "seer" (*dṛk*) and the "seen" (*dṛṣya*). Through a lot of intricate discussion, it is shown that the seer is the unchangeable Consciousness or the knowing principle that cannot be recognized easily, because it is itself attempting to do the seeing or knowing. Just as the eye cannot see the eye, the seer cannot know itself as an object. "How can one know that by which all this is known?" (*Bṛhadāraṇyaka Upaniṣad*, IV.5.15). And yet, itself the knower, who else is there to know it? The seer or the knower is in reality the innermost consciousness within us, the *ātman,* "the light of lights which is my inner being" (*Yajur Veda; Vājasneya Saṁhitā*, 34.1–3). Since whatever it can perceive (the seen or known) cannot be itself (the seer or knower), it therefore has to resort to elimination to recognize itself – a process symbolized by the famous words, *neti, neti* meaning, "It is not this, it is not this" (*Bṛhadāraṇyaka Upaniṣad* II.3.6). The ātman is finally said to be able to recognize itself only through intuitive knowledge and it is therefore said to be *svasākṣi* (self-cognized) (*Vivekacūḍāmaṇi*, 216). This knowing is not an objective but an intuitive knowing, "just as one knows of one's own existence even without the aid of a mirror" (*Amṛtānubhava*, II.76).

The Ultimate Reality

The idea of a single ultimate reality (*Brahman*), the basis of the physical universe appears early in the *Vedas*: "I know the drawn out thread in which all these creatures are strung. I know the thread's thread. I know the great *Brahman*" (*Atharva Veda,* X.8.38). But it is the *Upaniṣads* that elaborate on the details of this monistic idea of a single reality Brahman manifesting as the universe and its diverse objects, including human beings – the doctrine of *advaita*, monism. "Ever unborn, He is born in many forms. In Him alone reside all living things" (*Māhānārāyaṇa Upaniṣad*, 1.2). The relationship of the individual consciousness with this Reality is also stated. The ātman, the individual source of consciousness within a person, is not different from Brahman, the Universal Consciousness, but only appears to be separate because of the limiting adjuncts of the body and mind. The conclusion is finally reached that this (apparent) sundering from that reality is the true cause of insecurity and suffering in life, and reunion (or rather recognition of the essential oneness) with that reality is the only way to lasting, unqualified peace.

The Scientific Approach

Throughout the *Upaniṣads*, the approach is always investigative, and never dogmatic. The Truth is mentioned, but the pupil is expected and encouraged to question it and confirm it for himself, by his own efforts. The criteria of truth are said to be not just *śruti* (scriptural authority), but its conjunction with *yukti* (reasoning) and *anubhava* (experience) (Nikhilananda 1997: 17). "The true nature of things is to be known personally…and not through a sage. What the moon exactly is, is to be known with one's own eyes; can others make him know it?" (*Vivekacūḍāmaṇi*, 54).

Monism was therefore not the only doctrine that was existent, though it was the dominant one. The spirit of enquiry dominated philosophical thought (*darśana*) both in ancient and medieval India, and a wide spectrum of philosophical ideas was explored. At one extreme of this diverse spectrum was the purely materialistic doctrine of the pre-Buddhistic Cārvāka school, which approximated to pure hedonism. There were also the Pūrva Mimānsa of Jaimini, the Uttara Mimānsa ascribed to Vyāsa, the Sāmkhya of Kapila, Patanjali's Pātānjala, Gautama's Nyāya, and the Vaiśeṣika of Kānada. At the other extreme was the *bhakti* (devotional) tradition, with its total emphasis on love of God. But even within this devotional tradition, a variety of philosophical thought was expressed, and (apart from monism) there were several doctrines to explain the relationship of the human with the Divine. The *dvaita* (dualism) school taught that the soul (or self) and God are eternally separate. Its most important proponent was Mādhvācārya, a mediaeval philosopher and religious teacher of South India. The school of Viśiṣta Advaita (qualified monism) of Rāmānuja (eleventh century AD, South India), stated that the individual souls were very close to God and a part of him, but not one and the same ("like seeds in a pomegranate"); while the Śuddha Advaita doctrine ("pure" monism) of Vallabhācārya of mediaeval India made a fine distinction between the individual souls and God, saying that they are related "as sparks to a fire."

Advaita and Science

Science and religion do not always agree with each other. Religion is generally a matter of faith, whereas science depends upon plausible theories and empirical confirmation.

Advaita seems to offer a model of spirituality which agrees with science on these points. In this philosophy, there is no separate individual soul (there is only an illusion or appearance of a separate self or soul). The reality of God according to this theory is that he is the Universal Consciousness, the Source or Ground of all being, and not a personal, anthropomorphic, all-powerful entity. And finally, these things are definitely not asked to be accepted on trust. The individual is encouraged to find out for himself and confirm and corroborate these findings on his own.

Thus advaita presents to the world perhaps the most elegant, the most feasible, and the most scientifically acceptable of all theories of ontology. Advaita has also been shown to be closest to the new physics and quantum mechanics (Capra 1976; Goswami 1993).

Bhagavad Gītā and Karma-Yoga

Probably originally composed in about 1500 BCE, the *Bhagavad Gītā* is considered to be as authoritative as the *Vedas*. The philosophy in the *Bhagavad Gītā* (BG) is generally consistent with the advaitic tradition, though like the *Upaniṣads*, the followers of the non-advaitic traditions interpret it differently. However, its most important scientific contribution to the world is the thoroughly practical philosophy of *karma-yoga* (lit. the art of action, BG: II-50). Consistent with modern management principles as well as modern psychology, karma-yoga teaches an attitude to be adopted toward everyday duties and actions. Excessive concern about results interferes with the efficiency of the activity. Specifically, karma-yoga suggests performing action without worrying unduly about the results – *karma-phala-tyāga* (lit. surrender of the fruits of action) (BG, II.47–48, XII.8–11).

Buddhism

The Buddha

Whereas a large part of Vedāntic philosophy involved intricate discussions on consciousness, the Buddha (sixth century BCE) took a refreshingly different approach. At a young age, the Buddha, then Prince Siddhartha Goutama, was deeply disturbed by what he saw as the terrible inevitabilities of life: suffering, old age, and death. Desperately seeking a solution, and dissatisfied with the answers the scholars offered, he set out to discover the truth on his own. Rejecting all authority, discarding all theoretical speculation, he struggled for many years until one day, illumination dawned upon him. The Buddha spent the rest of his life spreading his message, until he died at the age of 80.

The Buddha proposed that ordinary human existence is an unsatisfactory state in which people make themselves miserable as a result of a basic misunderstanding of their own nature, and that there exists another way of being in this world, *nirvāṇa* (*nibbāna*), which is a release from this misery. Nirvāṇa is not some superhuman state, but rather a natural way of being, accessible to any human being. The way to nirvāṇa does not require acquisition of special powers, nor withdrawal from life or any other extremes. It is therefore called the "middle way."

The Buddha decried appeals to authority or tradition. He proposed a highly scientific, completely empirical approach, without recourse to any pre-existing theoretical concepts. He offered no theory of God and discouraged all speculation on the subject, and restricted himself to purely practical teaching. Based upon a systematic rational analysis of the problems of life, his teachings offered a way to their solution. A psychologist and a philosopher, he formulated his own experiential techniques to study the mind.

The Buddha's teachings include a set of concepts of how the mind works – the oldest psychology of which the world has any record (Anderson 1979: 5). In the Buddhist view, the person is seen not as a solid reincarnating entity, but rather as a flow of mental processes. At any one time, a human being is an aggregation of events, and that aggregation is constantly changing. There is thus no identifying essence at the core of any human being – no eternal soul, no *jivātman*. In other words, the "me" is not a person, but a process, and that process is in a state of constant flux, like a flowing river. This is the principle of *anātman* (no-soul). However, this concept of no-self is most definitely not a dogma. The correct Buddhist position is not to hold any dogmatic views, but rather to see things objectively as they are without mental projections (Anderson 1979: 29–31).

The Buddha is also said to have formulated and taught a detailed step-by-step practical technique to approach the realization of the state of *nibbāna*. This technique is called *Vipaśśanā*.

The Technique

Vipaśśanā means knowledge by seeing, clear perception. It means to observe reality in the right way – as it is, and not as it appears to be, colored by belief and imagination (Goenka 1994). The Vipaśśanā technique is a type of meditation – an observation-based, self-exploratory journey into one's own mind.

Vipaśśanā meditation trains the concentrated attention to follow the mechanics of mental processing with the base of concomitant physical sensations, in a detached fashion (Fleischman 1986). As the sensations arise and pass away, the wisdom of impermanence arises in the mind (everything is impermanent – *anicca* – nothing is eternal) and one attains equanimity amidst life's vicissitudes. The mind is gradually deconditioned (Goleman 1977), and life becomes characterized by increased awareness, reality-orientation and peace (Fleischman 1986). Man is led away from narcissism to mature, social love, and this personal transformation becomes the catalyst for social change and development (Fleischman 1991).

Mindfulness

Vipaśśanā consists ultimately in arriving at a state of mental alertness or attentiveness to the present, both with respect to the outer world, as well as to the inner – the workings of the mind. It is an ongoing process and results in enhanced insight and psychological maturity, as well as equanimity. The spontaneous (not enforced), easy state of mental alertness or awareness which results is known as *sati* (mindfulness), and could be described as a prospective, ongoing awareness of thought and action (as opposed to analysis – which is retrospective deliberation).

Buddhist mindfulness practice has some strong similarities to Gestalt therapy of Western psychology. Both emphasize the *how* of life rather than the *why* (unlike Freudian psychoanalysis). Repression of feelings is not advised, nor is change through inner or outer coercion. Emphasis is on being attentive, perceiving the truth, and being free. As in Gestalt therapy, Vipaśśanā meditation involves focusing on the actual, reduction of conceptual activity, and noninterference in the flow of experience (Anderson 2003: 85).

Vipaśśanā is considered a perfect antistress remedy, an effective cognitive technique for the development of self-awareness (Kutz 1985), and an excellent human potential development method and tool for self-actualization (Chokhani 1995). Vipaśśanā transforms one's approach to life and its vicissitudes including disease, and even death, which one now is able to face with serenity and fortitude. Though Vipaśśanā is not advocated for treatment purposes, it may have therapeutic value, and it has been suggested that combining and integrating it with psychotherapy may offer synergistic advantages (Kutz 1985). Studies carried out on the impact of Vipaśśanā in jails in India have reported its efficacy as a reformatory measure.

Self-Reliance

The Buddha always stressed the importance of self-discovery, and nonreliance on external authority, even his own. Scientific to the end, his dying words were "Be ye lamps unto yourselves. Rely on yourselves, and do not rely on external help. Look not for assistance to anyone besides yourselves – either now or after I am dead" (Burt 1955: 49–50).

The Buddha's teachings have been kept alive in true Eastern tradition by several Buddhist Masters.

Jiddu Krishnamurti

Krishnamurti (1895–1986) was probably the most remarkable spiritual scientist in recent Indian history. Fiercely independent, his approach was in many ways reminiscent of the Buddha's. He was dismissive of authority (including his own) and tradition, and had a completely empirical approach without recourse to theoretical speculation. His "choiceless awareness" sounds similar to Buddhist mindfulness. Like the Buddha, he encouraged people to be their own spiritual guides, and even insisted that he wanted no followers. "To follow another is evil," he said, "it does not matter who it is" (Krishnamurti Information Network).

But whereas the Buddha left a detailed step-by-step methodology, Krishnamurti decried all methods and techniques in the spiritual search. "Truth is a pathless land," he declared, "and you cannot approach it by any path whatsoever" (Krishnamurti Foundation Trust Ltd.). Again, whereas the Buddha created and left behind an organization, the *sangha*, to carry his message, Krishnamurti was against any organization in the spiritual field, and in his own case, allowed only the most perfunctory of organizations for the limited purpose of preserving an authentic record of his message.

"Discovered" as a young boy by members of the Theosophical Society who were convinced that they had found the modern messiah, Krishnamurti was declared the new World Leader and, by the 1920s, was attracting worldwide attention. Then in 1925

Krishnamurti experienced a mysterious spiritual awakening, and in 1929, in an act of renunciation, he abandoned the Theosophical Society, cut himself off from all organizations, and from that time until his death, traveled round the world speaking as a private person – a secular philosopher with no affiliation to any religion, sect or dogma.

The Core of the Teachings

Krishnamurti taught that man, out of his insecurity, has built within himself images as a fence of security – symbols, ideas, beliefs – religious, political, personal. Man's perception of life is shaped by these concepts established in his mind. His thinking, his relationships and his daily life are dominated by these images. They divide man from man, and are the cause of the disorder that pervades the consciousness of mankind, and which prevents human beings from properly working together, ultimately resulting in widespread sorrow, conflict, and misery.

The root cause of this delusion is in the fact that we are ignorant of the general nature of our own processes of thought. To be free from this delusion, we must observe the workings of our own minds. Through observation – close attention to and observation of the activity of thought (Krishnamurti called this "meditation") – one discovers the lack of freedom. One does this observation without choice, without criticism, without acceptance or rejection. The very act of this meditation then, in itself, brings order to the activity of thought without the intervention of will, choice, decision, or any other action of the "thinker." The noise and chaos which are the usual background of our consciousness die out, and the mind becomes generally silent. Our day-to-day work is not affected adversely (to the contrary, it becomes more efficient), because thought arises whenever needed for some genuinely valid purpose, and then stops until needed again.

In this silence, said Krishnamurti, something new and creative happens that is of extraordinary significance for all of life. This something cannot be conveyed in words, so he did not attempt to do so. Rather, he asked those who were interested to explore for themselves, through actual attention to the nature of thought.

Man does not have to go to a hermitage or forest to be free. Freedom is found in the "choiceless awareness" of our daily existence and activity. When man becomes aware of the movement of his own thoughts he will see the division between the thinker and thought, the observer and the observed, the experience and the experiencer. He will discover that this division is an illusion. This will lead to pure observation which is insight without any shadow of the past or of time. This timeless insight brings about a deep radical mutation in the mind – and then there is love, compassion and intelligence.

Truth (spiritual truth) cannot be found through any organization, creed, dogma, priest, or ritual, nor through philosophic knowledge, psychological technique, or intellectual analysis. Man has to find it through the understanding of the contents of his own mind, through observation.

Krishnamurti's teachings are of considerable relevance to mental health. It has been suggested that many of his ideas could be assimilated into modern psychiatric practice and aid toward promotion of mental health (Rao 1995).

These scientists of the spirit from the land of the *Vedas* have much to offer to the world. Their discoveries may well complement modern scientific advances to make for a better future. While modern science has explored outer space, these are the scientists who have explored inner space. While modern science has perfected some kinds of technology, they have perfected the techniques of self-actualization. Whereas science and modern medicine have gone far ahead in studying and treating disorders of the mind, the spiritual psychology of the East has studied and perfected the further development and evolution of the human mind beyond the so-called normal (Wilber 1977, 1989). Perhaps a meaningful synthesis of the wisdom of East and West can lead us to the next phase of human evolution, to a better and more loving human existence, what has been aptly termed the "Next Enlightenment" (Anderson 2003).

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Sde Srid Sangs Rgyas Rgya Mtsho

ZHEN YAN

Sde srid sangs rgyas rgya mtsho is a famous Tibetan politician and naturalist. Nicknamed Sde pa, he was born in the water snake year of the eleventh Rab-byung (Tibetan calendar, 1653) in the Northern suburb of Lhasa, Tibet. His father's name was A sug, and his mother, Bu khrid rgyal mo.

Politically, he was a person who inspired controversy, either commendatory or derogatory. But he was a great naturalist. His contributions in Tibetan medicine greatly promoted the development of this branch of science during his time.

Since he was a very talented child, he came to the attention of the fifth Dalai Lama Ngag dbang blo bzang rgya mtsho, who paid special attention to his education. He was summoned to the Dalai Lama's Potala palace to learn the classics of the Buddhism, apparent and esoteric sects. He had many tutors. 'Dar pa was the tutor for languages, Sanskrit and calendar-mathematics; Rong ge ngag dbang for astrology; Lhun sdings rnam rgyal rdo rje for allegorical trees, body measurement, and esoteric recipes. Thus, he became a versatile scholar with a high reputation.

The fifth Dalai Lama assigned him to the post of Sde srid (the Regent or Prime Minister), which was like giving wings to a tiger. During his tenure as Sde srid, he used any leisure time to take advantage of having access to many rare documents and materials available in the palace. He was very erudite in natural sciences, including medical science. His works, for instance *Baidurya dkar po* (White Lapislazuli), and *Baidurya ser po* (Yellow

Lapislazuli), deal with the calendar, mathematical sciences, and religion. However, his achievements in medical science will be emphasized here.

First, he studied *Rgyud bzhi*, the most important ancient Tibetan medical canon. Due to his political position, he had contact with many famous physicians. He admired Dar mo sman rams pa blo bzang chos grags very much, claiming that he was very erudite and had many esoteric effective recipes. He learnt from the different revised and annotated editions produced by the new Gyu thog yon tan mgon po, the greatest ancient Tibetan medical figure. He also made his own annotations and revisions on *Rgyud bzhi*.

Rgyud bzhi, authored by Gyu thog rnying ma yon tan mgon po, or the old Gyu thog, is written in archaic Tibetan language, which is hard to read; moreover, it is written in the form of an ancient Sloka-poet form, which is difficult to comprehend. Based on his experiences and practice, he adopted all the merits from different schools and physicians, discarded the erroneous and extracted the essence. With all these elements as a basis, he wrote a new detailed commentary on *Rgyud bzhi* with the title *Gso ba rig pa'i bstan bcos sman bla'i dgongs rgyan rgyud bzhi'i gsal byed baidurya sngon po'i malli ka zhes bya ba bzhugs so* (The Medicine Buddha's Decorated Four Tantras Annotation, The Blue Lapis Lazuli), or *Baidurya sngon po* for short. The book, twice as long as the original *Rgyud bzhi*, was finished in 1687. Since this is a comprehensive text embodying the merits of all scholars with refined contents, easy to read and understand, many scholars appreciate it. It has become the standard commentary on *Rgyud bzhi* and is treated as a compulsory text for learning it.

Sangs rgyas rgya mtsho also wrote many other medical books. Among them, *Gso rig sman gyi khog 'bugs* (History of Tibetan Medicine) is the most famous and important. Its full title is *Dpal ldan gso ba rig pa'i khog 'bugs legs bshad baidurya'i me long drang srong dgyes pa'i dga' ston bzhugs so* (General Introduction to Medicine, The Happy Feast of Immortals). This is by far the most authoritative text in Tibetan medical history. Furthermore, he was not satisfied with *Baidurya sngon po* only, so he wrote another book, *Man ngag rgyud lhan thabs* (Supplement to Secret Tantra) to make up for the deficiencies of the original classic. His medical works number over 20.

Sangs rgyas rgya mtsho was very enthusiastic about education in Tibetan medicine, paying attention to the training of successors. Right after the enthronement of the fifth Dalai Lama, the spiritual leader ordered that a medical school be established at 'Bras spungs Monastery in the Western suburbs of Lhasa, enrolling young people from the region with *Rgyud bzhi* as its main curriculum. Moreover, the Dalai Lama also instructed the restoration of the class in Xigatze to continue its training of Tibetan medical workers. The title of the class was changed to *Shen xian yun ji si* or *Drang srong 'dus pa'i gling* (Monastery for Aggregation of Immortals). Again, *Rgyud bzhi* was its main curriculum. Unfortunately, the latter was suspended upon the death of the Dalai Lama.

Several years later, Sangs rgyas rgya mtsho selected the site of Lcag po ri (Iron Hill) just opposite the Potala Palace to set up another medical school in line with the will of the late Dalai Lama. The curriculum included, in addition to *Rgyud bzhi*, other books such as *Zeng bu si bu yi dian mi jue ben ji* (Supplements to Collection of Man ngag rgyud) and *Cao yao mi fang* (Secret Herbal Formulary). Practice was also summarized. For instance, herbs were collected each year in the mountains, and students were encouraged to recognize various medicinal herbs and gain a better understanding of nature.

Sangs rgyas rgya mtsho set up an advanced medical class within the Potala Palace, and famous physicians were invited to teach. To improve teaching efficiency, Sangs rgyas rgya mtsho designed and produced a set of intuitive teaching tools, hanging painting scrolls, called *Sman thang* in the Tibetan language.

Under the auspices of Sangs rgyas rgya mtsho, the drawing of a series of *Sman thangs* was initiated. Sangs rgyas rgya mtsho used his *Baidurya sngon po* as a basis for the paintings and, by 1688, a series of 60 paintings had been completed. But, Sangs rgyas rgya mtsho was not satisfied, and he added more detail of pulse feeling, urine analysis and moxibustion, and sketching the actual samples of herbs collected from places throughout the region. Thus, a complete set of 79 paintings was finally produced in 1704.

As an epochal event in the history of Tibetan medicine, Tibetan medical paintings include all aspects of the medical field, such as the origin of medicine, fundamental theory, physiology, anatomy, etiology, pathology, therapeutic methods, surgical instruments, symptoms of all clinical aspects, diagnostics, materia medica and prognosis, and medical ethics as well which is not only the first of its kind but also the only example in the history of world medicine. This popularized medical knowledge with intuitive education, playing a very active role in the spreading and popularization of Tibetan medicine. It is a rare valuable historical relic with very high value that has attracted much attention around the world.

Sangs rgyas rgya mtsho was a great medical man. He made substantial and distinguished contributions to the development of Tibetan medicine. Unfortunately, his political notions clashed with other politicians, and the relationship among them deteriorated after the death of the fifth Dalai Lama. He was assassinated by his enemy and died a premature death at the age of 53.

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Seafaring

Robert G. Bednarik

When humans began to cross sea barriers, they demonstrated what they were capable of by harnessing nature. This may have been the most consequential single achievement in human history, because it marked the advent of the domestication of natural systems – the evolution of technologies that harness such energies as wind, wave action, current and buoyancy. The importance of this is not so much in the expanded ability of colonization or the introduction of "assisted locomotion", but in the cybernetic feedback derived from the conscious manipulation of natural systems and its impact on the cognitive and intellectual development of hominins. From an archaeo-technological perspective, early maritime navigational ability provides a more accurate determination of maximal technological capability than any other available evidence – rather in the same way as space travel does today. Hence there are several good reasons to take a special interest in how, when and where seafaring began.

No physical evidence of Pleistocene seafaring has ever been reported, nor have we any credible depictions of watercraft in the rock art or portable art of the Ice Age. Direct archaeological evidence of navigation peters out between 8,000 and possibly 10,500 years ago (Bednarik 1997), consisting of Mesolithic paddles from Holmgaard (Denmark) and Star Carr (England); a worked reindeer antler that may have been a rib of a skin boat in the Ahrensburgian of Husum (Germany); and the somewhat younger canoes and dugouts from Pesse (Holland, 8265 ± 275 carbon years), Noyen-sur-Seine (France, 7960 ± 100 carbon years), and Lystrup 1 (Denmark, 6110 ± 100 carbon years) (Zeist 1957; Arnold 1966; Clark 1971; Ellmers 1980; McGrail 1987 1991; Bednarik and Kuckenburg 1999). Watercraft and paddles of the late first half of the Holocene are also known from two Japanese sites (Aikens and Higuchi 1982: 124; Ikawa-Smith 1986). Bitumen-covered wooden slabs thought to have been part of boats, about 7,000 years old, were found in the Kuwaiti desert, in a stone building at the site As-Subiyah. The subsequent development of watercraft in the Middle East and later elsewhere is not considered here; it does not refer to the beginnings of seafaring.

Indirect evidence of maritime travel occurs in a variety of forms: as human occupation evidence, human remains, rock art or exotic materials found in the archaeology of islands or continents that were never connected to another landmass since humans first appeared. For instance, such evidence can be in the form of insular obsidian on the mainland, as that from Frachthi Cave in Greece, 11,000 years old (Perlés 1979; Renfrew and Aspinall 1990). Much earlier sea crossing and island colonization is indicated by Mousterian tools on Kefallinía, west of Greece (Kavvadias 1984; Warner and Bednarik 1996), and by the presence of Clactonian-like stone tools and human remains in Middle Pleistocene sediments on Sardinia (Martini 1992; Bini et al. 1993; Ginesu et al. 2003). Crete was also occupied during Palaeolithic times, as indicated by human remains of a modern specimen with preserved archaic features (Facchini and Giusberti 1992: 200). In Japan, Palaeolithic seafaring is demonstrated by the remains of four humans at Okinawa (Baba 1998) and by transported obsidian at Kozushima (Anderson 1987), in North America by the two femora fragments and one humerus from Arlington Springs on Santa Rosa Island (reportedly 13,000 years old). However, in comparison to the seafaring evidence in the region of Indonesia and Australia, most such finds from Europe and elsewhere are comparatively recent. The only evidence of a Lower Palaeolithic island occupation outside that region is that from Sardinia, on the order of 300,000 years old. It seems also probable that the first colonizers of Europe crossed the Strait of Gibraltar, even though secure evidence for this is lacking (Bednarik 1999a).

In March 1957, Dutch researcher Theodor Verhoeven found stone implements eroding from a fossiliferous deposit at the site Ola Bula in Flores, a geologically recent island of Indonesia (Verhoeven 1968: 400). A leading archaeologist, Henri Breuil, recognized among these finds a number of typical Lower Palaeolithic stone implements (Verhoeven 1958: 265). In mid-1963, Verhoeven succeeded in demonstrating by excavation the contemporaneity of Flores artefacts with fossil remains of *Stegodonts* (extinct elephants) at a second, nearby site, Boa Leza. Johannes Maringer, an archaeologist of the Anthropos-Institut, Germany, joined him in 1968 and the two excavated together at Boa Leza, Mata Menge and Lembah Menge. The three sites occur within easy walking distance and are all exposures of a geological stratum rich in fossil remains and stone tools (Maringer and

Verhoeven 1970a,b,c, 1972, 1975, 1977; Maringer 1978). This deposit is overlain by a series of rock facies up to 120 m thick, so there can be no question about the great antiquity of this presence of humans on an island that has never been connected to any other landmass. Initially this evidence was estimated to be up to 830,000 years old, based on the geology, palaeontology and the presence of tektites[1] (Koenigswald and Ghosh 1973). Subsequent palaeomagnetic analyses at Mata Menge (Sondaar et al. 1994; Bednarik 1995) suggested that the Matuyama-Brunhes reversal to normal polarity (780,000 BP) occurs just below the fossiliferous stratum. Later applications of fission-track analysis of zircons yielded datings of stone tool-bearing sediments from Boa Leza, Mata Menge, Koba Tuwa and Ngamapa, and all fell between 750,000 and 850,000 years BP (Morwood et al. 1999) (Fig. 1).

It thus seems soundly demonstrated that *Homo erectus*, currently the only available hominin candidate, was sufficiently well established on the island of Flores towards the end of the Early Pleistocene to leave behind numerous major deposits of stone tools. Flores is separated from Bali, the furthest extension of the Asian mainland during the Pleistocene (at times of low sea level), by two other islands, Lombok and Sumbawa (as well as several smaller islands which may have been connected to the larger ones at times of lower sea level), and the lack of any former land-bridge between Bali and Lombok was initially recognized by Wallace (1890). While this is based primarily on biogeographical observations, it is supported by the continuing uplift in the "inner arc" of the Indonesian archipelago, which amounts to at least several hundred metres over the past million years in this tectonically active subduction zone. Despite the rich mainland fauna of both extant and fossil terrestrial eutherians (placental mammals) that can be found as far east as Bali, few of them ever reached the islands of Nusa Tenggara, or southern Wallacea (Bednarik and Kuckenburg 1999: 108–109). Some, such as the dog, pig and macaque, were probably carried by humans, while small mammals, mostly Muridae (mice, rats, voles and relatives), probably crossed on floating vegetation (Diamond 1977). Elephants, however, swam to many of the islands of Wallacea (Hooijer 1957; Verhoeven 1958, 1964; Glover 1969; Bednarik 1999b) and the Philippines (Koenigswald 1949), where they underwent speciation and dwarfism. Elephants are superb long-distance swimmers, able to swim 48 km at sea and at a speed of 2.7 km/h (Johnson 1980). Hominins, however, lacked the trunks and swimming ability of elephants. Even deer, hippos,

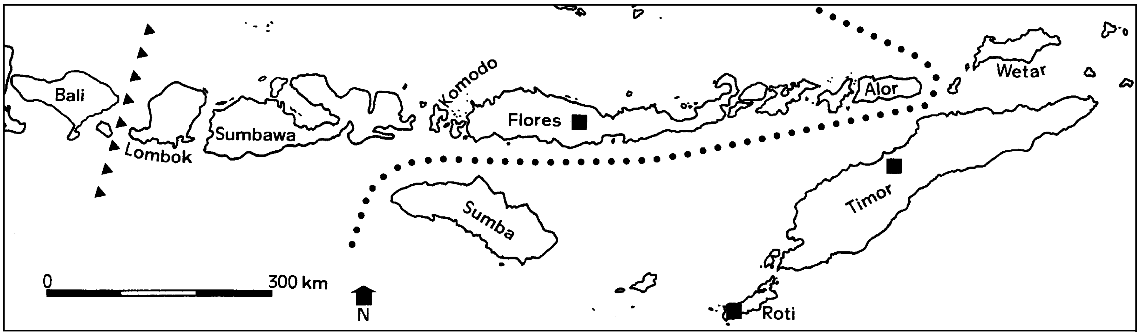
Seafaring. Fig. 1 *Stegodont* remains and stone tools in solid siltstone deposit, ca. 840,000 years old, Boa Leza, Flores. Photo by author.

tapirs and pigs, four of the most capable terrestrial long-distance swimmers, never colonized Wallacea unaided (Fig. 2).

In 1998, Australian Bednarik demonstrated the contemporaneity of human occupation with a *Stegodont*-dominated Middle Pleistocene fauna in West Timor (Bednarik 1999b). His fieldwork in Timor and Roti has involved several Pleistocene sites in the island's western half (East Timor having become politically stable only recently), focusing on the Weaiwe valley near Atambua. There, a sequence of Pleistocene sediments occurs above estuarine clay deposits containing an abundance of marine shells and snails. This demonstrates an uplift of well over 300 m since they were formed. The Weaiwe Formation, a Pleistocene conglomerate, has yielded remains of Stegodontidae from six sites now (Bednarik and Kuckenburg 1999), and evidence of human presence in the fossiliferous stratum occurs at two, Motaoan and To'os (Bednarik 1999b). At the time of its formation, the Pleistocene occupation layer was located close to sea level, which could itself have been much lower at the time.

All of the islands from Bali to Timor and Roti are well visible from the shores of departure, but once the Middle Pleistocene mariners had settled Timor, they could travel no further. The shores of Australia have never been visible from Timor, at any sea level, and it appears that the lack of visual contact prevented the human colonization of Australia for many hundreds of millennia. The initial landfall in Australia is presently thought to have occurred about 40,000–60,000 years ago. By that time, it appears, the Ice Age seafarers had acquired sufficient experience to venture into the unknown, to depart without the certainty of seeing their destination. It would have been known to them since time immemorial that there was a large landmass to the south. They could have predicted this from plumes of smoke occasionally rising from grassfires in

[1] Tektites are glassy objects that are thought by most scientists today to be melt products of terrestrial rocks formed by hypervelocity impacts of large, extraterrestrial objects.



Seafaring. Fig. 2 Map of southern Wallacea (Nusa Tenggara), Indonesia. The presumed dividing line between the Eurasian and Australian continental plates is shown dotted, and Wallace's biogeographical line is between Bali and Lombok. The squares indicate known hominin occupation sites of the Early and Middle Pleistocene.

Australia, from cumulus clouds regularly forming over the land, from the movements of waves, currents, migratory birds and turtles. But there is a great leap from merely predicting the existence of land, to having the courage of embarking on a journey of no return to an unseen shore.

A good deal of evidence from about 33,000 to 27,000 years ago indicates that many islands near northern Australia had been settled by that time. These amazing seafarers, with their still essentially Middle Palaeolithic technology, undertook lengthy journeys to in some cases very small target landmasses (Bednarik 1997). Most of these islands could not have been sighted until a raft reached their proximity; this is the case with the Monte Bello Islands (100 km from Australia), Gebe Island (west of New Guinea), New Ireland (east of New Guinea), and Buka Island (180 km from New Ireland). It thus seems very probable that the maritime competence of the much later Polynesians was the ultimate outcome of a process that began almost a million years ago.

The complete lack of any direct physical evidence of maritime technology from the entire Pleistocene renders it pointless to speculate about the circumstances of these endeavours without additional information. No sustained replicating experimentation of archaeology had been conducted in relation to this subject before 1996. Since then, the First Mariners Project (►http://mc2.vicnet.net.au/home/mariners/web/mariners.html) led by Bednarik has set out to determine the most likely means employed by *Homo erectus* in crossing Lombok Strait >840,000 years ago, and the most likely circumstances of first landfall by *Homo sapiens* in Australia and elsewhere. The project investigates all demonstrated human sea crossings of the Pleistocene and plans to replicate many of them. Archaeologically derived knowledge about the technology of the periods in question, particularly in stone tool knapping, wood and bone working, serves as a reference source for these projects (Bednarik 1997, 1999b, 2001a). Some aspects of relevant material use can be replicated precisely on the basis of form of, and work markings on, archaeological finds, as for instance Middle Palaeolithic bone harpoons or Lower Palaeolithic wooden artefacts. Others must be determined according to systematically derived probability estimates based on experimentation. Expeditions endeavour to create authentic conditions for the construction of a series of primitive vessels and their sailing across the sea barriers in question. This involves, for instance, the use of appropriate stone tool replicas in felling and working bamboo, and in constructing and sailing the rafts. Hundreds of issues of technology need to be addressed, including the means of carrying freshwater, of fishing at sea, of locating sources of stone tool materials for raft construction, issues of maritime design, and the procuring, selection, treatment and utilization of materials for the construction of vessels and equipment (Fig. 3).

Seafaring. Fig. 3 Palaeolithic bamboo raft in heavy seas on Timor Sea, its bow rising several metres above the water. Photo by author.

The first full-size experimental vessel was launched at Oeseli in southern Roti in early 1998 and sailed for sea trials with a crew of eleven (Bednarik and

Seafaring. Fig. 4 Use of a firebox on a Palaeolithic vessel, the fire having been lit by traditional method. Photo by author.

Seafaring. Fig. 5 A dorado fish just harpooned with a Middle Palaeolithic weapon is about to be gutted with a stone flake. Photo by author.

Kuckenburg 1999). Some aspects of this 23-m-long, ocean-going bamboo raft of about 15 tonnes plus cargo were judged to be unsuitable and the vessel was beached for destructive sampling and material testing. A radically different, simpler design led to an 18-m bamboo raft of only 2.8 tonnes. It travelled with a crew of five men from Kupang to Darwin in December 1998, sailing part of the 1,000-km journey under extreme conditions (Bednarik 1999b; Bednarik et al. 1999). In March 1999, a simple 11-m bamboo platform set out from the eastern-most point of Bali to attempt a crossing of Lombok Strait. It was forced north by strong seas and the attempt was abandoned. But by the end of that year, a similar, 12-m-long simple platform of bamboo, lacking any sail or means of steering, was being built for a second attempt. This vessel was as rudimentary as a raft can possibly be, weighing only 1,080 kg. It crossed Lombok Strait successfully with a crew of 12 men in January 2000. The experiment showed how even a treacherous stretch of sea such as Lombok Strait could be crossed with purely Lower Palaeolithic means (Bednarik 2001b). Similarly, the 12-m *Rangki Papa* ("Father of all Rafts", in the local dialect) succeeded with a crew of twelve in October 2004 in crossing Sape Strait, which separates Sumbawa from Komodo and Flores. In that experiment, filmed by *National Geographic*, the assembly of the 970 kg bamboo vessel took only 4 days. The experiments in the Mediterranean had commenced earlier, in September 1999, on the coast of Morocco, where two prototype rafts were constructed entirely with Lower Palaeolithic stone implement replicas, and then taken for sea trials. One of these vessels, a pontoon-type raft, was made of cane, the other of inflated animal skins (Bednarik 2001a) (Figs. 4 and 5).

The primary purpose of these experiments is to examine each of the many variables involved in Pleistocene seafaring quantitatively, to create the conditions for constructing multiple scenarios within a realistic framework of probability. In this procedure, the confidence that the most probable scenario can convincingly be identified is a function of the variables or determinants accounted for satisfactorily. Therefore numerous experiments are essential, and all need to be conducted under controlled conditions. While the most sensible, economic or logical course of action is not necessarily the one always taken by hominin mariners, there are several arbitrary limiting factors. For instance, these journeys had much to do with survival, and we can reasonably assume that they were on the very limits of the technologically possible at the times in question (Bednarik 1999c). The most probable scenarios can then be tested by reference to known parameters of technological competence at the time in question. These are derived from the archaeological research forming part of the overall project. This would seem to be the only scientific method available to us to generate informed and plausible explanations for the very early maritime feats of hominins.

See also ►Seafaring

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Seafaring in the Polynesian Outliers

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Observers, for many years, viewed indigenous Pacific Islands seafaring as a vanishing art, largely confined to the Central Carolinian atolls of Micronesia. Yet, in a number of small, remote Polynesian communities, traditional vessels and knowledge of how to use them are an active, ongoing concern. Our awareness of these systems of knowledge and practice is preserved in works on Ontong Java and Nukumanu (Sarfert and Damm 1929; Haddon and Hornell 1975 [1936–1938]; Feinberg 1995), Taumako (Davenport 1962, 1964, 1968; Lewis 1972; George 1998, 1999, n.d.; Vaka Taumako Project 1997, 1999), and Anuta (Feinberg 1988, 1991). Important information also is presented on Kapingamarangi by Lieber (1994) and on Tikopia in Firth's voluminous writings.

Generalizations about these "Polynesian outliers" are difficult. They range from communities like Sikaiana (Donner 1995), where sailing canoes have been entirely abandoned, to such isolated specks of land as Taumako and Anuta, where traditional equipment and techniques remain in use or are remembered to a remarkable degree. Even in precontact days, the Polynesian outliers incorporated a good deal of diversity. On Ontong Java, Nukumanu, Takuu, and Nukuria, vessels as well as sailing and wayfinding techniques closely resembled those of Micronesia; on Tikopia and Anuta, maritime technology and practice have been closer to the standards typical of Polynesia. Meanwhile, the impressive seafaring technology of Taumako (Duff Islands) and the Polynesian Reef Islands of the eastern Solomons combines elements known from Eastern Polynesia, the central outlier atolls, and Micronesia (Fig. 1).

Canoe Construction and Design

Hull design in the central and northern Polynesian outlier atolls resembles that reported for the Micronesian Caroline and Marshall Islands. This is particularly evident in the voyaging canoes that have been described for Takuu (Haddon and Hornell 1975) and Nukumanu (Sarfert and Damm 1929; Haddon and Hornell 1975; Neyret 1977; Feinberg 1995), and in the model voyaging canoes that Takuu craftsmen still produce for sale to art collectors and tourists. These vessels were 40–50 ft long, constructed with deep-V hulls, rigged with triangular pandanus-leaf sails, and were symmetrical from end to end, making bow and stern identical. The outrigger float was significantly shorter than the hull, and small shelters might be built on the outrigger platform, which was always kept to windward when the vessel was underway. These atolls also produced smaller canoes, most of which were round-bottom dugouts, that might be sailed, poled, or paddled. Since the late nineteenth century, large voyaging canoes have no longer been built. On some atolls like Sikaiana (Donner 1995), canoes have been almost totally abandoned except for very small vessels that are intended for fishing on the lagoon, although there is evidence of significant canoe voyaging in times past.[1] Small fishing canoes intended for calm water are also used on Ontong Java, Nukumanu, and Takuu. Somewhat larger canoes may be used to transport cargo to and from visiting ships or for hauling copra and taro from the outer islets. Nukumanu still construct and use large canoes for voyaging to Ontong Java, across 30 miles of open ocean. Contemporary Nukumanu voyaging canoes may be as long as their predecessors, but they are less carefully constructed and resemble the smaller ones in design. They may be rigged for sail, but Nukumanu prefer outboard motors for propulsion, especially on longer journeys. In 2000, Nukumanu islanders told Feinberg that fiberglass motor-driven boats on all of these atolls are gradually replacing canoes (Figs. 2 and 3).

On Taumako (Duff Islands) and the Polynesian Outer Reef Islands of Nifiloli and Pileni, voyaging canoes are called "canoes of Lata." Lata, a widely recognized Polynesian culture hero, is said to be the first person to build and sail a voyaging canoe of the type known as *te puke*. These are built with a roundish hull that is hollowed out from a single log. The top is boarded over and made watertight, except for the area enclosed by a riser box, which provides access for bailing and stowage of nonwater-sensitive cargo and ballast. When under sail the hulls are almost entirely submerged. The crew stays on one of two platforms that straddle the riser box and outrigger beams. Although there is one outrigger float (*ama*) per canoe, it may be fashioned from as many as four float timbers lashed together, depending on how much flotation is needed. The crew situates itself on whichever platform

[1] According to elderly Duff Islanders, the Sikaiana were in regular communication with Taumako prior to the 1917 influenza pandemic, and they ordered and used large voyaging canoes from Taumako.

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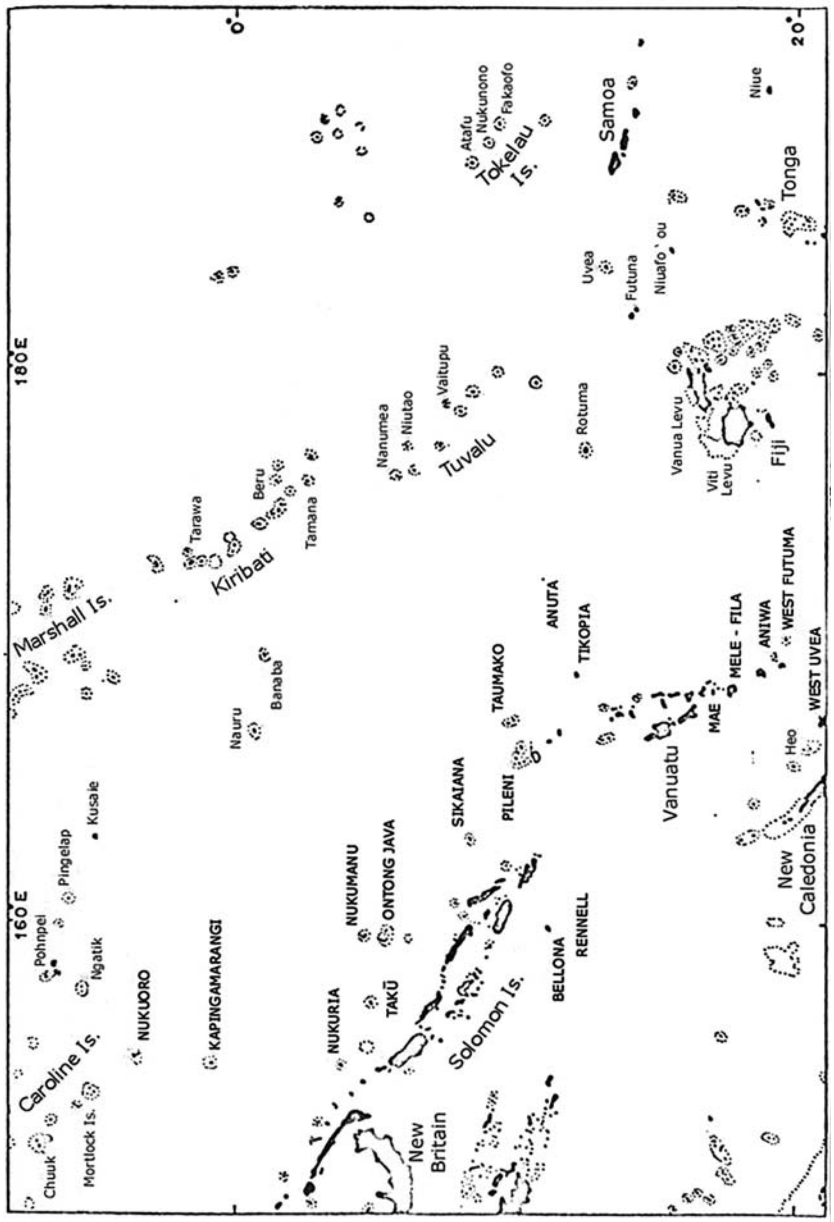

Seafaring in the Polynesian Outliers. Fig. 1 Map of Polynesian outliers and surrounding islands.

is most appropriate for sea conditions and the trim of the cargo. The predominantly submarine hull is subject to less surface tension and wave action than more conventional hulls, making them considerably faster. To the best of our knowledge, this hull design is unique to Taumako vessels.[2] Like the vessels of the central outlier atolls, as well as some from the Polynesian heartland (e.g., the Tongan *kalia*), *te puke* are equipped with shelters on the outrigger platform.

Taumako sails are made from panels of plaited pandanus mats, sewn together vertically to form a graceful, slender foil, or delta wing shape. Unlike many Pacific Islanders who have abandoned pandanus sails in favor of cloth, Taumako sailors prefer pandanus, which they say lasts longer and is easy to maintain and repair. The design resembles "crab-claw" sails of Tahiti and Hawai'i as depicted by artists on early European voyages of exploration, but its symmetrical shape, with long, slender, arcing wingtips, has few parallels in Oceania (Fig. 4).

[2] We must note, however, that few ancient hulls have been recovered from Pacific waters. Perhaps, with further research, we will find evidence of submarine hull shapes from other parts of Polynesia.

Seafaring in the Polynesian Outliers. Fig. 2 Nukumanu outrigger sailing canoe under sail on lagoon.

Seafaring in the Polynesian Outliers. Fig. 3 Small Nukumanu outrigger sailing canoe immediately after launching from beach on lagoon side of the village islet.

Seafaring in the Polynesian Outliers. Fig. 4 *Te puke* type voyaging canoe from Taumako island under sail on open sea.

Most canoes of this description have been constructed on Taumako on order from other communities in the Santa Cruz Islands and elsewhere in the Solomons. In the 1920s, over 200 *te puke* were observed to be sailing in what is now Temotu Province (Davenport 1968). Generally, the Outer Reef Islanders specialized in navigation while the Taumako specialized in canoe building.

For a period of a few decades in the middle to late twentieth century, construction of *te puke* was almost abandoned because of depopulation and suppression of voyaging by colonial authorities. The last working *te puke* broke up off Nifiloli in 1963, although a few local vessels of other designs kept sailing between Santa Cruz (Ndeni) and the Reef Islands until the early 1970s. However, since around 1980 – and particularly since the mid 90s – interest in actively making and using traditional voyaging canoes has revived, in large part thanks to the activities of the Vaka Taumako Project (see below).

Te puke canoes (*nga puke*, pl.) are distinguished from other Taumako vessels by their very large cargo carrying capacity. They are made of heavier and harder woods than other canoe types, have a riser box that lifts the outrigger beams some three feet or so above the top of the hull, have a shelter on the windward platform, and are at least 36 ft in length. Older Taumako state that until Lata made the first *te puke*, they depended on double-hulled *vakalua* for interisland travel. *Nga puke*, being lighter and faster, offered superior performance. One that a group of Duff Islanders sailed from Taumako to Vella Lavella in 1980 was observed by a Solomon Islands government ship to be cruising at a speed of ten knots.[3] With their massive outrig and ingenious lashings, *te puke* are also very strong and seaworthy (Fig. 5).

Te alolili canoes are lighter and faster, designed to carry people and light cargo. They range in length from 18 to 33 ft. The Taumako also make smaller, less elaborate outrigger canoes called *te alotovi*, which may or may not be rigged for sail. And they construct monohulled, nonoutrigger paddling canoes, on which they may either rig lateen sails made of rice bags or add a wooden plank to serve as a motor mount. They use these primarily to transport cargo within the Duff Islands and to visiting government ships. For some purposes they, like other islanders, would like to have fiberglass canoes propelled by outboard motors, and in 2001 there were at least two working outboard engines on Taumako. Scarcity of fuel, however, normally precludes their use. As of January 2002, Taumako still

[3] In 1979 people of Taumako built a *te puke* to represent the Solomon Islands at the 1980 Pacific Arts Festival in Port Moresby. The voyage from Taumako to New Guinea had to be cut short for political reasons. Local officials required them to travel via Honiara, the national capital, which meant taking a risky and nontraditional route. Those officials then held the canoe so long that the seasonal winds ceased before the crew could navigate the vessel from Vella Lavella in the Western Solomons to Papua New Guinea.

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Seafaring in the Polynesian Outliers. Fig. 5 "Earth oven" and "fish eye" lashings on cross beams and outrigger struts of *te puke* canoe.

Seafaring in the Polynesian Outliers. Fig. 6 Outrigger canoe of *vaka pai manu* type, rigged with rectangular sail, on beach at Anuta island.

had no fiberglass vessels. However, such canoes from Lata, the Temotu provincial capital, occasionally go to the Duffs on emergency missions.

Canoes on Tikopia and Anuta more closely resemble those documented in the so-called Polynesian Triangle. Anuta is a tiny volcanic island with a small reef flat and no protected water. As a result, Anutan canoes tend to be larger than their Tikopian counterparts. Otherwise, they are similar in design. Hulls are of deep-V construction. They are hewn from a single tree and generally built up with one plank to increase freeboard. Unlike canoes of the Santa Cruz Islands and the Polynesian atolls to the north and west, Anutan craft have a distinct bow and stern, and the outrigger is always kept to port regardless of one's heading in relation to the wind. They range up to about 35 ft in length and average 20–25 ft, with a few that are much smaller. Virtually all Anutan canoes have the same design, with high gunwales and carefully carved bow and stern covers to minimize shipping of water as one passes through the surf and sails on choppy seas. Anutans and Tikopians who live in the central Solomons, either in Honiara or the Russell Islands, have more sheltered water and less time for fishing than their compatriots at home. Their canoes, therefore, are smaller, are usually designed to be paddled rather than sailed, are not augmented by gunwale planks, and typically lack bow and stern covers. Canoes of this type are known as *tovi*; the larger, more elaborate canoes with ornately carved bow and stern pieces are termed *vaka pai manu* "birdlike canoes." The bow and stern pieces (*puke*) are intended to resemble birds (Figs. 6 and 7).

Like the Taumako, Anutans still make their canoe hulls exclusively from local materials – primarily wood and sennit cord. They do not use nails, screws, or other commercial fasteners. They occasionally employ a piece of Styrofoam for caulking, and commercial glue sometimes replaces breadfruit sap to help caulk the joint between the plank and the main hull. However, the only commercial product that they use with any regularity is water-resistant paint, which they apply in an effort to protect the hulls of their larger vessels.

Seafaring in the Polynesian Outliers. Fig. 7 Anutan outrigger canoe of *tovi* type, on beach in Russell Islands. The canoe is rigged with a lantern holder for catching flying fish at night.

The sail and rigging show more Western influence than the hull. Stays may be commercial rope, and rectangular sails usually fashioned from cotton cloth have replaced the old triangular pandanus-leaf sails. Like many other Pacific Islanders, Anutans were happy to abandon pandanus sails, which become heavy and difficult to handle when they get wet. The rectangular sails were introduced in order to provide more surface area in proportion to the mast height. This increases the canoe's speed without decreasing stability; the tradeoff

Seafaring in the Polynesian Outliers. Fig. 8 Anutan child paddling a large bowl (*kumete*) through the surf on the reef flat at high tide.

is that rectangular sails do poorly beating against a headwind.

In addition to *vaka pai manu* and *tovi*, Anutans recognize outriggerless canoes, which they call *puai vaka* "egg canoes." However, they do not make such vessels. Their closest analogues are large wooden bowls (*kumete*) of the type that might be used for preparing puddings or making turmeric dye. These bowls are vaguely canoe-shaped and can be paddled if the sea is not too rough (Fig. 8).

Sailing Techniques

As Lewis (1972) noted, most of the Polynesian outliers use the Micronesian strategy of sailing with the outrigger to windward. In order to accomplish that, they tack by moving the mast, sail, and rigging to the opposite end of the canoe, converting the old bow into the new stern and vice versa. Tikopians and Anutans have adopted the more common Polynesian strategy of having a distinct bow and stern with the outrigger fixed to the port side of the hull. As a consequence, the outrigger is sometimes in the canoe's lee, and many hulls are constructed with a slight bulge on the port side to help keep the outrigger float from being submerged when the wind blows hard from starboard.

Among outrigger canoes, those of Nukumanu and Ontong Java, with their triangular sails, do a relatively good job of beating into a headwind, and Taumako's *te puke* may do better still. George found that one such vessel, *Vaka Taumako*, could point higher and go faster than her 32.5 foot-long gaff cutter rig. It made better than five knots at 75° off the wind in a steep, choppy sea and a twenty-knots breeze. In addition to being extraordinarily efficient, the Taumako sail and rigging may be trimmed to suit a wide variety of conditions.

Anutan vessels, with their rectangular sails, do not sail well unless the wind is either astern or abeam. Therefore, Anutans try to arrange their trips in such a way as to avoid having to beat against the wind. For example, their voyages to Patutaka, 30 miles to the southeast, are usually made during the trade-wind season but at a time when the wind shifts temporarily to the north or west. They assume that it will shift back to the southeast within a few days, and they will be able to journey in both directions with a favorable wind. Should they need to travel at much less than a 90° angle to the wind, they either wait for a change in weather, return to their point of embarkation, or stow their sails and paddle into the wind.

Navigation

Those communities that continue moderate- to long distance voyaging have retained much of their ancestors' knowledge of constellations, movement of astronomical bodies, and star paths. Feinberg (1988, 1995), for example, has documented the continuing astronomical knowledge of Anutan and Nukumanu wayfinders. Conversations with islanders from both communities over a period of several months in 2000 made clear to him that young people have perpetuated this knowledge. At the same time, however, astronomical knowledge in the late twentieth and early twenty-first centuries has apparently declined from what it was a century earlier. Present-day Anutans insist that members of previous generations knew more than they know, and similar views among Nukumanu appear to be confirmed by the reports of Sarfert and Damm, which list many more constellations than islanders recognized in the 1980s.

Both Nukumanu and Anutan navigators maintain their course by swells as much as by the stars, which cease to be helpful during the day or any time the sky is overcast. In this respect, they resemble most other Pacific Island voyagers, many of whom depend on swell patterns even when piloting large ships. Both Nukumanu and Anutans also distinguish between swells and reflected waves, which may be felt at distances of up to 20 miles from land and are useful for making landfall. These are more difficult to discern than ocean swells, and only a few of the most proficient navigators are able to use them effectively. Islanders insist that skill at detecting "land waves" was more widely distributed in their communities in earlier generations. Along with swells, islanders pay attention to wind patterns, which tend to be relatively stable even when stars and the sun cannot be seen.

Like Nukumanu and Anutans, Taumako and Outer Reef Islanders agree that much knowledge of celestial navigation has been lost over the past century.

The most authoritative commentator on this point is Taumako Paramount Chief Koloso Kaveia. Kaveia began his voyaging career as a small boy sailing on canoes based at Pileni in the Outer Reefs prior to 1920. Fellow islanders consider him to be the most experienced and distinguished living navigator and voyager. While Kaveia and other Duff Island navigators are familiar with star paths, however, they consider celestial movements and swell patterns to be secondary to knowledge of the "wind compass" (*nohoanga te matangi*).

Nohoanga te matangi is a comprehensive system that correlates information about wind directions, calendric seasons, and movements of celestial bodies with sea routes. It is not just a wind compass in the unexplained and often partial forms that have been previously reported (e.g., Lewis 1972). It is a tool, rather like a clearing house or slide rule, for bringing into relationship the various fields of information relevant to planning a particular voyage. Its use also presumes facility with weather magic to control wind and sea states, and this requires good command of the protocols for dealing with one's ancestral spirits. *Nohoanga te matangi*'s major elements include ten main celestial bodies that are used in navigation plus the two "wing stars" located to either side of each primary star. The "wing stars" are used in cases when the current, sea state, or wind conditions preclude reliance on the central star paths. Navigation also presupposes a working knowledge of *te lapa* – the luminescent lightning-like appearances that signal the direction and distance of land (see below).

In addition to wind, waves, and stars, islanders rely on a variety of subsidiary techniques to hold a steady course or to home in on a target island. In recent generations, some of these techniques have been abandoned and receded into legend. For example, Anutans say that dolphins, to which they refer as *nga ariki o te moana* (kings of the ocean) might lead a lost voyager to land. Nukumanu speak in similar terms of meteors, which they term *tanaloa* – the name for one of the great pre-Christian gods in much of Polynesia. Other subsidiary techniques are still relied upon and are apparently effective. Most islanders continue to observe the flight patterns of birds as a technique for land finding. Lewis (1972) has reported patterns of phosphorescence (*te lapa*) which Reef and Duff Islanders continue to employ for the same purpose. George has learned that Taumako navigators can make effective use of this phenomenon at impressive distances. In 1980, Kaveia used *te lapa* to find his way between the large islands of the Solomons chain, sometimes at a distance of over 110 nautical miles. It also appears that the appearance of *te lapa* from each island or reef has a distinctive character. The phosphorescent flashes shoot across the ocean surface and are easiest to see in the interstices of intersecting waves.

Social Relations

On Nukumanu and Anuta, navigators are admired and respected for their skill, but they do not hold a formal position. An Anutan navigator is known as *tau tai mau kaavenga* (expert at finding star paths), which is more a description the navigator's skill than a title. In neither community are there rites of passage that mark one's transition to navigator status; most men have some knowledge in this area, but some have considerably more than others. An expert navigator may come from any descent group and any social stratum, from chiefs to commoners. On both Nukumanu and Anuta, education in the skills of boat building, sailing, and navigation also is informal. There are no navigational schools, nor is there any formal apprenticeship. A novice watches the experts and learns primarily through emulation.

On Taumako, the navigator is a highly trained specialist. Kaveia apprenticed for many years with Pileni relatives, then married and returned to Taumako where he studied navigation with his father. In addition, a Taumako navigator must have a canoe and, in earlier times, contacts or partners on distant islands as well as access to red feather money and other valuables. An enterprising person of low rank can acquire the necessary assets, but high-status males have a clear advantage. Today, education in canoe building and navigation has been incorporated into the Vaka Taumako Project in an attempt to ensure the maintenance of older knowledge and practices.

Change

Seafaring practices have changed in all the Polynesian outliers over the past two centuries, but to different degrees and in different ways on different islands. The great voyaging canoes (*vaka hai laa* or *vaka fai laa*) of the central outlier atolls have not been produced since the late nineteenth century, but sailors from Nukumanu and Ontong Java continue to make the 30-mile voyage between the two atolls, and they sometimes still use wooden outrigger canoes powered by sail. Sikaiana, at the opposite extreme, has entirely given up production of ocean-going canoes. Even Anutans, whose seafaring activities depend entirely on outrigger canoes of traditional design, who regularly voyage 60 miles to Patutaka and back, and occasionally still sail to Tikopia, a 150-mile round trip, have replaced pandanus sails with cotton cloth or (occasionally) plastic sheets.

While much has been lost, some of the outliers have nonetheless maintained a good deal of their seafaring knowledge and continue to put it to good use. Anutan reliance on wooden *vaka pai manu*, held together with sennit cord, has continued uninterrupted to the present day. Equally impressive is Taumako's self-conscious effort to reverse a decline in seafaring knowledge through the Vaka Taumako Project – an educational enterprise intended to promote mastery of traditional canoe-building and voyaging skills among younger community members by constructing several *te puke* and *te alo* voyaging canoes and sailing them to remote destinations under the direction of skilled navigators. In 2001 the Vaka Taumako Project launched the first class of over 50 students. The students aim to learn eight necessary skills for building and navigating voyaging canoes using only traditional Polynesian methods. A 65-foot by 40-foot canoe house was erected to shelter and maintain three vessels that have been produced by the project. It is hoped that this canoe house will also serve as a classroom and archive for Taumako voyaging knowledge, and to accommodate visiting students and voyagers.

See also: ►Maps and Mapmaking: Marshall Island Stick Charts

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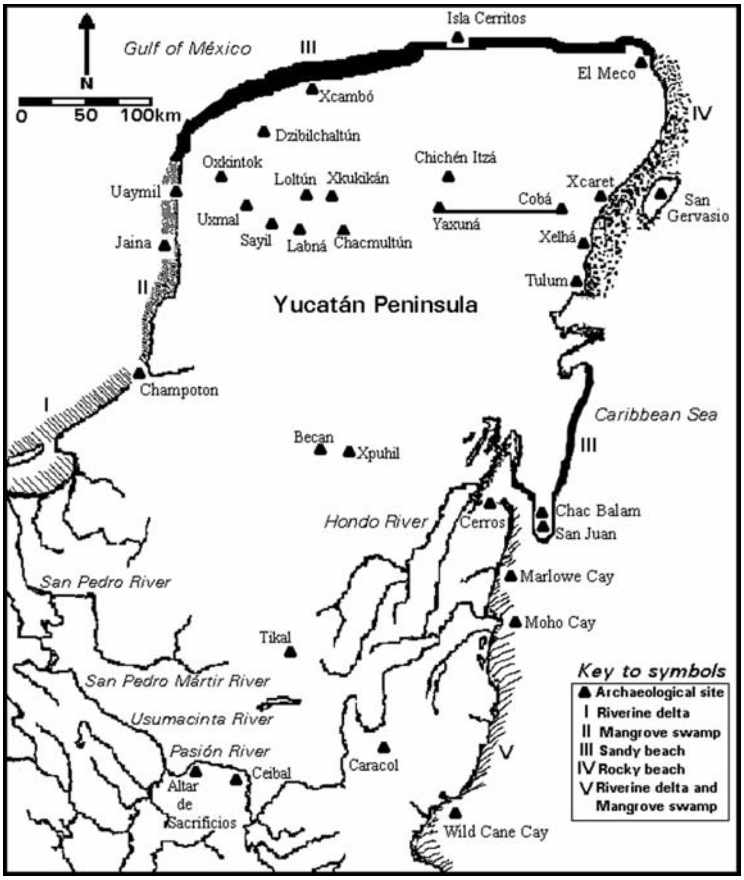
Seaports of the Maya

Rafael Cobos

The marine seacoast of the Maya area extends for more than 1,000 miles and is composed of different environments, which include sandy and rocky beaches, mangrove swamps, and riverine deltas (Fig. 1). These environments were occupied during pre-Hispanic times by individuals who founded numerous communities and built an elaborate infrastructure that caused the rise of seaports during the Preclassic (1200 BCE–AD 200), Classic (AD 200–1050/1100), and Postclassic (AD 1050/1000–1550) periods (Andrews 1990; Nondédéo 1998; Vail 1988).

Ancient Maya seaports are found either directly on the coast or less than 2 to 3 miles inland. As with other seaports in the world, ancient Maya seaports were permanently settled by individuals engaged in different duties that included the maintenance of their community by political, economic, social, and ideological activities. Ancient Maya seaports also provided shelter to sailors, traders, and the merchandise they transported. They facilitated the transportation of goods and gifts that were moved between close and distant regions; they were also used to satisfy basic as well as secondary needs of communities located a few miles inland or hundreds of miles away.

Early explanations about the function of ancient Maya seaports were put forward during the first half of the twentieth century. For instance, it has been suggested that settlements such as Jaina, located in western Yucatán, and Xcaret, located in front of Cozumel Island, functioned as an island necropolis and a port of embarkation to an offshore island respectively. Over the past 50 years, however, the Maya marine seacoast has been the focus of several systematic archaeological investigations, and previously assigned functions of pre-Hispanic coastal communities such as Jaina have been rejected. Regarding Xcaret, archaeological investigations have corroborated its role as a port of embarkation to Cozumel Island as well as a complex seaport that functioned during the Classic and Postclassic periods (Andrews 1990).



Seaports of the Maya. Fig. 1 Maya seaports located in México and Belize.

Systematic research conducted on several pre-Hispanic Maya coastal communities that functioned as seaports indicates that these ancient settlements were arranged in distinctive ways and date to different periods. The unique characteristics of ancient Maya seaports were the result of social, economic, political, and ideological processes that each of them experienced throughout time. For instance, archaeological investigations have revealed three different forms through which these marine seacoast settlements interacted with other marine coastal sites as well as with inland settlements. These three forms of interaction include the coastal port associated with a regional capital, trans-shipment seaports, and the seaport as a social, political, and economically independent unit. A description of each one of these follows.

The Coastal Port Associated with a Regional Capital

Isla Cerritos and Chichén Itzá exemplify the interaction and dependency generated between a top-ranking political unit and a lesser-ranking site. Isla Cerritos is an island off the northern coast of Yucatán whereas Chichén Itzá is located 55 miles directly south and inland (Andrews et al. 1988; see also ►http://www.ncf.edu/andrews/Index.html). The material expression of that dependency suggests that the coastal community of Isla Cerritos was subordinate to the political and economic control of Chichén Itzá to the extent that the main architectural group of the island reproduces on a lesser scale a group of buildings that characterize the regional capital, which include a temple, altar, and colonnaded hall. The contemporaneous nature of the coastal port and the regional capital is demonstrated by the presence of the same types of commercial and utilitarian ceramics. Obsidian found in the coastal port as well as in the regional capital reflects the same supply sources. The remains of shells discovered both in Isla Cerritos and in Chichén Itzá are integrated into the body of archaeological evidence, which demonstrates the interest that the regional capital had in making its presence felt in a very specific sector of the northern Yucatán coast between AD 900 and 1050/1100.

It has been proposed that other settlements located on the seacoast of Belize functioned as ancient

Maya seaports of major inland capitals. The examples include Marlowe Cay associated with Altun Ha, Ramonal-Condemned Point linked to Shipstern, and the Northern River Lagoon associated with Colhá. However, the relationship between Marlowe Cay, Ramonal-Condemned Point, Northern River Lagoon and major inland capitals continues to be speculative, because none of these Maya seaports has been investigated in detail.

Trans-Shipment Seaports

This type of seaport, which served a specialized function, is recognizable by the following characteristics: they are small settlements in comparison to other inland communities, they exhibit a minimum of formal architecture, they are strategic points in the movement of commodities and/or merchandise among regions, and they contain a wide variety of exotic goods by having been part of a complex system of trade or exchange (Inurreta 2004). To date, the best examples of trans-shipment ports analyzed in the Maya area are San Juan, Chac Balam, Moho Cay, Wilde Cane Cay on the coast of Belize, and Uaymil on the northern coast of Campeche (Guderjan and Garber 1995; Inurreta 2004; McKillop 1996, 2005).

For instance, Uaymil emerged as an important coastal port on the northern Campeche coast after AD 800. Uaymil maintained a close relationship with Uxmal and Chichén Itzá, and the archaeological evidence uncovered at Uaymil confirms that this port was founded during the apogee of those two major political units. Uaymil functioned as another link in the chain of coastal sites that facilitated the transport of commodities between Chichén Itzá, located in central Yucatán, and the regions of the western Guatemala highlands, central Veracruz, central México highlands, and western México. When we consider the very strategic location of Uaymil on the northern Campeche coast, along with its internal characteristics and the archaeological materials found at the site, we can interpret that Uaymil functioned as a trans-shipment station. Uaymil's role was to facilitate the movement of merchandise and goods that eventually arrived at Chichén Itzá via Isla Cerritos. Evidently, Uxmal – the great capital of the western portion of the northern Maya lowlands located 55 miles inland – also benefited from the specific role that Uaymil played during the tenth and eleventh centuries (Inurreta 2004; ►http://www.famsi.org/researchreports/bysite/uaymil).

The Independent or Autonomous Seaport

The third type of seaport documented in the Maya area is characterized by its autonomous role. In other words, this type of port was a social, political, and economically independent entity. The autonomous seaport was never under the jurisdiction or hegemony of larger and powerful political units, and this condition allowed such a port to rise and flourish in several environments and during different periods in the Maya area. For instance, Cerros in Belize was an independent seaport located in a region where the riverine delta meets the open sea. By the Late Preclassic period, Cerros functioned as a complex seaport with a site center housing monumental buildings with elaborate architecture and a large residential zone surrounding the site center. The strategic position of Cerros on the coast of northern Belize allowed this site to have access to commodities and merchandise that were transported from inland to the Caribbean Sea or vice versa (Robertson and Freidel 1986).

Xelhá was another autonomous seaport located on the east coast of the Yucatán Peninsula. Xelhá was first settled during the Late Preclassic period or around 100 BC, and was continuously occupied until the sixteenth century (Andrews 1990). The archaeological evidence suggests that Xelhá functioned as an independent seaport during the Early and Late Classic periods and seems to have played a key role in the exchange system of obsidian, jade, and other goods that circulated along the Caribbean Sea and between Central America, Belize, and northern Yucatán (Guderjan and Garber 1995; McKillop 1996; McKillop and Healy 1989). The role played by Xelhá as an important seaport might be attributable to its geographic position along an important marine route that was established by the fifth century.

At Cozumel Island the site of San Gervasio became a seaport by the ninth century. San Gervasio is located in the northern sector of Cozumel and the archaeological evidence suggests two important moments of occupation at the site. The first of this moments dates between the eighth and tenth centuries and corresponds to the Classic period. The second moment of occupation dates from the eleventh to the sixteenth centuries and this period ends around 1518 when the first European conquerors arrived at Cozumel. The role played by San Gervasio as an autonomous seaport during the pre-Hispanic era is attributed to two precious goods produced at the island – cotton for textiles and honey (Sabloff and Rathje 1975). Sixteenth-century historical documents confirm the production of cotton and honey at Cozumel whereas the archaeological data corroborate the important role that these precious goods must have had on the economy of San Gervasio (Roys 1957).

Other Maya seaports that rose as independent political entities include Jaina, Xcambó, and Tulum. The first two seaports flourished during the Classic period whereas Tulum's apogee dates to the Postclassic period (Andrews 1990). The importance of Xcambó as a seaport is attributable to its control of the large salt beds located on the central coast of Yucatán. It seems

Xcambó controlled the production of salt and exported this mineral to other communities located in the Maya area and beyond. The function of Jaina and Tulum as seaports might be explained by their strategic midpoint position along the commercial sea routes that dominated the Gulf of México (Jaina) and the Caribbean Sea (Tulum). In fact, Tulum was spotted by Spanish conquerors early in the sixteenth century and they described it as a town larger than Seville.

This information represents a small part of the tremendous potential that awaits discovery regarding the function of ancient Maya seaports. Future archaeological investigations will continue to contribute to the increase in our knowledge of the features that characterize such complex coastal communities.

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Seki Kowa

JOCHI SHIGERU

SEKI Kowa, also called Takakazu, was born about 1642, probably in Fujioka, Gumma, Japan. Seki is his surname, and Kowa is the Chinese reading of characters, so the Japanese reading is Takakazu. His middle name is Shinsuke and pen name is Jiyutei. He was born into a samurai warrior family, the second son of UCHIYAMA Shichibei Nagaakira (unknown–1662[1]), and he became a son-in-law of SEKI Gorozaemon[2] and succeeded to the SEKI family. First he became an auditor of TOKUGAWA Tsunashige (1644–1678) at Kofu (now Kofu, Yamanashi) about 1661, then a chief of the meal service section.[3] He lived at Yamabushi-cho (now Minami Yambushi-cho, Shinjuku, Tokyo) about 1695. In 1704, he became a chief of the Store Room of the Shogun's family, and finally became a landlord of a 300-person village.[4] The Shogun's government normally kept the family records of landlords. But since Seki Kowa's son-in-law, Shinshichiro (1690–unknown) lost his position, owing to his gambling activities, we cannot fix even Seki Kowa's birth year exactly.

Seki studied mathematics under TAKAHARA Yoshitane. Takahara Yoshitane was a disciple of MORI Shigeyoshi, who wrote the *Warizansho* (Books of Division 1622), the second mathematical book in Japanese. But Takahara Yoshitane was little known for his mathematical works. Basically Seki taught himself mathematics, using famous texts of Chinese and Japanese mathematicians, such as the *Yang Hui Suan Fa* (Yang Hui's Method of Computation 1275), which he copied in 1661, and SAWAGUCHI Kazuyuki's *Sampo Ketsugi Sho* (Solving Mathematical Questions 1659). He amended works of other mathematicians, and founded the Seki-ryu school. He is generally considered the founder of Japanese mathematics.

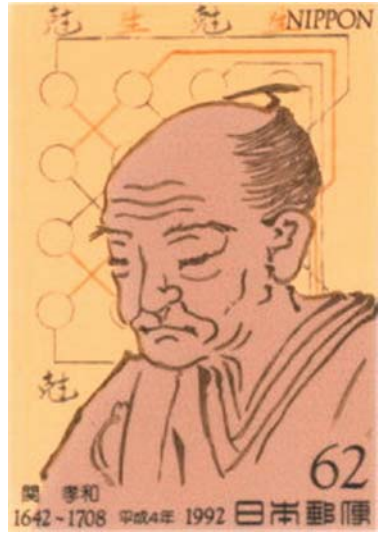
[1] In official documents, Uchiyama Nagaakira died in 1646, but Seki Kowa's youngest brother, Uchiyama Nagaaki (1661–1725) was born in 1661. So Uchiyama Nagaakira was alive in 1661 at least. More, Uchiyama Nagaakira's fathe was died in 1662 in these documents, thus we conclude that Uchiyama Nagaakira was died in 1662. (Jochi, Shigetin (2005): 19).

[2] Gorozaemon is a middle name, and the first name is unknown. Perhaps he is Seki Yoshinao (1591–1673) or part of another Seki family, Seki Toyofusa (about 1632).

[3] His annual salary was 200 *pyo* (150 kg of rice).

[4] His annual salary was 300 *pyo*, which is the same as being a landlord of a 300-person village. The samurai warrior who earned over 200 *pyo* could be received in an audience by the Shogun.

Seki Kowa. Fig. 1 Picture from the Kojukai, Shimminato, Toyama.



Seki Kowa. Fig. 2 Stamp issued in 1992.

The *Tianyuanshu* (lit. Celestial Element Method, Chinese Algebra System) had already been introduced from China by Zhu Shijie's *Suan Xue Qi Meng* (Introduction to Mathematics Studies 1299). This system was for the *Suan Chou* (*Sangi* in Japanese) – counting rods, in the Song and Yuan dynasties in China. In the Ming dynasty, however, new counting tools, *Suanpan* (*Soroban* in Japanese) – abacus – became popular, since no mathematicians understood the *Tianyuanshu* even in China. Japanese mathematicians taught the *Tianyuanshu* by themselves using a Korean edition of the *Suan Xue Qi Meng*. Sawaguchi Kazuyuki was the first Japanese mathematician who mastered it.

Traditional Chinese mathematics used counting tools, *Suan Chou* or *Suanpan*; they had no algebraic symbols. The position of rods (or beads of *Suanpan*) indicates numbers and the power of unknown numbers. This system could only operate with unknown numbers. Seki Kowa created *Tenzan-jutsu* (Japanese algebra system), which could operate with unknown formulae, making it possible to solve complicated problems.

Seki called his method *Endan-jutsu* or *Bosho-ho* (Methods of writing by the side). MATSUNAGA Yoshisuke (1693–1744), a mathematician of the Seki-ryu school, renamed it *Tenzan-jutsu*. Seki indicated one unknown number using one Chinese character and created the symbols of calculations and powers. And he solved the 1458 degree equation in the *Hatsubi Sampo* in 1674.

His works cover the following categories:

1. Japanese algebra system
2. Solution of higher degree equations
3. Properties (e.g., number of solutions) of higher degree equations
4. Infinite series
5. Approximate values of fractions
6. Indeterminate equations
7. The method of interpolation
8. Obtaining Bernoulli numbers using *Ruisai Shosa-ho*
9. Computing the area of polygons
10. Principle of the circle
11. Newton's formula using the *Kyusho* method
12. Computing the area of rings
13. Conic curve lines
14. Magic squares and magic circles
15. Mamakodate (Josephus question) and Metsuke-ji (the game of finding a Chinese character)

These categories had been very problematic before him, and he offered excellent solutions.

In 1712, TAKEBE Katahiro (1664–1739), Seki's student, edited Seki's works and published the *Katsuyo Sampo* 1 year before Bernoulli's *Ars Conjectandi* (1713). Seki obtained Bernoulli numbers using the *Ruisai Shosa-ho* system. It is a typical example of his mathematics. He also worked with what we call Pascal's triangle.

Seki computed to higher powers and obtained the fraction numbers of the last line of Table 1;

$\lambda_0 = 1,\ \lambda_2 = 1/2,\ \lambda_3 = 1/6,\ \lambda_4 = 0,\ \lambda_5 = -1/30,\ \lambda_5 = 0,$ $\lambda_6 = 1/42,\ \lambda_7 = 0,\ \lambda_8 = -1/30,\ \lambda_9 = 0,\ \lambda_{10} = 5/66,\ \lambda_{11} = 0$

$$\sum_{i=1}^{n} i^{\rho-1} = \frac{1}{p}\sum_{i=0}^{p-1} \left(\lambda_i(\rho, i)n^{\rho-i}\right)$$

These are just the same as Bernoulli's numbers.

He was able to compute too much higher numbers than other mathematicians before him, and he obtained the general rule by the inductive method. He, and mathematicians of his school, used this system habitually.

Seki Kowa. Table 1 Shosa-ho's table, Chap. 1 of the *Katsuyo Sampo* (1712)

	1	1											
x^2	1	2	(1)										
x^3	1	3	3	(1)									
x^4	1	4	6	4	(1)								
x^5	1	5	10	10	5	(1)							
x^6	1	6	15	20	15	6	(1)						
x^7	1	7	21	35	35	21	7	(1)					
x^8	1	8	28	56	70	56	28	8	(1)				
x^9	1	9	36	84	126	126	84	36	9	(1)			
x^{10}	1	10	45	120	210	252	210	210	45	10	(1)		
x^{11}	1	11	55	165	330	462	462	330	165	55	11	(1)	
x^{12}	1	12	66	220	495	792	924	792	495	220	66	12	(1)
Power	1	2	3	4	5	6	7	8	9	10	11	12	13
	1	$\frac{1}{2}$	$\frac{1}{6}$	0	$-\frac{1}{30}$	0	$-\frac{1}{42}$	0	$-\frac{1}{30}$	0	$\frac{5}{66}$	0	

Seki Kowa. Fig. 3 Seki's Tomb at Jorin-ji Temple, Ushigome, Edo (now Benten-cho, Shinjuku, Tokyo).

Seki died in Edo (now Tokyo), on December 5, 1708 (October 24, 1708, in the Japanese calendar).

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Seki Kowa's published writings are *Hatsubi Sampo* (Edo, 1674) and *Katsuyo Sampo* (Edo 1712). Other MS papers are collected in the Library of the Japan Academy (Nihon Gakushiin), Tokyo and Tohoku University Library, Sendai and others. Many important works were discussed in Vol. 2 of Fujiwara, 1954. Shimodaira, 1965 (Vol. 1) devoted many pages to Seki Kowa. All the works of Seki Kowa have been collected by Hirayama et al., eds., 1974. One of the best English discussions is Mikami, 1912.

Seki Kowa's main works:

1674. *Hatsubi Sampo* (Mathematical Methods for Finding Details). Edo: unknown.
1680. *Juji Hatsumei* (Comments of the Works and Days Calendar). n.p.
1681. *Jujireki-kyo Rissei no Ho* (Methods of Manual Tables of the Works and Days Calendar). n.p.
1683–1685. *Sanbu-sho* (Seki Kowa's Three Manuscripts). n.p.
1683–1685. *Shichibu-sho* (Seki Kowa's Seven Books). n.p.
1710. *Taisei Sankyo* (Complete Works of Seki Kowa). n.p.
1712. *Katsuyo Sampo* (Essential Mathematics). Edo: unknown.

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Settlements in Egypt: Alluvial Settlements in the Nile Valley (and Delta)

David Jeffreys

The River Nile forms a long thin strip of alluvial valley floor, rarely more than 15 km wide, through the hyper-arid desert of north-eastern Africa before fanning out into the Nile Delta north of Cairo. The Nile is fed by two main tributaries, the Blue and White Niles, which merge near Khartum in Sudan, and a minor tributary, the Atbara. The Nile Delta is now reduced to two main distributary channels, the Rosetta (Rashid) and Damietta (Dumyat) branches, with outlying residual canals serving Alexandria in the west and Pelusium in the east; in antiquity up to seven channels are recorded.

Before the construction of the first Aswan Dam in the late nineteenth century, the Egyptian Nile valley and the delta were subject to annual flooding due to monsoonal rains over the Ethiopian plateau which boosted the volume of the Blue Nile. The flood lasted several months, rising in late spring and receding in early autumn, and brought a new deposit of high-nutrient alluvium which provided the basis for Egypt's successful agricultural economy. Despite the popular picture of an idyllic, non-labour–intensive labour cycle, this flood-recession economy was vulnerable, being almost entirely dependent on a successful or "perfect" flood (i.e. neither too high nor too low), and left little resilience to fluctuation (Hassan 1993; 1997): there is for example hardly any evidence for man-made water storage facilities or canals serving marginal or extended catchment areas.

During the Epipalaeolithic period the Nile was building in response to changes in sea level; subsequently there was a down-cutting phase, with the result that the only surviving Palaeolithic sites are now preserved in the high terraces flanking the existing river valley. During the Neolithic (from 10000 BCE) the valley had again been building with alluvial sands and silts accumulating at the rate of about 10 cm per century. The valley floor today presents as a virtually dead flat plain dropping slightly to the eastern and western edges, and forming a slightly convex appearance with the highest, heaviest and newest sediments closest to the river. Throughout Egypt and Sudan the course of the Nile and its subsidiaries is of relatively low sinuosity, although this changes across the delta flood plain.

Upstream of Aswan and the first cataract lies that section of the valley known as Nubia (also Kush, Wawat or Napata); during the 3,000 years of pharaonic culture in Egypt there was a long and complex history of exchange and interaction between the two polities. Culturally Egypt and Nubia seem to follow a similar trajectory up to the foundation of a unified cultural and political Egyptian state in about 3000 BCE, with similar traditions in their lithic and ceramic industries. Thereafter Egyptian material culture develops differently into the highly distinctive pharaonic style in dress and body decoration, pottery production and metal-working, visual representation, and architecture. In Egypt both valley and delta were divided administratively into large land parcels or provinces called *nomes*, each with a local capital. In the Valley these nomes generally straddled the river; in the Delta they were determined by the changes in the distributary system and usually lay between the main channels. In Egyptian texts Nubia is recorded in less detail, and seems to be divided into ethnic/geographical zones: the part north of the second cataract, closest to Egypt's southern frontier at the first cataract, was under Egyptian control through most of the second and first millennia BCE. The desert regions outside the alluvial corridor were only lightly inhabited, except for the Saharan oases, but were exploited for their mineral contents, especially gold, high-grade building and sculptural stones, and pigments, and as an access to the trading routes of the Mediterranean and Red Seas and the African interior.

Settlement archaeology in Egypt is, astonishingly, still in its infancy (O'Connor 1993), and may never achieve its full potential with the onset of modern threats including industrial and residential development, climate change and the rise in the groundwater table brought about by the construction of the Aswan high dam in the 1960s. Traditionally the emphasis in exploratory fieldwork has been on the burial grounds of the valley edges and visible monumental architecture within established archaeological sites such as Thebes (Luxor). A critical factor in the recognition and recovery of information from Nile valley settlements is the mean rise of the valley floor over the past 5,000 years, which has had the effect of obscuring even quite well established settlements or those which have been abandoned by the river as it has shifted course. Stratigraphically shallower and more deeply buried sites, such as the older, shorter-lived towns, and ephemeral rural habitations of all periods, tend therefore not to survive unless they are on the higher ground at the valley edges. We are just beginning to understand just how much settlement archaeology has yet to be recorded from the examples of sites such as Avaris–Piramesse, the sixteenth- to twelfth-century royal capital in the northeastern delta also known by the modern names of Tell el-Daba/Qantir (Bietak 1996), where magnetometer survey has recently revealed huge areas of built environment lying beneath what is now agricultural land which is in private or municipal ownership. In Memphis, a far more extensive settlement area was visible in the eighteenth and nineteenth centuries than can be seen today. How zones such as these are to be treated in the future is yet to be resolved: no effective strategy has yet been proposed for their management, and archaeologists currently proceed largely through private negotiation, returning the land for agricultural or other destructive use after survey and/or excavation.

In Egypt, discussion of settlements has therefore focussed until recently on an impossibly small sample of sites which are almost all atypical of conditions in the Nile valley, leading one leading Egyptologist in the past to suspect that pharaonic Egypt was a "civilization without cities" (Wilson 1960). The handful of sites most often referred to are:

- The Middle-Kingdom (Twelfth Dynasty, eighteenth century BCE) site of Illahun (also known as Lahun or Kahun);
- The New Kingdom (fifteenth–fourteenth centuries) artisan village of Deir el-Medina on the Theban west bank;
- The newly discovered workers' quarters to the southeast of the Giza pyramids; and
- Particularly the large royal Eighteenth Dynasty (fourteenth century) town of Amarna, including its outlying suburbs, flanking necropolis, and another artisans' compound somewhat similar to Deir el-Medina.

None of these towns are strictly speaking "alluvial", however: they are all establishments built (probably deliberately) on the desert edge, whose layout was almost certainly unaffected by the river, and apart from Amarna they are attached to specific monumental building projects, all funerary. Paradoxically there is better data for Nubia, largely due to the intensive series of archaeological surveys in that region, especially the international UNESCO project in the 1960s in advance of the construction of the Aswan High Dam (Säve-Söderbergh 1987). Some of the best-known settlements of all periods are now those in Nubia, as for example the large town and cemetery at the local capital of Kerma, lying in the Nubian heartland above the second cataract (Bonnet 1995, 2000).

In both Egypt and Nubia the tendency was to construct the main settlements in the two main areas not constricted by the floodwaters, that is on the desert margins and the riverside levees (Butzer 1976). It is no accident that many of the earliest known settlements are on the lower desert regions to the east and west of the main alluvial zone, although this itself raises the question whether traces of settlement in other parts of the valley might have been removed by movements in the main and subsidiary channels. In the Delta settlement was more or less confined to natural marine and riverine sand banks (often called "turtlebacks") projecting above the general level of the flood plain. Largely due to the lack of any effective national survey strategy over the years, the impression is given of a gradual migration of settlement from the desert to the flood plain, as seen in the case history of the important pre- and proto-dynastic site of Hierakonpolis (Hoffman et al. 1986). Regional studies at this site and elsewhere (e.g. Memphis) have shown that river movement in both directions was a determining factor in the success and survival of flood plain communities, and the study of post-pharaonic settlements has shown that viability was dependent on the means to provide high ground beyond the reach of the floodwaters. This might be through lateral migration following the levees, or the rapid vertical development of residential building to maintain high, dry living conditions. Over time continued occupation must have been impossible to sustain in certain areas: there are some graphic accounts in more recent times of urban blight due to the rising water level, and examples of structures dating from the Late Antique (Byzantine) period having to be abandoned during the seventeenth to nineteenth centuries as the mean level of the inundation gradually rose. Many towns co-operated in the maintenance of river defences on an annual basis, and the fear of their failure is occasionally alluded to in the pharaonic literature. Paradoxically, religious sites in valley regions were especially vulnerable, because they tended to remain low-lying: they were sacrosanct and did not attract vertical accretion through new construction over the decay of earlier building fabric. There is even some evidence that temples were in fact occasionally flooded: such events were regarded as catastrophic, despite the symbolic inundation-based character of religious architectural ideology. It is worth remembering that while this was an ever-present danger in antiquity and into medieval times, conditions have been quite different for the past century, with perennial irrigation, and increasing urban and suburban sprawl, now possible through the construction of the successive Aswan dams. An appreciation of former living conditions is therefore possible today only through pre-twentieth century documents, notably the excellent series of early landscape photographs dating from the mid-1800s to the early 1900s.

Other considerations aside, it is clear that a seasonal pattern in behaviour and mobility must have applied to the annual rhythm of urban living: during the sowing and harvesting seasons, farmers may well have spent most of their time in temporary accommodation in the countryside, migrating to the desert edges and the main urban areas during the flood. In view of the impermanence of many kinds of rural and at least some kinds of urban habitation, it is perhaps interesting that there should be evidence of a considerable attachment to place. Eulogies of cities survive in the written record, probably the best known being a "hymn" to the city of Memphis (Caminos 1954).

The more typical types of flood plain town share several defining characteristics. Some, but by no means all (and perhaps even a minority) had defensive walls, although the river and municipal earthworks seem to have doubled as military defences; all known large conurbations contain at least one religious centre, with the identity of the cult varying with location; these temples and shrines often had enclosure walls of their own, which have a defensive appearance but are not necessarily built primarily for that purpose (Stevenson Smith 1998). Future work may confirm the suspicion that some major cities, such as Memphis and Thebes, which are often described as capitals, may at times have been long ribbon developments built along the river banks rather than the more familiar model of a highly nucleated, densely occupied urban core (Jeffreys and Tavares 1994).

The only complete town site that survives today in any detail above ground is Amarna, built by the pharaoh Amenophis III and his son Akhenaten (Amenophis IV) in the fourteenth century BCE as a breakaway royal city for the celebration of a new solar cult (Kemp and Garfi 1993). Significantly this is one of only a very few urban regions to be surrounded by boundary markers in the form of rock-cut inscriptions declaring the intention of the ruler, ranged along both sides of the valley but in sight of the town centre. This was probably because the territory for the new foundation was appropriated from the existing nearby provincial capital of Khmunu (Classical Hermopolis Magna, modern Ashmunein), although the major part of the town is on the low desert, not the alluvial plain, probably to maximise the agricultural yield of the requisitioned section of valley floor. Amarna consists of distinct zones representing various discrete functions:

– Residential zones of all social ranks (royal palaces, elite villas interspersed with dependents' quarters, and purpose-built artisanal compounds);
– Religious (temples and solar shrines), economic (food storage and food preparation areas);
– Administrative (police barracks, libraries or storage for diplomatic correspondence) and
– The outlying mortuary districts, including the royal tombs, segregated from the private tombs in a valley due east of the town centre.

Amarna illustrates an interesting tendency in settlement selection, which highlights the importance of landscape symbolism: the "royal valley" is thought to focus sight lines on the central feature of the rising sun, and is embodied in the Egyptian name of the town, Akhetaten ("horizon of the Aten" or sun-disk). In the same way prominent landscape features at other sites acquired symbolic importance, notably at Thebes with its pyramid-shaped mountain on the west bank, and Memphis, at the southern apex of the Delta, with its high-profile layered cliffs to either side (possibly the origin of its earliest name "White Walls").

Even within communities some common features can be identified. Temples conform to a highly distinctive and recognisable pattern, with almost universal features such as the twin-towered pylon featuring flagpoles and monumental statuary, colonnaded courtyards and hypostyle halls with clerestory windows and embrasures; dark and restricted inner sanctuaries; artificially created sacred lakes, and not infrequently causeways, often flanked by ritual statuary such as sphinxes, which linked separate enclosures. There even seems to be a standard plan for houses, the quadripartite ground floor layout incorporating an entrance chamber, communal room and split back section used for different purposes and sometimes featuring a stair to an upper storey or roof terrace (there is evidence for multi-storey structures from both archaeological and representational evidence). Living units of this kind usually occur in terraces along axial or subsidiary streets and alleys, as at Amarna, Deir el-Medina, Karnak and Memphis. Other evidence comes from funerary architecture: it is very likely that tomb plans at different times reflect the general layout of town houses as also illustrated in tomb scenes, with (for example in the New Kingdom) entrance halls, atria that might contain pools or gardens, and back rooms which become sanctuaries and statue rooms in the funerary context. Some tombs at this time have miniature pyramids over or behind the sanctuary, which are certainly an exclusively funerary feature.

For elite residential structures we are more or less dependent on Amarna, where they take the form of villas or compounds freely dispersed through the northern part of the city, and Illahun, where they form a suite of terraces either side of the main street. Relatively few royal palace structures are recorded in any detail (Malqata at Thebes; Piramesse/Qantir in the delta; three separate palace compounds at Amarna; Balat (Ayn Asil) in the Dakhla Oasis (Soukiassian et al. 1990); the short-lived early New Kingdom site of Deir el Ballas just north of Thebes; and a supposedly "ritual" palace at Memphis). There are in addition small "palace" structures incorporated in the large mortuary temples of the Theban west bank, especially those of Ramesses II (the Ramesseum) and Ramesses III (Medinet Habu) (O' Connor 1989).

See also: ►Hairstyling in Egypt, ►Metallurgy in Egypt, ►Stone in Egypt, ►Tombs in Egypt

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Sexagesimal System

Marvin A. Powell

The sexagesimal system was an ancient system of counting, calculation, and numerical notation that used powers of 60 much as the decimal system uses powers of 10. Rudiments of the ancient system survive in vestigial form in our division of the hour into 60 minutes and the minute into 60 seconds. Origins of the system of counting are essentially irretrievable because they lie in the period before the invention of writing. They are associated with the ancient Sumerians, whose language incorporated the only known system of sexagesimal counting. The Sumerians were probably also the inventors of the system of calculation, which seems to have its origin in a system of counters (small clay objects also referred to as tokens or calculi) representing the units 1, 10, 60, 60 × 10, 60^2, $60^2 \times 10$, and 60^3. This counter-calculation system may go back as far as ca. 3500 BCE. The method of numerical notation apparently originated from the system of counters by adapting it to a form that could be represented in writing when the first writing system was invented ca. 3000 BCE.

By 2000 BCE this had developed into a system of sexagesimal place notation that functioned like our decimal system but with several important distinctions. Whereas the decimal system uses ten unique symbols, plus a period or comma to separate fractions from integers, the fully developed sexagesimal system of notation used only two unique symbols (those for 1 and 10) and essentially ignored our distinction between fractions and integers. These features, as well as lack of a symbol for zero, reflect its origins in the system of calculating with counters: zero would not have been represented in a system of counters (obviously, one does not count something that does not exist), and unique symbols for the integers 1–60 would have been excluded for practical reasons. Lack of a distinction between fractions and integers goes back to the fact that fractions are essentially alien to prehistoric systems of counting. Names for small quantities that we would call fractions are based on subdivisions of the weight system (*mina* and *shekel*) and were clearly not thought of as fractions in our sense of the word. In keeping with this picture is the symbol for medial zero that appears in Babylonian mathematical texts of the late first millennium BCE. This so-called *zero* is really nothing but a "spacer" symbol and reflects the practice (occasionally observable in surviving texts) of leaving a blank space where we would place a zero.

During the third millennium BCE, this Sumerian sexagesimal system was adopted, along with other features of Sumerian culture, by Semitic-speaking Akkadians, and the Akkadian language, which – like Sumerian – was written in cuneiform script on clay tablets, served as the vehicle for its diffusion and preservation. As an essential part of the education of scribes, it was still very much alive when Greeks conquered the Near East in the time of Alexander the Great. The two centuries of Greek presence in Mesopotamia (330–129 BCE) facilitated the incorporation of Babylonian mathematical astronomy into the Western tradition, and with it also came knowledge of the Babylonian sexagesimal system. This, however, seems never to have been used systematically by Greeks outside of Babylonia. Division of the circle into 360° is a vestige of the Babylonian system that has been transmitted to us by the Greeks.

Modern knowledge of the existence of an ancient sexagesimal system goes back as far as the recovery of Greek mathematics, beginning in the Renaissance. Little, however, was known about its true character until the middle of the nineteenth century when decipherment of cuneiform writing revealed the system in its developed form of the first millennium BCE. Speculations about its origins have tended to postulate conscious creation, as opposed to gradual evolution.

The 360-day year and choice of 60 as base (because 1, 2, 3, and 5 are all prime factors) are among these theories, all equally without evidence. Only in the twentieth century has the Sumerian system of counting become relatively well understood, and the role of clay counters as prototypes of number symbols has only become clear in the last decade.

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Shamanism in Pre-Columbian Mesoamerica

Keith Jordan

Shamanism is a term used by anthropologists and historians of religion to describe similar systems of religious thought and practice centered on the role of ritual specialists who enter trance states in order to communicate with the supernatural world for the benefit of their communities. Derived from an indigenous Siberian term for such a practitioner, shamanism is distributed through Asia from Siberia south to Korea and Vietnam. Across the Pacific, it is characteristic of Inuit culture and of many Native American groups throughout North, Central, and South America. It has been used as a model for understanding religious experience and ritual process in New Guinea and other regions of Oceania and to classify the belief systems of peoples from the San Bushmen of southern Africa to the pre-Christian Lapps. It has been posited as the first human religion, the inspiration behind the cave art of Ice Age Europe, and even suggested as prevalent in Bronze and Iron Age Europe.

The shaman is a specialized ritual practitioner who is adept at entering altered states of consciousness understood as journeys to the spirit world. Ritual, asceticism, music, and hallucinogenic plants may be employed to facilitate entry into visionary experiences. The other world entered by the shaman may be conceptualized as the land of the dead, the realm of animal or nature spirits, or the domains of various deities. At least in Asian and American shamanism, the universe is pictured as divided into upper, middle and lower worlds, connected by a central vertical axis, often a World Tree spanning the cosmos from the bottom of the underworld to the farthest regions of the sky. The shaman is able to visit these other worlds by traversing the central axis or similar portals, often via a state experienced as flight, in order to interact with supernatural beings for the good of the community. The purpose of the voyage may be to obtain cures and defeat witches on behalf of an individual client, as is frequent in small hunter-gatherer societies, or to control weather, promote the fertility of game and agriculture, and predict the future. Generally, shamans are “called” to their vocation by unusual hallucinatory experiences, personality traits, dreams, or by a prolonged or severe illness. They train by serving as apprentices to older shamans, and frequently attain full status by initiation rites and/or visionary experiences in which they are symbolically killed and reborn to their new identities. In many varieties of shamanism, the specialist cultivates a relationship with an animal spirit as a familiar and/or alter ego, and is believed to take the form of this animal when traveling the spirit world.

Shamanic practices are still prevalent among some contemporary Native Mesoamerican groups, notably many Maya communities in Chiapas, Yucatan and Guatemala, where shamanism mingles with Christian beliefs, and the Huichol of northern Mexico. Because of these ethnographic observations and because of the shamanic features of pre-Columbian cosmologies, anthropologists and art historians have employed shamanism extensively over the past several decades as a heuristic device for understanding ancient Mesoamerican beliefs. However, some of these interpretations seem to be better founded than others.

The so-called Olmec culture of the Early to Middle Formative Periods (ca. 1500–400 BCE), centered on the Mexican Gulf Coast states of Veracruz and Tabasco, has been conceptualized by many scholars as the “mother culture” of Mesoamerica, the origin of the basic traits shared by all later Middle American civilizations and of an art style diffused from central Mexico to El Salvador and Honduras. More recently, other archaeologists argued that the Olmec were a “sister” culture to their contemporaries and successors. Rather than originating the art style associated with them by champions of the “*cultura madre*” view, they may have produced the finest and most monumental expressions of a pan-Mesoamerican art style which did not originate on the Gulf Coast. Olmec portable stone carvings frequently depict men who appear to be transforming physically into jaguars, the most common animal ally or alter ego for modern Central and South American shamans. In some of these images, human features predominate, while in others varying mixtures of human and feline traits seem to represent shape shifting in varying degrees of progress. One of these figures, now in the Princeton Art Museum, bears an engraving of a toad on its head, and toad bones occur in refuse at the Olmec site of San Lorenzo. This is further evidence for shamanic practice: *Bufo marinus* and other toad species are a source of potent hallucinogens. The shamanic model, as proposed by Peter Furst, F. Kent Reilly and others, fits the evidence well in this instance, though caution is always required in comparing the visual culture of a Mesoamerican group which has left us no written records with ethnographic data collected thousands of years later and from across wide expanses of North, Central, and South America. Equally intriguing but uncertain are interpretations of the body postures of Olmec portable figures as positions facilitating meditative states and the cultivation of trance.

Olmec monumental reliefs at the sites of La Venta and Chalcatzingo, and paintings at Oxtototitlan, showing elaborately costumed figures emerging from the mouths of monsters, have also been given a shamanic interpretation. Reading backwards, from the beliefs of contemporary Maya shamans and the inferred practices of their Classic Maya predecessors, these saurian, ophidian and/or feline mouths represent symbolic portals into the earth and underworld, or perhaps to the celestial realms. The richly garbed figures are Olmec kings performing the functions of the shaman, in these instances journeying to the spirit world to obtain adequate rainfall and agricultural bounty for their polities. They may be the earliest instances of a conception of otherworldly portals in zoomorphic form that has survived to the present Mesoamerica. The difficulty, however, with readings of this sort is that they are inferences based on chains of extrapolations from the historic to the pre-Hispanic Maya and then back to the Olmec. Even assuming the continuity of use of such motifs, disjunctions in their meaning might be expected over time and across geographic and linguistic boundaries.

The late Linda Schele used the shamanic beliefs and practices of contemporary Maya as a fruitful analog for comprehending Classic Maya ritual and iconography, like the images of ancestors conjured through “Vision Serpents” by the bloodletting rites of Classic Maya kings. These represent supernatural portals to the realm of the ancestors and are analogous to the supernatural serpents that swallow and excrete contemporary Maya shamans in their initiatory experiences. Similarly, her work led to the identification of a class of supernatural beings represented in Classic Maya art as the spirit alter-egos of Maya rulers, called *wayob* in the accompanying texts. Her work has received considerable support from the ongoing decipherment of Maya glyphs but is not without its critics. These point out, among other things, that the autosacrifice of blood from their tongues and genitals by Maya rulers may not be physiologically conducive to trance states as claimed in Schele’s original formulation.

The iconography of ceramic sculpture accompanying burials in the Late Formative to Classic shaft tombs of West Mexico has been interpreted by analogy to the shamanism of the Huichol and other contemporary indigenous groups. The most prominent proponent of this approach, anthropologist Peter Furst, identifies horn-like protrusions on the heads of some anthropomorphic figures as a mark of shamanic status akin to the coiffures of historic Sioux medicine men and the horns of shamanic figures in Asian myths. First interprets the emaciated or skeletal state of some of the humans in West Mexican ceramic effigies as representing forces of renewal rather than death, by analogy to the initiation experiences of contemporary shamans who are stripped of their flesh in visions and reconstructed by the spirits in their new identity as ritual practitioners. (Jill Leslie Furst has used the same complex of imagery as a fruitful heuristic device for interpreting the meaning of skeletal deities in Mixtec manuscripts as gods of fertility and rebirth.) The geographic proximity of these West Mexican sites to the current territory of the Huichol and other tribes with strong shamanic traditions supports Furst’s readings, but again caution is required in generalizing meanings across great expanses of time. Contra Furst, Mark Miller Graham interprets the “horns” of West Mexican tomb figures as conch shells symbolic of rulership. While not dismissing the presence of shamanic themes and imagery in this art tradition, he emphasizes the manipulation of such ideas by pre-Hispanic political elites to maintain their status, over what he criticizes as the ahistorical generalizations about visionary experiences in Furst’s writings.

In other instances, the attempt to read ancient Mesoamerican images through a shamanic lens seems strained and stretched. Some scholars seem to interpret every form, material, and function of any given pre-Columbian art object as related to shamanism, as though the culture consisted of little other but such religious practices. A recent catalog of pre-Columbian art from Mesoamerica, lower Central America, and the Andes in the Michael Carlos Museum at Emory University seeks to interpret almost every formal and iconographic feature of portable objects like ceramic vessels in terms of ethnographic observations of shamanism often removed in time by centuries and often by geographical distances of hundreds of miles. Designs on Central American ceramics, for instance, related to the altered perceptions of the shamanic trance; the rattles attached to effigy vessels attempt to evoke the sound of animal allies. All of these interpretations are brilliant and creative. Some may be quite accurate, while others may be stretching the concept of shamanism as a hermeneutic tool for interpreting pre-Columbian art to its limits and beyond. In the present state of knowledge and absence of written records for most of this material, these interpretations are largely unverifiable. There is always the risk of projecting the ethnographic present onto the archaeological past, when, because of the lapse of intervening centuries and the major cultural changes wrought by Christianity and European conquest, ancient beliefs may have been quite distinct from their latter-day descendants in the same region. When analogies to pre-Columbian material are sought in modern shamanistic complexes as far away from Mesoamerica as the North American Plains and the Amazon, their explanatory value becomes more questionable.

Recently, some Mesoamerican scholars, notably the American art historians Cecelia Klein and Esther Pasztory, have sharply criticized the characterization of pre-Columbian art and religion as shamanic. They point out that most societies described as having shamanistic religions in the ethnographic literature operate on a far less complex level of social organization than the civilizations of Mesoamerica. They question the validity of using a construct developed to explain religious behavior among hunter-gatherers or small villages for understanding Mesoamerican state-level societies, like the Aztec and Maya. In the case of the Aztec at least, it is clear that religious life was dominated not by shamans but by a vast bureaucratic hierarchy of priests, most of who were probably not natural born visionaries. Although the mercurial Aztec deity Tezcatlipoca may have had shamanic origins, he was the patron deity of the Aztec monarchy. For the Classic Maya, hereditary sacred monarchs performed the rites characterized as shamanic—clearly a different social context than most of the behaviors classified as shamanism in other parts of the world. On the other hand, Furst contests these critics' categorization of shamanism as limited to relatively egalitarian hunter-gatherer groups, pointing out the dominance of shamanism in several northern South American agricultural town societies.

Some critics equate the use of shamanism to explain pre-Columbian cosmology and symbolism with the romantic primitivism of the New Age movement and its fetishization of Native American religions. Yet, much of Schele's and others' work on Classic Maya shamanism has been confirmed by—and has stimulated—recent epigraphic work. It appears that the beliefs of modern Native Mesoamericans can serve as springboards for framing hypotheses about the ways of their ancestors, but caution is needed to avoid overspeculation and casting the past in the mold of the present.

See also: ►Mesoamerican Casmology

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Shanghan Lun

RICHARD BERTSCHINGER

The *Shanghan Lun* (Treatise on Cold-Induced Fevers) by Zhang Zhongjing was written about AD 210. It is the first important practical work in Chinese medicine that has come down to us. The legend is that within a period of 10 years nearly two-thirds of Zhang's village died of illness, mostly from infectious diseases. Zhang, seeing so much suffering, forced himself to find a way to save them, and looked up the ancient prescriptions and read the ancient books. At the end of the third century, after the political turmoil accompanying the breakup of the Han dynasty, the book was reorganized and edited. In the eleventh century, the Song scholar Lin Yi further recompiled and divided it into two sections: the *Shanghan Lun* as we know it today and the *Jingui Yaolue Fang Lun* (Treatise on the Golden Casket Collection of Prescriptions).

Most admirable in Zhang was his scientific approach to medicine. He berated doctors who used secret remedies to dupe people, saying "what looks magnificent on the surface may be rotten underneath." He attached great importance to close observation and early treatment of conditions, adjusting the remedies to suit the disease and changing the medicine as the cure progressed. He deplored the frequent use of purgatives. As a mild laxative he prescribed pig's bile mixed with vinegar poured into the rectum through a bamboo tube. He observed the fluctuation in temperature during fevers, and devised a model for the progression of disease based upon the separation of *Yin* and *Yang* into *Shaoyang*, *Taiyang*, *Yangming*, *Shaoyin*, *Taiyin*, and *Jueyin*. This has been a most influential categorization in Chinese medical literature.

Earlier works had recorded the reaction of the pulse to pathological conditions, but Zhang extended his theory to included the pulse's reaction to the effects of drugs.

About 200 simple herbal medicines were then known, of which the most common were emetics, purgatives, and antipyretics. For instance rhubarb, sodium sulfate, and croton plant were used as purgatives. For reducing fever there was scutellaria, cinnamon bark, ephedra, and bupleurum. As emetics the stalks of various gourds or melons, and parts of the gardenia were recommended. Such remedies are now in use throughout the world. Rhubarb, for instance, was introduced into Europe in the fifteenth century, and imported up to the ninetieth century. The action of ephedra has been mimicked by modern drugs and is invaluable in asthma.

As analgesics and sedatives, various parts of the aconite plant and almond were used. Almond extracts are still used to relieve coughing. Aconite was toxic, but with extreme care it could be useful as a cardiac tonic and nervine. Ginger, licorice, dates, onion roots, and orange peel were used as digestives.

Artificial respiration is mentioned and the use of it in suicides by hanging. In cases of poisoning, water was forced down the victim's throat to wash out the stomach – much as in modern hospitals. In diet, Zhang also forbade the use of food derived from animals which had died from disease, and stressed the importance of proper storage and hygiene.

His whole work is a clear example of early scientific method. His manner, most obviously suited to herbal medicine, has been largely adopted by the modern Chinese in their presentation of Chinese traditional medicine. With its differentiation of disease by signs and symptoms, it guides the student into a clear etiology, differentiation of condition, treatment plan, and prescription – whether treatment by acupuncture, herbal medicine, massage, diet, or therapeutic exercise is intended.

See also: ►Zhang Zhongjing

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Sharaf al-Dīn al-Ṭūsī

JAN P. HOGENDIJK

Little is known about the life of Sharaf al-Dīn al-Muẓaffar ibn Muḥammad ibn al-Muẓaffar al-Ṭūsī. He was born in Ṭūs (Iran), probably around 1135. He spent part of his life in Syria and Iraq, and died in Iran around 1213. He had a number of pupils, including the famous polymath Kamāl al-Dīn ibn Yūnus.

Sharaf al-Dīn al-Ṭūsī was one of the best mathematicians of the Arabic tradition. His most important work is a treatise on cubic equations, in which he develops the theory quite beyond the limits reached by al-Khayyām. The Arabic mathematicians only considered positive coefficients, and they therefore distinguished various types of cubic equations, such as $x^3 + bx = c$, $x^3 + c = bx$, $x^3 = bx + c$, $x^3 + ax^2 = bx + c$, $x^3 + bx = ax^2 + c$, and so on. For all these types, ʿUmar al-Khayyām indicated a geometrical solution of a positive root x (negative and zero roots were not taken into account). For al-Khayyām, the coefficients a, b, c were not in the first place numbers: a was a line segment, b was a rectangle, and c was a parallelepiped. Using these data, al-Khayyām constructed two conic sections, and he supposed that these conics intersected in a point P. He then constructed x by means of P. It is obvious that this procedure only works if point P exists. For some types of cubic equations (for example $x^3 + bx = c$ and $x^3 = bx + c$) it is easily proven that a point P always exists, so the equation always has a root x. For other types of cubic equations (such as $x^3 + c = bx$) P may or may not exist, depending on the coefficients of the equation. The only way in which al-Khayyām could find out whether point P existed was by actually drawing the conic sections, which could be done with limited accuracy (it is unclear whether al-Khayyām ever constructed a root x this way, because the subject seems to have been of theoretical interest only). Thus it was not precisely clear when a cubic equation like $x^3 + c = bx$ had a root.

For the particular case of $x^3 + c = ax^2$, some predecessors of al-Khayyām had shown that a root x exists if and only if $c \leq (4/27)a^3$. Thus these mathematicians knew in advance whether a root existed, and they only needed the conic sections to construct x. Sharaf al-Dīn showed that similar (but much more complicated) conditions exist for all types of cubic equations which do not always have positive roots. He meticulously proved the correctness of these conditions by means of the methods of "geometrical algebra" used by Euclid in Book II of the *Elements*. He then gave a geometrical construction of the roots x, and (unlike al-Khayyām) a numerical procedure, which could be used to approximate the roots with any desired accuracy. In the theory of cubic equations, no further progress was made until the discovery of the algebraical solution in Italy after 1500.

In addition to his treatise on equations, Sharaf al-Dīn wrote two short works on elementary geometry. He also invented the "linear astrolabe," consisting of a staff with a plumb line and two cords. The staff contained the markings of the North–South line of an ordinary astrolabe. Although this instrument is easier to construct than an ordinary astrolabe, it does not look nice and it is not user-friendly. Thus it is not surprising that no examples have survived.

See also: ►ʿUmar al-Khayyām, ►Ibn Yūnus

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Shen Guo

Fabrizio Pregadio

The Chinese scholar, statesman, and scientist Shen Guo was born in 1031 in present-day Hangzhou (Zhejiang). Born into a family of gentry, he entered civil service in 1054, holding minor posts in different provinces where he distinguished himself in a series of projects involving water control. After passing the national doctoral examinations in 1063 he moved to the capital, Kaifeng, and in 1072 was named Director of the Astronomy Bureau. In that position he reorganised the Bureau, planned a program of astronomical observations, and devised a calendar that was effective from 1075 to 1092. His work as astronomer alternated with missions to the provinces, where he was again able to display his skills in hydraulic engineering. The relief maps he made in 1074 (using wooden plates, sawdust impregnated with glue, and melted wax) are among the most celebrated specimens of Chinese cartography.

The whole of Shen's career was influenced by his partnership with Wang Anshi (1021–1086), the leader of the "New Policies" (*xinfa*) group which advocated a reform program aimed at strengthening the central government, regulating finances by law, and exploiting nature for the state's benefit. Shen's memorials to Emperor Shenzong (r. 1067–1084) on a variety of subjects – including military strategy and tax levies – won approbation in a dozen instances. In a related development, Shen was sent as an envoy to the Khitan court in 1075, and, in a feat of diplomacy, was able to put at least a temporary end to the borderland skirmishes and the repeated Khitan claims of Chinese land.

Following his diplomatic victory, Shen Guo was appointed Finance Commissioner in 1077, but that very year also marked the turning point of his political fortune. The opponents of the "New Policies" had succeeded in pressing Wang Anshi into retirement. Shen was in turn charged with duplicity in his fiscal policies, and demoted. Three years later, partially rehabilitated, he was sent to the Shenxi province as

Commissioner for Prefectural and Military Affairs. In 1081 he obtained an important military victory against the Tanguts. One year later, however, he was held responsible for the disastrous defeat that the Chinese troops suffered in the same area, and put on probation.

Shen spent the following years completing a map of the territories under Chinese control, for which he was commissioned by the Emperor in 1076. When he submitted it to the throne in 1088, his rewards included the right of choosing his residence. He thus moved to the "Dream Brook," a garden estate that he had bought some years earlier near present-day Zhenjiang (Jiangsu), and devoted most of his time to writing, until his death in 1095.

Shen Guo's writings include treatises on administration, military strategy, astronomy, medicine, poetry, ritual, and several other subjects. His best known work, entitled after the name of his retreat, is the *Mengqi bitan* (Brush Talks from Dream Brook). Written in the final years of his life, and supplemented by two shorter works probably published posthumously, it consists of about 500 jottings on disparate matters, usually short and organized into topics. The original edition was in 30 chapters, of which 26 are extant. Of special importance from the point of view of the history of science are the sections pertaining to mathematics, astronomy, meteorology, optics, physics, geology, and medicine.

To give only a few examples, chosen among the more important parts of his work but clearly inadequate to reflect the richness of its contents, in the field of astronomy Shen Guo described solar and lunar eclipses, studied the moon phases, and provided reasons for the apparent planetary motions. During his appointment as Director of the Astronomy Bureau, moreover, he modified the design of the sighting tube pointing to the Pole Star in the armillary sphere. In the field of geology he recognized the origin of fossils, and gave an account of the role of erosion. Other jottings are concerned with magnetism, the production of inverted images on concave mirrors, the formation of rainbows, the fall of a meteorite, and the process of printing. All this adds to his skills in cartography and hydraulic engineering.

As several scholars have remarked, Shen Guo never attempted to organize his observations into a general theory. His work is, in many ways, the product of an exceptionally bright mind, motivated by a sharp curiosity in observing, understanding, and describing whatever phenomenon aroused his interest. This was by no means limited to natural processes or to man-made techniques. One chapter of the *Mengqi bitan* deals with supernatural matters, which the author treats with the same sympathy he accords to the other fields that attracted his attention. For a proper assessment of Shen Guo's personality and production, the "scientific" features of his works should be evaluated without neglecting their own context or disregarding other features which we might label as "unscientific."

From another point of view, Shen Guo reveals the short-comings inherent in the equation between Daoism and scientific progress on one hand, and Confucianism and scientific conservatism on the other, which has influenced some recent work in the history of Chinese science. While Daoists were not interested in nature per se (nature was before all an "image," *xiang*, of the absolute principle, the *Dao*), Shen Guo shows that interest in natural facts could be, and indeed was, actively pursued by a "Confucian" scholar and state administrator.

See also: ►Calendars in China, ►Astronomy in China, ►Maps and Mapmaking in China, ►Armillary Spheres in China

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Shibukawa Harumi

Nakayama Shigeru

Shibukawa Harumi (1639–1715) was a Japanese astronomer and calendar reformer whose distinguished service in calendar reform led to his appointment in 1685 as official astronomer.

The Chinese lunisolar Xuan-ming calendar, adopted in Japan in 862, had not been reformed for more than 800 years. Over the centuries the discrepancy in the length of a solar year had increased so that by Harumi's time there was a 2-day delay in the winter solstice.

With able diplomatic skill, Harumi urged that the Shogunate government undertake calendar reform. In 1669 he began conducting astronomical observations, probably the first systematic observations made in Japan. Following the procedures of traditional Chinese astronomy, he set up a gnomon and measured the lengths of shadows at various points before and after the winter solstice, in order to calculate the time of occurrence. He was especially interested in the Shoushi calendar of the Yuan dynasty (1279–1368), a crowning achievement of calendrical astronomy adopted in China in 1282, and his observations were based upon its methods.

In his reference to Western theories, Harumi based his information on scanty sources and came to regard Western astronomers as "barbarians who may have theories but cannot prove methods." It is regrettable that sufficient material for evaluating Western theories was not available to him.

During the eighteenth century Japanese astronomy altered its orientation from China to the West. Harumi belonged to the first generation of astronomers who, with only limited knowledge of Western astronomy, began evaluating the merits of both systems.

See also: ►Calendars

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Shipbuilding in India: Wadia Shipbuilders

RAJESH KOCHHAR

The British created a vast overseas empire through their supremacy over the high seas. In their colonial enterprise they were ably assisted by the Wadia shipbuilders of Bombay (old spellings are advisedly used) who, drawing on their own skills, local tradition and the raw material available, provided the British navy and merchants with excellent ships.

In the year 1498, Portuguese arrival in India by an all-sea route introduced the navy as a factor in the geopolitics of India, placing the landed rulers at a disadvantage for all times to come. The Portuguese and the Dutch success brought the British to the Indian west coast in 1608, after four years, they inflicted a crushing defeat to the Portuguese at sea. The Portuguese were fanatically anti-Muslim and particularly severe on the Haj pilgrims. The victory of the religiously neutral British was viewed with relief by the Mughal emperors who in turn granted them attractive trade concessions. It was the desire to get such concessions enforced at lower levels that fuelled the (British) East India Company's territorial ambitions. Ironically, the British task was made easier by the Portuguese themselves.

The island of Bombay, which the Portuguese had taken over in 1534, was ceded and granted to the crown of England in full sovereignty under a marriage treaty signed in 1662. Never before had the dowry of a princess been so detrimental to the interests of a kingdom. Bombay was an excellent natural harbour. More importantly, unlike Surat where the British had been permitted to set up their headquarters, it laid outside the territorial reach of the Mughals. The Portuguese viceroy of Goa, Antonio de Mellow de Castro, had boldly declared: 'I foresee that India will be lost the same day on which the English Nation is settled in Bombay' (Da Cunha 1900, cited in Wadia 1957: 9). These words turned out to be prophetic indeed.

The instructions from London were 'to keep Bombay always the seat of our power and the centre of our trade in India'. It gradually became an attractive destination for the native settlers especially the Indian Zoroastrians, the Parsis, who particularly valued the religious freedom and the business opportunities the new city offered.

Until this time, the British had been getting their ships repaired and built mostly in Surat. Like many coastal places, Bombay already had facilities for building small vessels, 'but no proper establishment with a dockyard, attendant builder and ancillary factories for rope-making, coopering, etc, existed' (Wadia 1957: 119). What lent urgency to the establishment of a proper shipbuilding facility at Bombay was the harassment from 1707 of foreign ships by a fleet led by Kanhoji Angre (anglicized to Connajee Angria and variously spelt) and his successors till their defeat by the British in 1751.

The first priority for Bombay was to build coastal boats. The man of the hour was Lowjee Nusserwanjee (ca. 1700–1774) who had been working for a Parsi shipbuilder in Surat since his boyhood and was known to the Bombay officials as the foreman responsible for actually building the ship 'Queen'. In March 1736 he, along with ten other carpenters, came to Bombay expressly to build a grab [a usually two-masted, square-rigged coastal vessel]. When the Master Builder, Mr. Robert Baldry, died in 1740, no replacement was sought from Britain. Instead Lowjee was given the charge. From 1740 till 1764 he was generally designated Master Carpenter and subsequently Master Builder.

It was under his guidance that the first dry dock was built in 1750, and others were added later. A subsidiary dock, the Mazagon, was built in 1774. There was also a small private dock, Old Mughal dock, built around 1835, which was rented out to the Peninsular & Oriental Company in 1854 for their new mail service between Bombay and Suez. Remarkably the government post of Master Builder remained in the family for six generations till 1884, when the dockyard was transferred from the Bombay government to the Indian. There were other Wadias working in junior dockyard positions where they continued until 1913. The Wadia skills were made use of by foreign governments, companies and merchants. The family name Wadia, meaning boat builder in Gujarati was not used in official records, even though later Master Builders sometimes signed their names as Lowjee. All official correspondence was however addressed to the formal name consisting of the given name followed by the father's.

In the first phase of shipbuilding in Bombay, the emphasis had been on repairs and construction of coastal boats for protection. Things soon changed. Increased merchant activity and marine rivalry in Europe resulted in large-scale felling of oak trees in Britain. In 1772 the Company was prohibited from building any large ships. It therefore shifted the shipbuilding activity to India. In any case, teak was a better material than oak.

The dockyard was at its zenith during Jamsetjee's tenure (1792–1821) while his son and successor Nowrojee (1821–1844) 'was the last person to enjoy all the rights and privileges attached to the office. After his retirement there was an all round decline in ship building in Bombay' (Wadia 1957: 296). The golden age of shipbuilding in Bombay however spelt disaster for the teak forests in India. The forests in Gujarat and Konkan were soon exhausted and the Malabar forests severely depleted. It is only when iron and steel ships came into increased use that in 1847 a conservator of forests, Dr. Alexander Gibson, was appointed in Bombay.

Racism

Although the Wadias were well regarded in official circles, they did come across racism. In a particularly unsavoury incident, in 1781, a dockyard carpenter was flogged in a visiting British navy ship on suspicion of petty theft. When the Master Builder Bomanjee Lowjee himself went to the ship to remonstrate, he was also struck. He immediately wrote to the government stating, 'unless they could be supported in their station with reputation they must with reluctance request permission to quit the place and the employment they held under the Company'. When the ship commander stood his ground, it was left to the admiral to write 'a healing letter' (Wadia1957: 164).

The next Master Builder's revenge against racism was subtler. The frigate Marquis Cornwallis built by him in 1800 for the Company was found to be so beautifully constructed and of such great strength that the Admiralty purchased it four years later. On the kelson [the timber immediately above the keel] he secretly carved the words: 'this ship was built by a d…d Black Fellow AD 1800'. Jamsetjee himself drew attention to this when the ship, since renamed Ackbar, returned to the Bombay docks many years later (Wadia 1957: 191).

In 1810, the Wadias built a 74 gun vessel 'Minden' for the British navy, their first ship-of-the-line built outside the U.K. At the same time in competition to Bombay, a similar vessel was built at Kidderpore on subscription by Calcutta inhabitants and presented to the British navy, which however was not impressed. The Minden saw service during the British-American War of 1812. Francis Scott Key wrote the lyrics of the US national anthem in 1814 aboard the 'Minden' where he was detained.

Steam Navigation

Once James Watt's steam engine became available it was used for propelling ships. The lead came from the United States, which had no roads or canals, but had large tree-lined rivers that would not mind inefficient engines. The first practically successful steam vessel on a river was launched in 1807 and on the sea the next year. Britain soon caught up, with the British navy acquiring its first steamer in 1819. Incidentally, the first steam-propelled vessel in India was fitted with an engine and built to the plan brought from England in 1819. It was built for Nawab Ghazi-ud-din of Oudh at Lucknow for use as a toy.

The Calcutta merchants were keen to introduce steam navigation on three routes: on the placid north Indian rivers; in the opium and tea trade with China; and between Calcutta and England via the old Cape of Good Hope route. Early steam machinery was rather daunting. It used coal voraciously and was extremely complex for easy maintenance. The merchants neither had the capital nor the patience to experiment. The Company, divested of its trade monopoly in 1813, had no intention of sinking its money into steam for trade, but it had wars to win. The initiative by private individuals looks significant in retrospect but was economically unviable in its time. What gave steam navigation the initial boost was the amphibian Burmese war of 1824–1826. An 8 HP engine privately brought to Calcutta in 1817 or 1818 was used to power a paddleboat that carried troops over creeks and estuaries of the Arakan coast. Similarly, in 1825, the Company bought a private river steamer 'Diana' built two years previously to operate against the monsoon winds. It was dubbed 'fire devil' by the hapless Burmese (Bernstein 1960: 30).

Bombay's interest in steam was even more pronounced than that of Calcutta and Madras. Monsoon winds made it easier for a sailing ship to reach Calcutta than Bombay. Steam would give Bombay the benefit of its shorter distance to Europe. After waiting for six years for the court of directors to respond to 'a distinct official proposition' first made in 1823, the Bombay government decided to go ahead on its own, and got the Wadias to build a steamer, cleverly named 'Hugh Lindsay' after the sceptical Company chairman. It was a small ship of 411 tons with two 80 HP engines, launched in 1829. In the next four years, it made a total of five voyages to Suez, all heavily subsidized. Average receipts from passengers and letters stood at Rs.14,225 as against the expenditure of Rs.46,250. The acclaimed success of 'Hugh Lindsay' in contrast to the declared failure of 'Enterprise' in its voyage to Calcutta via the Cape established the viability of the over-land route (Khan 1971). This had far-reaching and widespread consequences. Bombay became a gateway to India. The Red Sea and the Persian Gulf were scientifically surveyed and the Suez Canal was dug. More importantly all the countries en route lost their independence.

Introduction of steam navigation did not mean the immediate end of sailing ships. The commercial viability of steam came only when engines were greatly improved and ships were made of iron and then of steel. This effectively brought teak ship building at Bombay to a close, bringing to an end a fascinating chapter in colonial history.

From 1736 to 1884, the Wadias built a total of 334 vessels for a wide variety of owners: the East India Company, private merchants, the Nizam of Hyderabad, the Imam of Muscat and the British navy. Out of these 334, thirty-nine were either specifically built for or subsequently acquired by the British navy during 1777–1849. (For completeness, it may be added that from 1885–1936, another 46 vessels were built at the Bombay dockyards.) If we were looking for a single ship to sum up the career of the Wadia shipbuilders, it would have to be the frigate 'Trincomalee' built in 1817 and probably the oldest ship still afloat. It served the British Navy for 76 years and was then sold off. It was renamed 'Foudroyant' about 1902 and used for the training of boys in seamanship. The original name was restored in 1993 and after that the ship itself. It is now open to visitors at the Hartlepool Historical Quay.

The Wadias received three land grants in Bombay, in 1783, 1821 and 1849 (in two installments) and in 1884 on the retirement of the last Master Builder. In addition, there were a number of presents of medals, rulers and shawls. The prestige carried by the shipbuilding Wadias helped other members of the clan in establishing themselves in various lines of business.

From Ships to Industry

The introduction of steam necessitated the upgrade of Wadia skills. Master Builder Nowrojee Jamsetjee (1774–1860) sent his son Jehangeer Nowrojee and nephew, Hirjibhoy Merwanjee, for an extended stay during 1838–1841 in England, where they studied naval architecture at the Royal Dockyard at Chatham under the Master shipwright. Jehangeer rose to become the Master Builder himself.

Historically, far more significant was the fifteen-month England sojourn during 1839–1841 of Ardaseer Cursetjee (1808–1877) then an Assistant Builder at the dockyard and son of Cursetjee Rustomjee who later (1844–1857) became the Master Builder. 'The prompt repair of the engines of the numerous steamers' arriving in Bombay posed a problem. 'Few of the European engineers and drivers could withstand the climate, and those who were enabled to do so proved so troublesome that a remedy for the inconvenience appeared of paramount importance' Cursetjee 1840: v). The remedy was Ardaseer's officially sanctioned and partly financed visit. While in England, he spent his time getting practical experience in construction and maintenance of steam engines and moving in influential circles. He successfully applied for the post of Chief Engineer and Inspector of Machinery at the Company's factory and foundry in Bombay. The Bombay newspapers variously commented that there would be a 'body of English workmen' under his charge.

This appointment in turn helped him to become the first Indian to be elected as a Fellow of the Royal Society of London in 1841. The distinction seems to have had no impact whatsoever in India. Bombay was perhaps too practical to make sense of an honour bestowed in London, while it was too early for Calcutta to be interested. In any case the Royal Society then was more of a gentleman's club than the learned body it became later. Ardaseer was in effect introduced to India 100 years later, in 1944, by the visiting Secretary of the Royal Society. Belatedly, in 1969, an Indian stamp was issued commemorating Ardaseer Cursetjee (Kochhar 1993).

The Wadia's familiarity with the steam engine had far-reaching consequences. It led to the mechanization of the textile industry. Ardaseer Cursetjee's son Nusserwanjee, who had joined the dockyard in 1844 at the age of twelve, quit his job six years later as he was directed to Manchester by the well-known Parsi textile magnate and philanthropist Sir Dinshaw Petit to select machinery and engines for Petit's textile mill. Nusserwanjee in turn sent his son Nowrosjee 'to school in Liverpool and for factory training'. In 1879 Nowrosjee Wadia set up the Bombay Dyeing and Manufacturing Company, which has maintained an uninterrupted record of dividend payment since 1885. Nowrosjee established another successful mill, the 'Century Mills', which however was sold by his other heir (Koffend 1979: 37–41). The Bombay Dyeing's former Chairman Mr. Neville Ness Wadia, in 1994, did not seem to know much about his FRS ancestor, certainly not that he had published a diary from England. He was greatly helpful in providing source material on the Wadias to this writer.

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Shizuki Tadao

Nakayama Shigeru

Shizuki Tadao was a Japanese natural philosopher, born in 1760. He was adopted by the Shizuki family, whose head was a government interpreter from the Dutch. In 1776 he became an assistant interpreter, succeeding his adoptive father, but he retired from that post the following year because of ill health. After leaving public service, he spent the rest of his life in the private study of Dutch books and in contemplation. He died in 1806.

He wrote books about the Dutch language and partially translated the Dutch translation of Engelbert Kaempher's *Geschichte und Beschreibung von Japan* (History and Description of Japan). But Tadao's major work was *Rekisho shinsho* (Introduction to True Physics), a compilation of his own theories on natural philosophy, inspired by his translation of the Dutch version of John Keill's *Introductio ad veram physicam* and the *Introductio ad veram astronomiam*.

In advocating Newtonianism, Keill's work had a polemical tone, and more importantly and quite unlike the readjusted interpretations of later authors, it dealt in abstractions and included a great many elements of natural philosophy. The book especially suited Tadao's inclination toward natural philosophy and Tadao thus became the first Newtonian in the East. He established unitary *qi* (energy) and its dual function (rarefaction and condensation) as the basis for his natural philosophy. He was not successful, however, in relating the natural philosophy that he derived from the theory of monistic *qi* to Newtonian dynamics.

Tadao also raised the question of why the planets rotate and revolve in the same direction in planes not greatly inclined to the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). He proposed a hypothesis concerning the formation of the planetary system, which resembles the celebrated hypothesis of Kant and Laplace.

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Shushu Jiuzhang

Ulrich Libbrecht

The *Shushu Jiuzhang* (A Mathematical Book in Nine Chapters) is a Chinese mathematical work, written by Qin Jiushao and published in 1247. This book is one of the highlights of Chinese mathematics of the Song-Yuan period, 960–1368.

The work is not organized according to mathematical methods, but topically arranged according to domains of administrative practice, with the exception of Chapter 1. The nine chapters are as follows:

1. Indeterminate analysis (*Dayan*);
2. Heavenly phenomena, which dealt with chronological and meteorological questions;
3. "Boundaries of fields," which covered surveying;

4. "Telemetry" or measuring at a distance, a kind of prototrigonometry;
5. Taxes and levies of service;
6. "Money and grain," i.e., taxes;
7. Fortifications and buildings;
8. Military affairs; and
9. Commercial affairs.

An investigation of the socioeconomic information contained in the work proved that all the information was indeed related to the Southern Sung society, especially regarding money and currency (including paper money), credit systems, commercial life, harmonious purchase (*heti*), transportation problems, construction of dikes, taxes and levies of service (*fuyi*), architecture, military affairs, and astronomy. This could mean that the work was written for practical purposes, although it was, partly because of the Mongol invasion of China, never used as a handbook for practical training.

The basis for the common arithmetical procedures was the ancient mathematical classic, the *Jiuzhang Suanshu*. There was one method, the *dayan* rule, which Qin Jiushao learned when he worked in the Board of Astronomy. This method is preserved only in Qin's work.

As for notation and terminology, it is important to note that the zero was printed for the first time in this book, so that we have a complete decimal place-value system. The arithmetical algorithms are the traditional ones, as are the geometrical methods and trigonometrical procedures. The most important part of the work is the "algebra." This dealt with simultaneous linear equations, determinants, and series and progressions. Also covered were numerical equations of higher degree, an extension of the method for square and cube root extraction used in the *Jiuzhang Suanshu* and the *Ten Books of Mathematical Classics*. This method is the same as the Horner–Ruffini procedure. The most important part is undoubtedly the Chinese Remainder Theorem, solved by means of the *dayan* rule. It is the solution of the problem:

$$N = r_1(\mathrm{mod}_1) = r_2(\mathrm{mod}_2) = \cdots = r_n(\mathrm{mod}\, m_n).$$

It is remarkable that Qin Jiushao was able to solve problems where the moduli are not relatively prime – a method not known to Euler and Gauss, and only solved definitively by Stieltjes in 1890.

See also: ►Qin Jiushao, ►Liu Hui and the *Jiuzhang Suanshu*

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Silk and the Loom

Dieter Kuhn

In China the raw material silk dominated textile technology as a whole, and dictated the development of looms and their technology in particular. Thus the weaving methods and the patterns depended to some extent on the loom technology available.

The biological prerequisites for silk production on a commercially significant scale are domesticated silkworms *Bombyx mori* L. (sericaria) [*jiacan*] which belong to the family Bombycidae in the order of the Lepidoptera nocturno and various mulberry trees of the family of the Moraceae, such as the *Morus alba* Linn. (*baisang*), *Morus bombycis* Koidz. (*jingsang*), and *Morus alba* var. *multicaulis* (*lusang*), commonly called the domestic mulberry (*jiasang*). Silkworms are generally fed with the fresh leaves of the mulberry tree.

Not only were these two prerequisites present from an early stage in China, as can be seen from pictographs on bone inscriptions of the Shang era, but their biological connection was also recognized. Various archeological discoveries, fragments of textile, and imprints show that in many areas of Neolithic China a form of silk technology already existed which clearly belonged to a long and practically, perhaps even experimentally, oriented agricultural tradition. The production and treatment of silk had begun many years before and by then had already reached a high technical level. So far the earliest find of silk in China is dated between 2850 and 2650 BCE. The earliest cocoons of the domesticated spinner are from the Tang dynasty (618–907).

To understand the importance of silk as far as weaving and the development of weaving patterns are concerned, it is essential to look at the genuine properties of a single silk thread. Unlike other textile fibers silk is not spun but reeled. Silk-reeling (*sao si*) involves taking up the ends of fibers from several cocoons and combining them into a thread. It takes place just before the moth tries to break through the cocoon. This timing is crucial if endless silk threads are required. The length of the cocoon-filaments which can be obtained varies between 700 and 900 m, but without a silk-winding instrument, a reel, and a water basin in which to float the cocoons, silk-reeling cannot be performed. Through the centuries hand-driven silk-reeling was practiced as a seasonal business in small-scale family production. From the terminology used it is certain that prototypes of silk reels and silk-reeling frames (*saochechuang*) were known in the Zhou period. The earliest detailed description of the treadle-operated, highly mechanized silk-reeling frame is from ca. 1090.

Loom weaving, the production of even-textured fabric, requires that the warp threads be kept at a consistently high level of tension. The warp threads (*jing*) are those which, in parallel, run lengthwise across the loom; the weft threads (*wei*) are introduced laterally at right angles to them. A high weaving tension necessitates the use of comparatively elastic warp threads of a kind not naturally found in raw silk. This elasticity is obtained through winding or throwing or else doubling and twisting the thread. Various spinning techniques could spin the thread in the requisite manner. In China the spindle wheel (*fangche*) had been in use since the middle of the first millennium BCE. The spindle wheel was not only very efficient in the spooling of threads, which means transferring a thread from a reel to a spindle, but also most useful in the processes of doubling and quilling, when an empty spindle is filled with a twisted thread which now combines two or three threads in one. Much has been published about the origin of the spindle wheel in the East and in India, but all the pictorial and textual evidence available points to China as the geographical area where the spindle wheel originated in the context of silk technology, especially the spooling and doubling process, as pictured on some Han stone reliefs. It took a long time before the spindle wheel made its appearance in Europe in the thirteenth century. All these inventions and innovations in the processing of silk threads have to be seen in the context of the treadle-operated loom (*jiaotaji*) which was equipped with two treadles in order to mechanize the opening (*kaikou*) of the shed. Thus a clear shed for the shuttle (*suokou*) was formed through which the weft thread could be passed. Such a loom was employed to weave simple tabby fabrics to standards on a large scale. From its structure it may be described as a combined horizontal–vertical or oblique warp sheet loom (*xiezhiji*). Depictions of the loom on stone reliefs from Han times which were found in Shandong, Jiangsu, and Sichuan provide ample evidence of this type of loom. A more complicated loom with a treadle mechanism for the forming of the shed and a system of draw cords (*tihuaxian*) or pattern rods (*wen 'gan*) which looped the warp threads required for the pattern already existed in Zhou times.

If maximum benefit was to be got from the exceptional length of the silk threads, then it was only logical to dress the loom with a silk warp. For this one needed a warp beam (*jingzhou*). The width of the fabric was determined by the length of the warp beam, and by the ideal working width for the weaver, who not only inserted the shuttle containing the weft, but also operated the treadles with her feet so as to form the sheds. In addition, she would have to perform other operations in order to create the particular pattern. On account of these factors, most fabrics of the Han era as well as later generally had a width of about 50 cm (two *chi* and two *cun*). The length varied between 9 and 12 m. The qualities of silk as an ideal warp thread and hence too the dominance of the warp in the weave resulted in the weave pattern being created by accentuating the warp threads. From the Zhou era (1045–221 BCE) until the early Tang era (618–907), therefore, Chinese silk possesses a warp pattern unlike that of other cultures, which, due to differences in the raw material, was produced on wholly different looms and which is weft patterned. Only in Tang times did the patterning technique change to the weft, which resulted in more colorful fabrics. Although it is known from a few silk fragments that the weft pattern was practiced in early China, the change in weaving technique in Tang times was certainly due to influence from the region of Samarkand or Persia.

Several types of looms were already in use and operated as early as Han times (206 BCE–AD 220). They are documented in historical works from Han and Jin times, and especially in the agricultural and encyclopedic works from the Song, Yuan, Ming, and Qing dynasties (960–1911).

The loom which combined 70 or even more movable shafts (healds) with the function of many treadles (*duozong duonie*) was widespread. Although this type of loom was difficult to set up, it was operated until recently in Sichuan province. The big advantage of this type of loom was that one weaver could operate it easily and quickly. Furthermore its advanced and highly efficient patterning equipment qualified it for the production of so-called brocades and other complicated weaves.

Another type of loom which is not clearly distinguished in the Chinese publications from the abovementioned loom made use of figuring healds or pattern rods (*tihuazong*, *wen 'gan*), which were manually lifted. Textual sources mention up to 120 patterning devices. This ingenious hand-operated patterning device was already used on the backstrap loom (*yaoji*) in very early times. The simple backstrap loom originally had no wooden frame but consisted exclusively of functional parts. The weaver sat on the ground. In many old publications it is depicted with a wooden framework. It was used until recently. The earliest weaving implements which may be ascribed to such a loom were excavated from the site of Hemudu, datable to ca. 4300 BCE. It may be justified to assume that the patterning technique with pattern rods which can be created in a sitting position on the ground is older than the use of looms with shafts and treadles which require a wooden frame. Although the simple type of backstrap loom was an excellent device for weaving on a comparatively small scale, it had its obvious limitations which were set by the length and width of the circular warp. In the view of Chinese textile historians this loom with pattern rods belongs to a loom category either of an early primitive type or of ethnic minorities. Only after the horizontal backstrap loom had been equipped with a real warp beam, supported by a wooden framework, which helped to facilitate its operation, can it be regarded as a loom which worked economically and which was suitable for silk weaving with patterning on a large scale. In all probability and in the opinion of a few eminent Western weaving specialists, such a loom with two shafts producing a tabby ground and a system of pattern rods of the heddle rod type that were lifted by the weaver as required by the pattern was the type of loom used and preferred to all others for the production of complex-patterned weaves before Tang times in China.

The third type of loom before Han times was a forerunner of the Chinese drawloom. It employed a string heddle patterning device (*shuzong tihua zhuangzhi*) and a simple treadle-operated shedding device. During Eastern Han times its equipment was improved in such a way that the whole "machine" (*ji*) gained the structural and functional features of a real drawloom (*hualou tihuaji*). This drawloom was equipped with a figure or harness tower and all the lifting devices for the warp threads required. Furthermore there were lifting and depressing shafts. It was operated by a weaver and a drawgirl. This type of loom, which was fashioned in a large variety, dominated the production of high-quality polychrome-patterned silk fabrics until the late nineteenth century when Western looms were introduced into China. Some Western historians of weaving technology have ruled out the use of a drawloom in Han times in China and suggested that it was invented somewhere in the region of Samarkand, Persia, or even the Near East. To support their notion they practically demonstrated that even difficult polychrome weaves could have been produced on pattern rod looms. However the "Rhapsody on Women Weavers" bears witness to the fact that the drawloom with all its characteristic features was already in use in the big workshops of China as early as the first half of the second century AD. The earliest technical description and illustrations on the subject were published in the *Ziren yizhi* (Traditions of the Joiners' Craft) of 1264.

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Sinān ibn Thābit

Yvonne Dold-Samplonius

Abū Saᶜīd Sinān ibn Thābit ibn Qurra was born in Baghdad ca. 880. He was the son of the translator and scientist Thābit ibn Qurra (ca. 830–901), who dedicated his *al-Dhakhīra fī ᶜilm al-tibb* (Treasury of Medicine) to him, and the father of the mathematician and astronomer Ibrāhīm ibn Sinān ibn Thābit (908–946). His family came from Ḥarrān, crossroads of caravan routes and cultures on the Upper Euphrates, and the religious center of the Sabian sect. One of the most famous physicians of his time, he directed the hospitals and medical administration of Baghdad under the reign of the Abbassid Caliph al-Muqtadir (908–932). He also served as physician to him and to his successors al-Qāhir (932–934) and al-Rāḍī (934–940). Under the former's persecution of the Sabians Sinān had to convert to Islam. He later fled to Khurāsān, and returned when al-Rāḍī came into power.

Sinān's work, as catalogued by Ibn al-Qifṭī, can be divided into three categories: historical–political, mathematical, and astronomical; no medical texts are mentioned. None of it is extant. In the first category he wrote a description of the life at the court of Caliph al-Muᶜtaḍid (892–902), his father's protector, and a sketch for a government along the lines of Plato's *Republic*. Both treatises are mentioned by al-Maᶜsūdī, who criticizes the latter, adding that Sinān should rather have occupied himself with topics within his competence.

Four mathematical treatises are listed, of which two cannot be by Sinān, since the dates given were in the second half of the tenth century. Of the remaining two, one is connected with Archimedes' *On Triangles*, whereas the other consists of an improvement, with additions, of the book by Aqāṭun (Yāqūt = Euclid), *On Elements of Geometry.*

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As to the third category, only the content of the *Kitāb al-Anwāʾ*, dedicated to al-Muʿtaḍid, is somewhat known through excerpts given by al-Bīrūnī in the *al-Āthār al-bāqiya min al-Qurūn al khāliya* (Chronology of Ancient Nations). A *Kitāb al-Anwāʾ* is a kind of almanac describing the astrometeorological properties (*anwāʾ*) of the individual days. Sinān's almanac is fundamentally based on an anonymous Arabic translation of Ptolemy's *Phaseis*, in which he provides the times of the rising and setting of prominent fixed stars. Other sources are Ibn Māsawayh (d. 857) and Hippocrates, as well as personal contributions by Sinān. According to al-Bīrūnī, Sinān also relates an Egyptian theory and one by Hipparchus, on where to fix the beginnings of the seasons. Another treatise, seemingly also of astrometeorological content, is on the assignment of the planets to the days of the week, composed for the Sabian Abū Isḥāq Ibrāhīm ibn Hilāl (ca. 924–994). The seven planets were important in Sabian religion; each one had its own temple. Ibn al-Qifṭī lists several works on Sabian rites and religion. Sinān died, probably in Baghdad, in 943.

See also: ►Thābit ibn Qurra, ►Astronomy in Islam, ►al-Bīrūnī

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Siyuan Yujian 四元玉鑒

Karine Chemla

This book (*The Jade Mirror of the Four Unknowns*, also translated as *Precious Mirror of the Four Elements*) by Zhu Shijie 朱世傑, dating from 1303, appears to represent the most advanced achievement of the mathematical tradition of polynomial algebra or the "procedure of the celestial unknown (lit.: origin) 天元術" which developed in North China in the second half of the thirteenth century. Jock Hoe (1977) describes the history of its reception among mathematicians and historians in both East and West. The *Siyuan yujian* shares the same basic features with the first book that has come down to us on this topic, Li Ye 李治's (or Li Zhi 李治's, according to the name chosen for this scholar) *Ceyuan haijing* 測圓海鏡 (Sea Mirror of the Circle Measurements, 1248). The mathematical knowledge it contains is presented in the form of problems, the first four of which lay the foundations for the whole book by gradually presenting, though extremely concisely, how to use polynomials with up to four indeterminates to solve given problems. Mirroring the intimate relationship that the right-angled triangle had with the topic of algebraic equations, and later of polynomials, from the very first appearance of these matters in China, these problems all concern the right-angled triangle, as do 101 of the 284 problems that follow in the *Siyuan yujian*. Once a problem is set, Zhu suggests the choice of one or several unknowns to form polynomials on the basis of the conditions given in the terms of the problem. In the case when one unknown suffices, like Li Ye, Zhu forms two *polynomial expressions*, representing the same quantity, and thus by elimination between them establishes an algebraic equation, a root of which is the unknown sought. Since Zhu does not explain the algorithms, similar to the so-called Ruffini–Horner ones, that can be used to determine this root, he seems to have assumed the reader's knowledge of this procedure. They are found in Qin Jiushao 秦九韶's *Shushu jiuzhang* 數書九章 (Writings on Mathematics in Nine Chapters, 1247) and seem to be common knowledge in the milieu developing the "procedure of the celestial unknown." Yet Zhu elaborates them further, especially in cases where the result is a rational number; he then systematically introduces techniques to expand the root sought.

太
0
729
–81
–9
1

***Siyuan Yujian* 四元玉鑒. Fig. 1**
$729x^2 - 81x^3 - 9x^4 + x^5$.

These polynomials he uses are written in the form of an array of numbers, as in Fig. 1, where the indeterminate and its successive positive or negative powers receive a positional expression. Note that the writing of a polynomial differs from the writing of an equation, as in Fig. 2, in that

–3888
0
729
–81
–9
1

Śaṅkara Vāriyar. Fig. 2 $x^5 - 9x^4 - 81x^3 + 729x^2 - 3888 = 0$.

2	0	太
–1	2	0
		1

Śaṅkara Vāriyar. Fig. 3 $x^2 + 2xy + 2y^2 - y^2x = 0$.

	–1	太		–1
			1	
–1	0	–1		

Śaṅkara Vāriyar. Fig. 4 $xyz - xy^2 - x - y - z = 0$.

the constant term of the polynomial is indicated, being accompanied by a character, thus allowing the polynomial to contain any power of the indeterminate.

When more than one unknown is needed, Zhu designs several equations involving them, which he represents by tables of numbers, where again position is used to express the various powers of the unknowns. For two unknowns, the vertical direction refers to one unknown whereas the horizontal one refers to the other; the surface of the plane suffices for any monom to be represented by its coefficient written in an appropriate place on the counting board, as in Fig. 3. Yet for three or four unknowns, limitations occur in the representation of all possible monoms and new positions on the counting board are brought into play, but in a less systematic way, as in Fig. 4.

In contrast to equations with one unknown, such equations need the constant term to be indicated by a character. Once these equations are determined, elimination is performed between them until an equation with only one unknown is obtained, which is then solved. Several techniques are used for this purpose, the most basic one resembling the elimination between linear equations put into play by the algorithm to solve systems of simultaneous linear equations presented in the Han book *Jiuzhang suanshu* 九章算術 (The Nine Chapters on Mathematical Procedures). The difference lies in the fact that now the terms involved in the procedure of elimination are polynomials, and no longer numbers. Stress must be placed on a conceptual gap. In contrast to the case for one unknown, the only one Li Ye dealt with, the elimination no longer bears on polynomials representing a given *quantity*, but rather on equations with several unknowns representing a *relationship* between the unknowns.

In the rest of the book, this apparatus is applied to all kinds of mathematical situations, such as geometry and summation of series, involving various applications to economic or social life.

See also: ►Zhu Shijie, ►Mathematics in China, ►Li Zhi (Li Ye), ►Qin Jiushao, ►Liu Hui and the *Jiuzhang Suanshu*

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Śaṅkara Vāriyar

K. V. Sarma

Śaṅkara Vāriyar (ca. 1500–1560) was a brilliant expositor of astronomy and mathematics who hailed from Kerala in the south of India. He belonged to the *vāriyar* community which was professionally assigned to certain peripheral duties in temples. Śaṅkara was a direct disciple of the well-known Kerala astronomer Nīlakaṇṭha Somyāji (b. 1444). Among other teachers whom he mentions in his works are Dāmodara (ca. 1450–1550), Jyeṣṭhadeva (ca. 1500–1610), and Citrabhānu (ca. 1475–1550). Śaṅkara mentions that his commentary on the work *Pañcabodha* was completed on the day 1,692,972 of the Kali era, which occurs in AD 1534, from which his date is definitely ascertained.

Śaṅkara Vāriyar wrote an advanced astronomical manual entitled *Karaṇasāra*, to which he added a gloss of his own. But he is better known for his elaborate commentaries on such standard works as the *Līlāvatī* of Bhāskarācārya, the *Tantra-saṅgraha* of Nīlakaṇṭha Somayāji, and the anonymous *Pañcabodha*. The two commentaries, the one on the *Līlāvatī*, called *Kriyākramakarī* (Sequential Evolution of Mathematical Procedures) and that on *Tantrasaṅgraha* called *Yuktidīpikā* (Light on Astronomical Rationale), are highly significant writings in Indian mathematical literature. After giving the meaning of each textual verse or group of verses from these two texts, Śaṅkara sets out the background and evolution of the enunciation commented on, the different aspects thereof, and the step by step derivation of the relevant formula or procedure. This exposition of rationale, couched in simple verses and often running to several pages, serves to give an exposure to Indian mathematical thinking and open up the normally unexpressed mental working of the Indian mathematician, which has led most modern historians of mathematics to presume that much of Indian mathematics and astronomy was borrowed and not original. The rationale elaborated here relates, among other things, to the summations of series, the circle and the irrationality of π and pulverization in the field of mathematics; and the theory of epicycles, ascensional differences, rising of the signs, and problems based on the gnomic shadow, in astronomy. These commentaries are valuable also for the information on earlier authors like Mādhava and Saṅgamagrāma and their theories.

See also: ►Nīlakaṇṭha Somyaji, ►Rationale in Indian Mathematics

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Song Ci

Hong Wuli

Song Ci was born in Jianyang in 1186 of the Southern Song Dynasty and died in 1249 in Guangzhou. He was a forensic scientist, an expert in legal medicine.

A native of Jianyang (now Jianyang County, Fujian Province), Song Ci was born to a family of middle-class bureaucrats. His father was Song Huifu. He was well educated and passed the feudal examination at the highest (imperial) level. He held several posts, including the confidential secretary of the local government, county magistrate, and provincial officials until he was promoted to the provincial official responsible for law suits and jail affairs. At that time, most feudal officials did not take their responsibilities seriously, especially those involving the law, resulting in the pile up of unsolved law suits. Many were legal offenders themselves. Song ordered deadlines to sort out all these cases. Eventually, he cleared a backlog of over 200 cases (Gao 1978).

During his tenure, he set up a whole series of rules for examiners of the wounded or the dead. He stressed that legal medical experts or officials must, under the accompaniment of an examiner, arrive at the spot as soon as possible, and that no fumigation or incense was to be used. The officer or expert should examine the case in person, instead of hearing the examiner's report. He also claimed that "the most important issue in criminality is the death sentence, which should be carefully understood at the very beginning of the case by serious investigation". He also pointed out that the malfeasance of prison officials always begins with a tiny error during the investigation. Lack of experience and cursory investigation are the direct causes of wrong cases and unjust verdicts. He criticized or even punished those fraudulent examiners whenever cases were in question, and he pondered carefully and conscientiously so that few wrong conclusions were drawn (Song 1981). Based on his long-term practical experience, he compiled, in 1247, the famous *Xi yuan ji lu* (*Collected Records of Washing Away the Wrong Cases*, also translated as *The Washing Away of Wrongs*) which is the earliest work in medico-jurisprudence both in China and abroad. This book has been translated into several Western languages (Jia 1984).

See also: ►Forensic Medicine in China

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Song Yingxing and *Tiangong Kaiwu*

PAN JIXING

Son Yingxing (alias Changgeng, 1587–ca. 1666) was a great scientist and thinker of the seventeenth century. He was born in Fengxin county in Jiangxi province in 1587. After graduating from the county school he became *jüren* or a successful candidate in the imperial examination at the provincial level in 1615. He took part in the highest imperial examinations in Beijing six times, but failed to become a *jinshi*. After that he decided to give up Confucianism and turned to the practical knowledge of natural science. From 1635 to 1638 he taught at Fenyi county school; then he was appointed the prison officer of Tingzhou prefecture in Fujian province from 1638 to 1640. In 1643 he worked as the magistrate of Bozhou prefecture in Anhui province. After the Ming dynasty (1368–1644) was overthrown by Manchu-Qing rulers, Song lived at home as a hermit until his death in about 1666. He had extensive knowledge in both humanistic and natural sciences. He traveled from the south to the north to obtain practical knowledge of agricultural and industrial techniques as well as political and economical information on Chinese society. This made it possible for him to write more than ten books, most of which were completed at Fenyi from 1636 to 1637.

The *Tiangong Kaiwu* (Exploitation of Products from Nature by Means of a Combination of Artificial Skills and Natural Power, also translated as The Creations of Nature and Man, 1637) is his most important work. It consists of 18 chapters on 33 departments of agricultural and industrial production including grain planting, sericulture, spinning and weaving, dyeing, salt and sugar making, vegetable oils, distiller's yeasts, ceramics and porcelain, metallurgy and casting, paper and ink making, coal, alum and copper producing, carriages and shipbuilding, cold weapons and firearms, and pearl and jade exploiting. Apart from detailed descriptions of the above-mentioned techniques, there are 123 useful illustrations in this book. It recorded many advanced technical achievements from the distant past until the Ming dynasty and made a comprehensive generalization them. Some had been rarely talked about in previous works, such as improving paddy and silkworm varieties through artificial hybridization, smelting zinc from calamine, smelting wrought iron from pig iron, producing alloys of copper and zinc, etc. This work also developed many advanced technical ideas, especially the *Tiangong Kaiwu* thought which emphasized the coordination between mankind and nature as well as artificial skills and natural power in order to exploit various products from nature for people's use.

Not only was the *Tiangong Kaiwu* welcomed in China, but it also spread to Japan and Korea from the seventeenth to the eighteenth centuries and became a popular reference work for Japanese and Korean scholars during the Edo period (1608–1868) and the Yi dynasty (1392–1910). It was reprinted in Osaka in 1771. During 1830–1840 five chapters of it were translated into French, then into English and German. The part on sericulture was cited by Charles Darwin and highly valued. In 1869 many chapters on industrial techniques were collected in the *Industries anciennes et modernes de l'Empire Chinois* published in Paris. The first four chapters on agriculture were translated into German in 1964; 2 years later the whole book was published in English in the United States. It was regarded as an "encyclopédie technique" by French sinologist Stanislas Julien of the nineteenth century, and Joseph Needham, the British scholar, called Song a "Chinese Agricola" or "Chinese Diderot." It has now become a world-famous classical scientific work.

Among Song's existing works there are also the *Ye Yi* (Proposals to the Court from Common People, 1636), *Si Lian Shi* (Poems on Praising the Good and Pitying the Foolish, 1637), *Lun Qi* (On the *Qi*, 1637), and *Tan Tian* (On Celestial Bodies, 1637). The *Ye Yi* reflected the author's political and economic thought. He put forward a plan of political reform for the Ming court for averting the political and economical crisis in society. He considered that social wealth was created by labor and that currency should not be the definition of wealth. He believed that increasing social wealth meant producing more consumable goods. Therefore, his ideas are similar to those of Adam Smith.

The *Lun Qi* is a work on natural philosophy. It explains the formation and composition of all things by means of a combination of the theory on the *qi* and the new theory of *yinyang* and five elements. He introduced a new conception of *xing* (form or shape) between the *qi* and five elements, and he explained the material unity in the composition between organic and inorganic substances. He also discussed the idea of conservation of matter in this work. It also dealt with acoustical problems, and pointed out that the formation of sound is the result of the vibration of substances, and the medium of the spread of sound is the air. Song considered that the spread of sound in the air should be in the form of a water wave; he thus put forward a preliminary conception of a sound wave.

In his astronomical work, the *Tan Tian*, he criticized a traditional theory that the solar eclipse was connected with human affairs. He thought that all things including the sun are always changing. He said: "Therefore, the sun today is no longer the same one as yesterday." Most of Song's advanced philosophical thought was further developed by another great philosopher, Wang Fuzhi (alias Chuanshan, 1619–1692). Those in academic circles are familiar with his scientific achievements, but much less familiar with his political, economic, and philosophical thoughts, because those works were only found in the mid-twentieth century and have not been carefully studied yet.

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Sphujidhvaja

K. V. Sarma

Sphujidhvaja was apparently of Greek descent, and flourished in Western India under the patronage of the Kṣatrapa ruler Rudradāman II. He wrote the extensive genethlialogical manual entitled *Yavanajātaka* (Horoscopy of the Greeks) in AD 270, which shows the position and influence of the stars at one's birth. Towards the close of his work, Sphujidhvaja says that, before him, in AD 150, the great Greek genethlialogist Yavaneśvara redacted into Sanskrit prose a Greek astrological work, so that it could be studied by those who did not know Greek, and that he, Sphujidhvaja is composing a versified redaction of the work of Yavaneśvara. The work reveals Sphujidhvaja as a competent scholar, a master of Sanskrit versification, and an expert genethlialogist.

Sphujidhvaja states that he composed the work in 4,000 verses. But the only manuscript of the work available today contains only 2,300 verses. In this imperfect manuscript, the first few sections are numbered, but not so the subsequent ones, which number, in all, 79. Possibly several sections are lost. In these 79 sections, the work covers a large number of aspects of horoscopy and natural astrology, including:

- Zodiacal signs and planets, their icons, nature, and relationships
- Iconography of *horās* and decons
- Astrology of conception, birth, and nature
- Horoscopes
- Planetary placements and combinations affecting human beings
- Prediction on the basis of questions
- Reconstruction of lost horoscopes
- Omens and dreams
- Military astrology

The several aspects of each of these topics are looked at from different points of view, and intimations, indications and predictions based thereon are stated categorically.

It is interesting that, although based ultimately on a Greek text, there was substantial Indianization effected in the *Yavanajātaka*. This was accomplished by using Indian equivalents to Greek terms, adopting Hindu deities in place of Greek ones, incorporating the names of Hindu castes and professional orders, mentioning local manners and customs, and the like. *Yavanajātaka* was looked upon as authority by all later Indian genethlialogists and used as such even in the foremost of Indian texts like *Bṛhajjātaka* and *Bṛhatsaṃhitā* of Varāhamihira, *Sārāvalī* of Kalyāṇavarman, *Praśnavidyā* of Bādarāyaṇa, and many others.

The significance of *Yavanajātaka* stems from another point as well. The work refers to contemporary social orders, professions, religious classes and groups, items of ordinary use, manners and customs, dress, and a host of other things related to the life and society of the times. The information provided by the work on these subjects makes it a good source for the study of the culture and civilization of India during the early centuries of the Christian era.

See also: ►Astrology in India, ►Yavaneśvara, ►Varāhamihira

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Śrīdhara

R. C. Gupta

The mathematical works of Śrīdhara were very popular and made him quite famous. In spite of his great popularity, some controversies have been raised about his life, work, and time, such as whether he was a Hindu or a Jaina, and whether he wrote before or after Mahāvīra (ninth century AD). Some uncertainties exist because Śrīdhara's works are not fully extant. Often he is confused with other authors of the same name. Here we shall give views which are now generally accepted.

Like so many ancient Indian authors, Śrīdhara did not provide any information about himself in his works. Other sources have not been helpful in finding any glimpse of his personal life. So we do not know his parents or teachers, or even where he was born, educated, or worked. But some evidence shows that he was a Saivite Hindu. An example in his *Pāṭīgaṇita* is about the payment for the worship of the five-faced Hindu god Śiva. He starts his *Triśatikā* with a homage to the same god. However, in a manuscript which has a possible commentary and additional examples written by an apparently Jaina writer, the word "Jinam" is found in place of "Śivam". This led to the claim that Śrīdhara was a Jaina, but other evidence does not support this view.

More serious is the controversy about Śrīdhara's time. That he lived after Brahmagupta is evident from the fact that he literally quoted (and criticized) a rule from Brahmagupta's *Brāhmasphuṭasiddhānta* (AD 628). The most significant question in this connection is whether Śrīdhara wrote before or after Mahāvīra, whose date of ca. AD 850 is certain. There are similarities in the works of these two mathematicians. Most scholars believe that indications generally place Śrīdhara before Mahāvīra. A new fact has come to light recently; David Pingree found that a rule of Śrīdhara's had been quoted by Govindasvāmin (about AD 800–850) in his commentary on the *Horāśāstra* of Parāśara (under 14.97). This latest and direct evidence once again supports the generally accepted view of placing Śrīdhara in the eighth century or ca. AD 750.

Śrīdhara is known to be the author of the following three works on mathematics:

1. *Pāṭīgaṇita* (on arithmetic and mensuration)
2. *Pāṭīgaṇita-sāra* (an epitome of the above)
3. *Bījagaṇita* (on algebra)

The *Pāṭīgaṇita* is a standard Indian treatise on practical mathematics meant "for the use of the people". It is also called *Bṛhat-Pāṭī* (Bigger Pāṭī) and *Navaśatī* (Having Nine Hundred) because it is believed to have 900 stanzas. Unfortunately, it is not extant in full; the available text contains only 251 stanzas. In terms of topics, treatment of definitions, logistics, mixtures of things, and series are available in full, but that of the plane figures is incomplete. Many other treated topics are mentioned in the list of contents, but they are totally missing from the manuscript. These were excavations, piles of bricks, sawn pieces of timber, heaps of grain, shadows, and the mathematics of zero (whose loss is quite sad).

The *Pāṭīgaṇita-sāra* is also called *Triśatī* or *Triśatikā* because it was a "Collection of 300 verses". It was the author's own summary of the larger work on the subject.

Śrīdhara's *Bījagaṇita* (Algebra) seems to be lost completely. We know about it from a statement of Bhāskara II (AD 1150) who also quoted a rule from it. The rule gives a method for solving any quadratic equation and has also been quoted by others. Many other rules from different works of Śrīdhara have also been quoted by various writers. This shows the popularity of his works.

A recently discovered work called *Gaṇita-Pañcaviṁśī* is also stated to be from the pen of Śrīdhara, but it may not be his genuine work. Similarly, a number of astronomical, astrological, and other works authored by different persons of the same name have been ascribed wrongly. Confusions were created both by the similarity of names and also by the proximity of their dates.

In India, ten has been the base of counting since very early times. But the number and names of decuple terms used in the decimal numeration were at variation throughout the ancient period. Later on, the decuple terms were used to denote the notational places when the positional system was developed, and their number was standardized to 18 (which was a traditionally sacred number). Śrīdhara gave a definite list of 18 terms which became standard in Indian mathematics. It runs thus: *eka, daśa, śata, saharsa, ayuta, lakṣa, prayuta, koṭi* ($=10^7$), *arbuda, abja* (or *abda*), *kharva, nikharva, mahāsaroja, śaṇku* (or *śankha*), *saritāṁpati, antya, madhya*, and *parārdha* ($=10^{17}$).

Among the arithmetical rules discussed in the *Pāṭīgaṇita, Sūtra* 49–50 gives a formula for finding the time in which a sum lent out at simple interest will be paid back by equal monthly installments. Under the *Sūtra* 63–64 he presents the famous problem of a Hundred Fowls, in which we have to solve the indeterminate equations in integers. [The hundred fowls problem goes like this: Roosters cost 3 coins each chicks are 3 for 1 coin. If 100 fowls are purchased for exactly 100 coins. Then how many of each are bought?]

S

For mensurations related to a circle, Śrīdhara used the approximation $\pi = \sqrt{10}$, a very ancient Indian value. But there is some evidence to show that he used $\pi = 22/7$ in the lost part of *Pāṭīgaṇita*.

Another of Śrīdhara's great achievements was his mensuration of the volume of a sphere.

See also: ►Mahāvīra, ►Algebra in India, ►Mathematics in India, ►Bhāskara

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Śrīpati

Kripanath Sinha

Śrīpati was the most prominent Indian mathematician of the eleventh century. He was the son of Nāgadeva and lived in Mahārāṣṭra. He flourished during the period from AD 1039 to 1056.

General appreciation for Śrīpati's fame as a mathematician is based on his arithmetic, *Gaṇitatilaka*, and the two mathematical chapters of his astronomical work entitled *Siddhāntaśekhara*. The 13th chapter, the *Vyktagaṇitādhyāya*, contains arithmetical rules, series, mensuration, and shadow reckoning. The 14th chapter, the *Avyaktagaṇitādhyāya*, is one of the few extant Hindu works on algebra. The only edition (by Kapadia) of the *Gaṇitatilaka* contains a valuable commentary by Sihatilaka (ca. AD 1275).

Besides including in his works selected rules of his predecessors, Śrīpati enriched Indian mathematics by giving some improved and some original rules. The *Gaṇitatilaka* contains the earliest known treatment of simple addition and subtraction in any Indian work. Also included is the earliest version of our angular method of addition used to check the accuracy of a sum and simplify addition. The *Vyktagaṇitādhyāya* gives an improved rule for the volume of an excavation.

The *Avyaktagaṇitādhyāya* contains most of Śrīpati's original ideas and rules. In it, he presents the idea of an extensive system of symbolism in algebra, the only Hindu treatment of the cubing of signed numbers, and explicit recognition of the nature of imaginary quantities that is second only to Mahāvīra's. He also provides the earliest versions of our ordinary method of solving simple linear equations by using inverse operations and an early formal treatment of factorization. The rules not only give the ordinary method of factoring based on successive division, but also provide an additional method for factoring a non-square number by expressing it as the difference of two squares.

Śrīpati also displayed his mastery of indeterminate equations by giving an improved rule for solving the factum and original rules for solving the pulverizer. He also described an original method to obtain rational solutions of the square-nature.

All Śrīpati's works are in verses. The *Siddhāntaśekhara* contains only rules, but the *Gaṇitatilaka* is written in an autocratic style of teaching strategy, in which a rule is followed by plentiful exercises. The book is quite secular in nature. According to the author's testimony, it was written for public use. It contains arithmetical and commercial rules, and some problems solvable by simple linear, quadratic, and radical equations. A garland problem and numerous other fanciful problems included in the book make it pleasurable and interesting. The practical and aesthetic values of the *Gaṇitatilaka* cannot be underestimated.

Śrīpati, however, also had some weaknesses. His mathematics of division by zero is all wrong. In the *Vyktagaṇitādhyāya*, he uses the term *caturbhuja* to mean a square, a quadrilateral in general, a cyclic quadrilateral, a quadrilateral with equal altitudes, and an isosceles trapezoid. Because of this inconsistency, his rules on mensuration of quadrilaterals are hard to interpret.

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Stars in Arabic–Islamic Science

Paul Kunitzsch

The Arabs in pre-Islamic times – mostly Bedouins, in the Arabian peninsula – already had a good knowledge of the stars. They used certain stars or asterisms for orientation in their desert travels, to fix seasons, and to predict weather, especially rain. For the last two purposes they developed a system of so-called *anwāʾ* (sing. *nawʾ*), in which a star or asterism was observed setting shortly before sunrise and another simultaneously rising, just opposite (the latter one was called *raqīb*, with respect to the first one). At an unknown time and through unknown channels they received – most probably from India – the system of the 28 lunar mansions (*manāzil al-qamar*), stars or asterisms along the path of the moon, near the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The indigenous *anwāʾ* were then merged with the lunar mansions, and the 28 mansions were given names from among the former *anwāʾ*. All the five planets visible to the naked eye seem to have been known, since the Arabic language has old indigenous names for them: Mercury – *ʿuṭārid*, Venus – *al-zuhara*, Mars – *al-mirrīkh*, Jupiter – *al-mushtarī*, and Saturn – *zuḥal*. Also, fragments of the Babylonian zodiac seem to have reached the Arabs in pre-Islamic times, though their location in the sky was different from that in Babylonian and Greek (and modern) astronomy; the figure corresponding to Gemini (*al-jawzāʾ*), for example, was located in the stars of Orion, or the figure corresponding to Aquarius (*al-dalw*) in the Pegasus square. Such star lore was also much used in classical Arabic poetry, in pre-Islamic times and afterward. From the ninth century on, Arabic lexicographers and philologists collected the dispersed elements of old Arabic folk astronomy and put them together in special monographs (called *Kutub al-anwāʾ*, Books of the *anwāʾ*). From these, more than 300 old Arabic names for stars and asterisms could be recovered.

A new development began after the Muslim conquest of the lands of the Middle East. Now the Arabs came into contact with Greek science as transmitted and practiced in learned circles, mostly by Christian monks and scholars, in the area. After a period of undocumented first contacts, from the eighth century on, Greek scientific texts were translated into Arabic in great numbers. Scientific astronomy in the Islamic world therefore was largely built on Greek knowledge, with additional elements received from India and Persia. Greek cosmology and Greek theories of the planets, the fixed stars, and other celestial phenomena formed the basis of Arabic–Islamic astronomy. Later Muslim astronomers continued to work with this material, developed it, and introduced many corrections and improvements. But the "Copernican revolution" did not reach the Islamic world; Arabic–Islamic astronomy continued to be Ptolemaic into the nineteenth century.

On the (fixed) stars, the main source for the Arabs was Ptolemy's *Almagest*, which contains in Books VII and VIII a catalog of 1,025 stars arranged in 48 constellations and listed with their ecliptical coordinates, longitude and latitude, and magnitude. These 48 constellations (which also live on, in modified form, in modern astronomy) and the derived nomenclature of the 1,025 known stars were used by Muslim astronomers through all times, in books as well as on instruments (astrolabes, celestial globes, quadrants). To make the catalog valid for all times, Ptolemy proposed to add to the longitudes of the stars a constant of one degree in 100 years, to correct for precession. The Muslim astronomers very soon (in the ninth century) found a better value, one degree in 66 years; later also one degree in 70 years and other values were used. The pictorial figures of the constellations were also basically taken from Greek models; only details of the physiognomy of human figures and clothing were more or less adapted to contemporary local styles.

The main Arabic work on the fixed stars and the constellations was the *Book on the Constellations* by the Persian astronomer Abu'l-Ḥusayn al-Ṣūfī (903–986); al-Ṣūfī anxiously followed the Arabic versions of the *Almagest*, added criticisms based on his own observations, but established his star catalog exactly according to the data given in the *Almagest* (adding a constant of 12°42′ to the longitudes, for precession, for his epoch AD 964). For each constellation al-Ṣūfī added two drawings, one showing the figure as seen in the sky, and the other showing it as seen on the celestial globe (where the figures appear as seen from outside the globe, with the right and left sides reversed against the sky view). Most Islamic globe makers, through all centuries, followed al-Ṣūfī's models in depicting the constellation figures.

Several Islamic astronomers established star catalogs in the manner of the *Almagest*: al-Battānī (epoch 880, precession constant added 11°10′), al-Ṣūfī, al-Bīrūnī (epoch 1031, precession constant 13°0′), and Ulugh Beg (epoch 1437, own observations, but some stars taken over from al-Ṣūfī). Besides these big catalogs, smaller star lists were drawn up by very many astronomers, for use on astrolabes or other instruments. Most of the catalogs and star lists, however, were not obtained through observation; they were adapted from the *Almagest* or derived catalogs by adding the precession constant to the longitudes. A small list of 24 stars obtained through independent observation was established by the astronomers of the caliph al-Maʾmūn for the epoch 214 Hijra = AD 829–830; also other star tables were afterward derived from it by adding the precession constant.

Other celestial phenomena, such as comets or meteor showers, were not considered by the Arabic–Islamic astronomers. Following Greek cosmological theory, they supposed these to belong to the sublunar sphere, i.e., the space between the Earth's surface and the moon, and not to the sphere of the stars. The fixed stars in their opinion were all situated on the farthest, eighth sphere, beyond the seven spheres of the planets and the sun and moon. It was mostly in chronicles and in astrological works that such phenomena were registered, and they were usually regarded as bad omens indicating evil events.

Through Latin translations in late tenth and mainly in the twelfth century in Spain, many star names of Arabic origin entered the West and continue to be used in Western astronomy, mostly in heavily distorted spellings, today.

See also: ►*Almagest*, ►Precession of the Equinoxes, ►al-Ṣūfī, ►Celestial Vault and Sphere, ►Maps and Mapmaking: Islamic Celestial Maps, ►Ulugh Beg, ►al-Battānī, ►Lunar Mansions

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Stars in Chinese Astronomy

Sun Xiaochun

In Chinese astronomy, stars were called *Hengxing* (fixed stars) or *Jingxing* (warp stars), while planets were called *Xingxing* (movable stars) or *Weixing* (web stars). The traditional Chinese sky was composed of 283 constellations which included 1,464 individual stars. This unique system was first established by Chen Zhuo, an astronomer of the Three Kingdom period (AD 220–280), who collected knowledge about stars from the Han time and summarized it in a new catalog of stars. According to Chen Zhuo, these constellations belonged to three separate astronomical schools: 93 constellations belonged to Shi Shi (Master Shi), 118 to Gan Shi (Master Gan), and 44 to Wuxian Shi (Master of Wuxian). There were also 28 lunar mansions (*Xiu*), which were very important in the Chinese sky. Stars of the three astronomical schools were preserved in the *Kaiyuan Zhanjing* (Treatise on Astrology) of the Kaiyuan period (AD 729) from the Tang Dynasty (AD 618–907). After Chen Zhuo little was changed of the Chinese system of constellations.

The observation of stars started as early as civilization began. Among the oracle bone inscriptions from the Shang Dynasty (ca. sixteenth–eleventh centuries BCE) some stars were mentioned. In the *Shangshu* (Historical Classic), the paragraph concerning four cardinal asterisms has generally been agreed to be the record of the observation of stars from before the twenty-first century BCE. But before the Han Dynasties (106 BCE–AD 220), no description of the total sky existed; only 38 star names were mentioned in pre-Han literature. These stars were either of the 28 *Xiu* or were very popular stars such as *Beidou* (Ursa Major), *Niulang* (α Aql), and *Zhinü* (Vega, α Lyr). They appeared in folklore and poems. During the Warring States period (480–222 BCE) there lived two famous astronomers, Shi Shen and Gan De, who were founders of two of the abovementioned astronomical schools. But what were called Shi Shi's and Gan Shi's constellations did not seem to exist in their own time; they were later developments of the nomenclature of stars during the Han. The earliest descriptions of the total sky was in the *Tianguan Shu* (Monograph on Heavenly Officers) by Sima Qian (145–86 BCE) in which 91 constellations including about 500 stars were mentioned. The earliest star catalog, giving coordinates of 92 leading stars of Shi Shi's constellations and of 28 determinative stars of the 28 *Xiu*, were observed a few decades after Sima Qian. That is, the evidence shows that Shi Shi's constellations were scientifically established during the Former Han (206 BCE–AD 25). Shi Shi's constellations consisted of the brightest stars in the sky. They served as the referential system to constellations of other schools. Most constellations of Gan Shi and Wuxian Shi were just fill-ins among Shi Shi's constellations. It is quite certain that the constellations of the three schools obtained their complete forms during the Han times. Chen Zhuo's work was to summarize them.

Constellations in the Chinese sky are much smaller than the Greek ones. A constellation usually includes several stars linked together with imaginary lines. Some constellations are even composed of single stars. Constellations were called inner ones or outer ones according to their location to the North or South of the equator.

The 28 *Xiu* were the basis of the Chinese sky. They spread near the equator and served as one of the dimensions of the Chinese polar-equatorial coordinate system. One coordinate corresponding to the Right Ascension was given as the hour distance to the determinative star of a certain *Xiu*, which was almost always the most western star in the *Xiu*. With great circles linking the determinative stars and the North Pole, the celestial sphere was divided as segments of an orange. Constellations were described in the sequence of the *Xiu* as they were located.

Historical research shows that the 28 *Xiu* are much earlier than the whole constellations of the three astronomical schools. Some star names seemed to be direct derivations from the mythological, legendary, or astrological meaning of the *Xiu*. A complete set of the names of the 28 *Xiu* was discovered on a lacquered box cover excavated from a tomb dated from 433 BCE. The *Xiu* were formed into four groups of seven which were called Four Images. The Four Images corresponded to the four cardinal points in the sky and the four seasons of the year.

Ancient India and the Islamic world also had similar lunar lodge systems. It is certain that these three systems were originally related. But when and where they were first constructed and how they diffused is still an unsolved problem.

Another feature of the Chinese sky is the existence of the three-wall system. There were three enclosed areas in the sky: *Ziwei Yuan*. *Taiwei Yuan*, and *Tianshi Yuan*. The meaning of *Yuan* is a wall, which was formed by stars surrounding the enclosed area. *Ziwei Yuan* indicated that polar area which included 15 constellations, and the wall was formed with 15 stars. *Tianshi Yuan* and *Taiwei Yuan* indicated two other groups of constellations between *Ziwei Yuan* and the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course). The former had 13 constellations, and the wall was formed with 22 stars; the latter also had 13 constellations, but the wall was formed with ten stars. The names of the three-wall system might have existed early, but their use to indicate groups of constellations was rather late, probably after Chen Zhuo.

Since the Tang Dynasty, the three *Yuan* and the 28 *Xiu* became the main structure by which the stars were organized. The famous astronomer Li Chunfeng (AD 602–670) used this system to describe the sky in *Jinshu Tianwenzhi* (The Astronomical Chapter of the History of the Jin Dynasty, AD 265–420).

The names of the Chinese constellations provide a unique document to be studied. The way stars were named was completely different from the Greek. Stars were organized into a heavenly human society. In the sky you can see:

- Emperor, queen, and princes
- Royal court and clan
- Imperial bureaucracy and administration
- All kinds of buildings and facilities, even a toilet in the sky
- Military installation, armies, and weapons
- Traffic and transportation
- Rituals, ceremonies, and pictures of social life
- Philosophical and religious concepts
- Mythological and legendary figures
- Local states and geographical features

It is a total cultural complexity projected in the sky. In the polar area, for example, the *Ziwei Yuan* was furnished with an emperor, queen, princes, royal high-ranking officials, and facilities in a court. There was one constellation called the North Pole, *Beiji*, the brightest star of which was called *Di* the Emperor. The *Ziwei Yuan* was just like a royal palace; it took the polar area and all the stars turned round it. It reflected the social order of the imperial society of ancient China, as Confucius analogized: "He who is a governor because of his Virtue may be compared to the North Pole Star, sticking to its place and all stars turning about it." In other parts of the sky, social life pictures were reflected.

The *Tianshi Yuan* was a heavenly market, in which all kinds of shops were marked. The Autumn harvest of peasants, the imperial hunt ceremony, and cavalry troops could also be found in the Chinese sky.

Because the appearance of a certain part of the sky is related to seasons, and because it also changes with the precession of the sky, seasonal considerations may help to estimate the time when these earthly happenings were projected in the sky. By and large this practice happened during the Han and was carried on with the impetus given by the philosophy of *Tian Ren Gan Ying* (The Interaction between Heaven and Human Beings) which came to a climax during the Han and which urged a new type of astrology by means of division of the sky. The sky was constructed as a heavenly imperial society so that astrologers could interpret imperial society straightforwardly in correlation with the terrestrial society. Stars in the Chinese sky provided a basis for ancient Chinese astrology.

Throughout the history of China, there has been continuous observation of stars. Although the constellations have been kept basically unchanged, new measurements of the position of the stars were made in almost every dynasty. Star maps were made to study the sky. The earliest existent star map is from the *Dunhuang* collection of manuscripts of the Tang Dynasty. More accurate and scientific star maps are from the Song Dynasty (AD 960–1279). The Suzhou Astronomical Chart on a stone plate made in AD 1274 is well known. Almost all stars in the Chinese sky were carved quite precisely on the planisphere. The star map was based on the observations made during the Song. Even the supernova of the year of 1054 in Taurus was marked on the star map.

Since the late Ming Dynasty (AD 1368–1644), European astronomy began to influence China. Star catalogs and star maps were made in the way Westerners did. Traditional stars were identified with the sky and more stars were observed. But the framework of the traditional constellations was not abandoned. Newly measured stars were counted as supplementary stars in old constellations. New constellations were added only in the southern sky, where stars had not been registered by ancient Chinese astronomers. The pioneer work of this kind was done by Xu Guangqi (AD 1562–1633) and the German Jesuit Adam Schall von Bell (AD 1592–1666) in *Chongzhen Lishu* (Calendrical Treatise of Chongzhen Period, AD 1628) at the end of the Ming Dynasty. In this book, 23 new constellations including 126 stars were constructed in the southern hemisphere of the sky. Their work paved the way for the Chinese sky to be absorbed into world astronomy.

See also: ►Lunar Lodges, ►Gan De, ►Astrology in China, ►Astronomy in China

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Stone in Ancient Egypt

JAMES A. HARRELL

Rock Varieties and Sources

Much of what remains of ancient Egypt consists of stone (De Putter and Karlshausen 1992; Klemm and Klemm 1993, 2001; Aston et al. 2000; Baines 2000). There are building stones for temples, pyramids, and tombs; ornamental stones for vessels, sarcophagi, shrines, stelae, statues, and other sculptures; gemstones for jewelry; and utilitarian stones for tools, weapons, pigments, and other applications. Still other stones were processed to extract their precious metals. These remains range in age from the Late Predynastic period (beginning about 3200 BCE) to the Roman period (ending about 400 AD; Table 1). In common parlance, the term "stone" includes "rocks" as well as the "minerals" they contain. There are three general categories of rocks – sedimentary, igneous, and metamorphic, and these are further subdivided according to their textures and constituent minerals.

Sediments (mud, sand, and gravel) deposited on ocean floors and land surfaces are hardened into sedimentary rocks through a variety of lithification processes, including compaction, cementation, and recrystallization. Continental sediments are derived from weathered and eroded pre-existing rocks, and are deposited mainly by rivers but also occasionally by wind, glaciers, and other processes. Marine sediments,

Stone in Ancient Egypt. Table 1 Ancient Egyptian chronology

Late Predynastic Period (3200–3000 BCE): Dynasty 0
Dynastic or pharaonic Period (3000–332 BCE): Dynasties 1 to 30
Early Dynastic Period (3000–2686 BCE): Dynasties 1 and 2
Old Kingdom (2686–2160 BCE): Dynasties 3 to 8
First Intermediate Period (2160–2055 BCE): Dynasties 9 to early 11
Middle Kingdom (2055–1650 BCE): Dynasties late 11 to 14
Second Intermediate Period (1650–1550 BCE): Dynasties 15 to 17
New Kingdom (1550–1069 BCE): Dynasties 18 to 20
Third Intermediate Period (1069–664 BCE): Dynasties 21 to 25
Late Period (664–332 BCE): Dynasties 26 to 30
Greco-Roman Period (332 BCE–395 AD)
Ptolemaic Period (332–30 BCE)
Roman Period (30 BCE–395 AD)

in contrast, are composed mainly of biogenic material (hard skeletal parts of algae, protozoa, and especially invertebrate animals) or inorganic precipitates produced by evaporation of seawater, but also sometimes include continental sediments carried by rivers to the seas. Other sedimentary rocks are the result of secondary mineralization of pre-existing sedimentary rocks.

Sedimentary rocks used by the ancient Egyptians include: limestone (from biogenic marine sediments); rock gypsum and rock anhydrite (both from evaporative marine sediments); sandstone, including siliceous (quartz-cemented) sandstone or quartzite (from continental sediments and, in part, shallow nearshore marine sediments); and travertine and chert (both from secondary mineralization of limestone). Nearly all the ancient quarries for limestone, travertine and chert were located in the hills and cliffs bordering the Nile River valley between Cairo in the north and Isna in the south. Some limestone was also quarried along the Nile Delta's Mediterranean coast near Alexandria. Quarries in the Nile valley from Isna southward into northern Sudan supplied the sandstone. Rock gypsum and rock anhydrite were obtained from Egypt's Red Sea coast, and rock gypsum also came from the Faiyum in the Western Desert. A beautiful blue rock anhydrite comes from an unknown source and may have been imported into Egypt.

Igneous rocks form through the crystallization of magma (molten rock). They are referred to as "plutonic intrusives" when they form deep below the Earth's surface, "volcanic intrusives" when emplaced in the shallow subsurface (dikes and related rock bodies), and "volcanic extrusives" when coming from a volcano and deposited on the surface (lava flows, and airborne pyroclastic falls and flows).

Igneous rocks used by the ancient Egyptians include: granite, granodiorite, quartz diorite, diorite, and pyroxenite (plutonic intrusives); andesite and dolerite porphyries as well as other porphyritic rocks (volcanic dikes and lava flows); basalt and obsidian (volcanic lava flows); and tuff and related rocks (volcanic pyroclastics). Apart from the famous granite and granodiorite quarried at Aswan on the Nile River, the igneous rocks came from the Faiyum in the Western Desert (basalt) and especially the mountains of the Eastern Desert (all other rocks, excluding obsidian). Obsidian (volcanic glass) does not occur in Egypt, and was imported from the eastern Mediterranean and southern Red Sea regions.

Metamorphic rocks are derived from pre-existing sedimentary, igneous or other metamorphic rocks through the application of high pressures, high temperatures, or chemically active hydrothermal fluids deep below the Earth's surface. The metamorphosis occurs in the solid state (without melting) through secondary mineralization and recrystallization. The resulting rocks are either foliated, with a parallel alignment or planar segregation of their constituent minerals, or non-foliated.

Metamorphic rocks used by the ancient Egyptians include anorthosite gneiss and tonalite gneiss (foliated); and marble, metaconglomerate, metagabbro, metagraywacke, serpentinite, and steatite (non-foliated). The anorthosite gneiss comes from the Nubian Desert west of Lake Nasser, and the other rocks were quarried in the mountains of the Eastern Desert.

The other stones employed by the ancient Egyptians are minerals found mostly within the plutonic and metamorphic rocks. These are the gemstones used for jewelry and include: amazonite, a variety of microcline feldspar; emerald, a variety of beryl; garnet; peridot, a variety of olivine; numerous varieties of quartz (agate, amethyst, carnelian, and other colored chalcedonies, jasper, milky quartz, and rock crystal); and turquoise. These minerals were quarried in the Sinai (turquoise), St John's Island in the Red Sea (peridot), the Nubian Desert west of Lake Nasser (agate, carnelian, and other chalcedonies); and the mountains of the Eastern Desert (all the rest). Lapis lazuli, a gemstone rock rather than a mineral, was also widely used in Egypt but was apparently imported from Afghanistan. The plutonic igneous and metamorphic rocks are also the source of much of ancient Egypt's gold, copper, silver, tin, and some iron and lead, with sedimentary rocks supplying additional copper, iron, and lead. All of these were obtained from the Eastern Desert with much of the copper (derived from malachite) also coming from the Sinai.

Plate tectonics and other earth movements in combination with erosion processes have brought the originally deeply buried sedimentary, igneous and metamorphic rocks to the surface in Egypt. The geologic map in Fig. 1 shows the generalized distribution of these rocks. The exposed plutonic igneous and metamorphic rocks, which form mountains in the Eastern Desert, are commonly referred to as the Precambrian “crystalline basement” and in Egypt are over 550 million years old, whereas the sedimentary and volcanic igneous rocks are mostly less than 100 million years in age. For images of many of the stones used by the Egyptians (especially the ornamental varieties) as well as information on the ancient quarries, see the author’s website at ►http://www.eeescience.utoledo.edu/egypt/.

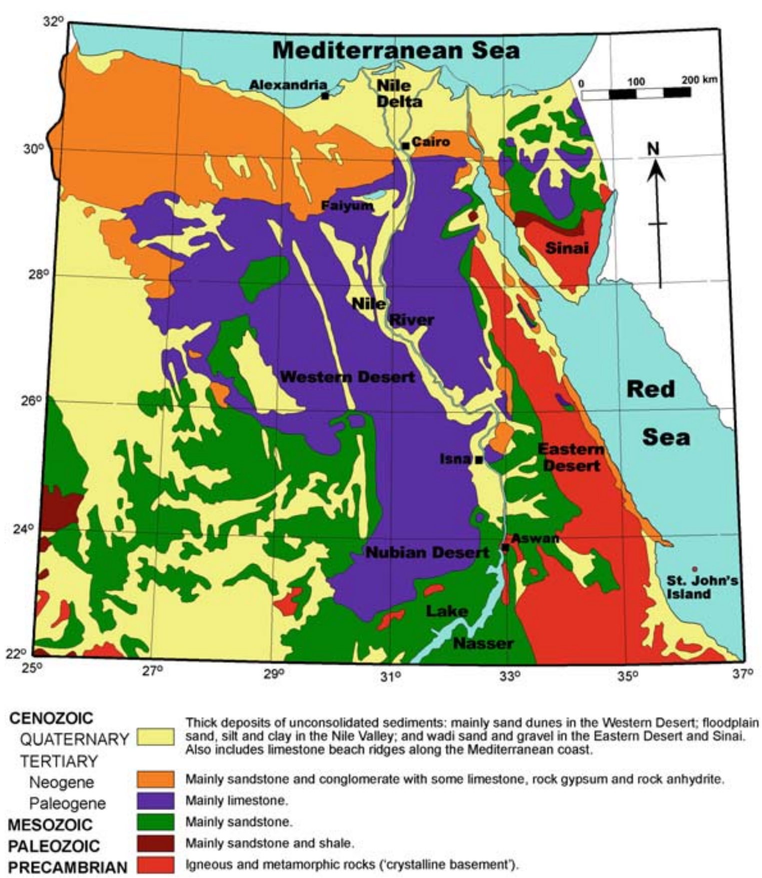
Building Stones

Limestone and sandstone were the main building stones of ancient Egypt. From Early Dynastic times onward, limestone was the material of choice for pyramids, mastaba (bench-like, rectangular) tombs, and temples within the limestone region. From the late Middle Kingdom onward, sandstone was used for all temples within the sandstone region as well as many of those in the southern part of the limestone region. Both limestone and sandstone were also employed for statuary and other non-architectural applications, when harder and more attractive ornamental stones were not available. Along the Red Sea coast, the temples and other important buildings of the Ptolemaic and Roman periods were built with the locally available rock gypsum and rock anhydrite.

Ornamental Stones

In contrast to the drab, unpolished building stones, those employed for ornamental applications, have attractive colors and patterns, and also take a good polish due to their greater hardness. The principal applications of the various stones and their periods of use are as follows:

1. Exterior veneer on pyramids: Old Kingdom – granite and granodiorite



Stone in Ancient Egypt. Fig. 1 Generalized geologic map of Egypt (adapted from an unpublished geologic map by the Egyptian Geological Survey and Mining Authority).

2. Pyramid capstones: Old and Middle Kingdoms – granodiorite and possibly basalt
3. Linings of burial chambers and passages in pyramids and mastaba tombs: Early Dynastic period through Middle Kingdom – granite, granodiorite, and siliceous sandstone
4. Door lintels, jambs, and thresholds of temples: Early Dynastic through Roman periods – granite, granodiorite, and siliceous sandstone
5. Temple pavements: Old Kingdom – basalt and travertine
6. Temple columns: Old and Middle Kingdoms – granite
7. Interior wall veneer, pavement, and columns for temples and other buildings: Roman period – andesite-dacite porphyry, granite, granodiorite, metaconglomerate, metagabbro, metagraywacke, pegmatitic diorite, quartz diorite, rhyolite porphyry, tonalite gneiss, and trachyandesite porphyry
8. Basins: Roman period – granite, andesite-dacite porphyry, and tonalite gneiss
9. Barque shrines: Middle and New Kingdoms – granite, siliceous sandstone, and travertine
10. Small statue shrines (naoi): Old Kingdom through Roman period – granite, granodiorite, metagraywacke, and siliceous sandstone
11. Obelisks: New Kingdom and Roman period – granite; and New Kingdom only – metagraywacke and siliceous sandstone
12. Offering tables: Old Kingdom through Roman period – granite, granodiorite, metagraywacke, siliceous sandstone, and travertine
13. Small vessels and figurines: Late Predynastic period through Old Kingdom – andesite porphyry, anorthosite gneiss, basalt, granite, metagraywacke, obsidian, pegmatitic diorite, quartz rock crystal, red-and-white limestone breccia, rock gypsum, serpentinite, silicified (petrified) wood, travertine (the most commonly used stone), tuff, and tuffaceous limestone; and Middle Kingdom and Second Intermediate period only – blue rock anhydrite
14. Canopic jars[1]: Old Kingdom through Roman period – travertine
15. Sarcophagi: Old Kingdom through Roman period – granite, granodiorite, metagraywacke, and siliceous sandstone; Old through New Kingdoms only – travertine; New Kingdom through Late Period only – metaconglomerate; and Late Period only – basalt
16. Small to colossal statues and other sculptures: Early Dynastic through Roman periods – granite, granodiorite, metagraywacke, red-and-white limestone breccia, siliceous sandstone, and travertine; Old and Middle Kingdoms only – anorthosite gneiss; early New Kingdom only – marble and pyroxenite; Late Period only – dolerite porphyry; Late through Roman periods only – basalt and metaconglomerate; and Roman period only – andesite-dacite porphyry
17. Scarab and shabti[2] figures: New Kingdom through Roman period – metagraywacke, serpentinite, steatite (usually glazed), and travertine
18. Stelae: Old Kingdom through Roman period – granite, granodiorite, metagraywacke, and siliceous sandstone; and Late Period only – metaconglomerate
19. Cosmetic and ceremonial palettes: Late Predynastic and Early Dynastic periods: metagraywacke. Note that many of the above objects were also carved from non-ornamental limestone and sandstone.

Gemstones

The many precious and semi-precious gemstones available to the ancient Egyptians were employed primarily for beads, pendants, amulets, inlays, and seals. Agate, amazonite, carnelian (including sard) and other colored chalcedonies, garnet, jasper, lapis lazuli, obsidian, rock crystal and milky quartz, steatite (usually glazed), and turquoise were used from the Late Predynastic through Roman periods. Amethyst was employed mainly during the Middle Kingdom and again during the Ptolemaic and Roman periods. The Romans were the first to use emerald and peridot for jewelry, and also imported into Egypt other gemstones from India, including aquamarine (beryl); carnelian, onyx, sard, and sardonyx (all varieties of chalcedony); and sapphire and ruby (corundum).

Utilitarian Stones

Perhaps the heaviest used and least glamorous stone employed by the ancient Egyptians is chert, which is also commonly referred to as flint. From Predynastic times onward it was used for tools (awadze, adzes, knife, and sickle blades; axe and pick heads; choppers; drill bits; and scrapers) and weapons (dagger blades, and spear and arrow points). Even when metals (copper, bronze, and later iron) became commonplace

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[1] Canopic jars were containers (usually four) found in ancient tombs which stored organs and viscera which were believed to be essential for the dead person's existence in the afterlife.

[2] A shabti was a model servant figure which was supposed to do the hard work for the deceased in the afterlife.

for these applications, chert was still a popular low-cost alternative. For tools and weapons requiring the sharpest edges, imported obsidian was employed. A wide variety of stones, especially hard ornamental ones, were used for the heads of maces, a club-like weapon.

From Late Predynastic times into the Late Period, the quarrying and much of the carving of ornamental stones was done with hard, fracture-resistant stone tools known as pounders and mauls. These were primarily of dolerite, but siliceous sandstone, anorthosite gneiss, and fine-grained granite were also occasionally used. These same rocks were also employed as grinding stones for smoothing rough, carved stone surfaces. The actual polishing of these surfaces was probably done with ordinary, quartz-rich sand of which Egypt abounds. For the softer sandstone and limestone, picks of chert (as well as metal tools) were employed.

Eye shadow made from finely ground galena (dark gray) and malachite (green) was used by both Egyptian men and women. The grinding was done on cosmetic palettes carved mainly from metagraywacke. Egyptian temples and tombs were richly painted with bright primary colors made largely from ground stones: azurite (blue), gypsum and limestone (white), hematite ochre (red and orange), limonite ochre (yellow and brown), and malachite (green).

Grinding stones for grain have been used throughout Egyptian history, and generally were carved from the harder and less valuable ornamental stones, such as granite, granodiorite, and siliceous sandstone. During the Ptolemaic and Roman periods, large numbers of grinding stones made from vesicular basalt were imported.

Extra 1: What is in a name?

A persistent problem in Egyptian archaeology is the misidentification of ornamental stones. The primary sources of these errors are archaeologists, museum curators, and art historians who are unfamiliar with correct petrological nomenclature as applied by geologists. Geologists themselves have also contributed to the problem by applying different, competing rock classifications to the stones. It is not uncommon to see objects carved from the same stone referred to by multiple, contradictory rock names in museum exhibits and catalogues as well as in reference works. This is not only a great source of confusion to the general public, but it has also misled some scholars into thinking the different rock names refer to different materials. A classic example of this problem is the stone known by the technically correct name "metagraywacke" (a slightly metamorphosed greywacke sandstone to siltstone), which is commonly referred to incorrectly as "schist," "slate," "basalt," and "siltstone." "Travertine" is another notorious example. This stone, which consists of the mineral calcite, is frequently called "alabaster," which in geological nomenclature is a rock consisting of the mineral gypsum. In an effort to avoid this misidentification, travertine is increasingly being referred to as "calcite-alabaster" or simply "calcite."

Another commonly misidentified stone is the "granodiorite" from Aswan, which is often referred to as "black granite," "diorite," or "basalt." For example, the famous Rosetta Stone, which provided the key to translating Egyptian hieroglyphic writing, is widely described as basalt when it is actually Aswan granodiorite. A final example is the anorthosite gneiss from the Nubian Desert, which is frequently misidentified as diorite.

Extra 2: Bekhen-Stone to Basalt

Basalt is the fine-grained, black volcanic rock seen in lava flows all over the world. What few realize is that the word *basalt* is of ancient Egyptian origin. It began in the third millennium BCE as *bekhen*, which was the ancient name for a dark grayish green metagreywacke, a slightly metamorphosed greywacke sandstone to siltstone, quarried in Egypt's Wadi Hammamat. During the Greco-Roman period *bekhen* was transliterated into *basanites*, and during the Middle Ages a transcription error in a copy of Pliny the Elder's "Natural History" changed *basanites* to *basaltes*. This error went undetected in subsequent centuries when Pliny's description of the misnamed *basaltes* as having a "dark color and hardness of iron" was mistakenly thought to refer to the volcanic rock that today we call *basalt*.

Extra 3: Limestone or Concrete Pyramids?

The Old Kingdom pyramids at Giza, Saqqara, and other nearby necropoli on the Nile River's west bank have long been recognized by Egyptologists and geologists as having been constructed with blocks of limestone. The limestone for the bulk of the pyramids, the "core blocks," came from quarries excavated in the limestone bedrock surrounding the pyramids. A better-quality limestone, with a uniform light gray color and finer texture, was applied over the core blocks to form the pyramids' exterior surfaces. These "casing blocks" came from the Tura–Masara quarries across the Nile River, on its east bank.

In the early 1990s, these long-held beliefs about the building materials for the pyramids were challenged by David Davidovits, a French materials scientist, who claimed the pyramids were made from poured concrete rather than quarried limestone. Although the "concrete pyramids" hypothesis has received a lot of attention in the international media, Davidovits has so far failed to convince any Egyptologists or geologists of his views. The reasons for this are twofold. First, Davidovits' arguments ignore and run counter to nearly all archaeological and geological evidence bearing on the pyramids. And second, Davidovits has been unable to experimentally produce a concrete resembling the pyramid stones using the techniques he thinks the ancient Egyptians employed.

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Stonemasonry of the Incas

Jean-Pierre Protzen

> And what one admires most is that, although these [stones] in the wall I am talking about are not cut straight but are very uneven in size and shape among themselves, they fit together with incredible precision without mortar (Acosta, lib. 6, cap. 14; 1962:297).

Like Father Acosta in the seventeenth century, the modern traveler stands in awe before the Inca walls of huge stones, some weighing over a hundred metric tons, tightly fitted together. They wonder about how people who did not know the wheel and had no iron tools transported and dressed stones of that size, and mated them one to another in such a way that, as the saying goes, not even the blade of a knife could be inserted into the joints. Answers to these questions have been replete with speculations ranging from the intervention of extraterrestrial beings, to the application of an herb, the juice of which softened the stone, to the more prosaic investment of an immense labor force. Recent studies of Inca construction, however, demonstrate that the awe-inspiring, tightly fit megalithic masonry was well within the technological reach of the Incas (Protzen 1985, 1986, 1993). It is to be hoped that the fantastic tales of extraterrestrial intervention will be put to rest once and for all.

Quarrying

The Incas did not practice quarrying in the proper sense. The stone is neither cut off a rock face nor is it detached from bedrock by undercutting. The Incas gained their building stone either by picking suitable blocks out of a rockfall or by prying it loose from fragmented rock faces. Large blocks of five or more tons were only minimally shaped in the quarries; all the fine work was done at the construction site. Smaller building blocks were dressed on most sides in the quarries, and only the finishing and the fitting to other stones was reserved for the site.

The Incas chose the stones to be quarried with great care. Proper workability, texture and color of the stone mattered a great deal and they often went far out of the way, up to 30 km from a construction site, to quarry the appropriate stone. To access the quarries and transport the stones, the Incas built well-engineered roads, 4 to 5 m wide. For example, to get a specific rose rhyolite for the so-called Sun Temple at Ollantaytambo and reach the quarries of Kachiqhata, the Incas built enormous ramps, the total construction volume of which exceeded the volume of quarried stones by a factor of 40. This is the price the Incas were willing to pay for a select stone.

Cutting and Dressing

To cut and dress stones the Incas used simple river cobbles of various sizes as hammers. These tools and their fragments are found in abundance in the ancient quarries scattered among roughed out building blocks and in the quarrying waste. The hammerstones are easily distinguished from other stones by both their shape and their petrological characteristics; they are water-worn rounded stones of materials different from the quarried stone and the surrounding bedrock. The hammers come in different sizes; some are as small as an egg, others are the size of a football, and others still are two to three times the size of an American football. The largest of these hammerstones were used to break up and roughly shape the raw stones, the medium sized to dress the faces of the building blocks, and the smallest to draft and cut their edges and corners. The technique involved is exactly as Garcilaso de la Vega "El Inca" described it: "The quarryfolks,..., who had no other instruments to work the stones, but some black cobbles they called hihuana (sic. for hihuaya), with which they dress the stones by bruising rather than cutting." (lib II, cap. XXVIII; 1976:119, tomo I).

Indeed, when hitting the workpiece straight on with a hammer stone one crushes the rock producing little more than dust. However, if one increases the angle of impact to about 15 to 20°, little chips can be torn off. By further increasing the angle to some 45° by imparting a twist to the hammer just before impact, larger chips can be removed, thus accelerating the process considerably. The impact of the hammer leaves a small pitmark on the workpiece. Such pitmarks can be observed on every face of every building block in every Inca wall of cut stones, regardless of the building blocks' material. Smaller, finer pitmarks found along the edges of the building blocks indicate that smaller stones were used to cut the edges. The particular technique in cutting edges requires that the edge be shaped by hitting the workpiece with grazing blows directed away from the workpiece, which results in corners with dihedral angles larger than 90°. It is these obtuse angles that account for the characteristic beveled joints of Inca cut stonemasonry and that brings about the chiaroscuro effect.

Extensive experiments have demonstrated that the process is relatively easy, effective and precise, and not as time consuming as one might assume. Twenty quarry people working side by side could rough out a block 4.5 m long, 3.2 m wide, and 1.7 m high – the dimensions of one of the largest building blocks in an ancient Inca quarry near Ollantaytambo – in less than 15 days.

Fitting

The most intriguing question about Inca cut stonemasonry concerns the precision fitting of the blocks. It has been repeatedly argued that the Inca stonemasons ground the blocks into place using a mixture of sand and water. The evidence, however, does not support this hypothesis. Where walls have been dismantled or fallen apart one finds the exact imprint of the stones which have been removed or fallen off. Very often the shape of the imprints determines a unique position for the stone it once accommodated. To grind in a stone, however, requires that the stone can move freely along a path in at least one direction. Thus, the ground stone would fit in any, and not just one, position along that path. Furthermore, if the stones had been ground into place the joints should show signs of abrasion, but they do not. Instead one finds the typical pitmarks which result from pounding.

The imprints seen on dismantled walls indicate that when laying a wall, the Inca stonemasons left the top face of every new course uncut until it was to receive a new course. The bottom face of the block of the new course was cut first, and a suitable bed was carved out of the course already in place. A similar approach was used for the rising joints; it is the side of the block already in situ that was carved to match the precut shape of its new neighbor. The technique used appears to have been one of trial and error. The masons started by outlining the shape of the new stone atop the course it was to be fitted to and proceeded to carve out a bed. By trying the fit time and again the masons obtained a perfect match. Granted, the trial and error technique is a tedious one, and perhaps not very convincing if one considers megalithic building blocks of several dozens of tons. However, it works and does not postulate the use of tools and machinery of which no traces have been found. The Incas had plenty of time and manpower at hand. Since they moved huge blocks over many kilometers, it is not inconceivable that they were capable of setting up a stone several times to achieve the desired fit. It is of course also conceivable that the Inca stonemasons knew of another technique to transfer the shape of one stone to another without actually trying it in successive steps. Vincent Lee has in fact proposed such a technique. Inspired by log cabin builders, Lee suggests that the shape of one stone was scribed onto the other with an ingenious but simple device consisting of a stick and a plumb bob. Although very plausible, Lee's hypothesis does not bear out in the field, as will be shown below.

Assemblage

When assembling a wall, the Incas often had several construction crews working simultaneously and side-by-side. Where two crews met in a course the final gap in the wall was closed with a "wedge" stone introduced into the masonry bond from the front of the wall. Because in the last gap there is not enough room to maneuver the stones for the usual one-on-one fitting, the Inca stonemasons hit on the ingenious idea of the wedge stone that fits to its neighbors only along a very narrow band near the face of the wall. Once one knows what to look for, it is relatively easy to spot wedge stones in an Inca cut-stone wall and to determine its construction sequences. If scribing had been the predominant fitting technique, there would have been no need for wedge stones: even the last stone could have been scribed for a perfect match and lowered into place. But many wedge stones clearly were not lowered into the gap they were intended to fill, since they are wider at the bottom than at the top.

Transporting

Another vexing problem is how the Incas transported and heaved enormous building stones. Rough abrasion marks found on building blocks at Ollantaytambo suggest that the stones were simply dragged along the ground. From these marks it is even possible to determine the direction in which the blocks traveled. The dragging of big stones is consistent with chroniclers' reports: "These Indians used to move very large stones with muscle power, pulling them with many long ropes of lianas and leaf fibers,..., and they [the stones] are so big that fifteen yokes of oxen could not pull them." (Gutierrez de Santa Clara lib. 3, cap. 63; 1904–1929:550). And dragging big blocks involves large transportation crews: "Four thousand of them were breaking stones and extracting stones; six thoudand were hauling them with big ropes of hide and leaf fibers;..." (Cieza de León cap. LI; 1967:170)

Six thousand people dragging a stone is not unreasonable; many Old World transportation problems were solved with very large work forces. Engelbach, for example, calculated that it would have taken 6,000 men to haul the unfinished obelisk at Aswan from the quarries to the Nile. The questions raised by a transportation crew as numerous as this, which remain largely unanswered, are how the crew was harnessed to the stones and how it negotiated turns on the narrow roads on the steep slopes of the Andes.

An experiment carried out in 1994 in the town of Ollantaytambo involved the dragging of a 14 t heavy Inca building block a distance of about 150 m. One hundred and eighty four people from the town, men and women, volunteered for the task. They were given no instruction of how the task had to be performed. They brought ropes, which they wrapped around the block like a net in such a way as to have six leading ropes extending from the stone in the direction it was to be pulled. The 184 people were distributed over the six leading ropes, which they grabbed and leaned into to drag the block the requisite distance with relative ease over a surface roughly equivalent to the roads from the quarries.

Antecedents

John Hemming argued emphatically that the high skills of the Inca stonemasons "cannot have been developed in the century or less of Inca ascendance. Architecture anywhere in the world evolves from precursors". Here, the precedent is Tiahuanaco at the south end of Lake Titicaca. Tiahuanaco has some of the world's finest stonemasonry: carefully fitted rectangular ashlars, and exquisitely worked monolithic gates and statues. It is said that Pachakuti, the 9th Inca, was so impressed by this stone work when he first saw Tiahuanaco that he advised his architects to take careful note of how this masonry was made because he wanted Cuzco to be built in the same manner. It is also said that he imported Qolla laborers from the Lake Titicaca area to work on construction projects (Sarmiento de Gamboa cap. 40; 1943:111–112). But because Tiahuanaco culture developed at least a millennium before the Incas, and may have reached its peak some five to six centuries before Pachakuti's rise to power and nothing similar has been built in the interim, one may question why the Qolla laborer should remember any of the ancient techniques.

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Stone Tools in Mesoamerica: Flaked Stone Tools

Bradford W. Andrews

Flaked stone tools in pre-Hispanic Mesoamerica were used for a wide range of domestic, *militaristic, and ritualistic activities*. Geographically, Mesoamerica refers to present-day Mexico, Guatemala, Belize, and parts of Honduras and El Salvador. Undoubtedly, the most popular tool was the prismatic blade that was usually made of obsidian, the most important toolstone in the region (see obsidian Note). Simpler flake tools and biface implements, such as projectile points and knives, were also present throughout Mesoamerica. These implements, however, were not as important as blade tools except during early Mesoamerican prehistory, or at sites like Colha in the Chert Bearing Zone of Belize where obsidian was scarce (Fig. 1) (Hester and Shafer 1994; Shafer and Hester 1983). This discussion focuses on the Mesoamerican blade technology, but flake and biface technologies are also briefly reviewed. Reference is made to chronological trends and how blades and other items were produced and used.

Early Prehistory-Flakes and Projectile Points

Research indicates that as early as 15000 BCE small foraging groups who made impressive projectile points inhabited much of Mesoamerica (MacNeish 1976; Weaver 1981). These groups are referred to as Paleo-Indian (prior to 7200 BCE) "big-game" hunters. They employed a biface technology requiring the use of percussion and pressure techniques to shape biface (e.g., projectile points) and uniface (scrapers) tools. The manufacture of biface tools like projectile points require the removal of flakes from both sides, or "faces" of *a relatively flat piece of stone*. Uniface tools like many scrapers, in contrast, are made by removing flakes from only one side of *a piece of stone*. The flaking techniques used to make both types of implements are similar, so they are referred to here as products of biface technology.

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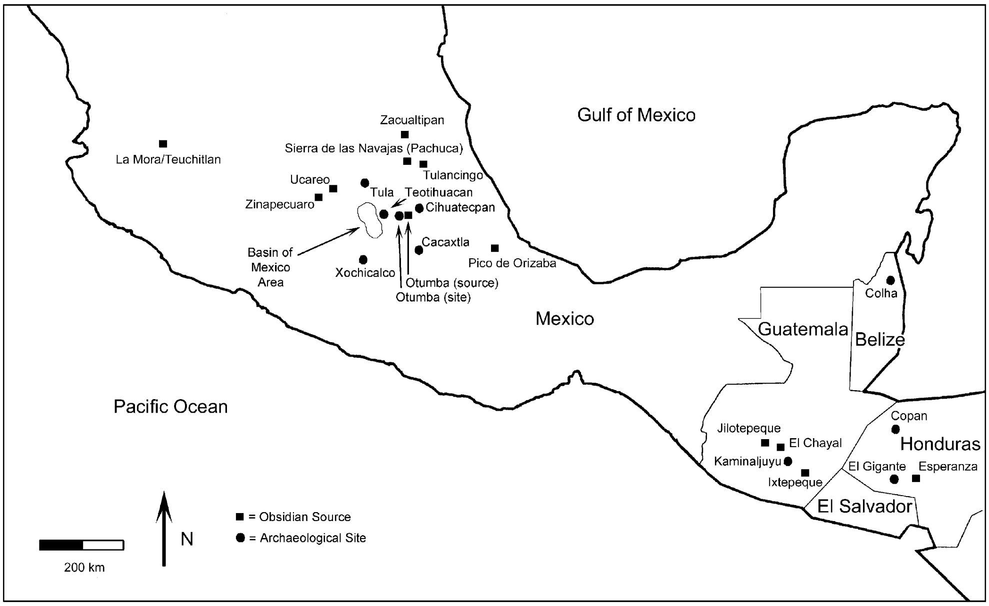


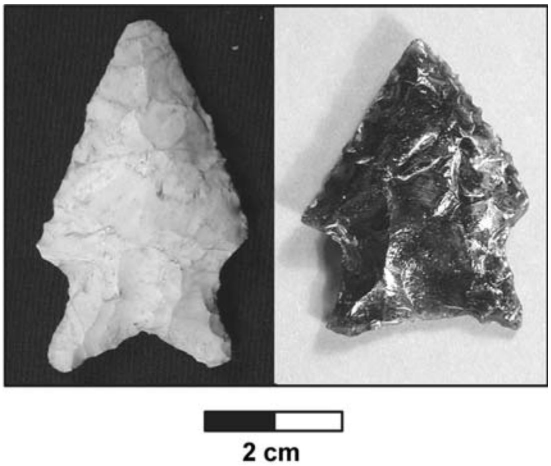
Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 1 Map of Greater Mesoamerica. Illustration by the author.

Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 2 The direct freehand percussion technique. Illustration by Karen Andrews. Used with her permission.

Paleo-Indian bifaces were initially made from large flakes using direct percussion, which were then "thinned" with pressure. Direct percussion involved directly striking a piece of raw material (i.e., nodule, flake, or blade) with a stone, bone, antler, or wood hammer (Fig. 2) (Hester 1972: 99). In contrast, the pressure technique involves placing a tool of bone, antler, or wood against the edge of a piece of raw material and pushing on it to "press" off flakes.

Many Paleo-Indian points in Mesoamerica were the fluted varieties associated with the Clovis and Folsom Traditions (Weaver 1981). Clovis points have been found in Northern and Western Mexico, and as far south as El Salvador (Weaver 1981). In Central Mexico, a similar development referred to as the Cordilleran Tradition emerged around 13000 BCE; it was associated with the appearance of pressure flaked, willow-shaped projectile points, crude blades, and scrapers (MacNeish 1976: 322, Fig. 2). Early Paleo-Indian points were hafted on spears and used as thrusting weapons. By about 9000 BCE, however, the *atlatl*, or spear thrower appeared, providing hunters with greater thrusting force and accuracy (MacNeish 1976: 324). In the Aztec language of Nahua, the word atlatl refers to what is known in English as the spear thrower. This device consists of a stick that supports a dart-tipped shaft. During the throwing action, the stick acts as an extension of the arm and a lever that propels the "butt" end of the dart shaft generating greater thrusting power and accuracy than a shaft thrown by hand (Adams 1977: 339). Point size is usually used to differentiate larger spear points from smaller atlatl points, with atlatl points measuring generally less than 6 or 7 cm in length. This criteria is subjective, however, and many finely flaked points dating to this period could have been either spear or atlatl points (Fig. 3).

The appearance of the spear thrower occurred in tandem with the gradual replacement of big-game hunters by groups who foraged for a wider range of plant and animal resources. This shift is associated with the Mesoamerican Archaic period (7200–2500 BCE). Generally, Archaic flaked stone tools are characterized as expedient (Clark 1987), consisting of simple flakes made with direct percussion or bipolar percussion. Bipolar percussion involved striking the top of a cobble resting on an anvil stone, enabling the transmission of force from both "poles" of the cobble; this technique is effective for reducing small pieces of raw material that



Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 3 Paleo-Indian projectile points from El Gigante cave, Honduras. Photos by Tim Scheffler. Used with his permission.

Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 4 The bipolar percussion technique. Illustration by Karen Andrews. Used with her permission.

are otherwise difficult to flake (Fig. 4). Unmodified tools, or those flaked into slightly refined forms, were "amorphous" in form and their production resulted in a miscellany of chunks and shards. This expedient technology is found in Mesoamerica from the Basin of Mexico (Boksenbaum 1980; Tolstoy et al. 1977) to the Pacific coast of Guatemala (Fig. 1) (Coe 1961). Expedient techniques for making flake tools continued well into the Preclassic (2500 BCE–AD 300) period (Aoyama 1994: 136; Clark 1987).

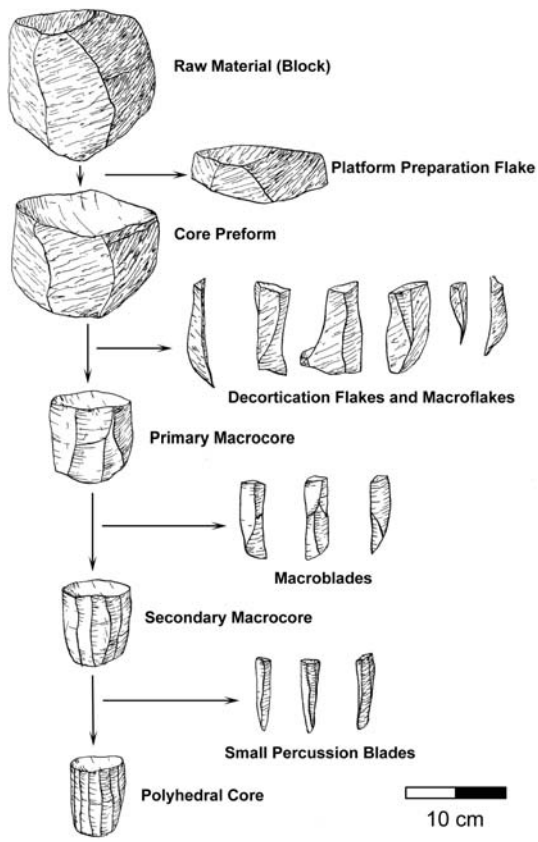
Mesoamerican Blade Technology

Even though a few pressure blades may have been made in Central Mexico after 3400 BCE (MacNeish 1964), blade production did not become prominent until the Middle Preclassic (900 to 300 BCE) period (Hirth and Flenniken 2002: 123). The factors responsible for the emergence of the Mesoamerican blade technology remain a topic of debate (See Origins of blade technology Note). By the time socially complex societies like Teotihuacan (AD 100–650) and Xochicalco (AD 650–900) (see Fig. 1 for site locations) had emerged, blade production had become a specialized occupation carried out by skilled craftsmen. Teotihuacan, located near the Basin of Mexico (Fig. 1), had an impressive population of 125,000 people by AD 500, most of whom performed their domestic cutting *and piercing* activities with blade tools. As such, evidence for specialized blade production has been used to study the complexity of this society's economy (Andrews 2002; Millon 1973; Spence 1981, 1987). Recent research has examined the skill of blade makers to determine *how* often they worked (See Measuring skill Extra).

The Mesoamerican blade technology resulted in the production of similar types of tools (Clark 1989a, b; Sheets 1978a, 1983), although some spatial variation did exist (Flenniken and Hirth 2003). This variation can be attributed to numerous factors including distance to obsidian sources, the quality of different types of obsidian, how it was acquired (e.g., directly from the source, in the marketplace, etc.), different production techniques, and localized demand for specific types of products (Hirth and Andrews 2002).

In general, blades were detached from cylindrical cores using percussion and pressure techniques. Obsidian was acquired from quarries in the form of blocks and nodules (Darras 1994; Healan 1997; Pastrana 1998) and as cobbles in stream deposits (Spence 1981). The initial step involved making a core platform. A platform is the surface where force was applied to remove blades. Large platform preparation flakes were detached from the upper end of the pending core (Fig. 5). This procedure created a smooth concave surface on a core preform (Clark and Bryant 1997). Sometimes platforms were further modified with pecking and grinding (See Pecking and grinding Note).

Next, relatively large decortication flakes and macroflakes were detached from the lateral sides of the core preform (Fig. 5). Decortication is the removal of the cortex or weathered surface of the stone. Additional macroflake detachments gave the preform more symmetry, resulting in a primary macrocore with irregular ridges on its lateral facets. Then, macroblades were removed from the primary macrocore to make a secondary macrocore (Fig. 5). Macroblades were



Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 5 Schematic diagram of the initial steps in core production. Illustration by author.

Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 6 Broken macroblade biface tools discarded at a blade-making workshop at Teotihuacan. Photos by Alejandro Serabia. Property of the author.

relatively long, parallel-sided items with one or more dorsal ridges (Kerley 1989: 165). These blades were roughly 2.5 cm wide and more than 1 cm thick (Hirth and Andrews 2002: 4). By themselves, macroblades were sturdy cutting implements, but they were also further shaped into more specialized biface tools (Fig. 6) (Andrews 2002; Hester 1972). Macroblade removal created a series of parallel, irregular ridges running the length of the core. Next, small percussion blades were detached to make the polyhedral core (Fig. 5). These blades are thinner than macroblades, with widths of less than 2.5 cm, and their removal created more regularized parallel ridges running the length of the core.

Most initial core shaping and blade-making activities were accomplished with direct percussion. Indirect percussion, however, was also probably used. This technique involved placing one end of an antler, bone, or wood punch on a platform and then striking the opposite end with a hammer stone (Bordes and Crabtree 1969; Crabtree 1968, 1972; Hester 1972); it permits more precise control over the transmission of force than direct percussion (Fig. 7). As a consequence,

Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 7 The indirect percussion technique. Illustration by Karen Andrews. Used with her permission.

relatively standardized percussion blades can be made with indirect percussion. Although still a subject of debate (Pelegrin 2003), the recovery of extremely symmetrical macroblades at sites like Kaminaljuyu in the Maya region (Fig. 1) suggests that indirect percussion was used in ancient Mesoamerica (Hirth 2003).

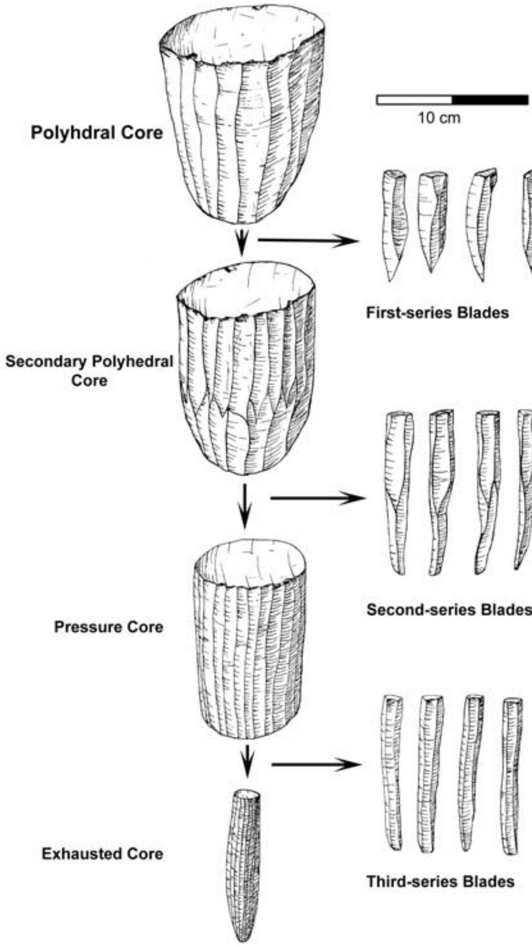
The polyhedral core was reduced to make the delicate pressure blades that were common place in ancient Mesoamerica. The Aztec technique for making these blades has been reconstructed according to historic information and replication experiments (Clark 1989c; Crabtree 1968; Sahagun 1963: plate 778; Titmus and Clark 2003; Torquemada 1975; Tudela and Corona Nuñez 1977). The reconstruction proposes that seated craftsmen secured cores against an immovable object with their feet, and then used their stomach muscles and torso to "press," or push blades off with a long-handled wooden stick called an *itzcolotli* (Fig. 8) (Clark 1989c: 153; Titmus and Clark 2003). In some areas of Mesoamerica, however, pressure blades were also removed with a hand-held technique (Flenniken and Hirth 2003).

First-series blades were the initial pressure blades removed from a polyhedral core (Fig. 9). These blades eliminated irregular ridges left by the blades previously removed with percussion. Sometimes second-series blades were taken off after first-series blades depending on the shape of the polyhedral core (Clark and Bryant 1997: 115). If the core was cone-shaped, first-series blades often extended only part way down the sloping core face, resulting in a secondary polyhedral core. In turn, second-series blades were removed to extend the parallel ridges the entire length of the core.

The product of first- and second-series blade detachments was the pressure core (Fig. 9). Pressure cores yielded third-series blades that are generally regular and consistent in shape (width and thickness) and have two dorsal ridges, *thereby making them prismatic in* cross section. The dorsal ridges were mechanically important because they helped "guide" the transmission of force from the platform resulting in successful pressure blade removal.

Many pressure blades were further modified in a variety of ways. Most of them were snapped into

Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 8 Gene Titmus removing pressure blades using an Aztec *itzcolotli*. Photos by James Woods. Used with his permission.



Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 9 Schematic diagram of pressure blade production. Illustration by the author.

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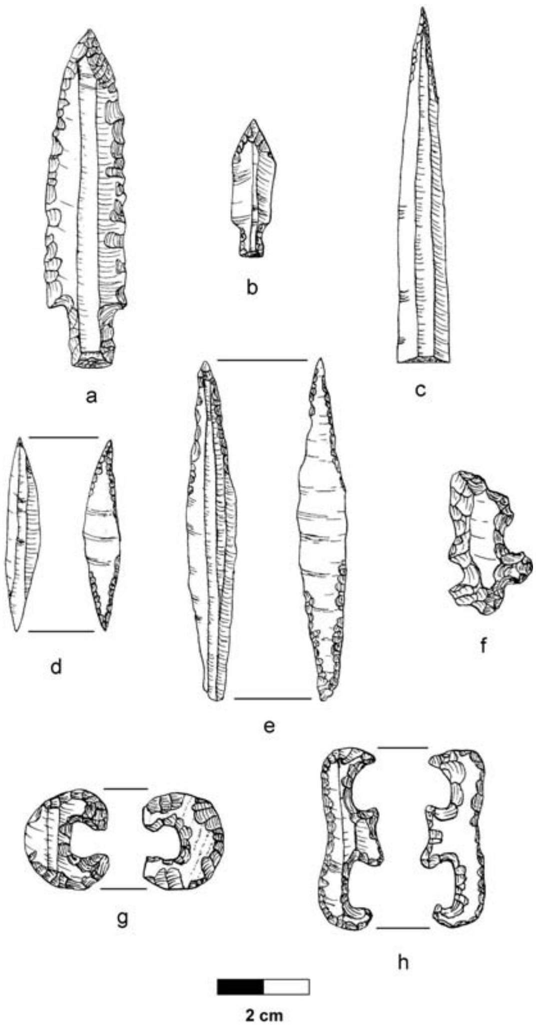
sections and used for cutting activities. One parallel edge could be hafted in a piece of wood or bone, making the section easier to handle. A piece of wood or bone was incised deep enough to insert the blade section, which was then secured with a sticky adhesive composed of pine pitch and ashes.

Pressure blades were also made into specialized forms such as projectile points, lancets, and notched eccentrics. Small pressure blade projectile points were used for hunting and warfare. Many of these items were too small to be propelled effectively with a spear thrower (Fig. 10a, b). Consequently, their size and minimal weight indicates that they were used to tip arrows propelled with a bow. This conclusion is interesting because small blade points occur in archaeological deposits that supposedly predate the Postclassic (AD 900) introduction of the bow in Mesoamerica (See Introduction of the bow in Mesoamerica Note).

The slender needle-like, lancet blades (Fig. 10c–e) may have been used in textile production, but they were most important for bloodletting (Clark 1980; Flannery 1976; Parry 1983; Sugiyama 1995). Historic sources and ritual archaeological contexts where lancets have been found indicate that they were used to draw blood (Clark 1989d: 314; Durán 1971: 263; López de Cogolludo 1957; Motolinía 1950; Nuttall 1903; see Landa in Tozzer 1941: 113–114). Lancets are often portrayed in bloodletting rituals depicted on Mexican and Maya codices, Maya monuments, and polychrome vessels (Clark 1989d: 314). As an act of auto-sacrifice, this practice was essential for appeasing the gods by providing them with blood nourishment (Berdan 1982; Hassig 1988; Hirth 2000).

Eccentrics made from pressure blades occur in a variety of strange shapes including crescents and trilobal sections (Fig. 10f–h). Pressure blade eccentrics may have functioned as ornamental elements sewn on articles of clothing (Spence 1996). They also probably had symbolic significance because many of them have been found in burials and ritual cache deposits (Gamio 1966; Moholy-Nagy 1989; Parry 2002; Stocker and Spence 1973; Winter 1989).

The end byproduct of the core-blade sequence was the exhausted pressure core, often measuring no more than 1.5 cm in diameter (Fig. 9). At some sites like the Aztec city of Otumba (Otis Charlton 1993) and the pre-Aztec city of Xochicalco (Fig. 1), lapidary craftsmen used exhausted cores to make beads (Fig. 11). The slender cores were fractured into sections using bipolar percussion and then ground and polished to perfection.



Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 10 Specialized tools made from pressure blades at the site of Xochicalco: (a, b) projectile points; (c–e) lancet blades; (f–h) eccentrics. Illustration by author. Property of Kenneth Hirth. Used with his permission.

Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 11 Beads-in-progress from the elite zone of Xochicalco, Mexico. Inset illustration by Luis Gonzalo Gaviño, property of the author.

Mesoamerican Biface Technology

Biface flaking techniques were used to make impressive biface and uniface items for domestic, military, and ideological purposes. One important utilitarian uniface artifact in Central Mexico was the maguey scraper (Fig. 12). The maguey plant (*Agave atrovirens*) was a valuable source of water, food, fiber, and fuel, among other things (Evans 1990; Sauer 1963; Sheehy 2001). Near Teotihuacan, large maguey scrapers at the Aztec (AD 1350–1520) period site of Cihuatecpan were made of relatively coarse obsidian from the source of Otumba (Fig. 1). Maguey scrapers were used to process maguey fibers and to initiate the flow of a sticky liquid that was converted into a fermented drink called *pulque*. Evidence suggests that pulque was a valuable source of nutrition and potable liquid in large cities like Teotihuacan where sanitation was a serious problem (Sheehy 2001: 265).

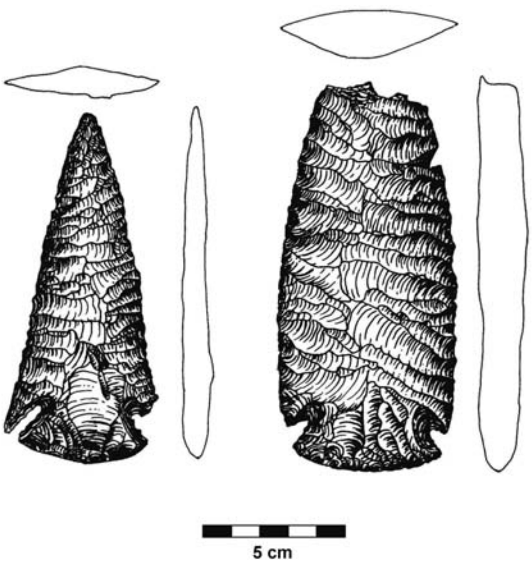
Large, impressive bifaces were used for combat and may have had symbolic significance given the central importance of warfare, conquest, and human sacrifice that emerged during the Classic period (AD 300–900) (Fig. 13). These items occurred in many forms. At Teotihuacan (AD 100–650), evidence has indicated that the large atlatl points for the city's army were made by craftsmen under the direction of state officials (Carballo 2004).

Like the small eccentrics made from pressure blades, the contexts in which large eccentrics have been found indicate that they had symbolic significance (Gamio 1966; Moholy-Nagy 1989; Parry 2002; Stocker and Spence 1973; Winter 1989). At Teotihuacan some of the most impressive eccentrics are anthropomorphic figurines (Fig. 14). Other impressive pieces appear to combine multiple symbols into one implement, such as a projectile point, a serpent, and a trilobal motif signifying blood droplets (Fig. 15). Many of these items were undoubtedly associated with warfare and sacrifice because they are often recovered in offerings with human sacrificial victims decorated as warriors (David Carballo Personal communication 2005).

At Xochicalco, ten impressive eccentrics were found together atop the site's major public pyramid. They occur in several forms including circular uniface elements (Fig. 16). These artifacts were probably components of public rituals that were conducted for the benefit of the masses (Andrews and Hirth 2005).

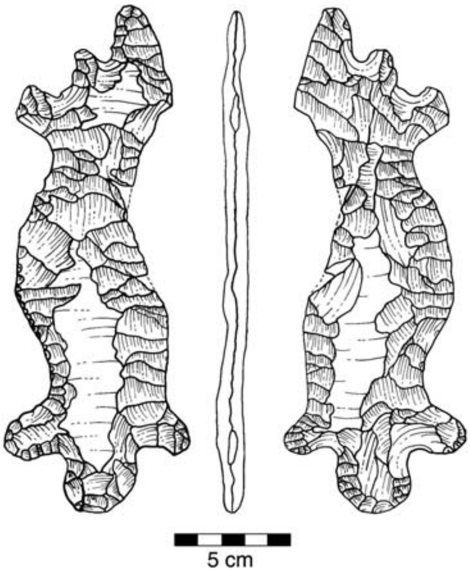
The stone tool technologies prevalent in pre-Hispanic Mesoamerica varied over both time and space. This discussion has provided a brief overview of the early flake and biface technologies, and a description of the blade and biface technologies prevalent from the time of Christ until the Spanish conquest in the early sixteenth century. The Mesoamerican blade technology was the most important, enabling the production of prismatic blades that were further shaped into different types of tools. Overall, flaked stone tool production in Mesoamerica provided a remarkable variety of highly functional implements used *for a variety of activities*.

Stone Tools in Mesoamerica: Flaked Stone Tools. Fig 12 Turtleback maguey scraper from the Aztec period Teotihuacan Valley. Photo by Susan Evans. Used with her permission.

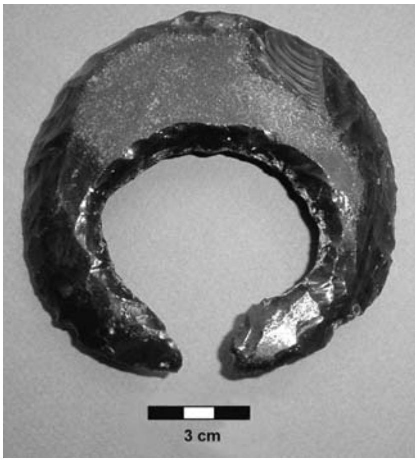


Stone Tools in Mesoamerica: Flaked Stone Tools. Fig 13 Large biface projectile points from the site of Xochicalco. Illustration by Luis Gonzalo Gaviño. Property of the author.

Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 14 Anthropomorphic figurine from Teotihuacan. Photo from the Proyecto Pirámide de la Luna. Used with the permission of Saburo Sugiyama.



Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 15 Eccentric from an offering found in the Moon Pyramid at Teotihuacan. This artifact combines projectile point, serpent, and trilobal blood droplet elements in its design. Illustration by David M. Carballo. Used with his permission.



Stone Tools in Mesoamerica: Flaked Stone Tools. Fig. 16 Crescent eccentric from Xochicalco. Photo by author.

Acknowledgements

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Extra: Obsidian in Mesoamerica

Obsidian is an igneous stone that is often described as “volcanic glass” (Whittaker 1994: 69). This siliceous material is created by the extremely rapid cooling of volcanic ejecta, a process that prevents the formation of any crystalline structure (Cobean 2002: 23). Obsidian is very smooth and glassy to rough or grainy in texture, and is usually black to gray in color, but it also can be red, brown, green, silver, and aquamarine. This variation in color is the result of chemical impurities. Obsidian occurs in block or tabular form in large veins, or as isolated chunks and cobbles in flows of volcanic material. It can also be found on talus slopes or alluvial streambeds in a “weathered” cobble form. Having eroded out of primary geologic context, the weathered cobble surface exhibits tiny cones or fracture planes that are produced by rolling action. Obsidian is easy to work with because of its noncrystalline structure and it produces an extremely sharp cutting edge. One disadvantage of obsidian is that it is brittle, so that tools and tool edges can break more easily than other flakeable stone like cherts and flints.

Throughout most of Mesoamerica obsidian was the primary raw material used to make flaked stone tools. In the region, obsidian flows are found in two major zones of geologically recent volcanism (Glascock et al. 1988). One major zone is an east–west trending band of sources scattered from the state of Veracruz on the Gulf of Mexico to the western state of Michoacán bordering the Pacific Ocean; well-known sources in this zone include Pico de Orizaba, Sierra de las Navajas (Pachuca), Otumba, Zacualtipan, Ucareo, Zinapecuaro, and La Mora/Teuchitlan (Fig. 1). The southern zone is located in Guatemala, El Salvador, and western Honduras; well-known sources in this zone include Jilotepeque, El Chayel, Ixtapeque, and Esperanza (Fig. 1).

Studies of obsidian artifacts from archaeological sites using techniques such as instrumental neutron activation analysis (INAA), X-ray fluorescence (XRF), and more recently, laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) have revealed that large quantities of these materials were transported across the landscape. By tracing the distribution of different sources archaeologists have been able to reconstruct routes of obsidian trade and transport and how they changed over time (Asaro et al. 1978; Boksenbaum et al. 1987; Braswell and Glascock 1998; Cobean et al. 1991; Glascock et al. 1991, 1994; Moholy-Nagy 2003; Nelson 1985).

Extra: Origins of the Mesoamerican Blade Technology

Hirth and Flenniken (2002: 123) have rightly pointed out that research on the origins of the Mesoamerican blade technology has been limited. Emerging *en force* during the Middle Preclassic (900–300 BCE), by 700 BCE prismatic blades had become the primary flaked stone tool from the Central Highlands to the Chalchuapa area of El Salvador (Aoyama 1994: 174; Clark and Lee Jr. 1984; Coe and Diehl 1980: 247–249; Grove 1974: 33, 48; Hirth and Flenniken 2002: 123; Marcus and Flannery 1996; Pires-Ferreira 1975: Table 5; Sheets 1978b: Tables 3 and 5; Sweeney 1983: 619).

Two researchers that have addressed the emergence of the Mesoamerican blade technology are Parry (1994) and Clark (1987). Their views are somewhat complementary, but they emphasize different factors. Parry (1994) suggests that the principal motivating factor may have been a demand for the production and exchange of many uniform, standardized implements. A blade technology enables such outputs, but a relatively high level of skill is required to make large batches of standardized blades efficiently. Hence, an increasing demand for blades during the Middle Preclassic created a need for blade-making craftsmen. These specialists supported themselves, at least in part, by exchanging blades at the regional and perhaps interregional level. Parry (1994: 94) further notes that many blade workshops are found in large settlements with monumental architecture, sometimes quite distant from obsidian sources. He tentatively states that this evidence may indicate that early craftsmen were attached, or sponsored by the ruling elites in these settlements.

Clark (1987) suggests that the widespread adoption of the Mesoamerican blade technology was related to the competitive elite behavior associated with ranked or chiefdom societies. These societies differed from the Archaic foraging groups (7200–2500 BCE) in that people lived in larger sedentary communities that were socially hierarchical (Webster et al. 1993). Clark (1987) maintains that there was no real technological advantage to a blade technology because the expedient flake tools made during the Archaic period were functionally adequate. Moreover, the Mesoamerican blade technology required specialized training because it was difficult to learn. It also required the organization of core production at the source and the transport of cores to the settlements where they were reduced. Consequently, Clark (1987) suggests that the adoption of this technology was complex enough to necessitate the sponsorship of the elites who ruled the early Mesoamerican chiefdom societies (Clark 1987: 274). Accordingly, these elites financed and organized the acquisition and production of cores and their distribution to blade-making craftsmen in large settlements.

Many researchers have debated various reasons why blade technologies arose at different times and places throughout the world. The Parry (1994) and Clark (1987) models for the emergence of Mesoamerican blade technology cannot be used to explain the adoption of blade technologies in societies that were less complex than chiefdoms (Hirth and Flenniken 2002). Worldwide examples include the Paleolithic and Neolithic blade technologies of Europe, Asia, and North Africa (Inizan and Lechevallier 1990; Pelegrin 1997; Tixier 1976), the Paleolithic microblade technologies of Siberia and Japan (Flenniken 1988; Kobayashi 1970), and the microblade technologies of North America (Andrefsky 1987; Arnold 1985; Bradley and Yevgeny 1996; Magne 2004; Morrow 1988; Parry 1994; Rasic and Andrefsky 2001; Reid 1976; Yesner and Pearson 2002). These societies ranged from highly mobile to relatively settled groups who probably never attained the level of social complexity typically associated with chiefdoms.

The adoption of blade tools in northwestern North America may relate to functional aspects of the technology (Yesner and Pearson 2002). This argument recently summarized by Magne (2004: 94) states that microblades were a "response to any of several possible causes, such as lithic raw material shortage alleviated by efficient blade production, preference for composite slotted armaments, or resource uses for which microblade design is most efficient, such as slicing, peeling, piercing..." It has also been suggested that blade technologies may be best suited to societies where the tasks involved in food acquisition or production (subsistence tasks) were predictable (Rasic and Andrefsky 2001: 77). Here the manufacture of standardized blade "replacement" parts for tools repeatedly used for the same tasks would be technologically efficient.

The development of craft specialization and exchange (Parry 1994), and the competitive elite behavior associated with emerging chiefdom societies (Clark 1987) indeed may have played a role in the emergence of the Mesoamerican blade technology. The functional argument that blades are better for economies with predictable subsistence tasks also deserves consideration. The Mesoamerican Preclassic period (2500 BCE–AD 300) was associated with a profound shift from small-scale foraging societies to larger settled chiefdom societies. Hence, compared to the nomadic foraging lifestyle of the Archaic period, the daily tasks associated with settled agricultural economies during the Preclassic were certainly more predictable because they were tied to the strict seasonal cultivation of specific crops. Moreover, the patchy distribution of obsidian across the landscape would have made a blade technology more effective for supplying the needs of large settlements with tools from distant sources. Craft specialists producing highly standardized blades for specific tasks would have been able to efficiently supply the needs of people in very large settlements.

Extra: Measuring the Skill of Ancient Blade-Making Craftsmen

In ancient Mesoamerica obsidian blades were made by specialized craftsmen. Some researchers have recently begun to focus on measuring the skill of these craftsmen as a means for identifying how much time they devoted to blade-making activities (Andrews 2003; Clark 2003; Clark and Bryant 1997; Hirth and Andrews 2005). Defining the time spent making blades is important because it helps archaeologists infer how many blades were in demand and how much economic exchange there was between members of an ancient society. This kind of information reflects the complexity of a society's economy. Unlike the modern world where everyone specializes in a particular job, most prehistoric societies were primarily composed of people who provisioned themselves with all their daily needs. As societies became larger people began to specialize in different occupations and exchanged their products for things they did not produce. Hence, the level of specialization in a society is a measure of economic inter-dependency.

Measuring craftsman skill is founded on the assumption that aptitude should vary according to the amount of time invested in blade production (Clark 2003); in other words, highly skilled craftsmen should be those who made the most blades. Essentially, this assumption is based on the premise of "practice makes perfect" (Clark 2003).

So, how does one go about measuring the skill of ancient blade-making craftsmen in Mesoamerica? The one advantage to studying flaked stone artifacts is that they are made with a reductive technology. That is, flaked stone tools are shaped by reducing, or removing pieces of stone from a larger stone until the desired form is achieved. The pieces that are removed are called byproducts. Careful study of the byproducts of Mesoamerican blade production has made it possible to identify those artifacts that are mistakes, items that represent one means for measuring craftsman skill.

Mesoamerican blade craftsmen usually made blades in household workshops (Clark 1997; Healan 1986; Hirth 1995, 2002; Spence 1981, 1986, 1987). Several artifacts found at these workshops have been identified as mistakes; these items include the hinge-fractured blade and the plunging blade. A hinge-fractured blade is a blade that failed to extend all the way to the bottom of a core (Andrews 2003). The distal end of a hinged blade has a fracture plane that curves outward from its ventral to dorsal surface (Note No. 3, Fig. 17a) . These artifacts are mistakes because the craftsman's intent was to remove a blade that extended the entire length of the core. Also, hinged blades leave behind a deep scar that inhibits the removal of subsequent blades from that part of the core (Note No. 3, Fig. 17b).

A plunging blade removes the distal tip of core (Andrews 2003). In contrast to the hinge fracture, a plunging blade's ventral surface curves inward at the bottom of the core thereby removing more core length than intended (Note No. 3, Fig. 17c) (Clark and Bryant 1997: 123; Crabtree 1972). This mishap reduces the length of subsequent blades, thereby reducing the overall amount of cutting edge that can be produced from a core. The forces resulting in the production of these mistakes are described in detail elsewhere (Andrews 1999, 2003; Clark and Bryant 1997; Santley et al. 1986; Sheets 1978b).

It has been suggested that the frequency of mistakes in a collection of byproducts should be useful for measuring the skill of flaked stone tool craftsmen (Clark 1986, 2003; Sheets 1975, 1978b; Torrence 1986: 147). Consequently, comparisons of hinged and plunging blade frequencies from Mesoamerican blade workshops have been used to make comparative assessments of skill (Andrews 1999; Clark 1997; Hirth and Andrews 2005). Workshops with the highest level of skill have the fewest errors.

Preliminary assessments of craftsman skill at the immense Classic period (AD 100–650) city of Teotihuacan and the smaller Epiclassic (AD 650–900) city of Xochicalco indicate that Teotihuacan's craftsmen made fewer mistakes (Andrews 1999). Hence, based on the assumption that skill varied in relation to time spent in production, it appears that Teotihuacan's craftsmen made and exchanged more blades than the craftsmen at Xochicalco. This finding fits previous characterizations of Teotihuacan's economy as being highly complex (Millon 1973; Spence 1981), with many specialists throughout the city dependent to a significant degree on nonagricultural production for their livelihoods. In contrast, Xochicalco's economy appears to have been less complex, with more limited evidence of craft production and economic interdependence (Hirth 2000). In this way, measuring the skill of flaked stone tool producers has contributed to supporting earlier inferences about economic complexity.

Extra: The Pecked and Ground Core Platform

Another source of variation in the Mesoamerican blade technology was core platform treatment. Sometimes single facet platforms were pecked and ground, creating a flatter, slightly rough surface. This type of platform became widespread during the Postclassic (AD 900–1519) period (Garcia Cook 1967; Healan 1986: 141; MacNeish 1967; Tolstoy 1971), but it emerged in the preceding Epiclassic (AD 650–900) period (Hirth et al. 2003), and perhaps was present even earlier in some areas of Mesoamerica (Santley et al. 1995: 46; Sheets 1983: 216). The pecking and grinding of platforms took place during different phases of the reduction sequence throughout the region. For example, at Tula (Fig. 1), the capital of the Toltec empire, platforms were pecked and ground at the macrocore stage (Healan 1986: 141), whereas at Xochicalco, an Epiclassic (AD 650–900) city, they were pecked and ground on small, already partially reduced prismatic cores (Flenniken and Hirth 2003).

Experimental research suggests that this process involved initially flaking a platform as flat as possible with percussion and pressure techniques (Flenniken and Hirth 2003). Flattening the platform surface was important to minimize subsequent grinding expenditures. After flattening the platform, it was probably pecked with a flake of siliceous material such as chert or quartzite. Evidence suggests that this process could be efficiently accomplished by inverting the core in one hand and then striking it against a flake resting on an anvil stone (Flenniken and Hirth 2003: 104). Pecking produces hundreds of tiny fracture cones across the platform surface. When a platform was pecked sufficiently flat, it was then ground in a circular motion on a large, slightly concave grinding stone. The chert shatter produced during pecking efforts would have provided an efficient grinding substrate; experiments indicate that adding water to the substrate produced a very effective grinding paste (Flenniken and Hirth 2003). Other materials such as volcanic ash or quartz sand also may have been used as grinding substrate.

The pecked and ground platform modification made blade removal easier for two reasons. First, the tiny fracture cones produced during the pecking stage made blade removals easier (Flenniken and Hirth 2003). Experiments indicate that less pressure force is needed because the tiny microfractures help to facilitate a macrofracture, permitting successful blade removal. This outcome of the process was extremely important, especially at sites like Epiclassic (AD 650–900) Xochicalco where blades were detached by hand from very small (>8 cm in length) prismatic cores (Flenniken and Hirth 2003). Experiments have demonstrated that it is difficult to generate enough force with the hand-held technique to produce successful blades using cores longer than 8 cm in length. Second, the pecked and ground surface reduced the risk that the pressure tool used to remove blades would slip off the platform. This outcome aided the craftsman in the precise application of force.

Extra: The Bow and Arrow in Prehistoric Mesoamerica

The date when the bow and arrow became prevalent in prehistoric Mesoamerica is still a subject of debate. The established date for the introduction of the bow in North America is sometime around AD 200 (Holmer 1986), much earlier than what is generally accepted for Mesoamerica. Citing a lack of archaeological and iconographic evidence for the bow, Hassig (1992) has suggested that it did not become common in Mesoamerica until the Postclassic (AD 900–1519) period. Other researchers, however, have suggested that the bow was present during the Classic (AD 300–900) period (Linné 1934) or perhaps even earlier during the Preclassic (2500 BCE–AD 300) period (Tolstoy 1971).

One reason for believing the bow was common in Mesoamerica prior to the Postclassic period is the presence of small projectile points (>3 cm in length, Fig. 10b) at many sites predating AD 900. Many of them were fashioned out of prismatic blade sections that were made with pressure. The use of these implements as effective tips for spears or *atlatls* (spear throwers) is hard to imagine because they are so small. Indeed, research indicates that many *atlatl* points average over 4.5 cm in length (Thomas 1978: 469). As a result, it has been suggested that small points found in mortuary offerings at Classic period Teotihuacan may have had a ceremonial or ideological significance (Parry 2002).

Although small points predating the Postclassic period may have had a ceremonial function, recent research at the Epiclassic (AD 650–900) city of Xochicalco suggests that such items were used to tip arrows (Andrews and Hirth 2005). This conclusion supports earlier claims that the bow was present at Epiclassic Xochicalco (Sáenz 1961: 40–43, 1967: 10, 14) and at the contemporary site of Cacaxtla (Fig. 1) in the modern state of Tlaxcala (Baus de Czitrom 1986: 529). Most of the small points at Xochicalco have been found throughout the city in nonceremonial contexts. In addition, they comprise the entire collection of projectile points ($N = 83$) recovered in the city's public armory (Andrews and Hirth 2005). Hence, there is little doubt that these points were used to tip arrows, and given the central importance of militarism and conquest at Xochicalco (Garza Tarazona and González Crespo 1995; Hirth 1989, 2000), they were probably used for combat.

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String and Stories

David Turnbull

Elizabeth Barber in her classic *Women's Work: The First 20,000 Years* made the revolutionary observation:

> We don't know how early to date this great discovery – of making string as long and as strong as needed by twisting short filaments together… Soft flexible thread of this sort is a necessary prerequisite to making woven cloth. On a far more basic level, string can be used simply to tie things up – to catch, to hold, to carry. From these notions come snares and fishlines, tethers and leashes, carrying nets, handles, and packages, not to mention a way of binding objects together to form more complex tools… So powerful, in fact, is simple string in taming the world to human will and ingenuity that I suspect it to be the unseen weapon that allowed the human race to conquer the earth, that enabled us to move out into every econiche on the globe during the Upper Palaeolithic. We could call it the String Revolution (1994: 45).

Barber's insight – that the capacity to join things together through lashing, binding and knotting, with string or cordage is what enabled people to move – is of profound importance. It cannot, however, have occurred in isolation from two other essential capacities: movement and communication. How and why human movement is accomplished is central to our understandings of the growth and transmission of culture and civilisation and is thoroughly social and embodied. Movements are always performed by groups of people through the actions of their own bodies and are coordinated and motivated through ritual, music, dance and stories. Movements through the landscape also create trails both cognitive and material. 'We know *as* we go' (Ingold 2000: 230). Historically stories, string and trails were very likely co-produced with one another; they certainly inform each other mythopoetically through the fundamental commonality of narrative, journeying and weaving. Weaving and story telling reflect a common origin in the derivation of text and textile from the Latin verb *texere* to weave. Knowledge and stories are complexly intertwined with traveling, movement and journeys, as is reflected in the original Greek etymology of such terms as

- Symbol (to move or throw things together);
- Metaphor (to transport across space);
- Theory (from *theoros*, someone who travels to see things);
- Travel (from travail, to work);
- Episteme (putting oneself in a good position); and
- Method (from *hodos*, a traveling way).

What weaving, stories, and string share is the complex duality of tension and connection, difference and similarity. Stories join ideas, string joins things together and both are dependent on tension. String and cordage derive their connective capacity from tension in knots, binding, or twining. Weaving depends on the tension between the warp and the weft.

Stories and narrative have an essential tension or irony that comes from the listener's implicit double recognition that the coherence, the order we impose on the world, lies in linking things together, whilst also recognising that entirely contradictory orderings and associations are equally possible, and that in relating one narrative in terms of another stories are told and understood against the background tradition of other stories. Stories are a way of dealing with the ontological multiplicity or 'bothness' of life, the tensions and incommensurabilities between the contingent and the ordered, between the anomalous and the classified, between differing subjectivities, spatialities and temporalities, between the personal and the theoretical, the concrete and the abstract, the essential contradictions and the inexpressibility of human existence (Pelton 1980: 258). The trickster myth, that is common to so many cultures, reveals the multiplicities and tensions in the way the human world is storied and performed through language. In Norse mythology, for example, the links are apparent in the role of Loki the trickster god of mischief and destruction who also taught mankind the art of netting (Turner and van de Griend 1996). In Greek myth it was Athena the goddess of many things but especially love, procreation, wisdom, civilisation, strategy and weaving (Barber 1994: 241).

Barber's insight that string, an almost invisible and seemingly trivial soft technology, gave us the capacity to move, requires a radical rethinking of the stories we tell ourselves about the origins and nature of human civilisation and existence. Archaeology has, until now, celebrated early cultural development as basically lithic (related to stone) and technological, a process based in utilitarian stone tools and weapons, giving us a rather androcentric (centred or focused on males) picture of early man conquering the world with stone axes. Focusing on string brings into prominence the catching of small birds, animals and fish through netting. It emphasises the capacity for movement of humans by land and by sea. Most importantly it brings into visibility the early development of non-utilitarian ornamentation and symbolisation. These capacities for enabling symbolic expression, mobility, and relatively low key methods of hunting and tracking give a very different perspective on the early development of technology and culture. But, there are profoundly differing views about whether all this constituted a 'revolution' occurring in the Palaeolithic period around 26,000 BP as Barber believed, or whether they occurred considerably earlier and more incrementally. If so string was not a human innovation but a hominid one.

Two key areas in which the early uses of string are evident is in very ancient shell beads and in new datings of the earliest movements by sea. Recent discoveries of clusters of beads and pendants with drilled holes reveal the necessity of the almost invisible technology of the string, thread, cord or fibre to suspend them. At the same time they suggest the development of a capacity for reflection and symbolisation, for abstraction and communication. Such capacities are normally taken to be prototypically human, but there are some archaeologists who date ostrich shell beads in Africa as far back as 200,000 years ago (Bednarik 1997a–c). Recent finds, at Blombos in South Africa, of pierced shell beads showing signs of wear by threads or clothing are dated at around 75,000 years ago, and maybe as old as 280,000 (Douglas 2004: 26). Dating disputes will always permeate archaeology, but it is clear that Neanderthals made necklaces implying symbolisation and least proto-language (Arsuaga 2002). The other and most important development was travelling by boat across open sea passages. Australian Aborigines were perhaps the world's first sailors, arriving in Australia across an ocean gap of around 50 km at least 60,000 years ago. Water transport over this breadth of deep water would require string of some sort in the form of lashing and knots to tie together what was most probably a bamboo raft (Jones 1989; Thorne and Raymond 1989: 39ff).

The earliest direct evidence we have currently for string as twisted plant or animal fibre and hence as the basic component of clothing or textiles is 26,000 BP and there are figurines wearing string skirts which are dated around 20,000 BP. The use of twisted cords for weaving on looms has developed from the earliest times in cultures around the world from the Andes to China (Adovasio and Hyland 2000), as has the use of knots for mnemonics and decoration and the celebration of string in games and stories. Perhaps the most highly elaborated use of string was in the *quipu* of the Inca. Gary Urton's research suggests that these knotted strings were examples of how something as simple as string is capable of generating a hugely complex system of signification, codification and narrative (Urton 2003; Quilter and Urton 2002; Salomon 2004). Similarly Weiner (2001: 236) suggests that the *kirugu*, the sacred knotted cord of the Iatmul of the Sepik in Papua New Guinea maps out the stories of their migrations.

String, stories and trails, in their complex interactions and their multiple embodied skills and practices, may be the earliest of technologies and may well have been developed by our hominid ancestors, all of which should give us pause in our contemporary story tellings that locate our cultural origins in developments of stone technologies around 35,000–40,000 BP. Our cultural origins now look much less gendered, much less based in the technology of killing large animals, much less Eurocentric, and much less special to humans. We and our ancestors created trails, travelled by water, joined ideas and things together making ourselves and our world.

See also: ►Beads, ►Fishing Quipu

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Suanxue Qimeng

Karine Chemla

The *Suanxue qimeng* (*Introduction to Mathematical Studies*), the first book composed by Zhu Shijie, a Chinese mathematician of the Yuan dynasty, was published in 1299 (Du 1966; Ho 1970–80). It differs from his second one, the *Siyuan yujian* (1303), in that its mathematical content presents a stronger continuity with the Chinese mathematical tradition. Most of the topics treated in it can be traced back to the Han classic which founded this tradition, the *Jiuzhang suanshu* (*The Nine Chapters on Mathematical Procedures*, hereafter called The Nine Chapters), probably completed between the first century BCE and the first century AD. Indeed, Zhu Shijie deals there with the rule of three, the distribution into unequal parts, and their composition or reiteration along the lines opened by the sixth of *The Nine Chapters*. He also describes how to perform the same computations with fractions and presents algorithms to obtain areas and volumes, even though he considers some forms not found in *The Nine Chapters*. The rule of excess and deficit, which was transmitted to the West where it became known as the rule of false double position, receives in his *Suanxue qimeng* a presentation as complete as in *The Nine Chapters*, even though it had been partially forgotten and sometimes transmitted in an imperfect state during the time elapsed since the composition of the latter (Chemla 1997). Moreover, Zhu Shijie devotes a chapter to an improved presentation of the algorithm for the solution of systems of simultaneous equations given by *The Nine Chapters* and comparable to the so-called *Gaussian pivot method* (Chemla 1992, 1996).

In addition to this, the *Suanxue qimeng* includes the treatment of topics that had emerged in the previous decades in Northern China, Zhu Shijie's homeland, such as the "procedure of the celestial unknown", a technique that puts into play polynomial algebra to obtain an equation to solve a given problem (Du 1966).

Yet, in contrast to *The Nine Chapters*, Zhu Shijie, in a first part of the book, makes clear which algorithms can be used to perform the basic arithmetical computations on the counting surface and includes new procedures for such computations when particular numbers are involved. It is interesting that some of the procedures he described could be used later without change when the abacus replaced the counting surface. In this respect as in others, such as the treatment of topics like the summation of all kinds of series, the inclusion of tables of unit conversion, a style of practicing mathematics in close contact with the problems of socio-economic life, or the use of certain new technical terms, the *Suanxue qimeng* repeatedly evokes the writings of Yang Hui, a mathematician who had lived slightly earlier in Southern China (Lam 1979). Indeed, in contrast to the period before the unification of China under Mongol rule, when mathematics seems to have developed independently in the north and the south of China, the time of unification when Zhu Shijie worked might have allowed the partial merging of these two traditions; his book may be our first reflection of this (Du 1966).

See also: ►Computation: Chinese Counting Rods
►Liu Hui and the *Jiuzhang suanshu*

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Sugar in Latin America

JUDITH VIDAL

The sucrose from sugar cane is identical to that in beet sugar and other sugars such as glucose, dextrose, fructose, levulose, and lactose. The chemical formula for sucrose is the oligosaccharide $C_{12}H_{22}O_{11}$. After refining, sugar is 99.9% pure.

Sugar cane was first cultivated and processed in India thousands of years ago. Gradually, medieval trade routes brought the product and its cultivation to the Mediterranean basin and Madeira where it languished on a small scale until its introduction to the Caribbean and Brazil. Columbus took it to Hispaniola on his second voyage in 1493. Cortés took it to New Spain, Balboa to Central America, and Pizarro to Peru. It was in Brazil, however, that the efforts of Duarte Coelho Pereira converted his captaincy of Pernambuco into a prosperous sugar-producing center fashioned after the *engenhos* (sugar works) of Madeira from whence the first cuttings and processing technology came. This became the model for an industry so vital to Portugal they courted Dutch capital to finance the African slave trade to supply the necessary labor. In exchange, the Lowlands received the crude sugar for refining and distribution. So profitable was this arrangement that the Portuguese eventually abandoned their enterprises in the Far East for the Brazilian milk cow, as Emperor João III fondly referred to the flourishing colonial sugar industry.

Aside from the introduction of large-scale cultivation and processing, the techniques of sugar production changed little since the early days of Venetian and Dutch refining and trading monopolies. Cultivation was usually from small cuttings or rattoons planted in evenly spaced furrows and allowed to mature for periods from 6 to 18 months – depending on the type of cane, the time and amount of rainfall or irrigation, temperature, storms, quality of soil, disease, and pests.

Plantation owners and managers were constantly alert for crop dangers and began to employ technicians to advise them. They experimented with irrigation systems, tested new strains of cane from both seed and rattoon, and tried crop rotation. Harvest had to follow immediately upon maturation. Normally this was by hand-held machetes wielded by slave laborers. Sometimes they used slash-and-burn techniques.

Harvesting was simultaneously accompanied by manually loading the syrup-filled stalks into mule-drawn carts for transport to the sugar houses. The cane was then handfed through the vertical or horizontal cylindrical presses which were originally adapted from wooden olive presses. These were two- or three-roller, metai-clad, devices with gears powered by humans or animals (*trapiches*) or water (*engenhos*). The extracted syrup flowed through wooden troughs or, in some cases where capital and topography permitted, through Roman-style aqueducts to the boiling sheds. Large *engenhos* comprised thousands of acres with thousands of residents in self-sufficient hacienda communities. More modest enterprises relied on hand-carrying the crude syrup to nearby pots for boiling.

Early production systems were ecologically complete, for the crushed stalks (or bagasse) were dried and used as fuel to fire the boiling vats. The ashes and extraneous leaves and stalks were tilled back into the soil as fertilizer and also served as animal fodder. Slaves found that unprocessed molasses from pieces of stalk that were not disposed of quickly underwent inversion and began fermentation; this primitive rum was used as currency to reward slaves and keep them cooperative but was not recognized as a commercial product for export.

Until the nineteenth century, the juice from the raw cane went through a series of open-pot boilings at extremely high temperatures. This process was watched very carefully to avoid fire and to avert burning the sugar. Slaves ladled off the scum of debris which flocculated with animal grease at the top; other impurities settled to the bottom in sedimentation. Lime was then added to help clarify the syrup. This purification, also known as defecation, removed the maximum number of impurities. The clear syrup was then placed in evaporating pans. The sludge of megasse sugar was next scooped into hanging clay cones with open bottoms to allow the heavy brown molasses to drip out. The resulting crude sugar was about 96% pure and fit for transport in casks or in loaves.

Shipped to European ports, crude sugar was sometimes sold directly, but most was transshipped and refined by a process of reheating in huge vats to which water and bone carbon filters were added. After a series of washings, the clear liquid was evaporated in copper pans and allowed to crystallize or granulate – the finer the quality, the whiter the crystal. As with the processing of raw sugar, refining would remain unmodified until the nineteenth century introduced steam vacuums and centrifuges to the finishing processes.

Throughout the colonial period, every finishing process was done by the mother country or its agents, usually in the Lowlands. Therefore, refining always occurred in Europe. The most efficient refineries were scattered around Antwerp which remained the capital for finishing sugar until war razed the production centers and blockaded trade. Britain, France, and Germany then built their own refineries. Long before Britain took possession of sugar-producing lands, England monopolized refining and distribution industries. This availability of mass production coupled with a growing popular taste for sweetened coffee and bread with treacle (molasses) provided an amenable consumer base for the confection in England and on the continent which demanded the colonial product.

Having pirated the rattoons and seeds of Brazilian and Spanish haciendas, European powers sought to monopolize refining and trade. In 1662 Catherine of Braganza married Charles II of England; her dowry included former East Indian territories such as Bombay and Tangiers and also a taste for tea which swept the court with exceeding popularity and would eventually displace both coffee and cocoa as England's hot, sweetened beverage of choice.

The Caribbean was an entrepôt of plantation islands. England, Spain, Portugal, France, and Holland all engaged in slave trade with Africa, and all quickly learned the commercial value not only of sugar but also of its intermediary byproducts, molasses and rum. After the molasses dripped off the crude muscovado sugar, the syrup was fermented and distilled into rum on the islands as early as 1530 and used as currency to purchase African slaves. Molasses was shipped directly to North American ports where New England distilleries enjoyed a burgeoning business. From the time of the capture of Jamaica in 1655, rum was regularly issued to British sailors, for it lasted longer than the traditional ale on high seas at certain temperatures. In 1754 it was watered down to grog and freely rationed until the 1960s. The sugar interest monopolized parliament and led to colonial uprisings which reshaped the empire.

Britain and its competitors consolidated their territories and introduced technological advances. As early as 1794, steam was used to power a three-roller press in Jamaica. A similar steam-driven mill operated in Cuba in 1797 – 10 years before the first successful steamboat. These machines were neither uniformly nor extensively adopted and operated imperfectly. Early fixed iron rollers often clogged or broke when the woody stalks of older cane were fed through the press. Shutdowns were costly, for the syrup in cane spoiled if not processed within 3 days of harvest. Mechanical repairs and waiting for replacement parts also impeded production.

The vacuum pan was invented by Edward Charles Howard in England in 1813, but it was not introduced to the colonies until 1835. This pan admitted steam through holes in the pan's bottom which was lined by a filtering cloth and capped by a dome connected to an air pump with a condenser. Interior heating coils were added by Daniel Wilson, and in 1828 Louisiana planter Valcour Aime implemented these improvements in his sugar houses and also introduced the use of the polarimeter to value raw sugars in cane. Despite patent disputes a system of multiple evaporation in six to ten successive pans was widely adopted and diversely adapted throughout the world. Penzoldt's centrifugal machine invented in Germany in 1837 for drying wool was modified for sugar by Sir Henry Bessemer. Cane-processing technology was adapted for beet sugar. In London the Fairrie family experimented with decolorizing agents for their refinery and discovered animal charcoal.

With the mechanization of sugar in the latter nineteenth century came the professionalization of technical advisors and managers. Technical assistants had to know how to assemble equipment correctly, keep it in good repair, and operate it. Agricultural experts were consulted to identify the best strains of cane for a particular climate or soil. Hawaiian planters of the 1850s maintained an experimental station which offered soil analyses, pathology reports, and pest controls. Entomological research at the British Museum identified natural predators and prescribed counter parasites.

The first mechanized harvests were successful in Australia. In the 1960s, Cuba contracted with Soviet engineers to develop a combine harvester. The self-propelled model ruined the rattoons and the ground for several seasons. Eventually the Cubans developed a harvester but technical problems diverted its production to Australia in 1984.

The sucrochemical industry experimented with research and development. Cane sucrose sales were eroded by beet sugar, high fructose corn sweeteners (HFCS) in processed foods, and synthetic sweeteners. New applications included gasohol, furniture, paper, and plastics. Brazil was the only successful producer of commercial gasohol although Australia and the US successfully converted their sugar industries to gasohol production during World War II.

The original sugar-producing countries of Latin America and the Caribbean still produce their crops of precious cane, but unstable governments, lack of capital, natural disaster, and inefficient management hinder technological growth.

See also: ►Crops

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Śulbasūtras

K. V. Sarma

The *Śulbasūtras* are manuals in India which prescribe the construction of different types of fire altars. Every householder was instructed, by the Vedic religion, to maintain a sacred fire, primarily for daily worship and offerings. These fires, called *gārhapatya* (domestic), *dakṣiṇa* (southern), and *āhavanīya* (oblatory), were to be maintained, without their ever going out, in altars of different designs, such as circular, semicircular, square, rectangular, and triangular. Seasonal and special worships required altars with elaborate designs like that of an eagle with outstretched wings. The size, shape, direction, position, and the number and measure of the bricks used, and also the increase in the measure, for extraneous reasons, were all specified in the *Śulbasūtras*. These traditional practices are referred to in the *Ṛgveda*, the earliest of the Vedas, and elaborated in the *Yajurveda*. Later they came to be written down as manuals, supplementing the regular texts depicting sacrifices, and also in independent texts called *Śulbasūtras*. Adherents of different Vedas and Vedic schools had different *śulba* texts, named after the authors of these texts and pertaining to the Veda which they advocated. This is how the *śulba* texts named after Āpastamba, Bodhāyana, Kātyāyana, Mānava, Maitrāyaṇa, Varāha, Hiraṇyakeśin, Satyāṣaḍha, Vādhūla, and Laugākṣi, pertaining to one or the other of the schools of the *Yajurveda*, and *Maśaka Śulbasūtra* pertaining to the *Sāmaveda* came into being.

The *Śulbasūtras*, meaning pithy aphoristic statements (*sūtra*) for work with string (*śulba*), prescribes, by means of addition, subtraction, multiplication, division, and squaring, simple rules not only for the construction of circles, squares, rectangles, triangles, wheel-shapes, trapezia, and rhombi, but also for extending these figures by specific proportions as required in different sacrifices. It also specifies methods to reduce a circle to a square of equal area, and vice versa. A fine approximation of the value of the $\sqrt{2}$ is contained in the rule given in the *Baudhāyana-Śulbasūtra*: "Increase the measure of the side (of a square) by its third part, and the third part by its fourth part. The fourth part is decreased by its own thirty-fourth part. (The approximate diagonal will result.)" The rule gives the approximation:

$$\sqrt{2} = 1 + \frac{1}{3} + \frac{1}{3 \times 4} - \frac{1}{3 \times 34},$$

i.e., 577/408, i.e., 1.4142157, which is very approximate to the correct value of the $\sqrt{2}$.

The *Śulbasūtras* specify or give geometrical constructions for the following (1) to draw a straight line at a right angle to a given line, (2) to construct a square on a given side, (3) to construct a rectangle of given sides, (4) to construct an isosceles trapezium of given base, top, and altitude, (5) to construct a square equal to the sum of two squares, (6) to construct a square equal to the difference of two squares, (7) to construct a square equal to a given rectangle, (8) to construct a rectangle with a given side and equal in area to a given square, (9) to construct a square equal in area to a given isosceles triangle, (10) to construct a square equal in area to a rhombus, (11) to construct a square equal in area to a given circle, and (12) to construct a circle equal in area to a given square.

It would seem that the sacrificial hall of the Vedic Indians formed, as it were, the workshop and laboratory to formulate and develop their geometry.

See also: ►Geometry in India, ►Baudhāyana

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Sun Simo

Fabrizio Pregadio

The Chinese physician and medical author Sun Simo (alternative spelling: Sun Simiao) was a native of Huayan, in modern Shensi. His biography is so much a composite of fact and legend that it is even impossible either to substantiate or invalidate his traditional dates (581–682). From official, autobiographical, and hagiographic sources it emerges that he retired at an early age on Mount Taibai, not far from his birthplace. He repeatedly declined imperial summonses and official titles, but was almost certainly in Emperor Gaozong's retinue from 659 to 674, when he retired on account of illness. He seems to have spent an extended period in Sichuan, which may explain why many legends that concern him are located in that area. After his death he was venerated as *Yaowang* or "King of Medicine" (by which he is still known) in temples dedicated to him.

Sun Simo is the author of two of the most important Chinese medical compilations, the *Qianjin fang* (Prescriptions Worth a Thousand or, Remedies Worth their Weight in Gold), also known as *Beiji qianjing yaofang* (Important Prescriptions Worth a Thousand, for Urgent Need), and the *Qianjin yifang* (Revised Prescriptions Worth a Thousand). The former, in 30 chapters, was completed soon after the middle of the seventh century (apparently in 652). The latter, also in 30 chapters, dates from the late seventh century. Both works are preserved in editions derived from versions published in the eleventh century, when they were edited to be used as textbooks in the Imperial Academy of Medicine. In these texts, Sun provides an extended compendium of contemporary medical knowledge, arranged in sections dealing with such subjects as pharmacology, etiology, gynecology, pediatrics, dietetics, acupuncture, moxibustion, and specific diseases. Both texts include a wide selection of prescriptions (about 5300 in the *Yaofang*, about 2000 in the *Yifang*).

Among the many points of interest in these compilations, three deserve special mention. The first is the priority that Sun Simo accords to gynecology and pediatrics, the two branches of medicine with which he deals first in both works. The second is the importance given to medical ethics, reflected in this well known passage from the first chapter of the *Qianjin yaofang*: "When someone comes to look for help, a doctor should not question rank or wealth, age or beauty, nor should he have personal feelings toward that person, his race, or his mental capacities. He should treat all his patients as equal, as though they were his own closest relatives." The influence of Sun's medical ethics spread beyond China, reaching Korea and Japan through quotations of relevant passages in texts of these two countries.

A third aspect is Sun's relationship with Daoism (Taoism) and Buddhism. The nature of his involvement with the Way of the Celestial Masters (*Tianshi Dao*, one of the main traditions of liturgical Daoism) is debated. In the two chapters entitled *Jinjing* (Book of Interdictions) of the *Qianjin yifang*, Sun quotes formulas used in exorcist rituals by the Celestial Masters. This raises the issue of how he gained access to them. His interest in Daoism is also reflected in the chapter on "Nourishing the Vital Principle" (*Yangxing*), and in another extant text on physiological disciplines which is attributed to him, the *Sheyang zhenzhong fang* (Pillowbook of Methods for Nourishing [the vital principle]).

Another source which points to Sun's relationship with Daoism is the *Taiqing danjing yaojue* (Essential Instructions from the Books on the Elixirs of the Great Purity). This text –available in an excellent English translation – consists of a collection of alchemical methods, probably derived from the Six Dynasties compilations centered around the now lost *Taiqing jing* or Book of the Great Purity, one of the main early alchemical canons. Although Sun's authorship cannot be definitively proved, we know from his own witness that he was involved in the compounding of elixirs around AD 610. Among the medical disorders which he experienced, of which he left a first-hand account in his medical works, is intoxication due to elixir ingestion.

In addition to Daoism, recent research has pointed out Sun Simo's close connection with Buddhism. For example, he refers to Indian massage techniques, and mentions methods for the treatment of beriberi from works edited by Buddhist monks. Perhaps under the influence of Tiantai disciplines, he also introduced meditation in his medical practice. Moreover, the above mentioned "Jinjing" section of the *Qianjing yifang* includes incantatory formulas in Sanskrit. The main factor behind these Buddhist elements may have been Sun's interest in the doctrines of the Huayan school. Some passages of his texts, especially those on medical ethics, acquire new meaning if read in this light.

See also: ►Chinese Medicine, ►Acupuncture, ►Moxibustion, ►Medical Ethics, ►Alchemy in China

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Sun Zi

Ang Tian Se

Of all the mathematicians in ancient China, we know the least about the life of Sun Zi. The fact that he was given the honorific designation of *Zi* (Master) after his surname led some people like Zhu Zunyi (AD 1629–1709) to identify him with Sun Wu, a celebrated tactician in the sixth century BCE. Then Ruan Yuan (AD 1764–1849) assigned him to the late Zhou period of the third century BCE. With regard to the text written by Sun Zi, Dai Zhen, the eighteenth century scholar and mathematician, citing from internal evidence, argued that the text could not have been written earlier than the Han dynasty at the turn of the Christian era. Though this text by Sun Zi was listed in all the bibliographical chapters of the *Sui Shu* (Standard History of the Sui dynasty), the *Jiu Tang Shu* (Old Standard History of the Tang Dynasty), and the *Xin Tang Shu* (New Standard History of the Tang Dynasty), there was no mention of its author. This shows that as early as the middle of the seventh century AD, no one seemed to know who Sun Zi was.

Sun Zi had neither high political position nor influential social standing to merit a place in official history. He appeared to be merely a scholar with some Buddhist inclinations as is evidenced in a problem mentioning the length of a *sutra*. The mention of *wei qi* (encirclement chess), and the taxation in terms of silk floss in other problems indicates the text of Sun Zi could not have been written earlier than the third century AD and later than the fifth century. Thus we assume he lived around AD 400.

Sun Zi Suan Jing is the earliest existing text to provide a description of the rod numerals and their operations. It also gives the names of large and small numbers, tables of measures for length, weight, and capacity, as well as densities for metals. The most famous problem is the oldest example of the remainder problem which reads as follows:

> "Now there are an unknown number of things. If we count by threes, there is a remainder 2; if we count by

fives, there is a remainder 3; if we count by sevens, there is a remainder 2. Find the number of things."

The problem has since evolved into what is now known as the Chinese Remainder Problem. Written in modern form, the problem can be expressed thus:

$$N \equiv 2(\mathrm{mod}3) \equiv 3(\mathrm{mod}5) \equiv 2(\mathrm{mod}7).$$

It appeared that Sun Zi's solution of the remainder problem had been extensively employed by the ancient astronomers to perform complicated computations of the calendar. By the thirteenth century, the problem was fully developed by Qin Jiushao with a sophisticated method of solution which also tackled the difficult case where the moduli were not relatively prime.

See also: ►Computation: Chinese Counting Rods, ►Qin Jiushao

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Sundials in China

Edoardo Proverbio

The measurement of time has a long history in China. Besides clepsydrae and water clocks, sundials and incense clocks were the only timekeepers employed in the epoch preceding the introduction of mechanical timepieces.

The earliest form of timekeeper used in China appears to be the sundial. Although the use of a simple vertical pole, employed to determine the epoch of solstices by measuring the length of the sun's shadow, appears to go back to Shang times (ca. 1500–1000 BCE), it is more difficult to establish the epoch in which the shadow of a simple style was used in China to measure time. Perhaps the most ancient reference is the one made by Joseph Needham et al., contained in the *Shi Ji* (Historical Record), which goes back to the beginning of the fifth century BCE. This reference, as well as those in subsequent epochs, makes no mention of the typology of these ancient sundials. Among later apparent references to the building of sundials of the equatorial type, there is the one contained in the *Sui Shu* (History of the Sui Dynasty), which refers to a "graduated sundial" the shadow of which reproduced the motion of the heavens. It was built by Ge Heng, a master of astronomical learning and instrument maker active in about the middle of the third century AD. One of the first descriptions of a Chinese equatorial sundial that has come down to us is contained in the *Duxing Zazhi* (Miscellaneous Records of the Lone Watcher) by Zeng Minxing (ca. AD 1176) in which, among other references, it is stated that Zen Nanzhong, master of astronomy and a highly skilled instrument maker, who was active in Chiangsi province, invented and built many water clocks and sundials: "he also made two wooden dials with diagrams on them. One was set upon a wooden support for reading (the hours by) the sun's shadow" (cited in Needham 1986).

But the only extant ancient objects that appear to have been built and used as accurate timekeepers are the two so-called Han sundials, dated as former Han, perhaps going back to the second century BCE. These two objects have been interpreted in different ways. The most probable interpretation is, however, the one proposed by White and Milman in 1938. According to them the base-plate of these sundials was inclined in the equatorial plane, and the central gnomon was not a style but a rectangular plate connected with a perimetral T-shaped gnomon by a bronze bridge. Time would thus be shown by the position of the shadow of the peripheral gnomon in line with the bridge according to the graduation engraved on the face of the sundial. The season would be shown by the height of the shadow of the T-shaped gnomon on the central rectangular plate. Upon these ancient, supposedly equatorial solar timekeepers the graduations appear on one face only.

The most remote mention of the existence of Chinese equatorial sundials with surfaces graduated and a gnomon extending both above and below the equatorial plane plate appears to go back to the twelfth century. The *Duxing Zazhi*, mentioned above, reports the following passage: "So at Yunchang (Chiangsi province) he (Zeng Nanzhong) made a *Gui Yingtu* (diagram of the sun shadow) and constructed a sundial (*gui*). The dial was supported on posts so that it was high toward the south and low toward the north (i.e., in the plane of the equator). The gnomon pierced the dial at the center, one end pointing to the north pole and the other to the south pole. After the spring equinox, one had to look for the shadow on the side facing the north pole, and after the autumn equinox one found it on the other (the under) side" (Needham 1986). Numerous examples of late (Ming and Ching dynasties) Chinese equatorial sundials graduated on both sides have come down to us. The dials existing in the imperial palace at Beijing are of this kind.

Besides fixed equatorial sundials, two portable equatorial sundials made of lacquered wood, with inscriptions in red and black, or black only, were constructed in China, at least as far back as the Sung period (tenth–twelfth centuries). The largest production of these portable sundials appears to have been concentrated somewhere around the nineteenth century. Their construction is quite simple. They are generally composed of a rectangular piece of wood as a base plate with a compass needle having an azimuth graduation for meridian orientation set in it. A second, mobile lunette (the plate dial) is connected to the board at the middle.

The lunette is thus half the size of the base plate. The plate dial is graduated and may be raised or lowered to any desired angle so that the gnomon, fixed at right angles at the center of the graduation, may point at the pole whatever the latitude of the observer may be. The dial is then fixed in position by means of a ratchet prop. It is interesting to note that the latitude scale materialized by the position of the ratchet is given not in degrees or by the names of cities, but by the 24 fortnightly periods (*chi*) into which the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course) was subdivided in traditional Chinese astronomy. The hour lines of the equinoctial dial plate are also expressed in the so-called Chinese "double-hours" associated with the 12 ideograms of the duodenary cycle. In fact, despite their everyday, popular origin, these timekeepers seem to embody elements of the long tradition of Chinese geomancy or topomancy, divination by means of configurations of earth.

So we must believe that Chinese equinoctial sundials belong to the pure Chinese chronometric tradition, an interpretation that takes us back to the origin of the Chinese science known as *Feng shui* (geomancy, wind and water), based on the use of the geomantic compass, and of the ancient divinatory system based on the *Yijing* (I Ching, Book of Changes).

The first portable (and fixed?) horizontal solar time pieces were introduced into China starting from the end of the sixteenth century by Matteo Ricci and other Jesuit missionaries. Indeed, Father Ricci himself, in the preface to his memoirs, wrote: "As for their clocks, there are some which use water, and others the fire of certain perfumed fibers made all of the same size; besides this they make others with wheels which are moved by sand, but all of them are very imperfect. Of sundials they have only the equinoctial type, but do not know well how to adjust it for the position (i.e., the latitude) in which it is placed" (cited in Needham). The structure of these Chinese horizontal sundials which have come down to us is perfectly similar to that of the European "diptych" sundials, whose center of diffusion in Europe appears to have been Nuremberg in the late sixteenth century. Chinese horizontal sundials were not constructed before the end of the Ming dynasty (second half of the seventeenth century), and we have significant evidence showing that this kind of sundial was also employed more for geomantic purposes than as simple timekeepers.

Besides the two types of portable sundials so far mentioned, few specimens of a third kind of sundial, probably horizontal, consisting of a rectangular ivory plate, each one ruled for a different latitude, with hour and declination lines engraved, exist in China. The time of day and the period of the year were presumably indicated by the shadow of a style fitted into a central hole.

Unfortunately, given our still insufficient knowledge on the latter, as on other Chinese sundials previously discussed, it is often difficult to know exactly on what working principle they were based and the precise uses for which they were constructed and put to use. Even more uncertain is the epoch in which many portable Chinese sundials, still extant in museums and on exhibition, were built, where they were built, and by whom.

See also: ►Ge Heng, ►Geomancy in China, ►Feng Shui, ►Clocks

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S

Sundials in Islam

Boris A. Rosenfeld

The first sundials were formed by nomads who made holes in the tops of their tents. The sunbeam entered the tent through the hole and reached the floor or walls at different places at different hours. The time could be determined by the positions of these spots. From these developed the mural sextant described by the Islamic scientist and traveler al-Bīrūnī (973–1048) in his *Ḥikāya al-āla al-musammā al-suds al-Fakhrī* (Information on the Instrument Called the Fakhri Sextant) and instruments in the observatories of Ulugh Beg (1394–1449) in Samarqand and of Jai Singh (1686–1743) in Jaipur, Delhi and, other cities of India. In these instruments the sunbeams entered the instrument through the hole in its top and reach a special scale in its lower part.

The ancient Greeks invented sundials with gnomons, so that the time could be determined by the position of the shadow of the end of the gnomon on the plane or curved surface. The theory of sundials with gnomons obtained the name *Gnomonic*. Analogous sundials were used by ancient Arabs, Indians, and Chinese. Al-Bīrūnī in *Kitāb fī ifrād al-maqāl fī amr al-aẓlāl* (The Exhaustive Treatise on Shadows) wrote about all of these. All three nations measured the lengths of the shadows of a gnomon in parts: the Greeks in sixtieth parts, Islamic scientists in 12th parts called feet, Indians in seventh or 6.5th parts called fingers. The Greek division of the gnomon into 60 parts came from the tradition of Babylonian astronomers. The Arabic division is explained by their travels in deserts where they used their own bodies as gnomons and measured their lengths with their own feet. The Indians used the horizontal palms of their hands and erect fingers, and they measured the lengths of the shadows of their fingers on their palms with other fingers.

The most detailed descriptions of different kinds of sundials and of their theory appeared in the medieval Islamic countries. The first known to us, although nonextant, was written in Baghdad by Ibrāhim al-Fāzārī (d. ca. 777). It was called *Kitāb al-miqyās li ʻl-zawāl* (Book of the Gnomon for the Noon). The first extant Arabic treatise on sundials was also written in Baghdad by Muḥammad al-Khwārizmī (ca. 780–ca. 950) with the title *ʿAmal al-saʿāt fī basīṭ al-rukhāma* (Construction of Hour [lines] on the Plane of a Sundial). The sundial described in this treatise consisted of a horizontal marble board (the literal meaning of the word *rukhāma* is "marble board") and a gnomon (*miqyās*). When the sun accomplishes a visible diurnal circle on the celestial sphere, the shadow of the end of the gnomon describes an arc of a conic or (in the equinoctial days) a segment of a straight line on the plane of the sundial. On this plane the arcs of conics for the days of the entry of the sun in different zodiacal signs (beginnings of months of the zodiacal calendar) and a segment of the straight line for the equinoctial days are drawn. (For Baghdad these conics are hyperbolas). The hour lines are lines joining the points of these arcs and segments corresponding to the same hours of a day (in this treatise hour lines are straight lines). In the treatise the construction of this sundial is described and the tables for the functions necessary for this construction for different latitudes are given (the most detailed tables for 33° (Baghdad) and 34° (Samarra) are given). In al-Khwārizmī's treatises *ʿAmal al-miknasa* (Construction of al-miknasa) and *ʿAmal al-mukḥula li'l-saʿāt* (Construction of al-mukḥula for [determination of] Hours) different kinds of sundials are described. These include a horizontal plane sundial with a vertical gnomon used in *kanīsas* – churches or heathen temples – and a sundial with a conical surface whose name literally means "vessel for storing antimony (*kuḥl*)" because of its likeness to this vessel.

In the treatise by Thābit ibn Qurra (836–901) *Maqāla fī ṣifa al-ashkāl allatī taḥduthu bi mamarr ṭaraf ẓill al-miqyās fī saṭḥ al-ʿufq fī kull yawm wa fī kull balad* (Article on the Description of Figures Obtained at the Passing of the End of the Shadow of a Gnomon on a Horizontal Plane on any Day and in any Town), the horizontal sundial can be used at any latitude when the trajectories of the end of the shadow of the gnomon are arcs not only of hyperbolas but also of parabolas, ellipses, and circles. In his *Kitāb fī ālāt al-saʿāt allatī tusammā rukhāmāt* (Book on Horary Instruments Called Sundials) all kinds of plane sundials – horizontal, vertical, and oblique – are described.

Different kinds of sundials which secured the timely calls of Muslims for prayers are described in Arabic *zījes* (astronomical handbooks with tables) and in special treatises written by *muwaqqits* (timekeepers). Many kinds of sundials are described in al-Bīrūnī's book, *The Exhaustive Treatise on Shadows*, mentioned above. This is also true in the book by al-Ḥasan al-Marrākishī (d. 1262) *Kitāb jāmiʿ al-mabādī wa ʻl-ghāyāt fī ʿilm al-mīqāt* (Book of the Collection of Beginnings and Results in the Science of the Determination of Time). The time on sundials was measured not in astronomical hours equal to 1/24th of the day and night but in temporal hours equal to 1/12th of the day.

In later times oblique (not horizontal or vertical) sundials called *al-munḥarifa* were often used. Of particular interest is the treatise on these sundials written by the *muwaqqit* of the mosque al-Azhar in Cairo Sibṭ al-Māridīnī (1423–ca. 1495) *Risāla fī'l-munḥarifa wa ʻl-shākhis* (Treatise on an Oblique [sundial] and a Pole).

See also: ►al-Bīrūnī, ►al-Khwārizmī, ►Time, ►*Qibla* and Islamic Prayer Times, ►al-Māridīnī, ►Thābit ibn Qurra

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Surgery in Ancient Egypt

HEDVIG GYŐRY

In ancient Egypt, because a majority of the population had to endure hard physical toil, bone abnormalities such as arthritis, inflammation of the joints, bone attrition, kyphosis, osteo-arthritis, or tuberculosis were a common occurrence. None of these conditions were, however, considered surgical cases. The surgical repertory was limited. Both physical remains and written sources support the notion that operations were sporadic and minor, and that the emphasis was on physical treatment of fractures or dislocations, with a few cases of incisions or cuts into certain regions of the body. There were also various external organic alterations like abscesses, boils, fistulas, haemorrhoids, ulcers, and some superficial growths. Malfunctions of the nose, ear, and teeth were treated in this manner only occasionally. In treatment, the anatomical knowledge applied was taken from earlier medical observations and theories, not from the science of mummification. Good examples of this are the mummies examined by Regöly-Mérey: in seventeen cases, the brain was removed transnasally, in eight cases the frontal and facial sinuses were removed, and in five cases the pterygoid sinus had been opened up. Thus, these sinuses had to be penetrated with a hook, but none of these sinuses is ever mentioned in the medical treatises.

Sources

If we consider surgery (from the Greek *cheirourgia* meaning 'hand work') as a medical specialty that treats illness by operative manual and instruments, its most important characteristic is wound management. Looking at the ancient Egyptian word for physician, we find the *swnw* written with an arrow-shaped hieroglyph. It has been suggested that the arrow shape has its origin in the fact that the primary occupation of physicians was treating injuries received in combat. Physicians were experienced in removing arrows, similar to the god Thot, or perhaps they used arrowheads to lance abscesses. But a very limited number of pictures and only relatively few passages in the medical papyri describe surgical wound management in ancient Egypt. The Ebers papyrus (855–77), Hearst papyrus (217–27, 245, 260), London papyrus (29, 43–4) and, the most extensive, a complete scroll – the Edwin Smith papyrus – all contain descriptions.

References to surgical cases interspersed among prescriptions in the above-mentioned first three scrolls suggest that surgery was considered as part of any healer's art. This conjecture seems to be relevant for all three types of healers – physicians, priests, and magicians – since they are all named in the Smith papyrus when speaking about the examination of the patient's pulse. Ancient Egypt was, however, very advanced in medical specialisation and thus there might be a distinction among physicians dealing predominantly with surgical cases – as the priests of Sachmet are believed to have been specially trained surgeons (even for animals). Early distinction between surgery and pharmaceutical medicine is the most pronounced when looking at treatments of internal versus external cases: practically all the operations are directed at repairing external parts of the body, mostly for already existing damages.

The Smith papyrus was a manual for use by an army surgeon or practitioner for treating accidents or for teaching purposes. It is essentially a treatise on wounds, internal pathology, and bone surgery with meticulous clinical observations. It lists forty-eight cases of injuries and lesions along with the appropriate treatments. It follows the *a capite ad calces* (from the head to the calves) method, common in Western medicine until the Middle Ages. It starts with skull lesions, continues with caudal lying injuries on the head, in the neck, the clavicle, the humerus, the sternum, and the shoulders, and finishes with a description of the region of the spinal column, where it stops abruptly in the middle of the case of the fourth thoracic vertebra. But it was not the only ancient book in this field. It mentions, for instance, in case 5, another one, with the title 'On Wounds', the structure of which could be similar to that of the Smith papyrus. It contained case studies for medical treatment with explanatory glosses, but it might also have been a teaching book for anatomical and physiological features, since it is quoted as an explanation of a physical condition that results when the skull is splintered. The Smith papyrus is matter of fact and sober and would even fulfil today's requirements. The inductive process that deals with these cases is the oldest known example.

Case Study

The surgeon elicited information by questioning the patient or directing him to attempt certain movements or postures. His own ocular, olfactory, and tactile observations were then added. For case studies, conditions were closely observed, symptoms described and effective treatments noted in a remarkably scientific manner. These procedures were, however, accompanied by an equally important religious/magical rite, known from different sources. For instance, the ancient Egyptians believed that the illness passed into the bandage (called trap in Eb. 2) and thus, with the removal of the bandage, the illness was also thought to be removed.

Wound Repair

The ancient Egyptians regarded symptoms of infection as part of the recovery process. They also realised pain, but interestingly, they never mention anaesthesia for use in surgical interventions, although they had means for it. The silence can be the consequence of both its non-existing (e.g., holding the patient down) or having methods which were trivial – e.g., being drunken. Its only possible occurrence is an Old Kingdom circumcision scene (see a comprehensive description in the article Wound Healing).

Ancient practitioners were more deeply concerned with arresting haemorrhages, since the *mtw* (Eb. 871), tumours (Eb. 875), and wounds were susceptible to bleeding. The main wound repairing methods were bandaging with an ointment or poultice, scorching (Eb. 872, 876) and surgery. In doubtful cases, enforced bedrest and normal diet were often recommended to the patient until he reached the decisive moment when the healer could give either a positive or negative prognosis.

In many cases, as mentioned in Eb. 510–42, injury treatment was restricted to various medicaments. For instance, a typical first-day treatment was to put raw meat on the fresh wound, which induced haemostasis. A suppurating wound was likely to be cured by honey (Eb. 513), which is hygroscopic (capable of easily absorbing moisture) and stimulates the production of white blood cells, or by astringent herbs such as acacia leaves (Eb. 527). They also used wound dressings which combined, for example, honey and *snṯr* (incense, Eb. 515) or wax and *mrḥ.t* (grease/oil, Eb. 518), providing protection and promoting healing. Discharge and suppuration might also be treated by fat, ground peas and fermented barley bread, causing an antiseptic and hygroscopic effect (Eb. 522) – and, in the case of bread, possibly yielding penicillin. These last materials were given in sequence: (1) ox fat on the first day to induce the wound to become foul; (2) barley bread for drying it; then (3) several other things alone or in combination on the following 4 days. Thorn pricks (Eb. 726–32) were treated with poultices or ointments. Similar treatments could also certainly be applied to artificial wounds.

We do not know the criteria the surgeon used to determine the place for an operation, i.e., *ḏw-ᶜ* – 'knife-treatment'. Neither is a special operating theatre mentioned thus far, which may mean that the operation was performed at the patient's home.

Main Surgical Categories

Trauma (By Accident or Combat)

Based on many relatively good healing settings, we can assume that ancient Egyptian bone setting was advanced. Among the skeletal remains from ancient Egypt, there are innumerable completely healed limbs with good realignment of the bone, but most other bone settings often show gross shortening and misalignment. Since fractures of the femoral bones often healed without complication, it may indicate, on the one hand, that the virulence and incidence of pyogenic pathogens was lower than they are today, although their existence is proved by the frequency of osteomyelitis. On the other hand, based on the skeletal remains of pyramid workers and other Egyptians, it is obvious that fractured limbs were splinted using an advanced technique suitable even by modern standards. Cleverly, if only one of the bones of the lower leg or forearm was broken, the remaining intact bone could serve as a splint for the broken one, and healing was satisfactory. In instances where the damage was so severe, however, amputation was an alternative course of action.

Representations of injuries are relatively infrequent. Two of them are accurate enough to mention: the accidents drawn on the wall of the tomb of Ipui which happened in the joiner's shop and the pictures of the battle of Qades in various temples. Moreover, medical papyri, especially the Edwin Smith papyrus, are very accurate and detailed in the description of various types of injuries and their treatments. They tell us that the healer was able to characterise the most important types of injuries, impressive even by today's standards. They differentiated among various types of swellings, fractures, and joint injuries.

Besides the superficial wound (*wbnw*), they cured the *wbnw kft* – a deep gaping wound, as, for instance, in Sm. 28, where the most important clinical sign for an open oesophagus, drinking water regurgitating through the wound, is mentioned. The axillary could also be open (Sm. 47). The most common complaints, swelling and fever, indicate that wounds were often infected. In the special case of perforation, the word *thm* is used.

Wounds were often surgically treated by suturing with *jdr* stitching (Sm. 3, 10, 14, 23, 26, 28, 47) and/or bandaging (Sm. 2, 9, 10, 27, 47). Basic medicaments for curing were honey and fresh animal meat, but, in specific cases, many other ointments and poultices were also applied (Eb. 510–42). Sometimes a sequential approach was used (Eb. 522).

In the case of fractures, the ancient Egyptians differentiated a simple closed *sḏ*-fracture, where the bone is broken in two, from a commuted compound or impacted *pšn*-fracture, where the bone is broken in several places. As a diagnostic clinical sign of fracture, *nẖbẖb*, meaning, in all probability, 'crepitation', is mentioned. The standard procedure for the reduction of fracture was traction (Sm. 12, 35, 36). And, indeed, many humeri were found in graves still set in splints. The first procedure was, after realigning the broken limb, to set it either with a splint wrapped in bandages, or encased in a healing poultice cast that could be made of various (often unidentified) materials; as, for instance (just to mention some known substances), cow's milk mixed with barley (H 219) or acacia leaves bound together using gum and water (H 223). For reducing a fracture of the clavicle (Sm. 35), the ancient Egyptians also used a method still applied, but first described among Greek physicians by Hippocrates, by stretching the patient 'on his back with a folded cloth between the shoulder blades' and pulling 'on his two shoulders until the fracture falls into position'. Among the neurological complications, as in the case of an impacted fracture of the cervical vertebrae (Sm. 33), aphasia, unconsciousness and tetraplegia, are mentioned.

Concerning injuries to joints, dislocations (*wnẖ*) and sprains (*nrw.t*) were treated. In the tomb of Ipui in Deir el-Medineh, there is a picture of industrial accidents. Among them the use of Kocher's method for dislocated shoulders can be clearly discerned.[1] Other methods are described in the Smith papyrus, e.g., treatment for the dislocation of a jaw (Sm. 25). For neurological complications resulting from the dislocation of a cervical vertebra the inability to move the limbs, priapism, urinary incontinence, and intestinal dilatation with gas secondary to paralytic ileus are given (Sm. 31). In another case, a positive Lasague sign is described, i.e., pain due to a sprain of the vertebral column when the legs are extended (Sm. 48), which indicates a prolapsed lumbar intervertebral disc with nerve involvement.

Based on two ivory slabs bearing the names of kings Aha and Djer (both 1st Dynasty), some specialists assume the use of tracheotomy, a procedure that opens the airways to maintain breathing. The slabs represent a man kneeling, with his hands tied behind his back and with a pointed instrument directed at his throat. As the man holding the tool is seated, the scene is unlikely to be a battle scene, and, since the process is not repeated in later representations and the situation is not described in later medical texts, an interpretation of ritual execution (?) is also possible.

Skull Surgery and Trepanation

According to the Edwin Smith papyrus, the ancient Egyptians recognised brain disorders and performed skull repair. They were also the first in the history of medicine to identify the inner parts of the cranium, as *tpw*, the falx cerebri, or protruding dura mater[2] – based on the description, or as *ntnt*, the meninges (Sm. 6). They also provided vivid descriptions of the brain and cerebrospinal fluid.

Parallel to the development of weapons, the number of head injuries increased (Fig. 1), thus causing a discussion of the many cranial injuries in the Smith surgical treatise. The dominant factor in healing,

Surgery in Ancient Egypt. Fig. 1 Head of Seqenenre Taa II, showing multiple injuries acquired in battle. Source: LECA, A–P. La médecine égyptienne au temps des pharaons, Paris 1971, fig. 94, p. 372.

[1] For information on Kocher's method, see ►http://www.tki.unibe.ch/theodor.htm.

[2] The dura matter is the tough fibrous membrane covering the brain and the spinal cord and lining the inner surface of the skull. It is the outermost of the three meninges that surround the brain and spinal cord.

however, seems to be the *vis mediatrix naturae*, the expectant healing power of nature. This is also manifest by the signs of treatment on heads with cranial injuries found by Elliot Smith, Wood Jones, Courville, and, recently, Nerlich, which are far from adequate if any medical treatment's sign is present. A successfully recovered head injury to Amenemhab, who saved Thutmosis III from an attacking elephant in Nij/Mitanni, is known from literary tradition, while Breasted published the results of a palaeopathological examination of the mummy of General Ossi-numph-neferu, with a 7.5–cm long, caved-in, but completely healed, left side frontotemporal bone wound. This recovery is a great achievement even by current standards of surgical knowledge.

Craniotomies were well known in ancient Egyptian practice. A special treatment was trepanation, which is essentially making a hole in the skull without damaging the cerebral membrane. Today, only a few unquestionable cases are known of perfect healing at the edges that testify to a longer life, and, based on its absence in the Smith papyrus, it was certainly not regarded at that time as a medical treatment. But many other interventions were considered surgical, and some of them are given in the Smith papyrus with a modern scientific approach of clarity and diagnostic accuracy.

The first eight cases in the Smith papyrus deal with various injuries of the skull (for details, see *Wound Healing in Ancient Egypt*). Pathological descriptions give clues to the identification of symptoms such as meningeal irritation, cerebral prolapse, nuchal rigidity (stiff neck), trismus (lockjaw), tetanus, contracoup (brain injury), or hemiplegia (weakness on one side of the body). Complex case studies indicate a basic medical understanding of the function of the brain. They also knew their limits very well – when a cure was hopeless, palliative treatment was undertaken.

Plastic and Prosthetic Surgery

In some cases, wound treatment meant not only the healing of the wound but also the reconstruction of an earlier structure. Typical examples are Sm. 11–2 cases with plastic surgery of the nose. Besides the treatment of the fractured bone, by the usual means of application of *mrḥ.t* (oil/grease), honey and fibres, two fabric *ads* soaked into *mrḥ.t* were introduced into the cavity and applied to the bridge of the nose. Then the nose was bandaged above two linen pads, which protected the nostrils from distortion. The same reasoning led to the fixing of the auricle by means of a small cushion after the suturing of the ear in Sm. 23. Following local applications, a supportive bandage was also recommended for an ear wound in Eb. 766.

A surprising innovation in ancient Egyptian medicine was the use of prostheses (artificial limbs). We know that long ago there was a post-mortem nose prosthesis, for instance, on a Ptolemaic period Gamhud mummy, clearly shown by the fact that the straps are above the mouth and the chin, which then go to the base of the cranium where they are tied in a knot. Consequently, for a long time it was thought that restorative surgery was only used by embalmers to maintain physical integrity for eternal life.

There were doubts about the earliest prosthetic contrivance, two 4th Dynasty teeth fixed together by a golden wire, found in the Gisa cemetery. After a long debate, the conclusion seems to be that it was made for a dead person (The next artificial teeth, the holding of a maxillary bridge by a silver wire, were found in the Ptolemaic period.).

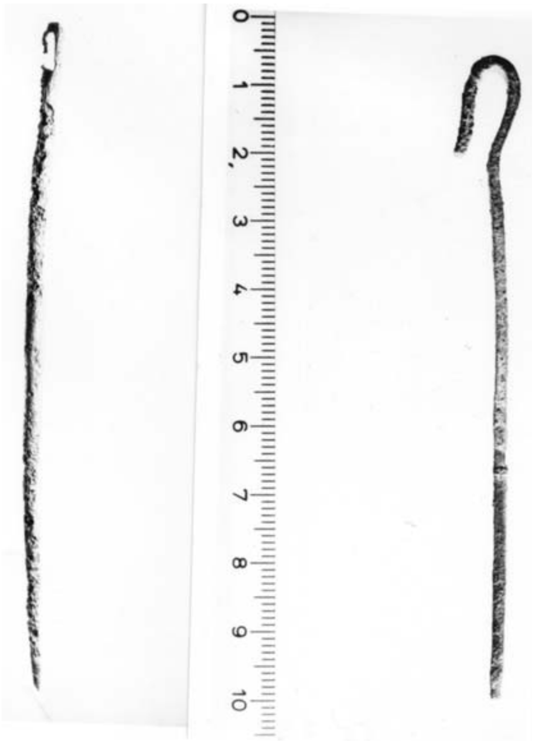
A prosthetic big toe, however, recently discovered in Thebes on a mummy of the 21st/22nd Dynasty in Tomb 95, was certainly made for a living person (Fig. 2). The linen-wrapped foot and leg show evidence that the amputation was cleaned and prepared for this device. The amputation is completely healed, and the wooden prosthesis, made up of three separate components, is worn on the sole, which indicates that the owner lived long using the prosthesis after the accident (As a reason for amputation of the toe, ischaemic gangrene has been suggested.). Another (in this case cartonnage[3]) toe prosthesis from Thebes around the same period, kept in the British Museum, was applied also to a living person; again, wear and subsequent refurbishment can be observed.

Pathological Extensions

Pathologies were well differentiated: several sorts of tumours, abscesses, cysts, swellings, boils, etc. (*ḥnḥn.t*, *ᶜ.t*, *sfṯ*, *ᶜnw.t*, *šfw.t*, *ḥsd*, *tw.w*, *bsj*, *ḥm*, *sẖ*, *bnw.t*, *wnm-snf*) are mentioned in the Ebers, Hearst and Berlin papyri, with very brief medical instructions. These might have been treated in the following ways:

- Medicaments, for instance, Eb. 51–581, 855–62, H 41, 132–33, 136–39, Bln. 52–7 or the last step in Eb. 877;
- … treat it similar to the treatment of the *s-ḥmm* "(firebolt?-man)" for scorching the skin-like flesh-protrusion in Eb. 863 or the (umbilical or epigastric?) hernia in Eb. 864;
- *ṯḥn* – piercing with the *Hmm* as in Eb. 865 for the ascites (fluid in the abdomen);
- *ḏw-ᶜ*-'knife-treatment', meaning, probably, excision, as in Eb. 866 for a vascular tumour (haemangioma?), Eb. 867 for a presumably subcutaneous lipoma; Eb. 868 for a possible sebaceous tumour with metastasis

[3] Cartonnage was papyrus or linen soaked in plaster, shaped around a body. It was used for mummy masks and coffins.



Surgery in Ancient Egypt. Fig. 2 Hook and needle in the Egyptian Collection of the Museum of Fine Arts, Budapest.

(*ʿ.t nt s*); Eb. 869 for an abscess; Eb. 870 for a swelling, the identification of which has several possibilities, such as a dermoid cyst lined with skin appendices, pilonidal sinus located in the midline or sebaceous cyst of the scalp, as, for instance, atheroma; Eb. 871 for an abscess in the axillary lymph glands;

- *ḏw-ʿ*-'knife-treatment' with heated (*sšmm*) knife as in Eb. 872 for a probable haemangioma;
- Either excision or scorching according to the state of the tumour, as in the first two cases in Eb. 876; or
- The tumour was left untreated, as Eb. 874. This might have been leprosy, or in Eb. 873, a possible cavernous haemangioma, or a twisted vascular swelling forming knot (in this case, however, the *mtw* should be straightened). The first two steps in Eb. 877 are still unidentified although cancer, cutaneous leprosy, bubonic plague, or neurofibromatosis have already been suggested. In the last step in Eb. 876, the ball-shaped extensions have tentatively been identified by Regöly-Mérei as varicosities.

In all the above cases, procedures are not described and thus nothing definite is known. The only complex and detailed surgical process is given in the Ebers papyrus (Eb. 875) – with various knife and forceps devices – and is, in all probability, the month-long treatment for dracunculiasis[4] (which may be the origin of the caduceus, the medical emblem with snakes), and thus a very atypical surgical invention.

Circumcision

Herodotos (II.37) wrote: 'They practice circumcision for cleanliness, for they set cleanliness above seemliness', but we find no mention of it in any medical or iatromagical text, and its two representations hint at a sort of feast for ritual initiation, probably for procreative purposes. Conceivably, the traditional practitioners had religious ties, and were most probably priests, since the fulfilling of the cleanliness doctrine was the most important one for temple workers. Based on a representation of the tomb of Ankhmahor, it was performed by a scalpel or some sort of blade. Following the Ptolemaic rule, physicians could do it, too, as later the use of Roman instruments, such as forceps and scalpels, was common in this field.

There is only one mention in the First Intermediate Period stele of Uha of circumcision being performed on females in Pharaonic times, where a crowd of men and women are participating in the cultic rites that accompanied the procedure. It seems, based on this mention of a communal feast, that female circumcision was also primarily ritualistic and it has been hypothesised that it was also associated with temple activities, although I think it was primarily the same sort of fertility rite as that for men – at least the above communal feast hints at it. We do not know, however, how popular the act was, or when, how or why it came into existence. In any event, it must have lost its festive side, as it never appeared again as a public act. It must not have been obligatory, since virgins were also referred to as *ʿmʿ.t*– 'uncircumcised', from the Middle Kingdom on. Based on the state of preservation of the pubic area on mummies, the fulfilment or non-fulfilment of the act of circumcision cannot be definitively determined. According to written sources, however, in Graeco-Roman times, nymphotomy/clitoridectomy seems to have been a widespread custom in Egypt. Soranus (2nd century BCE) first recommended the process for girls with excessively large clitorises. He gave as the reason for the operation the shame that results from its erection and the girl's excessive desire for sexual indulgence caused by the abnormality. According to Aetios, who used Hellenistic and Roman imperial sources, the ancient Egyptians excised the clitoris especially around the time when the girl was about to be married.

[4] Dranunculiasis, also known as Guinea worm disease, is a painful and debilitating infestation contracted by drinking stagnant water contaminated with Guinea worm larvae that can mature inside a human's abdomen until the worm emerges through a painful blister in the person's skin.

Burns

In the Ebers papyrus, there is a complete book on wounds originating from burns: 482–509. No. 482 lists a sequence of remedies which, it says, should be applied consecutively. In other cases, remedies applying an ointment or a bandage are the same during the entire treatment. Similar to cases in the London papyrus (15–21, 46–8, 53–61) and also among the Ebers papyrus prescriptions (482–500), magic spells had to be cast, referring to Horus having been burnt in the desert. According to the incantation of Eb. 499 which had to be recited with mother's milk, Isis used 'water in her mouth' and 'Nile springing between her thighs'. Mother's milk, gum, and ram-fur (having a high cholesterol content) were put on the burnt wound. As for surgical procedures, Eb. 504 speaks about opening a blister with a sharp thorn, and Eb. 501 mentions an incision on a blister sandwiched between two prescriptions, but, as usual, without any details.

Various Types of Bites

According to the Brooklyn herpetological papyrus, snakes and the effect of their bites were accurately identified, and their bites treated with rational medical care. The treatments comprised the application of a bandage with salt and natron,[5] both being antiagglutinant[6] and antihaemolytic[7] thus impeding the absorption of the venom; drinking of emetic remedies with various materia to get rid of venom by vomiting; fumigation as adjuvant; magical spells for general and specific divine help and/or the *ḏw-ʿ* 'knife-treatment' and the *tštš*-incisions in the swelling.

Other types of bites, such as those from crocodiles (Eb. 436, H 239–40, 243), lions (H 244) and humans (Eb. 432–35, H 21), were treated like any other wound, preferably by applying fresh meat on the first day and, subsequently, honey, wax, and *mrḥ.t* as in Eb. 435 or by using other herbal remedies, occasionally with the addition of some animal ingredients.

Dental Surgery

Dentistry is among the earliest medical fields in ancient Egypt. Even the first known Egyptian physician, Hesira, was a dentist. A wide range of dental treatments is listed in the medical papyri, such as filling teeth, treating gums or abscesses, and reducing halitosis. But no surgical inventions are mentioned, although an alveolar process using piercing to drain an abscess under the first molar has already been found in a mandible from the fourth Dynasty. Neither is tooth extraction described, and, based on the many abscesses and cysts found on mummies, was rarely, if ever, practiced.

Surgical Devices

There were several specialised surgical devices (Fig. 3), as various types of knives for cutting tumours, needles for suturing, several types of spatulas for applying the medicaments, 'fire drills', and metal cauteries for operations and disinfection. They made splints and bandages very skilfully, having specialised books on this topic – primarily for the embalmers, but as the Smith papyrus says, physicians used them as well. Hooks and forceps were probably also often common with the embalmers, although such devices as the small leather forceps, called *hnw*(*ḫ*) must have been a surgical speciality. They also used several natural objects, such as acacia thorns for cutting up blisters and the bulrush knife for removing elastic foreign bodies. Seemingly they were adapted to the various functions surgeons had to accomplish during the various stages of different types of operations. Parts of the instruments

Surgery in Ancient Egypt. Fig. 3 Prosthetic big toe from Thebes.

[5] Natron was a salt (sodium carbonate and sodium bicarbonate) that was used in the mummification process to dry out the body of the deceased in order to assist in its preservation.

[6] An antiagglutin is a substance that makes particles (such as bacteria or cells) stick together to form a clump or a mass.

[7] Haemolysis is alteration, dissolution, or destruction of red blood cells in such a manner that hemoglobin is liberated into the medium in which the cells are suspended, e.g., by specific complement-fixing antibodies, toxins, various chemical agents, tonicity, or alteration of temperature.

were also used for cosmetics; ointments were made and applied the same way for both purposes. The execution could have been of different quality according to the demand, although they are mostly primitive. The problem is, however, that only a few surgical devices survived (often unprovenanced), and representations are missing – the Kom Ombo temple relief originates from the Roman times, so ancient Egyptian and Roman medical instruments are already mixed. We do not have detailed knowledge of pharaonic surgical devices.

Surgeons

The practitioners of all the above procedures might have been very different people. Surgeons, i.e., medical practitioners specializing in surgery, seem not to have existed in the modern sense during Pharaonic times. Operations were performed by the practitioners, dentists, priests, or magicians. For combat/battle injuries there was a military physician, problems with teeth were handled by a dentist, complications of the ear or nose were treated by the specialist or by a general practitioner. For bites, the *ḫrp Srḳt*, the 'controller of Selket' was responsible, while circumcision might be the task of the *kz*-priests.

Surgical procedures are, however, attributed by Egyptologists most often to the priests of the lioness goddess, Sechmet, who were veterinarians (as the ancient Egyptian said: 'one who knows bull') too. Aha-nakht, a colleague of the *swnw* Hery-shef-nakht, of the Middle Kingdom introduced his picture in his Hatnub graffito with the words: 'The scribe of the hall of judgement, Aha-nakht. I am a wab priest of Sekhmet, capable and skilled of his brotherhood, who places hand on a man when he knows it (i.e., the illness), skilled in examining strongly and one who knows bulls', thus attesting to a medical connection for these priests. The *ḏw-ʿ* – knife-treatment, however, is said in Eb. 501 to belong only to the *swnw* physician as the secret knowledge of the beating of the heart belongs as well to the *swnw* as to the *wʿb* priest of Sekhmet and to the magician.

The account given in this article represents the state of surgery during the New and, probably, the Middle Kingdom periods in Egypt, since our sources date mainly from these periods, but it was probably not very different during the preceding and following periods. Wound management has always been an important part of human life and thus probably the first medical books (see Medicine in Egypt, especially the note on Egyptian Medical Papyri) already contained appropriate instructions. It is unknown, however, how much they differed from the Middle Kingdom methods, where the latest research places the original of the texts of the Smith papyrus. The concept was probably the same, as we find in the few New Kingdom Berlin papyrus prescriptions for bite and the very complex 30th Dynasty (?) Brooklyn Museum herpetological papyrus. A great transformation seems to have taken place only later, with the gradual fusion with Greek medicine via the Alexandria School.

Surgery would be used in ancient Egypt only if a cure could not be achieved by means of prescriptions or other methods, and if the patient was not in a terminal condition, when only palliative steps were taken. And, indeed, it was often the best solution as success would certainly not be guaranteed even in standard operations, in spite of the relatively advanced methods, due not only to imperfect anatomical knowledge, but also to the lack of both effective anaesthetics and of antiseptics and the low level of hygiene, which could lead to septicaemia.

See also ►Hair

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Surgery in Ancient India

A. R. Sankhyan

Ancient surgical practices included trepanation (also called trephination or trephining), the craniotomy or drilling and cutting through the skull vault. It was practiced either on the living person (antemortem) or just after death (postmortem). Squier (1863–1865) and Broca (1876, 1867) were probably among the first to draw attention to the antiquity of this practice in Peru. Piggott (1940) thought that it had begun in Europe around 5,000 years ago. In Asia trepanation is evident from around 4,000 years ago in the Bronze Age of Jericho in Palestine (Parry and Starkey 1936; Giles 1953). In the Indian subcontinent, trepanation was known among the Bronze Age Harappans (ca. 4300 BP) people of the Indus Valley Civilization (Sarkar 1972). He attributed a squarish hole on the right temporal skull of a child of 9–10 years skull found at Lothal, a Harappan site. Roy Chowdhury (1973) noticed the evidence of trepanation in two Harappan skulls (No. H 796/B and H 802/B from Cemetery R37), adding that a Kalibangan skull (another Harappan site) in Western India, was probably also trephined. This practice was also followed during the Iron Age of India, since a megalithic skull (M30) from Maski in Karnataka, South India, also showed evidence of trepanation in the form of two circular holes of 22 and 15 mm, respectively, on the either side of the sagittal[1] suture of the vertex (the top of the head) (Sarkar 1972). A Neolithic skull excavated at Burzahom in Kashmir shows more convincing evidence of trepanation (Roy Chowdhury 1973; Sankhyan and Weber 2001; Sankhyan 2004) practiced over 4,000 years ago. Although Āyurveda, Indian traditional medicine, talks about brain surgery during ancient times, unequivocal evidence of trepanation has not been discovered.

According to Brothwell (1994) trepanation as a surgical operation was widely established in many ancient societies of the Americas, Europe, Africa, and Asia. He assigned a time bracket of 4,000–5,000 years ago. He observed similarities in the techniques of trepanation across all continents; this suggests the transfer of surgical skills from one society to another.

The author drew specific attention to a multi-trephined skull from the Neolithic pit-dwellers of Burzahom in the Kashmir Valley of the northwestern Himalayas, as a more authentic case in the subcontinent contemporaneous with the Indus Valley civilization.

[1] The sagittal plane is a vertical plane passing through the standing body from front to back. The midsagittal, or median, plane splits the body into left and right halves.

The Site and Its Age

Burzahom is located about 10 km northeast of Srinagar in the Kashmir Valley, on a terrace of Late Pleistocene–Holocene Karewa deposits. The site was excavated over six seasons between 1961 and 1968 and has yielded ten human skeletons of different cultural stages: Neolithic, Neolithic–Megalithic, and early historic cultures. The early phase I of the Neolithic at Burzahom has not yielded any human skeletons; C^{14} dating has yielded an earliest possible date of 4,375 ± 120 BP. The C^{14} dates by Agrawal and Kusumgar (1965) and Agrawal et al. (1966) suggest ca. 4300–2000 BP dates for the various burial sites. The Neolithic Phase II burials, including the trephined Burzahom skull, fall into the 4300–4000 BP time bracket. The Neolithic Phase II has yielded seven human skeletons in burials (Basu and Pal 1980) including the trephined skull (SKL 7, BZH-3), known here as the Burzahom skull. The remaining three skeletons belong in the later Neolithic–Megalithic cultural complex.

The burials of Burzahom are of a type called pit burials. The burial of the trephined Burzahom skull had animal bones, antler horn pieces, and a circular soapstone disc associated with it. The skeleton was in its primary articulation and in a crouching position, oriented NE–SW and was found at a depth of 7 ft 4 in. (2.24 m) from the surface level. The skull was reportedly covered with red ochre; the author, however, finds no trace of this. The trephined side of the skull was lying upward, facing the surface.

The seven skeletons of the Neolithic Phase II were excavated from different burials of varying depths, ranging from 3 ft 9 in. (1.15 m) to 10 ft 7 in. (3.22 m) from the surface. Four were in primary articulation and three in secondary articulation or partially articulated, nearly in NE–SW orientation, some with and some without grave furnishings. One burial contained an earthen pot, two had barrel-shaped carnelian beads, and one had a circular stone bowl. One burial of the Neolithic–Megalithic phase had a dog skull along with the human skeleton. Burying a dog with a human is said to have been a practice among early Chinese (Roy Chowdhury 1973).

Anthropological Analysis

Among the ten Burzahom skeletons, five are of adult males, three of adult females, one of a juvenile, and one of a child. The trephined Burzahom skull is of a female aged 26–30 years. All crania are markedly dolichocranic (having a relatively long head) with great calvarial (relating to the skullcap) heights and with cranial capacities ranging between 1,469 and 1,493 among adult males, and between 1,353 and 1,413 cc among adult females. Average stature is 169.6 cm. The dental condition of all skeletons is good.

The trephined Burzahom skull has a cranial volume of 1,353 cc. The cranium shows left-sided swelling or exaggeration. The forehead is low, slightly receding and with a distinct postglabellar (the space between the eyebrows) depression. The nose was long. The cranium is much more elongated. The face is very narrow with a medium height, and the skull has a look typical of a female. All the skeletons from this site represent a homogeneous population. Greater proximity is shown toward mature Harappans (excavated from Cemetery R37) and toward the modern Punjabi people of northwest India.

Trepanation and Surgical Operation

A trepanated skull was first noticed by Allchin and Allchin (1968), but it was first studied by Roy Chowdhury (1973). Basu and Pal (1980) studied the skeletal features and also commented on Roy Chowdhury's work by questioning the use of trepanation for medical purposes. Here I reexamine the original skull and the arguments and counterarguments.

Observations

The skull shows multiple trepanations. In all 11 attempts at trepanation are evident on the cranium. Barring a minor depression on the top of the right parietal,[2] all attempts are on the left parietal bone. Depending on the nature and depth of the depressions and holes, we have distinguished at least four successive attempts or stages/sittings in the trepanation of this cranium. There are six completed perforations, which represent the final stage of trepanation. All holes are nearly circular or oval in outline, ranging in maximum diameter from 5 to 14 mm. Trepanation was probably begun at the posteroinferior end of the left parietal and at the top of the right parietal. These depressions are very shallow and elongated where only the outer table of the bone has been removed, probably for the initial treatment of the patient. Then trepanation was attempted (probably in a second sitting) at sites nos. 9 and 10 where the depressions are deeper with the outer table of the bone removed into the diploic (the central layer of spongy, porous, bony tissue between the hard outer and inner bone layers of the cranium) space, leaving the inner table intact. The next attempt was made at site no. 8 where a much deeper depression was created. A hole was not probably intended since another minor stroke here would clearly puncture the skull. In the final attempt at actual trepanation, six holes were made, apparently in a triangular fashion, three on the inferior and three on the superior parietal region.

[2] Either of two large, irregularly quadrilateral bones between the frontal and occipital bones that together form the sides and top of the skull.

Probably nos. 2, 3, and 5 were made first, followed by nos. 1, 4, and 6. This sequence is speculative but may be deducted from the nature of the holes. The first three are very neatly and very carefully made and are almost of the same size and outline. The same instrument most likely made them and there are no fracture lines emanating from them. The holes nos. l, 4, and 6, on the other hand, are bigger and were most likely made with a different single instrument. It is probable that the later holes were created at the terminal stage, with less care and more force, even blows; the vault was fractured as is seen from the fracture line connecting the three.

No instruments that could have been used in trepanation were found at the Burzahom site. However, other flint and bone instruments (but no bronze instruments typical of the roughly contemporaneous Indus civilization to the south) have been recovered. It is likely that drills or sharp flint knifes of various diameters were used on the skull for cutting or drilling. It is an attractive but purely speculative thought that at least an Indus civilization surgeon could have performed some of the trepanation on this skull.

It seems that the whole series of operations was performed in quick successive stages of short duration. No clear evidence of healing of the bone (osteogenesis and sclerosis) is visible inside or outside the punctured holes. Roy Chowdhury, however, believed that there is evidence of a ring of sclerosis (callous) around one hole, unfortunately failing to specify the hole. Basu and Pal (1980) did not recognize any evidence of sclerosis and came to the extreme conclusion that it was not a surgical operation either performed while alive or after death. Bone healing or callous formation is expected in an *antemortem* operation if the patient survived for a sufficient time to allow the process of bone formation. But, as argued above, the patient probably did not survive the last traumatic operation. Alternatively, the ring of sclerosis, which Roy Chowdhury reported but of which we have found no trace, could have grown during a relatively brief period between operations and so be slight enough for its existence to become a matter of opinion. Positive evidence for a surgical operation may be taken if the left increase in size of the skull is interpreted as an anomaly or cranial disease. We need not necessarily accept the argument of Basu and Pal that such an anomaly is within the normal range of cranial variation. No similar case has been found in other Burzahom crania. If even the very existence of cranial disease cannot be established without doubt, it is still less likely to establish what symptoms the afflicted owner of the skull might have exhibited. As it is, we can only speculate that the Burzahom woman with the at least slightly abnormal skull may have been insane, epileptic or otherwise "different" and such people were regarded with awe and fear in most early societies. As it is, we simply do not know. This is unfortunate, as it would have allowed some general conclusions to be reached on the reasons for this and other trepanations.

Basu and Pal (1980) believe that trepanation at Burzahom was done with the sole purpose of taking out roundels for cranial amulets, to be used for ritual or other votive offerings or magico-religious practices. They draw this inference from parallels in Oceania (de Morgan 1924) and Michigan (Gillman 1882) and further argue that the left portion of the trepanated side of the skull was facing upward and that the skeleton was treated with red ochre. The present author contests these arguments. First, there is evidence of red ochre treatment in most of the Neolithic Phase II skeletons at Burzahom, not only of humans but also of animals. As Basu and Pal themselves note "a distinctive feature of the human burials of phase II was the use of red ochre on bones of both human and animals" (1980:3). Another relevant point is that the skeleton of the trephined Burzahom skull SKL7 was in primary articulation, i.e., not disturbed by any agency after burial. Why were six holes cut and five more left as depressions? Neither figure 6 nor 11 is known to have had any religious significance in the area, then or now. Not much care is needed for cutting roundels from the skull of a dead person nor have other trepanated crania been found at Burzahom. If roundels were desired, we would find deep cuts around the circumference of incomplete holes, which is not what we find in nos. 7–11. Finally, there is no evidence of prehistoric or contemporary tribal or nontribal people of northwest India or of India in general using cranial roundels as amulets or for other purposes.

The very carefully performed trepanation at Burzahom with the strong likelihood of several different stages/sittings on a possibly anomalous skull does, in the opinion of the present author, argue for a clear case of surgery performed for predominantly medical reasons on a living person who has not survived the procedure. It should be borne in mind, however, that most primitive societies regard disease as an invasion of spirits, which are usually, but not invariably thought to be evil. Also, medical and surgical procedures in such societies are so closely intertwined with belief, ritual, and magic that they cannot neatly be separated. Cases of mental illness, epilepsy, and others are also widely regarded as messengers of the gods with the afflicted often given a very special, even sacred, position in society. Trepanation in the case of the Burzahom skull and elsewhere could merely represent the surgical part of a much more elaborate medico-ritual ceremonial procedure of which only the trepanated skull has come down to us.

Tello (1929), a Peruvian archaeologist, remarked, "Trepanations were done for spiritual, magical reasons, including perhaps cases of mental illness, epilepsy, or headache." The skull of the long-suffering Burzahom woman may throw some light on the riddle of how the centers of prehistoric trepanation came to use such remarkably similar techniques and procedures despite the enormous gaps in space and time separating them.

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Surveying

FRANK J. SWETZ

Surveying is the mathematical science that incorporates the application of geometric principles with concepts of measurement in order to delineate the forms, position, and extent of terrestrial features or man-made structures. It is an ancient activity that has been used by all urbanized societies. The establishment and maintenance of land boundaries, the construction of walls, and the lay out of irrigation systems and aqueducts rely on the use of some kind of surveying. Extent structures such as Stonehenge in England, the Great Wall of China, Machu Picchu in the Andes of Peru, the Great Pyramids of Giza, or the temples of Angkor in Cambodia testify to their builders' knowledge and use of surveying. However, all too often, in the ancient world, surveying activities were the closely guarded prerogative of an elite, members of a priestly or bureaucratic class. Knowledge of their mathematical discipline was usually transmitted orally from master to student. Such practices, combined with the ravishes of time, account for few existing documented records of old surveying practices and techniques. Therefore, much of what can be gleaned about surveying in early non-Western societies is speculative in nature and rests on extant archaeological and architectural evidence.

The most basic of surveying activities include the determination of straight horizontal and vertical lines and the establishment of a level plane upon which structures can be erected or reference slopes established. Instruments to achieve these goals are strikingly simple: straight horizontal lines can be obtained through the use of sighting poles or stakes and retained by the use of stretched cords or ropes; straight vertical lines are obtained by the use of a plumb bob, a weight suspended from a string, and a level plane can be constructed with the assistance of a leveling device such as a water-filled trench.

Rope Stretching

Herodotus (ca. 484–425 BCE), the Greek historian, attributed the origins of geometry to the Nile Valley of Egypt, where priest-surveyors stretched ropes to mark out land boundaries. These "rope-stretchers," or as Herodotus called them *harpedonaptae*, are the first historically recognized surveyors. Rope stretching activities also took place in Babylonia where ancient clay tablets mention the act of "stretching a field," that is using a rope to determine the dimensions of an agricultural field and denoting a particular individual as "the dragger of the rope," a surveyor. It appears that these early Egyptian and Babylonian land measuring activities were prompted by the need for royal levies. However, in the early Indus Valley civilization, rope stretching served another need. The *Śulbasūtras* (Rules of the Cord), compiled between the fifth to eighth centuries BCE, supply geometric prescriptions for the construction of ritual altars. These prescriptions were based on rope-stretching and were carried out by the Vedic priests. Later Pali literature makes mention of "rope holders" (surveyors) in reference to land measurements. In all early urbanized societies, rope stretching provided the basis for surveying.

Egypt

Surveying activities in Egypt certainly preceded the fifth century BCE observations of Herodotus. An inscription on the Palermo Stone dating from the Old Kingdom period of Egyptian history (ca. 3000 BCE) notes the existence of land surveys. Tomb inscriptions of about the same period mention the existence of land registry offices. A wall scene in the tomb of Menna at Thebes depicts surveyors at work. The scene shows two men measuring a field of corn with a long cord on which knots are marked at intervals of about 4 or 5 cubits. A standard measuring cord or rope of this period was 100 cubits (52.5 m) long. To obtain accurate vertical lines as well as to sight over long distances, Egyptian surveyors use the *merkhet*. This instrument also existed in Egypt from the earliest times; it consisted of a short plumb-line and plummet hanging from a holder that contained a sighting slit. Thus alignments could be made on distant objects. Merkhets were employed in the orientation of temples in a process called the "stretching of the measuring cord." Egyptian surveyors also employed two types of levels, the water level via a water filled trench which was suitable for large scale leveling, and the plumb-bob level erected with the aid of a wooden, right isosceles triangular frame work. Modern surveys have affirmed that the ancient Egyptians obtained very accurate results using their simple tools: the foundation for the Great Pyramid of Giza is almost perfectly level; boundary markers on the sides of the Nile River are aligned over long distances and a very accurate system of nilometers (flood gauges), were established along the Nile from its delta to the First Cataract, a marvelous feat of leveling.

Babylonia

Large scale construction projects existed in the Tigris-Euphrates region as early as 2300 BCE. The accomplishments of Gudea of Lagash, an engineer or architect of this time, is commemorated by statues which depict him holding a tablet containing scaled plans for a structure. These plans are superimposed on a rectangular grid. Both the use of scaling and a rectangular reference grid indicate the existence of a high level of surveying skill at this time. Further, extensive systems of irrigation channels relied on the establishment of adequate gradients or slope determined by leveling techniques. Fragments of Babylonian clay astrolabes dating back to the second millennium BCE have been found. With such instruments, observers of the time could determine angles of inclination; however, it is believed that these astrolabes were employed for astronomical sightings rather than terrestrial surveying.

Ancient India

Archaeological evidence from such sites as Mohenjo-Daro and Harappa, cities of the early Indus civilization (3500–2500 BCE) indicate that city planning principles were followed. Buildings were uniform in appearance, and roads were laid out at right angles to each other. The existence of sewerage systems as well as flowing aqueducts testify to a knowledge and use of leveling principles. Builders of the cities of Mohenjo-Daro and Harappa knew surveying. Linear measuring scales found at excavation sites in the region indicate the early Indus peoples employed a decimal system of measurement. This system was based on a "Mohenjo-Daro inch" of 0.67 cm. Further, at Lothal, the remains of a sighting instrument were found. The instrument consists of a hollow shell with four slits cut into its sides. These slits are situated at right angles to each other and allow for perpendicular sighting as would be necessary in surveying a rectangular road system. During the later *Śulbasūtra* period (800 BCE), bamboo poles, *saṇku*, were used for measuring and laying out circular regions, and a standardized chain or measuring rope, *rajju*, was employed. The *Śulbasūtra* texts describe an extensive mathematics supporting its rope stretching surveying techniques. Included in this mathematics was a theory of similar triangles.

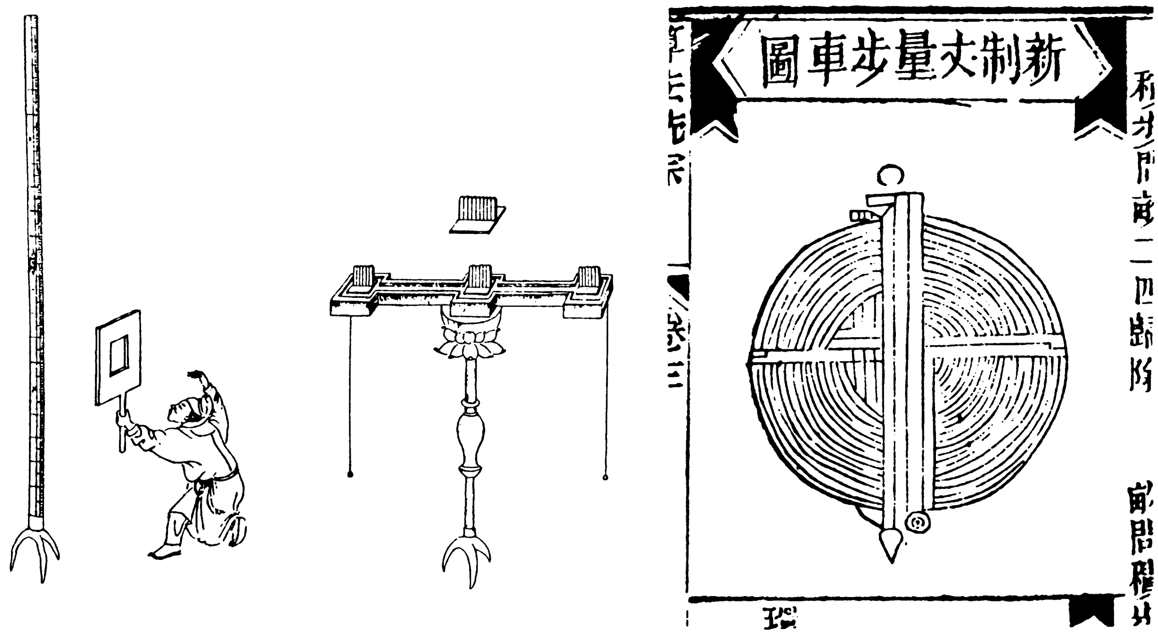
While works of later Indian mathematical authors primarily concerned applications of mathematics to astronomy, some also included mathematical information for surveyors. Āryabhaṭa I (476–550) in his *Āryabhaṭiya* (ca. 499) discusses procedures for finding areas and volumes of plane figures and solids. Brahmagupta (ca. AD 628) in his *Brahmasphutasiddhānta* (Correct Astronomical System of Brahma) provides much information relevant to the needs of surveyors including specific computation procedures necessary for working with a shadow gnomon, a sighting staff employed for inclined sightings, thus incorporating a concept of angle into surveying activities.

China and the Far East

Early Chinese society was river based. Settling along the banks of the Yangtze and Hwang Ho rivers, the Chinese people harnessed and controlled the rivers by a system of dikes, canals, and irrigation channels. These construction projects required a knowledge and use of land surveying. Surveying was openly recognized as an important societal activity; folk hero Fu Xi and legendary emperor–engineer Yu the Great were often depicted holding surveying instruments.

Discussions and illustrations in extant texts and reference works provide some knowledge of the instruments used by early Chinese surveyors. Calibrated sighting poles, *biao*, were used in conjunction with sighting tubes, *wang tong*, or sighting boards, *ce shi pai*. A water level, *zhun*, was employed for leveling and a bamboo measure tape, *bu che*, devised for chaining land. A primary surveying instrument was the L-shaped set square or gnomon, *ju*. The earliest documented reference to surveying is found in the *Zhoubi Suanjing* (The Arithmetical Classic of the Gnomon and the Circular Paths of Heaven, ca. 100 BCE–AD 100) where in a fanciful conversation between Zhou Gong, a duke of the Zhou dynasty (ca. 1030–221 BCE) and the Grand Prefect Shang Gao, the duke advises the Prefect in the use of the set square. More substantial information on the mathematics of surveying is supplied in *Jiuzhang suanshu* (The Nine Chapters on the Mathematical Art, ca. 100 BCE). The work contains nine chapters on specific applications of mathematics. Chap. 1, "Field Measurements"; Chap. 5, "Construction Consultations" and Chap. 9 "*Gougu*"(right-triangle) are directly concerned with surveying computations (Fig. 1).

In AD 263, the scholar-official Liu Hui wrote a commentary on the *Jiuzhang* and revised much of its contents. He paid particular attention to the ninth chapter and extended its collection of problems to allow for more surveying situations which involved the obtaining of measurements to inaccessible points. Liu stressed a technique called *chong cha* (double difference) requiring two distinct sighting observations from separate locations. At the beginning of the Tang dynasty (AD 618–906), Liu's problems involving double differences were separated from the *Jiuzhang* and made into an independent mathematical work on



a b c

Surveying. Fig. 1 Classical Chinese surveying instruments. (a) *Biao*, calibrated sighting pole; (b) water level, *zhun*; (c) *bu che*, a bamboo measuring tape. From Frank Swetz, *The Sea Island Mathematical Manual: Surveying and Mathematics in Ancient China*. Penn State University Press, 1992. Used with permission of the author.

surveying, the *Haidao suanjing* (Sea Island Mathematical Manual). In AD 656, the Royal Academy established an official curriculum to be used for the training of state officials. The *Haidao* was included among the ten mathematical works to be studied. Later, this curriculum was adopted in Japan and Korea where the instructions of the *Haidao* provided the basis for surveying. One of the most accomplished feats of early Chinese surveying was begun in the year 724 when the State Astronomical Bureau of the Tang dynasty initiated the first meridian survey in the ancient world. Under the supervision of the scholar Yixing, 13 observation stations were established near the meridian 114°E and between latitudes 29°N to 52°N. Observations were taken over a period of several years. The expedition determined the angular attitude of the north celestial pole above the horizon and recorded the length of shadows at noon for the summer and winter solstices and equinoxes.

The *Haidao suanjing's* problems became the basis of later works which considered surveying computations. In 1247, the mathematician Qin Jiushao published *Shushu jiuzhang* (Mathematical Treatise in Nine Sections). Three of its nine chapters concerned survey applications: Chap. 4 was entitled "Surveying"; Chap. 7, "Architecture"; and Chap. 8, "Military Matters" which concerned the use of surveying techniques for observing an enemy from a distance. His contemporary, Yang Hui wrote *Tian mu bi lei cheng chu jie fa* (Practical Rules of Arithmetic for Surveying). Toward the end of the Ming dynasty, Western influence began to penetrate China. In 1582, the Italian Jesuit Matteo Ricci arrived in Macao and eventually made his way to Beijing where he used his mathematical and scientific knowledge to win favor with the court. Ricci collaborated with the scholar Xu Guangqi to publish *Celiang fayi* (Essentials of Surveying) (1607–1608). This book introduced contemporary European survey and land measurement methodology to China. Xu himself was a skilled surveyor and wrote an appendix to the *Essentials of Surveying*. It appeared in 1608 under the title *Celiang i tung* (Similarities and Differences [Between Chinese and European] Surveying Techniques). From this period onward, surveying in China combined both European and traditional theories and practices.

The Islamic World

Islam did not emerge as an intellectual and political force until about AD 726 with the establishment of the ʿAbbasid Caliphate. From their capital in Baghdad, the early ʿAbbasid caliphs patroned the collection of scientific works and used this acquired knowledge to consolidate their religious and political empire. Their era was marked by the building of new canals, bridges and aqueducts and by the reconstruction of old Babylonian irrigation systems. Surveying was used in this work. While Muslims became the heirs of

Babylonian, Egyptian and Greek surveying theory, they soon became accomplished practitioners and innovators in their own right. Religious prescriptions required daily prayers toward Mecca; in turn, mosques had to be constructed facing Mecca. Thus determining the *qibla*, or direction of Mecca from a given location, became an important task for surveyors.

Muslim surveyors used several methods of leveling: the plumb-bob level was employed as well as leveling poles. Al-Khāzinī (ca. 840) and Ibn-al-ʿAwwām wrote on the use of leveling poles. The latter wrote a handbook for farmers that included the layout of fields. Right angles were laid out with the use of an L-shaped square, *kunija*. Abu'l Wafā (940–998) wrote about the use of such a square. The most complete early Muslim treatise on surveying was written by Muḥammad ibn al-Hassan al-Hasib al-Karajī (ca. 1000). It was entitled *Kitāb al ʿuqūd wa'l abniyah* (Of Vaults and Building). Al-Karajī discussed both the mathematical and practical aspects of surveying and provided specific instructions for the surveying of tunnels and underground aqueducts, *qanat*. Later writer Abū Saqr al-Qabisi introduced trigonometric methods into surveying computations.

The one area of surveying in which Muslim scientists and craftsman excelled was the design and utilization of measuring instruments. Their knowledge of the astrolabe was obtained from the works of Ptolemy. The first noted Muslim maker of astrolabes was al-Fazārī (d. ca. 777) who worked under the patronage of al-Mansur. By the end of the eighth century a number of scholars were producing works on the construction and use of the astrolabe. The most famous of these scholars was Māshā'allāh (762–ca. 815), a Jew who worked under Islamic patronage. His *Kitāb sana ʿat al-asturlāb wa l-ʿanal bihā* (Book of the Construction of an Astrolabe and Its Use) became the authoritative reference of its time. At a later date (ca. 1380), Chaucer used Māshā 'allāh's theories in his European introduction of the astrolabe as a scientific instrument. It was Muslim efforts that resulted in the astrolabe becoming a valued instrument in land surveying activities. Similarly, the Jacob's staff, a popular medieval instrument for determining planar angles, is believed to have reached Europe via Muslim sources and may have had its origins in navigational methods used by early Muslim traders. The oldest actual description of this instrument comes from a navigator's manual, the *Mohit*, written by Sidi al-Chelebri, captain of the Turkish fleet under Sultan Suleimann in 1554.

Pre-Columbian America

Although no written records exist to document the surveying knowledge of early native American civilizations, archaeological sites testify to these peoples' application and understanding of surveying techniques and principles. The city planning and construction carried out by the Olmec, Maya, Teotihuacan, Toltec, and Aztec peoples of South and Central America indicate that they undertook some surveying activities. For example, the Aztec capital of Tenochtitlan was laid out according to a grid system. It contained markets, palaces and streets and canals and held a population of approximately 200,000 people in the year 1521. Temples and ball courts were oriented to the four cardinal directions. Aqueducts brought fresh water into the city from many miles distant. Some of the Aztec surveying instruments are known by name; plumb line, *temetzlepilolli*; the water level, *atezcath*; set square, *tlanacazanimi*; measuring scale, *tlahuahuanoloni* and the construction compass, *tlayolloanaloni*.

See also: ►*Śulbasūtras*, ►Āryabhaṭa, ►Brahmagupta, ►*Zhoubi Suanjing*, ►Liu Hui and the *Jiuzhang Suanshu*, ►The *Gougu* Theorem, ►Liu Hui, ►Qin Jiushao, ►al-Khāzinī, ►Māshā'allāh, ►*Qibla*, ►Abu'l Wafā, ►al-Karaji, ►*Qanat*, ►Astrolabe ►Nilometer

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Surveying in Egypt

Hans Barnard

The English verb "to survey" refers to a variety of activities, two of which will be discussed here with an emphasis on the way in which these were practiced in Ancient Egypt. The first can be provisionally defined as the techniques to reduce reality to fit onto a map or a model, the second as the techniques to transfer the information and ideas reflected on a plan or a model to the real world. Up until very recently a surveyor would go into the field with two instruments, one to measure angles, such as a transit or a theodolite; and one to measure distances, such as a measuring tape or an electronic distance-measuring device (EDM). Modern technology has combined these two instruments into one, therefore referred to as a "total station," which can perform both functions. The underlying principles of surveying, and the fact that these are based on the accurate measurement of angles and distances, were already mostly understood in Ancient Egypt. It must be kept in mind that the Ancient Egyptian civilization lasted for more than 3,000 years and did change slowly but continuously. The technology and methodology of surveying will have been different during the various periods of Egyptian history (Table 1). From the available evidence it is not possible to determine an exact chronology of the discipline of surveying in Ancient Egypt and the following discussion will be thematic rather than sequential.

This evidence comprises a number of tools used for surveying, several plans and maps, inferences from marks and modern measurements in extant structures and a few surviving texts on the subject. The Moscow (or Golenischev) Mathematical Papyrus, probably written during the eleventh Dynasty (unknown provenance, now in the Pushkin State Museum of Fine Arts in Moscow), discusses a series of problems of the area and volume of complex shapes, including a curved surface (problem 10) and a truncated pyramid (problem 14). The Rhind (or Ahmes) Mathematical Papyrus, written around 1550 BCE but claiming to be a copy of a twelfth Dynasty text (found in Luxor, now in the British Museum in London) deals with a series of problems of area and volume, including the area of a triangle (problems 4 and 51), a rectangle (problems 6 and 49) and a circle (problems 38 and 50) as well as the volume of a cylinder (problems 41 and 43).

Surveying would have been needed in Ancient Egypt, from the Old Kingdom onward, for at least two important applications. First was the construction of the famous tombs, temples and pyramids, some of which still stand today and testify to the accuracy of the measurements. Second, and with a larger impact on daily life, were the measurements to restore the outlines of the agricultural fields after the yearly inundation of the Nile in July and August. The maximum height of the inundation, measured in Nilometers at several places, differed from year to year and with that the area of arable land. The available land needed to be redistributed each year and taxes were levied accordingly. This can be illustrated by the following remarks of the Greek historian Herodotus, who traveled through Egypt in the fifth century BCE.

> The King would send men to inspect and measure the loss of cultivated land in order that from then on some of the tax, proportionate to the report of the loss, might be remitted. I attribute the invention of geometry to this cause and from Egypt it spread to Greece (Herodotus, *History 2.109*, translation Shore 1987: 125).

Measuring distances in Ancient Egypt was done in the same way as it is still done today: by comparing an unknown with a known distance indicated on a tape measure or a ruler. Several ancient measuring rods have been preserved, most of them dating to the New Kingdom or later. Two were found in the tomb of Kha, the architect of the Pharaoh Amenhotep II (eighteenth Dynasty), in Deir al-Medina (near Luxor) and are now kept by the Museo Egizio in Turin. One was gilded and probably a gift not meant for daily use; the other is hinged and was most likely used by its owner during his work (Arnold 1991). Longer distances were measured with a rope that had knots at regular distances, an activity known as "stretching the cord" (Shore 1987). This rope, reminiscent of "Gunter's chain" used by 17th–19th century surveyors, is often depicted ending in the ram's head of the god Khnum, indicating the importance attached to the measurements and their accuracy. A depiction of land surveyors in action can be found on the top register of wall 5 in the tomb of Menna,

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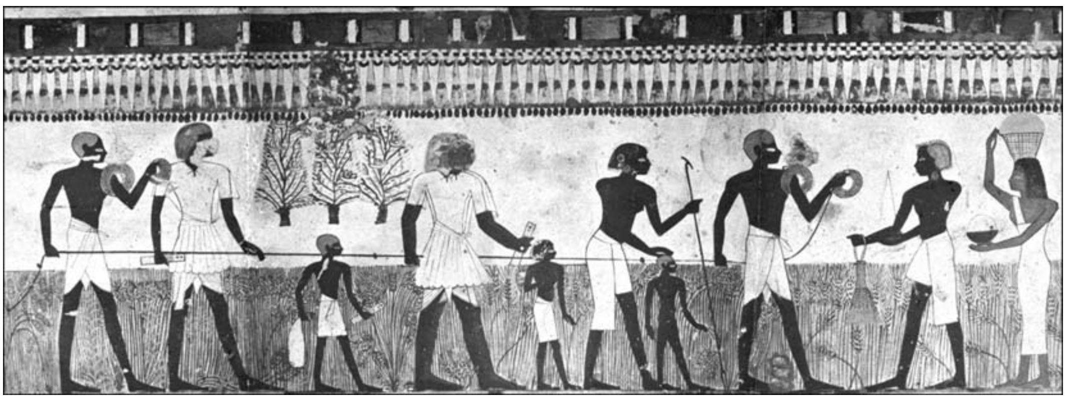
Surveying in Egypt. Table 1 The chronology of Ancient Egyptian civilization following Baines and Malek (2000: 36–37)

Period	Dynasties	Date
Early Dynastic Period	1st–3rd Dynasties	2950–2575 BCE
Old Kingdom	4th–8th Dynasties	2575–2150 BCE
First Intermediate Period	9th–11th Dynasties	2125–1975 BCE
Middle Kingdom	11th–14th Dynasties	1975–1640 BCE
Second Intermediate Period	15th–17th Dynasties	1630–1520 BCE
New Kingdom	18th–20th Dynasties	1539–1075 BCE
Third Intermediate Period	21st–25th Dynasties	1075–715 BCE
Late Period	25th–30th Dynasties	715–332 BCE
Greco-Roman Period	Macedonian and Roman rulers	332 BCE–395 CE



Surveying in Egypt. Fig. 1 Fragment of the top register of wall 5 of the 18th Dynasty tomb of Menna, showing land surveyors in action (photograph by Robert L. Mond and Ernest J. Mackay, 1914–1916, used with the kind permission of the Griffith Institute, Oxford, UK).

an administrator who lived during the reign of Pharaoh Tuthmosis IV or that of his successor Amenophis III (eighteenth Dynasty) (Fig. 1).

No single Ancient Egyptian unit of length can be given, as this not only varied over time, but also by purpose and place. Several systems existed simultaneously, as they did in Europe until very recently (the "Convention of the Metre" was signed in 1875 and the "International System of Units" in 1954 but neither are implemented, or even adopted, by all countries). The basis for the Ancient Egyptian unit of length was the cubit, the length from the elbow to the tip of the middle finger (Arnold 1991; Gillings 1982; Skinner 1954). A cubit was divided into seven "palms" and 28 "fingers" (one palm being four fingers). Two cubits seem to have been in use, the "royal cubit" and the "short cubit"; the former was most often about 524 mm (20.6 in.), the latter 449 mm (17.7 in.). A finger was therefore either approximately 19 mm (0.74 in.), when taken from the royal cubit, or approximately 16 mm (0.63 in.), when taken from the short cubit (Gillings 1982). It is possible that at times the short cubit was divided into only six palms, and 24 fingers (Skinner 1954). The royal cubit would then be close to one short cubit plus four fingers (one palm) long. A hundred cubits, 52.4 m (171.9 ft) in length, was called a *hayt*, a *khet* or, in the Greco-Roman period, a *schoenia*. An area of 100 × 100 cubits (a square hayr, khet or schoenia) was called a *setat* or, in the Greco-Roman period, an *arura*.

A remarkable additional unit was the *remen*, defined as half the diameter of a square with sides of one royal cubit in length. The length of this diameter is $\sqrt{2}$ cubits, which can not be written as the sum of reciprocal fractions (such as $\sqrt{2} = 1 + 1/3 + 1/13$), the notation system used in Ancient Egypt, but only as an unending decimal fraction (like $\sqrt{2} = 1.41421\ldots$). A remen would be about 371 mm (14.6 in.) or, by coincidence, almost exactly 19.5 fingers (Table 2). The advantage of the remen was that it allowed areas of land to be halved, or doubled, while preserving the proportions simply by changing the unit. A square with sides of a cubit, for instance, has twice the area of a square with sides of a remen and half the area of a square with sides of two remen (a "double-remen"). To calculate the area of a

Surveying in Egypt. Table 2 Overview of the most important ancient egyptian units of length

	Fingers	Cubits	mm	Square (cubits^2)	Square (mm^2)
Remen	19.5	$1/2 \times \sqrt{2}$	371	1/2	137,288
Cubit	28	1	524	1	274,576
Double-remen	39	$\sqrt{2}$	741	2	549,152

circle π (pi) was approximated as $(2 \times (1 - 1/9))^2 = 16^2/9^2 = 256/81$, which equals 3.16049... (whereas the correct value of $\pi = 3.14159...$).

Less is known about how angles, the second basic element of surveying, were understood in Ancient Egypt. There is ample evidence of the use of plumb bobs, often combined with a set-square or another device that could have served as a sight, which essentially create a 0° angle with the vertical (and a 90° angle with the horizontal). Some of these instruments were apparently used to establish levels (Arnold 1991; Lehner 1997). Marks representing different elevations are preserved in several structures amongst which are the fourth Dynasty Mastabet al-Fara'un, the burial complex of Pharaoh Shepseskaf, in Sakkara (near Cairo), the fifth Dynasty pyramid of Niuserra in Abusir (near Cairo) and the eleventh Dynasty temple of Mentuhotep in Deir al-Bahri (near Luxor). It has been suggested that water in channels cut for this purpose was used to create a level plain (Edwards 1993), which can be considered a 0° angle with the horizontal (and a 90° angle with the vertical).

It is unclear how a right angle on a given base line, essential for many surveying tasks, was constructed. There is no evidence that the special case of the theorem of Pythagoras, which proves that a triangle with sides of 3, 4 and 5 units will have one right angle, was employed (Gillings 1982). Over short distances a right angle could have been constructed by sighting over a set-square (Arnold 1991; Edwards 1993). The accuracy of this method could be improved by several techniques, but probably not sufficiently to account for the results evident from the surviving structures. Another way to construct a right angle is by establishing two large equilateral triangles with one side, and two corners, in common. The diagonals of the resulting rhomboid, one of which would correspond with the base line, will be at a right angle (Arnold 1991). What techniques were used to achieve the observed level of accuracy with the tools available at the time remains enigmatic, but the ancient surveyors could draw on generations of experience with the layout of agricultural fields and canals.

There is some archaeological and textual evidence about angles other than 0° and 90°, relating to the inclination of pyramids, pylons and the walls of buildings. This includes a set of preserved marks in the foundation trenches of Old Kingdom mastaba number 17 in Maidum (Arnold 1991) and problems 56–60 of Rhind Mathematical Papyrus (Gillings 1982). The angle of the face of a structure was described using the *seqet*, which can be defined as the length of the setback of the building from the vertical at a height of one cubit or, in modern terms, as the cotangent of the angle of the wall with the horizontal (Gillings 1982). A vertical wall has a seqet of zero and a wall with an inclination of 45° has a seqet of one cubit. The Great Pyramid in Giza, built by Pharaoh Khufu (Cheops) of the fourth Dynasty, rises at an angle of 51°52′ with the horizon and consequently has a seqet of 0.79 cubit (about five palms, two fingers). The measurements by the ancient surveyors were sometimes transferred to the structures under construction by elaborate means, such as the mud-brick walls under the outer court of the twelfth Dynasty pyramid of Senwosret in Lisht, believed to indicate the desired level to which the court had to be built up, or the lines of rock-cut postholes surrounding the Great Pyramid (Arnold 1991).

Measurements were not only needed to ensure a practical and secure structure, but often also to make it correspond to religious beliefs or cultic necessities. Despite a dearth of concrete information, the latter has become subject of much speculation. Many proportions of structures and angles of shafts are assumed to have had a special meaning, but these are rarely fully understood. The orientation of the pyramids according to the cardinal points is generally thought to have been motivated by stellar elements in the Ancient Egyptian religion. This orientation was most likely achieved by astro-surveying, performed by priests rather than surveyors. One instrument that was probably used for this is the *bay*, part of a palm rib with a slit at its base through which stars, or the sun, could be observed. A bay was used in combination with a merkhet, which doubled as a plumb bob and a sundial. A set of these instruments (now in the Staatliche Museum Charlottenburg in Berlin, found in Abydos?) once belonged to Hor, a priest of the twenty-sixth Dynasty. According to the inscription on the merkhet it "... knows the motion of the two discs (sun and moon) and every star..." (translation Wells 1999: 37). An inscription on the bay indicates that it is "... for indicating the commencement of a feast..." (translation Wells 1999: 37). With these relatively simple instruments it is possible to observe, through the slit in the bay, the passing of a star across a vertical line, established by the plumb bob attached to the merkhet. In the day, the bay would cast a shadow that could be aligned rather accurately because of the slit in the top. Either could be used to find true North, for instance by bisecting the angle of the rising and setting of a celestial body over a horizontal plane (Edwards 1993; Lehner 1997), or by observing the alignment of a pair of selected stars (Spence 2000). Surveyors would then again be needed to transfer the observations to the actual building under construction.

Celestial observation were also used for the first known attempt to calculate the circumference of the earth, by Eratosthenes during the reign of Ptolemy III Euergetes (246–221 BCE). Eratosthenes was born in Cyrene (Libya) and brought to Egypt as a tutor for the son of Ptolemy III and a librarian of the library of Alexandria (with about 500,000 'books'). Alexandria was the capital of Egypt during the Greco-Roman period and, at the time, the most powerful and influential city in the region. Thanks to the patronage of the Ptolemaic rulers and the renowned library, scholarly and scientific knowledge advanced greatly. Basing his calculations on the difference, on the same day, in the height of the sun in Alexandria and in Aswan, Eratosthenes came surprisingly close to the actual figure (Berthon and Robinson 1991).

See also: ▶Nilometer, ▶Maps in Egypt, ▶Mathematics

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Sūryasiddhānta

K. V. Sarma

The *Sūryasiddhānta* is a complete work on Hindu astronomy and is more popular and widely studied in North India than in the South. In order to enhance its prestige and antiquity, it is stated in the text itself (1.29) that it had been communicated by a representative of the God Sun to Maya, several thousand years ago. However, both internal and external evidence show that the work was composed between AD 600 and 1000. In about 500 verses, distributed through 14 chapters, the work deals with all aspects of Hindu astronomy, and also cosmology, geography, astronomical instruments, and time-reckoning. It follows the midnight day-reckoning.

The contents of the work are comprehensive. Chapter I speaks about the circumstances that led to the composition of the work, the aeons and aeonary revolutions of the planets, the principles underlying the computation of the planets and the nodes, the position of the planets at the beginning of the current aeon, the Prime meridian and local time, and the inclination of the orbits of the planets. The time units given in the work are more in conformity with the *Purāṇas* than with other texts on Hindu astronomy. Chapter II deals with the computation of the true motion and the true longitudes of the planets. Chapter III is devoted to the determination of the directions, place and time, and also the calculation of the precession of the equinoxes. It is noteworthy that the *Sūryasiddhānta* is the earliest available Indian text which contains a discussion of the calculation of the precession of the equinoxes. Chapters IV and V deal in detail with lunar and solar eclipses and their computation. Chapters VII and VIII are concerned with the conjunction of one planet with another, and a planet with a star, including their observation. Chapter IX deals with the determination of the heliacal rising of the planets and Chap. X with the phases of the moon. Chapter XI is concerned with the phenomenon of *pāta*. Cosmology and geography of the worlds and of the earth occur in Chap. XII. The construction of the armillary sphere and its working, and a mention of the main astronomical instruments form the subject matter of Chap. XIII. Chapter XIV enumerates and defines nine types of reckoning time, such as lunar, solar, siderial, tropical, etc.

The *Sūryasiddhānta* is indebted to earlier astronomers like Āryabhaṭa (b. 476) and Brahmagupta (b. 598) in certain matters like the inclination of the planetary orbits, the tabular Sines, etc. It is also to be noted that the *Sūryasiddhānta* does not include chapters on arithmetic, algebra, or astronomical problems, which are generally included in texts of this type.

The popularity of the *Sūryasiddhānta* is clear from the very large number of manuscripts of the work found throughout the land. About 35 commentaries on the work, written by scholars from different regions of India, and about 20 works, including planetary tables and manuals, based in the *Sūryasiddhānta*, have been identified. The popularity of the work is also reflected by the number of almanacs prepared on the basis of the *Sūryasiddhānta*.

See also: ►Astronomy in India, ►Precession of the Equinoxes, ►Armillary Spheres in India, ►Astronomical Instruments, ►Āryabhaṭa, ►Brahmagupta

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Suśruta

Guy Mazars

Suśruta is not the original author of the medical 'Compendium' which bears his name, the *Suśrutasaṃhitā*, which constitutes the major source of information about ancient Indian surgery. The treatise is supposed to contain the teaching of the god Dhanvantari, who was incarnated as Divodāsa, a king of Benares. Therefore it is not the personal work of Suśruta who had only recorded an already constituted medical tradition. The date of its redaction is not known. The basic text is supposed to have been revised and enlarged by an author called Nāgārjuna, which adds to the confusion, since there are several people named Nāgārjuna in Indian literary history. It is possible that the attribution of this name to the reviser of the text is but an echo of the legend which had the great Buddhist philosopher Nāgārjuna (first to second centuries AD) as a physician and alchemist. In any case, the teaching of Suśruta must already have been fixed at the time of the *Carakasaṃhitā* which refers moreover to the disciples of Suśruta for surgical treatment. The 'Suśruta's Compendium' was the object of very elaborate commentaries whose purpose was to clarify and add precision to the contents. The principal commentaries of the *Suśrutasaṃhitā* are those of Jejjaṭa (before the ninth century), Gayadāsa (eleventh century) and especially that of Ḍalhaṇa (eleventh to twelfth centuries) entitled *Nibandhasaṃgraha*.

In its present form the *Suśrutasaṃhitā* consists of 186 chapters which are divided into six large sections (*sthāna*):

1. Forty-six chapters in the *Sūtra* section deal with general questions such as medical training, diet or surgery.
2. Sixteen chapters in the *Nidāna* section deal with the diagnosis and prognosis of important ailments.
3. Ten chapters in the *Śārīra* section deal with the creation of the universe, embryology and anatomy.
4. Forty chapters in the *Cikitsā* section deal with therapy.
5. Eight chapters in the *Kalpa* section deal with poisons.
6. Sixty-six chapters in the *Uttara* section deal with diseases of the eye, ear, nose, and throat, paediatrics, seizures by evil spirits, dentistry and internal diseases in general.

The *Suśrutasaṃhitā* describes surgical operations which reveal the skill and the daring of the surgeons of that period: the lowering of cataracts with a needle, grafts for repairing the nose and the earlobe, procedures for the removal of stones in the urinary tract, resections of scrotal elephantiasis, Caesarean sections and surgical removal of a dead foetus from the womb.

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Swidden

Karl H. Schwerin

Swidden, also known as "slash and burn," "long fallow," and *roça* in Brazil, is a system of agriculture that involves clearing small areas within a forest, burning the slash (Figs. 1–4), and planting for 1–5 years (Figs. 5 and 6). The plot is then abandoned for 25–200 years – long enough for the forest to reclaim the cleared area. In contemporary Latin America this system may support as many as 50 million people.

In spite of the labor involved in clearing the forest, it is less than that required in clearing brush or turning under grass sod. This explains why fields are abandoned until the forest has regrown. In the tropics most nutrient and organic matter is locked up in the plants and trees, rather than in the soil. Thus, ash from the burned slash also frees nutrients for the crops.

A typical swidden planting mimics the diversity of the forest, with a variety of crops interspersed among each other, or planted in closely spaced zones within the field. In the Amazon–Orinoco drainages one may encounter 10–15 crops being grown together (Fig. 7). Once crops are planted, they require only one or two weedings before harvest (Fig. 8). In the tropics, harvest can extend over many months; just enough is taken from the field to provide for a few days or a week at a time. In a sense, then, the crop is stored in the field, rather than in a storehouse (Figs. 9–11). The labor required in swidden is minimal, averaging 2–4 h a day (though perhaps concentrated into 5 or 6 h two or three times a week).

Swidden crops are often limited to starchy staples, vegetables, and fruits, producing little protein. Thus subsistence is typically supplemented by fishing and/or hunting. Only in Mesoamerica, where beans are important, is the need for supplementary animal protein reduced somewhat.

Swidden. Fig. 2 Cachama: Field of Francisquito Martinez ready for burning. Cachama, Venezuela. Karinya Indians, February 1962 (photo by Karl H. Schwerin).

Swidden. Fig. 1 Mamo: uncleared swidden. Mamo, Venezuela. Uncleared farm plot thick with trees and undergrowth. Karinya Indians, March 1962 (photo by Karl H. Schwerin).

Swidden. Fig. 3 Cachama: Francisquito Martinez setting fire to field. Cachama, Venezuela. Karinya Indians, February 1962 (photo by Karl H. Schwerin).

Swidden. Fig. 4 Cachama: burning field of Francisquito Martinez. Cachama, Venezuela. Karinya Indians, February 1962 (photo by Karl H. Schwerin).

Swidden. Fig. 6 Manioc planting. Kuri, Honduras. Recently planted manioc stem; from this a new plant will grow. Miskito Indians, January 1981 (photo by Karl H. Schwerin).

Swidden. Fig. 5 Mamo: planting manioc. Mamo, Venezuela. Juan Guevara planting a manioc cutting with his machete. Karinya Indians, March 1962 (photo by Karl H. Schwerin).

Swidden. Fig. 7 Mamo: bananas, manioc, curagua. Mamo, Venezuela. A mixed planting. A strong fiber is extracted from the leaves of the curagua (*Brocchinia* sp.). Karinya Indians, April 1962 (photo by Karl H. Schwerin).

Swidden agriculture is often characterized as unproductive and destructive of soil fertility. In fact, during the first 1–3 years it is generally more productive than most permanent fields. The ash provides ready nutrients and there is little competition with other plants. The return on labor investment is even more rewarding.

After a few years productivity typically declines. Traditionally this was blamed on exhaustion of the soil. Extensive research indicates that this is due not so much to declining soil fertility, as to invasion by weeds and grasses which compete with crops for space and

Swidden. Fig. 8 Mamo: weeding field. Mamo, Venezuela. Juan Guevara weeding field with machete and garrabato. Karinya Indians, March 1962 (photo by Karl H. Schwerin).

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Swidden. Fig. 9 Cachama: Teresa Tamanaico pulling up manioc tubers. Cachama, Venezuela. Karinya Indians, July 1962 (photo by Karl H. Schwerin).

Swidden. Fig. 11 Cachama: Delia and Teresa Tamanaico stripping manioc tubers. Cachama, Venezuela. Karinya Indians, July 1962 (photo by Karl H. Schwerin).

Swidden. Fig. 10 Cachama: harvesting manioc. Cachama, Venezuela. Miguel Tamanaico and Delia Tamanaico harvesting manioc tubers. Karinya Indians, July 1962 (photo by Karl H. Schwerin).

Swidden. Fig. 12 Mamo: swidden cleared and uncleared. Mamo, Venezuela. Field of Juan Guevara with cleared ground in foreground, second growth of 1 year in middle ground, and uncleared wooded area in background. Karinya Indians, March 1962 (photo by Karl H. Schwerin).

nutrients. A further motivation for abandonment is that this tangled growth becomes a magnet for vermin, insects, and disease. Thus the farmer logically seeks out a new spot in virgin forest to clear another plot free of problems (Fig. 12).

Contrary to popular belief, this does not necessitate periodic village movement. Robert Carneiro has shown that 500 people practicing swidden agriculture could subsist permanently on 6,000 acres located within a 3-mile radius of their village. Other explanations based on social, political, or religious factors must be sought for the practice of moving villages.

There is much debate about the “backward” and “deleterious” effects of swidden agriculture. When practiced by a sparse, widely dispersed population, it does not seem to harm the ecosystem, and may in fact prove beneficial by opening up the forest canopy and stimulating new growth. Some ecologists believe that the equilibrium state under aboriginal conditions was grounded on periodic swidden clearing. On the other hand, when population growth intensifies clearing to a point where the forest can no longer regenerate itself, the result will be widespread environmental degradation. Throughout Latin America recent programs of development have led to widespread deforestation, replacement of swidden agriculture with more extensive systems such as livestock pasturing or machine cultivation, and resulting ecological degradation.

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Takebe Katahiro

JOCHI SHIGERU

Takebe Katahiro was born in 1664 at Edo (now Tokyo). His father, Takebe Naotsune, was a *Yuhitsu* (secretary) of the Shogun. In 1676, when he was 13 years old, he and his elder brother Takebe Kataaki (1661–1716) became pupils of SEKI Kowa (d. 1708) and studied mathematics. The Takebe brothers and Seki Kowa were colleagues in the Shogun's government, and their families were the same rank: 300 *koku*.[1]

Takebe's mathematical works are in three fields. One concerns completing the *tenzan-jutsu* or *endan-jutsu* (lit. addition and subtraction methods, Japanese algebra system), which was created by Seki Kowa. In the second work Takebe created the *tetsu-jutsu* (inductive methods). Using these methods he obtained the formula of $(\arcsin\theta)^2$. In the third, for computing the approximate value of fractions, he solved the Diophanine equations using the *reiyaku-jutsu* (continual division method). Takebe also worked in astronomy and geography.

In 1683, Takebe wrote his first work, *Kenki Sampo* (Studies for Mathematical Methods). The book provided counter-arguments for Saji Ippei's *Sampo Nyumon* (Introduction to Mathematical Methods, 1680). Saji had criticized Seki Kowa's *tenzan-jutsu* system in the *Hatsubi Sampo* (Mathematical Methods for Finding Details, 1674) and solved Ikeda Masoki's problems in the *Sugaku Jojo Orai* (Textbook of Mathematical Multiplication and Division, 1672). Takebe made good use of the *tenzan-jutsu* method for solving Ikeda's remainder problems.

Takebe commented on Seki Kowa's *Hatsubi Sampo* and published the *Sampo Endan Genkai* (Commentaries for Japanese Algebra System), in 1685. This is one of the best books for studying the *tenzan-jutsu* method.

Chinese mathematicians in the Song and Yuan dynasties used counting rods to solve higher degree equations of more than the fourth degree. There were two color symbols in the counting rods: red rods were plus and black were minus. They had no symbols to express power; the position of the rods on the counting board indicated the powers. Therefore, the system could not indicate complex expressions. For example, $1/(x-1)$, that is $(x-1)^{-1}$, was very difficult to indicate by that system. Seki Kowa abandoned the counting rods system and created algebraic symbols, which used Chinese characters for calculation with figures. This might be the first example of creating Japanese mathematics from the Chinese.

Takebe commented on the most important Chinese algebraic text in Japan at that time, *Suanxue Qimeng* (Introduction to Mathematical Studies, Zhu Shijie, 1299). He published the *Sangaku Keimo Genkai Taisei* (Complete Works of Commentaries on Suan Xue Qi Meng) in 1690. Seki Kowa and the Takebe brothers started to compile an edition of the mathematical works of *Seki-ryu*, Seki Kowa's school. After Seki died, Takebe Katashiro continued this work and published *Taisei Sankyo* (Complete Mathematical Manual) about 1710.

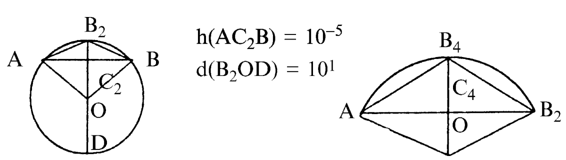
Takebe's main work is the *tetsu-jutsu* method, a sort of inductive method. He computed small natural numbers and then predicted infinite numbers. The computation was helped by the algebraic symbols of the *tenzan-jutsu* method. Using these methods, Takebe obtained the formula of $(\arcsin\theta)^2$. He computed the length of curve AB (hereafter s) using the diameter d and the length of straight line AB (h).

Takebe set up $d = 10$ and $h = 10^{-5}$. Then letting the half point of straight line AB be C_2, and the half point of curve AB be B_2, he computed the length of AB_2 (h_2). Then he computed the length of AB_4 as h_4, and continued to compute h_8, h_{16}, h_{32} and h_{64}. Takebe computed h_∞ using a sort of infinity series *zoyaku-jutsu* (extra division method), and obtained h_∞.

$$\left(\frac{s}{2}\right)^2 = 10^{-4} \times 1.000\,000\,333\,333\,411\,111\,225\,396\,906\,666\,728\,234\,776\,947\,959\,587\ldots$$

$$h(AC_2B) = 10^{-5},$$

$$d(B_2OD) = 10^1.$$



[1] His annual salary was 300 *pyo* (1 pyo was 60 kgs of rice), which is the same as a landlord of 300 person village.

Second, he indicated this value using h and d. The power 10^{-4} is h by d, and the approximate value of the coefficient is 1. Therefore,

$$\left(\frac{s}{2}\right)^2 = 1hd + 10^{-10} \times 0.333\,333\,511\,111\ldots.$$

Then he used the same method. The power 10^{-10} is h^2, and the approximate value of the coefficient is 1/3 using the *reiyaku-jutsu* method,

$$\left(\frac{s}{2}\right)^2 = 1hd + \frac{1}{3h^2} + 10^{-16} \times 0.177\,777\,992\ldots.$$

Takebe continued to compute as above, and he set the series as

$$\left(\frac{s}{2}\right)^2 = A_0 + A_1 + A_2 + A_3 + A_4 + \cdots.$$

He obtained

$$A_0 = hd, \quad \frac{A_1}{A_0} = a_1\left(\frac{h}{d}\right),$$
$$\frac{A_2}{A_1} = a_2\left(\frac{h}{d}\right), \quad \frac{A_3}{A_2} = a_3\left(\frac{h}{d}\right), \ldots$$
$$a_1 = \frac{1}{3}, \quad a_2 = \frac{8}{15}, \quad a_3 = \frac{9}{14}, \quad a_4 \frac{32}{45}, \ldots$$

He expanded them to the general series of a_n, which was

$$A_n = \frac{2n^2}{(n+1)(n+2)}.$$

Therefore Takebe obtained the formula

$$\left(\frac{s}{d}\right)^2 = 2\sum_{n=0}^{\infty}\left(\frac{(n! \times 2^n)^2}{(2n+2)!} \times \frac{h^{n+1}}{d^{n-1}}\right).$$

Takebe had no notion of triangle functions. However, if we set

$$\theta = \sqrt{\frac{h}{d}},$$

we can obtain arcsin $\theta = s/(2d)$. Therefore, his formula has the same value as the formula

$$(\arcsin\theta)^2 = 2\sum_{n=0}^{\infty}\frac{(n! \times 2^n)^2}{(2n+2)!} \times \theta^{2n+2}.$$

This work was described in the *Fukyu Tetsu-jutsu* (Inductive Methods) in 1722, and the special manuscript was sent to to Shogun in 1730.

The key method of *tetsu-jutsu* was computing the approximate value of decimal fractions. He named it the *reiyaku-jutsu*, which used the Euclidean algorithm to compute the value of continuing fractions. For example, to try to compute the approximative value of π using this method, we set;

$$\pi_n = 3.1415926, \quad \text{or} \quad 3 + \frac{1,415,926}{10,000,000}.$$

First, divide 10,000,000 by 1,415,926; the quotient q_1 is 7 and the remainder r_1 is 88,518. Next, divide the former divisor 1,415,926 by the remainder r_1; the quotient of q_2 is 15 and the remainder r_2 is 88,156. Next, divide the former divisor r_1 by the newer remainder r_2, and the quotient q_3 is 1 and the remainder r_3 is 362. Continuing this algorithm, the quotients are:

$\{q_1, q_2, q_3,\ldots, q_n\} = \{7, 15, 1, 243, 1, 1, 9, 1, 1, 4\}$,

$p_1 = 3 + 1/7 - 22/7 > \pi_n$,

$p_2 = 3 + 1/(7 + 1/15) = 333/106 < \pi_n$,

$p_3 = 3 + 1/(7 + 1/(15 + 1/1)) = 355/113 > \pi_n$.

$p_{2k} = q_0 + 1/(q_1 + 1/(q_2 + 1/q_3 + 1/(q_4 + + 1/q_{2n} + 1))) < \pi_n$,

$p_{2k+1} = q_0 + 1/(q_1 + 1/q_2 + 1/(q_3 + 1/(q_4 + + 1/q_{2n} + 1))) > \pi_n$.

The value of p_1 and p_2 had already been computed by the Chinese mathematician, Zu Chongzhi (429–500). Takebe concluded that Zu Chongzhi also invented the same method as his own *reiyaku-jutsu* and Zu Chongzhi's significant figures were seven decimal places, the same as the above computation. He admired Zu Chongzhi and named his book *Fukyu Tetsu-jutsu*; the title was connected with Zu Chongzhi's *Zhui Shu*.

In 1723, Takebe made a map of Japan under the order of Tokugawa Yoshimune, the eighth Shogun, this map is now lost. That year Takebe became a *Yoriai* (adviser) of the Shogun.

Shogun Yoshimune already permitted the import of foreign scientific books in 1720, if they were not related to missionaries. Knowledge of Western astronomy was imported in some Chinese translations. Takebe and his student, Nakane Genkei (1662–1733) translated Mei Juecheng's *Li Suan Quan Shu* (Complete Works of Calendar and Mathematics, 1723) and sent the manuscript (Japanese name *Rekisan Zensho*) to Yoshimune in 1733. It was published and read by many Japanese scholars. Kepler's newest opinion, the elliptical orbit of planets, however, was hidden by the missionaries who advised Mei Juecheng. It became known to the Japanese after Asada Goryu (1734–1799) translated Kepler's (Part 2 of) *Li Suan Quan Shu*.

Takebe was held in honor by Yoshimune, and he became a *Hoi* (Knight), and held successively better positions. In 1733, he retired, and he received a life annuity of 300 *pyo*. He died on July 20, 1739 (August 24, 1739 in the present calendar) at Edo.

Takebe was one of the best mathematicians in Japan. The Mathematical Society of Japan has presented the Takebe Katahiro Prize since 1996.

See also: ►Computation: The Chinese Rod Numeral System, ►Asada Goryu, ►Seki Kowa, ►Mathematics in Japan

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Tang Shenwei

HONG WULI

Tang Shenwei was a medical practitioner of the eleventh century. He was a native of Chongqing, Sichuan Province with the surname Shenyuan, and later he moved to Chengdu in the same province. He was born to a family of many generations of physicians and was an expert in medical science. During the Yuanyou period (1086–1094) of the Song Dynasty, his tutor was Li Duanbo. Tang inherited his tutor's medical knowledge and became quite adept at treatment. He was very virtuous, also he responded to any patient's call and never refused to see a patient, whether rich or poor. The only payment he asked was knowledge about a certain herb or an effective recipe (Tang 1957).

He was especially conversant in the herbal art. He compiled a 32-volume *Materia Medica of Classified Syndromes* which was based on the combination of two other existing herbological works, the *Jia you ben cao* (*Jiayou Materia Medica*) and *Tu jing ben cao* (*Illustrated Classic of Materia Medica*). He added a large amount of new material extracted from the classics of philosophy, history, and other branches of the natural and social sciences, as well as the Buddhist canon, with a total number of 1,746 herbal drugs (Tang 1904). In the field of traditional pharmacology, in addition to absorbing the knowledge inherited from earlier practitioners, he was full of initiative and creativity. Most of his experience was derived from his own long-term practice. He enriched the traditional herbological work by adding processing methods and effective recipes for each herb. Meanwhile, he was also a proficient clinical physician. He created a new style of combining medical practice with herbal knowledge to form the principle of "verifying the drug by recipes", which was quite helpful to clinical practitioners, thus pushing medical science forward a step further. His work was treated as an officially promulgated book on materia medica and circulated for several hundred years (Shang 1989). His working methodology and epistemology were praised and copied by later scholars in the same field. Tang exerted an especially profound influence on the work of the great naturalist of the Ming Dynasty, Li Shizhen.

See also: ▶Medical Ethics in China – Li Shizhen

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Tao Hongjing

FABRIZIO PREGADIO

The Daoist (Taoist) master, alchemist, and pharmacologist Tao Hongjing was born in 456 near modern Nanjing. He served in various positions at the courts of the Liu Song and Qi dynasties until 492. In that year he retired to Mount Mao, the seat of Shangqing or Supreme Purity, a Daoist tradition based on meditation and visualization techniques. The retreat he built on the mountain was to remain the center of his activities until his death in 536.

After his initiation into Daoism around 485, Tao set out to recover the original manuscripts, dating from about one century before, that contained the revelations at the source of the Shangqing tradition. Tao authenticated and edited the manuscripts, and wrote extended commentaries on them. This undertaking resulted in two texts completed in ca. 500, the *Zhengao* (Declarations of the Perfected) and the *Dengzhen yinjue* (Concealed Instructions on the Ascent to Perfection, only partially preserved). These and other works make Tao Hongjing the first systematizer of Shangqing Daoism, of which he became the ninth patriarch.

Since the establishment of the Liang dynasty in 502, Tao enjoyed the favor of Emperor Wu (r. 502–549), on whom he exerted remarkable influence. Shortly after, he began to devote himself to alchemical practices under imperial patronage. His main biographical source, written in the Tang period, has left a vivid account of these endeavors. Along with scriptural sources they testify to the importance of alchemy within the Shangqing tradition, which represents the first known instance of close links between alchemy and an established Daoist movement.

A third text on which Tao Hongjing worked during his retirement on Mount Mao was the *Bencao jing jizhu*, a commentary on the earliest known Chinese pharmacopoeia, the *Shennong bencao*. The original text contained notes on 365 drugs. To these Tao added 365 more, taken from a corpus of writings that he refers to as "Separate Records of Eminent Physicians." Tao's arrangement of the materia medica was also innovative. He divided drugs into six broad categories (minerals, plants, mammals, etc.), and retained the three traditional classes of the *Shennong bencao* only as subdivisions within each section. In a further group he classified the "drugs that have a name but are no longer used [in pharmacology]." Tao's commentary discusses the nomenclature, notes changes in the geographical distribution, and identifies varieties; it also includes references to the Daoist *Xianjing* (Books of the Immortals) and to alchemical practices. With the exception of a manuscript of the preface found at Dunhuang, the *Bencao jing jizhu* is lost as an independent text, but has been reconstructed based on quotations in later sources.

See also: ►Alchemy in China

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Taqī Al-Dīn

Sevim Tekeli

Taqī al-Dīn, Muḥammad al-Rāṣid ibn Maʿrūf, was a mathematician and astronomer. He was born in Damascus in 1521 and died in about 1585. He wrote several books on mathematics, astronomy, optics, and theology.

The most important of his books are: *Jabr wa'l-Muqābala* (Algebra), *Bughyat al-Ṭullāb min ʿilm al-Ḥisāb* (The Desire of Students for Arithmetic), *Sidrat al-Muntahā fī al-Afkār* (The Nabk Tree of the Extremity of Thoughts), and *Ālāt-i Raṣdīya li Zīj-i Shāhinshāhīya* (Observational Instruments of the Emperor's Catalogue), *Al-Kawākib al-Durrīya fī Bengamāt al-Dawrīya* (The Brightest Stars for the Construction of Mechanical Clocks).

From the point of view of the history of Ottoman science, the most important event of the sixteenth century was the foundation of the Istanbul Observatory, which Taqī founded under the sponsorship of Murād III (1574–1595). This observatory was an elaborate building which contained dwelling places, a library, and offices for the astronomers. It was conceived as one of the largest of the observatories of Islam and was comparable to Tycho Brahe's (1546–1601) Uranienborg Observatory built in 1576, equipped with the best instruments of his time in Europe. There is a striking similarity between the instruments of Tycho Brahe and those of Taqī al-Dīn.

The instruments of the observatory included the following. First there were those originally constructed by Ptolemy: the armillary sphere, the parallactic ruler, and the astrolabe. Then there were those invented by Muslim astronomers, such as the azimuthal and mural quadrants. Taqī al-Dīn invented the *mushabbaha bi'l manāṭiq* (sextant, an instrument with cords for the determination of the equinoxes), which was also an important invention of Tycho Brahe. In addition, he built a wooden quadrant for the measurement of azimuths and elevations, and clocks for the measurement of right ascensions of the stars. The latter was one of the most important discoveries in the field of practical astronomy in the sixteenth century, because in the beginning clocks were not accurate enough to be used for astronomical purposes.

In *The Astronomical Instruments of the Emperor's Catalogue* the author says, "The ninth instrument is an observational clock." The following statement is taken from Ptolemy: "I could have freedom of action if I were able to measure the time accurately. Now our master Taqī al-Dīn, with the help of God, upon the instructions of the Sultan, planned the observational clocks." *In The Nabk Tree of the Extremity of Thoughts* Taqī al-Dīn says, "We constructed a mechanical clock with three dials which show the hours, the minutes, and the seconds. We divided each minute into five seconds." On the basis of his observations, Taqī al-Dīn prepared astronomical catalogues and books.

Hipparchos (second century BCE) used the intervals of seasons for the calculation of the solar parameters. But the variation of the declinations around the tropics in 1 day rendered difficult the correct determination of the beginning of the seasons. In spite of this difficulty, the method was used for a long time. After him, al-Bīrūnī (d. ca. 1048), Copernicus (1473–1543), and Tycho Brahe were interested in this subject, and used a new method called "three points observation." Taqī al-Dīn, a contemporary of Tycho Brahe, says the following in *The Nabk Tree*: "The moderns follow the method of three points observation, two of them being in opposition in the ecliptic and the third in any desired place." This method was an important contribution to astronomy. By using this method, Copernicus, Tycho Brahe, and Taqī al-Dīn calculated the eccentricity of the orbit of the Sun, and yearly mean motion of the apogee. According to Copernicus the eccentricity is 1p 56′; according to Tycho Brahe it is 2p 9′, and according to Taqī al-Dīn it is 2p 0′ 34″ 6‴ 53⁗ 41′⁗ 8″⁗. As compared to modern calculation, Taqī al-Dīn's is the most accurate value. According to Copernicus the annual motion of the apogee is 24″; to Tycho Brahe it is 45″, and to Taqī al-Dīn it is 63″. Its real value is 61″. As far as world astronomy is concerned, Taqī al-Dīn's results can be said to be the most precise in the calculation of solar parameters.

The next important contribution of Taqī al-Dīn concerns the use of decimal fractions, the system of numerals formed from initial letters, used in the Hellenic world. This system hindered the development of algebra.

Al-Khwārizmī (d. 801) presented the decimal system which was inspired by Indians to the Islamic world. The application of this to fractions started with Abū'l-Ḥasan Aḥmad ibn Ibrāhīm al-Uqlīdīsī and continued with al-Kāshī (d. 1437). But its application to astronomic and trigonometric tables was realized by Taqī al-Dīn. Thus the tables of his *zīj* named Kharīdat al-Durar (*unbored pearl*) and a *zīj* were prepared using the decimal system and decimal fractions.

See also: ►Observatories, ►Clocks and Watches, ►Ottoman Science, ►Astronomical Instruments, ►Quadrant

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Technology

Arnold Pacey

The development of technology has usually been socially determined, changing in direction as different social formations have emerged. For example, there are important distinctions to be made between, first, small communities of farmers or dispersed groups of hunters with technologies outstanding chiefly for their adaptation to local *environments*; second, the larger kingdoms and empires, whose technology tended to be *engineering-centered*; and third, trading communities and merchants or entrepreneurs with *production-centered* technologies.

An initial problem in discussing technologies of the first kind is nomenclature. Weiner, who has discussed the remarkable protective clothing developed by the Inuit for life in the Arctic, has described these people as "the great pioneers of microclimatological bioengineering." This tribute to the control of body heat loss achieved by Inuit clothing is well deserved but places the skills of Arctic people within the wrong frame of reference. Their technology was environment-centered, not engineering-centered. On the one hand, they were adapting to a very demanding environment; on the other, they were making very efficient use of environmental resources. Thus, the animals hunted for meat were also a source of oil for lamps, bone for making needles and other tools, and the skins, intestines, and fibers from which clothing was made.

Archaeological evidence suggests that the invention of tailored skin clothing adequate to enable people to winter in the Arctic was accomplished in Siberia around 2000 BCE. After that, it was several centuries before oil lamps, houses built of snow, and dog sleds were developed by the people of the Dorset Culture, based on Baffin Island. Later still, improved boats and harpoons were developed by the Alaskan Inuit.

All these inventions, quite clearly, were the work of small, dispersed groups without centralized organization, and all were responses to an exacting environment. Perhaps what we ought also to remember is that for the Inuit, as for most non-Western peoples, the environment was endowed with personal and spiritual meanings, and with magical qualities. It was not merely the object of detached, if concerned, analysis that it has become for most Westerners. Thus, their technology was based on an organic world view.

The same points can be made about peoples inhabiting other environments, such as rainforests, deserts, steppes, or coastal and island situations. The efficiency with which resources were used by such people is illustrated by the estimate that in AD 1500 the Amazon basin supported a somewhat larger population than it did in 1990, yet without the extent of destruction of forest and fishery resources now taking place. Fruits, nuts, leaves, seeds, and roots were gathered for use as food and medicine. Fish and animals were caught, often using poison tipped spears, but with less ecological disturbance.

In some rainforests, notably in Central America as well as in Asia and Africa, people developed a form of agriculture in which a great variety of crops was raised while extensive tree cover was retained. Cereals such as corn in the Americas or rice in Southeast Asia were grown in forest glades with shade tolerant vegetables under trees. Those trees that were left unfelled or were newly planted would be selected according to whether they produced fruit, nuts, timber, fodder, or *materia medica*. Thus, an artificial rainforest was formed in a system often referred to as forest farming, forest interculture, layered gardening or, more recently, agroforestry. The key point – whatever the name – is that there would always be tree cover, and usually other vegetation, to protect the soil from erosion and to retain plant nutrients. By contrast, where rainforest is cleared for conventional western style agriculture, soils become degraded very rapidly.

In Africa, rainforest crop production became widespread only after the banana and Asian yam were introduced on the east coast by Indonesian traders and colonists around AD 400–500. In quite a short space of time, these crops were adopted by many gardeners across the continent, enabling populations in forested areas to increase considerably. In Central America, archaeologists have now shown that the Maya culture used forest farming with high yielding nut trees and manioc (cassava) as major crops around AD 600–900.

Other environment-centered technologies were those of people living in hot, dry, semidesert conditions who evolved sophisticated water conservation techniques. Some of these made use of small structures, such as check dams in gullies and spreader dikes on flatter ground – for example, in northern Mexico and Arizona – or else stone lines on contours (in the African Sahel). Others practiced the careful planning of fields in relation to rainwater catchment areas, and the construction of bunds to channel water and hold it on the land. Among the most elaborate rainwater harvesting systems of this kind were those of Nabataean farmers in the Negev Desert in Israel from about 200 BCE, and comparable systems in Morocco and elsewhere in North Africa. Small dams, river diversions, and the Persian *qanat* (wells linked by a tunnel) were other means of providing irrigation water to crops on a small scale.

Consideration of environment-centered techniques such as these offers a distinct perspective on early technology quite unlike the conventional view based on the materials from which tools were made, namely, stone, bronze, and iron. That view seeks to discover a pattern of tool use and metal-working skill common to all human societies, and ignores the environmental particularism emphasized here. It parallels the modern assumption that the principles of technology are independent of cultural values and underestimates the different ways in which human societies explored the varying surroundings in which they lived. By contrast, a perspective based on environmental adaptation allows one to recognize the extraordinary sophistication of some peoples who nominally remained in the "Stone Age" even in the early twentieth century, including the Inuit and some rainforest communities.

Viewed from another angle, however, the Neolithic period in the later Stone Age does seem to have been a time of particularly important innovation, at least for western Asia. It is associated with the first domestication of crops and livestock, and hence the invention of agriculture, probably associated with the earliest use of some of the water conservation techniques previously discussed. Complementing these innovations were others, such as pottery (and soon after, the potter's wheel), grain milling, tool-making, and textiles (with the looms on which they were woven). Many of these innovations relate to the domestic sphere of life, and it is likely, therefore, that many of the inventors concerned were women.

It would be a mistake, however, to assume that the invention of agriculture, the domestication of plants, and the appearance of pottery or textiles were unique events, each occurring only once in human history, in one part of Asia and then diffusing to other regions. Independent inventions undoubtedly occurred, just as different crops were domesticated in various places and at different times. For example, about 1500 BCE, corn (i.e., maize) and pottery were both known in Mexico, but not in Peru, where beans and peppers were cultivated. Thus, the two cultures may have developed agriculture independently of one another. Moreover, some plants were still being newly domesticated in the twentieth century, for one reaction to deforestation in Africa has been to cultivate a number of fruits and vegetables that people had collected from the wild until the loss of forest cover threatened their existence.

Reports from Kenya show how modern gardeners, usually women, have selected from wild varieties and have produced strains adapted for garden conditions.

Engineering-centered technologies developed in a very different context. They were characteristic mainly of kingdoms or empires whose labor resources and administration made large scale construction works possible. One view of the origins of engineering is that once agriculture was established, irrigation became necessary in many of the warm, dry countries of western and southern Asia to produce sufficient food for growing populations. The dams and canal systems necessary for irrigation could not have been constructed, it is argued, without recruiting a large labor force, and that in turn could not have been done except in centrally organized kingdoms. In this view, the need for irrigation canals and other hydraulic works dictated the formation of centralized government administrations with the coercive power and management skills needed to organize large scale construction works.

This theory about how hydraulic civilizations evolved does not apply everywhere, however, since empirical evidence shows that in many areas where irrigation was practiced, farmers did the essential earth moving and engineering work themselves, or with their neighbors through local systems of cooperation, but without central organization. This seems to be true for rice culture in China, according to Francesca Bray. Some of the biggest centrally organized engineering schemes prior to AD 605, involving thousands of laborers, were not for irrigation but for construction of transport canals for carrying grain to the capital. However, flood control and irrigation in north China did depend on large scale works, so the evidence is not clear cut.

In Mesopotamia and Egypt, much early irrigation was also on a small scale, dependent on manually operated water raising devices such as the *shaduf*. The type of crops grown and the seasons of cultivation meant that water requirements in early agriculture were much less than after the agricultural revolution of the Islamic period (after AD 700), when crops that demanded more water (including rice) were more widely grown. In Mesopotamia, large scale works were needed at an early date, but in most places it is hard to argue that the requirements of hydraulic management were sufficiently exacting to determine the development of centrally organized states. On the contrary, the prior existence of centralized political power made possible a wide range of construction programs that included fortifications, monuments, and temples, as well as hydraulic works, and it is impossible to say which kind of engineering came first. One of the earliest sites to provide evidence is Jericho, where defensive walls, but also big water tanks, have been found dating from before 6000 BCE. The pyramids of Egypt were among the largest construction projects ever conceived when they were begun about 2600 BCE. But a comparable amount of labor may have gone into embankments and canals built at about the same time for flood control and irrigation by the Sumerians in Mesopotamia. Thus, the evidence does not give a clear picture of hydraulic requirements, rather than other construction works, forcing the pace in either administration or engineering.

That brings us to a second hypothesis about how engineering-centered technologies evolved, suggested by Lewis Mumford and some like-minded commentators. This is the view that such technologies were related to the invention of institutionalized warfare. In early societies, conflicts were sometimes wantonly violent, but some groups had customs that enabled one side to signal a surrender before serious injuries were inflicted. Among a few isolated peoples in Africa and Oceania, conflicts between communities were still like this until recently, and observers note that, if somebody was killed, the combatants were so shocked that fighting immediately stopped. A ceremonial burying of spears and an exchange of cattle or captives would then settle outstanding issues.

Organized, lethal warfare had to be invented, perhaps during the Neolithic period, and possibly following the invention of agriculture, since agriculture made possible denser populations within which tensions could be greater. Also, agriculture produced the economic surplus needed to pay for arms and fortifications. The suggestion is that military institutions evolved from about this time and provided a model of how large bodies of men could be recruited, disciplined, and supervised while constructing fortifications, pyramids or hydraulic works. Many instances can be quoted of the administration of hydraulic installations based on military routines. In later times, at Marv in northern Iran, a water storage dam below the city was looked after by 400 “guards” who minutely regulated and recorded all outflows of water. The head of the water office had more authority than the local police chief, and when repairs to the dam or canals were necessary or when new works were needed, he could call up 10,000 people to do the work.

The development of warfare provided much other stimulus to engineering-centered technology. Mechanized fighting may be said to have begun with the clumsy, four-wheeled Sumerian chariot of about 2400 BCE. The Hittites, whose empire overlapped Asia Minor and Syria, invented some of the first effective siege engines around 1600 BCE and introduced the first iron weapons soon after. Horses were initially used mainly for drawing chariots, their full potential for warfare only emerging much later with the invention of the stirrup and its associated harness. This freed the rider’s arms to use weapons while he remained securely in the saddle.

The most famous of military inventions was, of course, gunpowder, known by AD 900, used in rockets by about 1100, and in guns before 1288. These inventions, developed within Chinese military institutions, were stimulated by earlier Indian discoveries about the chemical behavior of saltpeter, and by the use of incendiary weapons for naval warfare in Southeast Asia. The latter often depended on petroleum, obtained from surface oil seepages on the island of Sumatra. Although guns evolved more rapidly in Europe after 1300, China was the source of many ideas for gunpowder siege weapons used in the Arab world, and there were transfers of Chinese firearms technology to Korea and Thailand.

Considerable resources were needed for manufacture of the heavy cannons that had become widespread by 1500, and only the larger Asian empires could afford them in any number – but those that could were then able to expand their territory and consolidate their power. In India, the Mughal Empire's arsenals and gun-casting capability were important for its expansion between 1526 and 1700 In Persia also the new technology had a centralizing, consolidating influence during the reign of Shah Abbas (1587–1627), though his empire depended less on guns than did the powerful Ottoman or Turkish Empire, an exporter of guns and know-how. Given that most cannon were cast in bronze, McNeill has called this period a "second bronze age", referring to "gunpowder empires" not only in connection with Turkish, Persian, and Mughal rule, but also in relation to China and the Russian Empire in Asia.

The ships used in naval warfare and trade in Southeast Asia were of sewn construction, with rattan fiber holding together carefully fitted timbers in a flexible hull suited to landing on sandy beaches. They usually had outriggers and tripod masts to support sails, and regularly crossed the Indian Ocean. The Chinese, meanwhile, were building larger ships whose wooden hulls were held together with iron nails and had watertight bulkheads. China was also developing inland water transport on a large scale. The canals had ramps and spillways for moving boats between one level and another, but also incorporated the first pound locks and lock gates, introduced in AD 983 (a precisely dated invention).

One Western bias in understanding technology is a tendency to focus on the wheel and machines using wheels. But wheels did not always mean progress. Wheeled vehicles were used in the north and west of Africa around 500 BCE, regularly crossing the Sahara Desert. Yet they went out of use later when the camel was introduced, because camels provided much more efficient means of transport in a region with sandy deserts and no paved roads. For parallel reasons, wheeled vehicles were not much used in southern Asia. In Central America, rollers and wheeled toys have been found, but in a region where there were not animals capable of pulling carts, no purpose could be served by developing such devices.

The potter's wheel (and later lathes working on similar principles) were probably the first machines, around 3000 BCE, to use the wheel. Much later, a basic water powered corn mill evolved, with a vertical axle and propeller like blades below the millstones. One view is that this was a Greek invention made about the time of Alexander the Great. Another view, however, is that it arose out of the Hittite tradition of engineering which had earlier pioneered so much military equipment. After the Hittite empire collapsed around 1200 BCE, some aspects of its culture survived in Syria, and itinerant craftsmen perhaps reached Mesopotamia and Iran. It was probably in one of these countries that water mills originated. Since the same type of mill appeared in China not long afterwards, one might reasonably look for its origins close to trade routes with China. As for the introduction of the mill into Greece, this could be a by-product of Alexander's expedition through Iran to the Indus River in 330–323 BCE.

Some thousand years later, Iran was certainly where an early type of windmill was invented. It worked in much the same way as the vertical axle water mill, though mounted in a tower with vents in the walls to catch the wind.

Mumford sees these inventions as part of the tradition of innovation stemming from small dispersed communities rather than from centrally organized states. However, at Baghdad, which had about one million inhabitants in AD 1000, corn milling was carried out by a series of floating mills on the Tigris River which operated continuously, night and day. The water wheels were of the later undershot type, driving millstones through wooden gears. Other uses of water power in Iraq and Iran by AD 1000 were in sugar cane crushing mills, fulling mills, and mills for preparing the pulp for papermaking. Paper manufacturing had been introduced at Baghdad in AD 794, probably with the help of Chinese workmen, and pulping was water powered from about AD 950.

In all these instances, it would seem, we are no longer dealing either with the environment-centered technology of dispersed communities, nor with the labor intensive engineering of powerful centralized states. Rather, we are seeing the emergence of production-centered technologies in expanding industries. An even more striking example can be cited from northern China, associated with the use of blast furnaces for iron production. Methods of achieving high temperatures in furnaces were highly developed in China's porcelain industry as well as in metal smelting. Chinese iron masters had pioneered blast furnaces capable of melting large batches of metal, and output rose steadily to a peak in AD 1078. Moreover, the furnaces were owned and run by independent entrepreneurs whose market oriented, proto-capitalist operations are seen by McNeill as marking a turning point in world history.

More evidence that technology in China was moving into a new phase is provided by the great flowering of mechanical devices that were introduced there in the three or four centuries prior to 1250. They included spinning wheels, silk winding machines, and most striking of all, water-powered mills for spinning and winding thread of a local type comparable to linen. Some improvements in textile technology were due to women innovators, and many businesses were run in an independent, entrepreneurial style.

By contrast, much manufacturing in the major Asian empires was directed toward meeting state requirements for armaments, or the needs of royal palaces for luxury textiles, porcelain, and furniture. The most characteristic unit of production was the royal factory or *karkhana* in Mughal India, or the specialist porcelain factory or arsenal in China. At one time, 4,000 silk workers were employed in karkhanas in Delhi. Some may have been conscripted, and the factories were run in rather the same way as the labor intensive, state-run engineering works mentioned previously. Such factories were highly successful in meeting government requirements for arms or the court's demand for luxury goods, but could not respond readily to a varying market demand. Production for purposes of trade, and especially for export, flourished most markedly where merchants and other entrepreneurs could function independently. By 1700, India had become the world's greatest exporter of textiles, sending its cotton cloth to Europe, Africa, and many destinations in Asia. Both Indian and foreign merchants were involved, sometimes financed by the many Parsi and Gujarati bankers to be found in ports such as Surat.

It should not be thought, though, that proto-capitalist industrial organization was always favorable to the use of machines, water powered or otherwise. The high quality of Indian textiles was achieved by painstaking handwork and a very fine division of labor. British observers noted that cotton cloth would sometimes be worked on by four people for every one employed on the same tasks in Europe. Thus, the remarkably fine muslin produced in Bengal was the result of many detailed processes which would be simplified and reduced to a single operation in the West.

Indian cloth was also noted for the fastness and brilliance of the colors with which it was dyed, mostly using vegetable dyes, such as indigo and madder. However, some inorganic substances were also needed as mordants, and this gave rise to a significant chemical industry. For example, the alum used in madder dyeing was produced in Rajasthan by processing broken shale tipped as waste around copper mines. The shale was steeped in water. Aluminum compounds were separated from copper salts by differential crystallization. Then a reaction with saltpeter produced the alum. These chemical processes were operated on a substantial scale but using labor intensive methods and minimal equipment. Merchants and banks had ample funds to invest in the textile trade, but because wages were low, there was little advantage in financing better production equipment. Instead, most of the capital available was put into building ships to carry exported cloth. Thus, Indian shipbuilding developed to a very high level in the eighteenth century. Ships were built for Indian merchants and foreign traders, and from 1800 for the British navy. Meanwhile, cotton cloth, dyestuffs, and chemicals continued to be produced by laborious manual techniques.

Similarly in China, there were many flourishing industries, often organized on proto-capitalist lines, but the interest in mechanization evident before 1300 was not sustained, and indeed, some machines went out of use. Silks, porcelain, and cotton goods were produced in quantity, but mainly by labor intensive methods in an economy where wages were tending to fall. But, as in India, the production technologies involved are of considerable interest. Moreover, they are quite distinct from the environment-centered and engineering technologies discussed earlier. It is of particular relevance to observe that printing evolved as a production technology in China, and by 1600 had export markets in Korea and Japan. But the content of the books being printed was dominated by the literary interests of the bureaucrats who served the imperial government. Thus, relatively few books were of significance for the dissemination of technical information. It is worth recalling, though, that the first known printed book, the *Diamond Sūtra*, an extract from the Buddhist scriptures, dates from AD 868, and that by the eleventh century a few books on agriculture were being printed. In AD 1044, Zeng Gongliang published the *Wujing zongyao* (Collection of Military Techniques) that quoted the formula for a weak gunpowder mixture, and in 1313 a remarkable work appeared – *Nong Shu* (Treatise on Agriculture) by Wang Zhen – which, among other things, described water powered spinning mills.

But whatever limited writings there were on technical subjects, either in Islamic manuscripts or Chinese printed books, technology depended far more on knowledge, skill, and technique passed from one craft worker to another through processes of observation, personal contact, and apprenticeship. Nonverbal habits of thought and of getting the "feel" for how a process should work were undoubtedly central for innovation and learning.

Nonverbal communication, often in the form of a visual or experimental dialogue, was also the means whereby techniques were passed from one community or culture to another. Confronted with an unfamiliar product or process, a craft worker would not always copy it directly, but would "question" it to try and work out how the same result might be achieved by more familiar means, or how it might be reinterpreted to suit his or her community's culture or resources. Moreover, this dialogue or questioning approach could at times prompt entirely new lines of thought or innovation. For example, between the sixth and tenth centuries AD, the Chinese picked up ideas from India and Persia about chemistry, dyestuffs, textile printing, windmills, suspension bridges, and other matters. These were developed in entirely new ways as a result of being questioned and reinterpreted rather than being copied, and so contributed to some of the best known of Chinese inventions, including gunpowder and printing.

Between 1100 and 1800, and especially after their voyages of discovery began around 1450, Europeans were continually picking up ideas from other cultures: about water clock mechanisms, chemistry, cooking, and glassmaking from Islamic sources; about gunpowder, firearms, printing, and porcelain manufacture from China; and about metallurgy, cotton textiles, and dyestuffs from India. Few of these techniques were directly copied in any detail, but they became part of a dialogue in which Westerners did most of the questioning and learning – and in which they reinterpreted many techniques in terms of the Western enthusiasm for machines and mechanization.

This source of stimulus contributed significantly to the technology of the European industrial revolution, but that in turn brought a change in attitudes and relationships. A sense of technological superiority coincided with a tendency to use non-Western countries as markets for factory made goods and as sources of raw materials. Local manufactures in many parts of the non-Western world therefore declined. One striking feature of the late twentieth century has been a new openness in the West for dialogue with the environment-centered technologies practiced in the rest of the world. But, again, Westerners are reinterpreting everything they learn in terms of their own outlook, discarding the organic and holistic world views of other peoples and fitting everything into an analytical, scientific frame of reference. Thus, Inuit technology has been discussed in terms of "ice alloys" and "bioengineering" whilst indigenous rainforest technologies are being reinvented as "ethnobotany" and "agroforestry".

See also: ►Ethnobotany, ►Gunpowder, ►Paper and Papermaking, ►Colonialism and Science, ►*Qanat*, ►East and West, ►Western Dominance

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Technology and Culture

Claude Alvares

General accounts of the history of science and technology (or, more narrowly, of inventions) are scarce. The few that are available are also of fairly recent origin: obviously, the idea of a history of science (where science has been identified with Galilean science) and technology (identified with industrial technology) could not have appeared much earlier than this century. Not many people even know that the word "scientist" was first used by William Whewell in 1833.

Also, most available histories have remained the work of western scholars. This has not been an entirely happy circumstance. On the contrary, it has afflicted these histories with certain methodological and other infirmities which have had the effect of reducing them to mythological works. This is especially so when they are studied with regard to aspects of the history of science, technology, and medicine in the non-Western world.

One of the first is a history of technology and engineering written by Dutch historian Forbes. Forbes's work appeared in 1950 under the title *Man the Maker*. In it, he conceded that technology was the work of humankind as a whole, and that "no part of the world can claim to be more innately gifted than any other part." A few years thereafter, Forbes produced his rich and prodigiously detailed *Studies in Ancient Technology* which set out a remarkable description of the different technologies of Asia, Africa, pre-Colombian America, and Europe. However, it is in *The Conquest of Nature* that his Eurocentric assumptions came to the fore: in that work (as the title itself indicates), Forbes went on to subsume the technological experience of people from diverse cultures under a philosophical anthropology that was unmistakably Western, if not Biblical – the domination of nature myth originating in Genesis. And after a discussion about the grievous consequences of a seriously flawed modern technology, he ended his book promising redemption from the technological genie through the Christian event of Easter. How does one prescribe a text like this to Hindu, Chinese, or Arab readers?

Another influential work of about the same period is *A History of Western Technology* by a German scholar, Friedrich Klemm. In it, Klemm provided a picture of technological development in the West in which non-Western ideas and inventions had no hand at all. The English translation which appeared in 1959 barely mentions Joseph Needham's work on China in the bibliography. Klemm could not have substantiated his interpretation of Western technological development unless he consciously played down non-Western technology. In fact, the only quote on Chinese technology in Klemm's book is from the *Guan yin zi*, the work of a Daoist mystic of the eighth century AD: Klemm used it to prove why the alleged religiously colored oriental rejection of the world in China could not have provided a stimulus for the emergence of science and technology in that country.

This distorting Eurocentric perspective continued to hold sway even over the more standard (five volume) *A History of Technology* edited by Charles Singer, Holmyard and Hall. The first volume of this work appeared in the same year as Joseph Needham's *Science and Civilisation in China*, and the editors themselves acknowledged that up to the period of the Middle Ages in Europe, China had the most sophisticated fund of technological expertise. Three of the Singer volumes dealt with preindustrial technology, where logically China (and India) should have been given major space and Western technological development would have appeared in proper perspective in the nature of an appendix. However, Chinese, Indian, and other technologies were ignored and Western technology made the focus of the exercise.

In addition to manifesting such ignorance of non-Western science and technology, these histories suffered from another methodological limitation: they restricted themselves to a record of artifacts and machines disembodied from the latter's social and cultural contexts. The problem was eventually recognized by some Western scholars themselves.

These histories are evidence that the western scholars associated with them proved incapable of stepping out of their cultural cages, either knowingly or involuntarily. Either way, this eroded the credibility of their work as it exhibited both their lack of objectivity and their general incompetence when called upon to deal with societies other than theirs.

They show that our dominant descriptive and evaluatory ideas of technology and culture both in the Western and non-Western world have been formulated over the past couple of centuries with reference to the West's experience of these phenomena. Concepts and categories reflected from a limited area of human experience have been indiscriminately used to explain and assess the rest of the world.

New frameworks are therefore inevitable. We are in the posttraditional, postcolonial, and postmodern age. But unless the outmoded intellectual environment that engendered this subjective and tunnel-visioned output is rigorously dissected, analyzed, and then jettisoned, the new frameworks needed for the alternative histories and encyclopaedias intending to take their place are in danger of turning into copies of the old.

There are two preliminary aspects of this intellectual mal-development that need elucidation. First, there is the perception of humankind as *homo faber*, a tool-making animal, which is basically a reflection of fairly recent Western experience with the machine. Fascinated by the bewildering profusion of tools and machines, Western historians began to look at the ability to produce these as a special field with its own history and set out to create a distinct species of man in the image of *homo faber*. This scholarly creation had its repercussions in encouraging the overestimation of the singularity or uniqueness of Western culture in comparison with others (although all cultures are unique and incommensurate). The elaborate, embarrassing exercise in culture-narcissism soon became routine since it was not to be challenged for nearly a century. (It is important to point out that the *homo faber* idea is quite recent to humankind: it is consistently absent in not just other cultures, but even within a large part of the West itself.)

For instance, it was taken for granted that the system of production that got generated in the last century and a half in the West was the only one with any significance simply because in the light of the present – and to all appearances – it had apparently emerged as the dominant one. Therefore, its past was the only one worth considering. This notion was in turn bolstered by another: a self-generating model of technological development in which the historian attempted to trace the evolution of modern science and technology by working backward to the experiences and ways of thinking characteristic of Mediterranean antiquity. Thus the roots of modern technology were shown to be exclusively founded on the work of Greek and Roman thinkers, mathematicians, engineers, and observers of nature with no input from any other culture areas or people.

This brings us to the second aspect we have alluded to above, and this concerns the relationship between knowledge and power and the impact of this on interpretations of technology and culture. Throughout history, knowledge has generally remained closely linked with interests. Even when encyclopaedias, for instance, have traditionally sold themselves on the Francis Bacon principle that "knowledge is power", they too have continued to reflect an undeclared, equally influential, political principle – that "power is knowledge".

The intrusion of Europeans into non-European societies and the gradual establishing of political dominance and inequality between societies stimulated the inauguration of a new discourse about such societies. Political dominance came to be as routinely and unabashedly expressed in the form of knowledge as it was through the barrel of guns. Edward Said has already written on the invention of the discourse on "Orientalism" and its direct political uses. But there are less controversial discourses that have had even larger repercussions only now being acknowledged. As a result, much academic knowledge in the Western world about the non-Western world, particularly the latter's technology traditions, remains not only distorted or contaminated by the ethnic concerns, goals, theories, obsessions, and peculiar assumptions of Western scholars and universities; it is still largely defined, legitimized, and decided by them irrespective of whether there is any concurrence from the non-Western world.

The combination of these two aspects proved deadly: the emerging conception of Western man alone as *homo faber*, once it took firm roots within the situation of political dominance, rendered any appreciation of technique elsewhere – technique not necessarily reflected only in tools or machines – difficult and often impossible. In fact, the combination helped inaugurate its very own dark age. For it generated among Western (and not a few non-Western) scholars several major assumptions concerning technology and culture. We shall discuss three of these.

The first emerged in relation to Western man's attitude toward the past, particularly with regard to preindustrial technology. *Homo faber* exercised his new found power over the past by deriding it: this is reflected in the rewriting of history from today's perspective in which the past is seen as mere prelude to the present. Earlier technological innovations are considered primitive precursors of later developments. Here we have a good example of the parochialism of the modern/Western mind as it proceeds to take experiences of technology and culture exclusive not just to the late twentieth and early twenty-first centuries but to extremely small segments of the world population and makes these the basis for investigating, analyzing, assessing, and judging the general activities of human societies over hundreds of years. This was the case even when such societies were not so technologically enamored, dependent, or controlled as some of them seem to be now.

The second assumption relates to humankind's so-called unique propensities for technology when compared with that of the animal world, an uncritical theory best summed up in a single word: speciesism. After deciding on the issue of the comparative technological competence of all living species in its own favor, the West came to the conclusion that the rest of creation, because inferior, was expendable if so required to further its own scheme of things.

But it is the third assumption that concerns us most seriously here: it is the idea that Western man can be equally distinguished from non-Western societies as well on the ground that the latter, like the animal and other "lower" species, also lacked technological development as it emerged in the West.

This idea was appropriately reflected in academia in the emergence of two new sciences: the discipline of sociology, which focused on so-called advanced societies and their flair for technology; and the subject of anthropology which occupied itself with non-Western cultures, limited to primitive or preindustrial tools. Anthropology's political origins have been blandly asserted by Claude Levi-Strauss in his controversial Smithsonian lecture:

> Anthropology is not a dispassionate science like astronomy, which springs from the contemplation of things at a distance. It is the outcome of a historical process which has made the larger part of mankind subservient to the other, and during which millions of innocent human beings have had their resources plundered and their institutions and beliefs destroyed, whilst they themselves were ruthlessly killed, thrown into bondage, and contaminated by diseases they were unable to resist. Anthropology is daughter to this era of violence: its capacity to assess more objectively the facts pertaining to the human condition reflects, on the epistemological level, a state of affairs in which one part of mankind treated the other as an object.

It is within such an imperialist context that the histories and technological experience of non-Western societies could be written off or ignored: the latter, after all, were conquered peoples. When technology is seen through an anthropological prism, the emerging picture is bound to be far removed in character from a scenario that emerges from a sociological perspective. What is more, it is bound to be even more far removed from reality itself.

Some impression of that reality is discernible in the period before political dominance began to corrupt the objectivity of knowledge. Before the so-called "voyages of discovery," though non-Europeans were conceived as fantastic, wild, opulent, even monstrous, they were rarely considered inferior or backward; and even the actual European encounter with the scientific, technologic and medical traditions of non-Western societies was different from what eventually became the stuff of politically directed myths. In fact, from the day that the Portuguese mariner Vasco da Gama landed in India until almost three centuries later, Asia had a larger and more powerful impact on Europe than is normally recognized. Donald Lach has appropriately titled the first volume in his *Asia in the Making of Europe* "The Century of Wonder". It was not without reason that an Englishman of the time addressed the Indian Emperor by describing himself as "the smallest particle of sand, John Russel, President of the East India Company with his forehead at command rubbed on the ground." Nor can we forget that the first presents offered by da Gama to the King of Calicut included some striped cloth, hats, strings of coral beads, wash basins and jars of oil and honey. The king's officers naturally found them laughable.

It would take a few more decades before the Europeans landing in the Indian subcontinent would notice anything beyond gold and spices. But by 1720 and for a period of up to a 100 years, a new category of observers came visiting, some from newly formed learned societies in England. Their detailed reports were a result of the European quest for useful knowledge in different fields.

In his pioneering volume, *Indian Science and Technology in the Eighteenth Century*, the Indian historian Dharampal includes several accounts from these observers which describe among others the Indian techniques of inoculation against smallpox and plastic surgery. (While the first was eventually banned by the English, the latter was learnt, adopted, and developed.) The accounts also document Indian processes like the making of ice, mortar, and waterproofing for the bottoms of ships; water mills, agricultural implements like the drill plough, water harvesting and irrigation works, and the manufacture of iron and of a special steel called *wootz*.

More techniques (like those involved, for instance, in the manufacture of Indian textiles) are described in *DeColonizing History* (Alvares 1991) and *Science and Technology in Indian Culture* (Rahman 1984). But even this documentation, impressive as it is, is now recognized to be but the tip of the proverbial iceberg.

The Chinese, like the Indians at Calicut, had a similar experience with an embassy and its gifts from London. The edict of Qian Long to the embassy is worth quoting: "There is nothing we lack, as your principal envoy and others have themselves observed. We have never set much store on strange or ingenious objects, nor do we need any of your country's manufactures" (Fairbank 1971).

Immediately after the encounter, the graph of European reaction rises with esteem and wonder; and then, as political conquest and overlordship increase, the graph alters course and begins to record increasing denigration. A remarkable transformation of image thus takes place as the political relationship between Europe and non-European societies changes to the advantage of the former, rendering the Europeanization of the world picture almost an act of divine will.

By 1850, political dominance over the non-Western world was clearly installing distorted ideas not only about that part of the world but rebounding to distort Western man's image of himself as well. Already by 1835, for instance, the British had acquired a flattering notion of their own civilization (Victorian England was seen to be at the top of the pyramid of civilization) and a thorough-going contempt for Asia.

This contempt finds expression in the famous Minute of Lord Babington Macaulay:

> I have never found one amongst them (the orientalists) who could deny that a single shelf of a good European library was worth the whole native literature of India and Arabia… It is, I believe, no exaggeration to say that all the historical information which has been collected from all the books written in the Sanskrit language is less valuable than what may be found in the most paltry abridgment used at preparatory schools in England. In every branch of physical or moral philosophy the relative position of the two nations is nearly the same.

Dharampal has produced an interesting record of these assessments of science and technology in India among Western observers as the relationship between India and Britain changed to Britain's advantage.

Regarding the question of Indian astronomy, he discusses the case of Prof. John Playfair, Professor of Mathematics at the University of Edinburgh and an academician of distinction. Playfair studied the accumulated European information then available on Indian astronomy and arrived at the conclusion that the Indian astronomical observations pertaining to the period 3102 years BCE appeared to be correct in every text. This accuracy could only have been achieved either through complex astronomical calculations by the Indians or by direct observation in the year 3102 BCE. Playfair chose the latter. Opting for the former would have meant admitting that "there had arisen a Newton among Brahmins to discover that universal principle which connects, not only the most distant regions of space, but the most remote periods of duration, and a De La Grange, to trace, through the immensity of both its most subtle and complicated operations."

Similar attitudes prevailed concerning the knowledge of how Indians produced *wootz*. Heath, founder of the Indian Iron and Steel Company and later prominently connected with the development of the steel industry in Sheffield, wrote "... iron is converted into case steel by the natives of India, in two hours and a half, with an application of heat that in this country, would be considered quite inadequate to produce such an effect; while at Sheffield it requires at least four hours to melt blistered steel in wind-furnaces of the best construction, although the crucibles in which the steel is melted, are at a white heat when the metal is put into them, and in the Indian process, the crucibles are put into the furnace quite cold."

However, Health would not admit that the Indian practice was based on knowledge "of the theory of operations," simply because "the theory of it can only be explained by the lights of modern chemistry."

By the beginning of this century, the Western mind had already convinced itself that Western science and philosophy were the only approach to metaphysical truth ever attained by the human species and that the Christian religion provided wisdom and insight incumbent on all people everywhere to believe.

The result is reflected in the output of academia: a "history of art" turned out to be nothing but a history of European art and a "history of ethics" a history of Western ethics. While European music was music, everything else remained mere anthropology. The contemporary evaluation of human activity in the West as compared with the non-Western world was unabashedly provided by the late Jacob Bronowski in the Ascent of Man in words almost echoing Macaulay in 1837:

> We have to understand that the world can only be grasped by action, not by contemplation. The hand is more important than the eye. We are not one of those resigned, contemplative civilizations of the Far East or the Middle Ages, that believed that the world has only to be seen and thought about and who practiced no science in the form that is characteristic for us. We are active; and indeed we know, as something more than a symbolic accident in the evolution of man, that it is the hand that drives the subsequent evolution of the brain. We find tools today made by man before he became man. Benjamin Franklin in 1778 called man a 'tool-making animal' and that is right.

Now, there were obviously perverse consequences of such a view: scholars in several non-Western societies, schooled in an educational system imposed on their societies through the colonial establishment, readily incorporated similar ideas about their own histories. In an article in *Nature* 35 years ago, Joseph Needham had to chide a native scholar of Thailand for claiming that his own people had not made any contribution to science despite compelling evidence to the contrary. Nevertheless, the colonization project succeeded in convincing many non-European intellectuals and scholars that only the West was active. They facilely accepted the idea that activity per se was desirable compared to judicious or necessary activity; that only the West was capable of thinking in the abstract sense. If this opinion were carried to its logical conclusion, it would appear that if the rest of humankind had survived for hundreds of years, this must be due to some form of manna falling providentially from the heavens.

The damage done by these years of extremely ideological scholarship and a ruinous ethnocentrism to the history of technology was bad enough. Predictably, the impression of an empty technological wilderness invented by Western scholarship about non-Western societies had a parallel, simultaneous, destructive impact on the assessment of their cultures as well. So insidious was the nature of this outrageous assumption regarding Western and non-Western abilities, that even Joseph Needham, Mark Elwin, Abdur Rahman and a host of other scholars participated in pointless debates which often took it for granted. One major debate, for example, focused on why China (and India) did not produce either modern science or an industrial revolution on the European pattern, especially since Chinese technology had already reached a level of sophistication not yet attained in any other part of the world as late as the fifteenth century.

Attempted answers compared and contrasted the internal conditions within Chinese society with those within Europe; the argument eventually succeeded in establishing the conclusion that no scientific or industrial revolution occurred in China because the social conditions in China were not the same as those within Europe. Thereafter, a host of cultural and social factors were dragged out of context and labeled probable "obstacles" either to the development of technology or modern science.

A critique of the three assumptions we have surveyed above therefore becomes compelling and inevitable, if we are to eschew their myriad fallacies in future. We shall take each in turn.

The idea that the past was merely a prelude, and a primitive one at that, may come naturally to anyone who has begun to feel that the present era of technical change is inevitable. Yet future societies may assess their past (our today) basing themselves on values other than those celebrating mere technical change. Already mindless technical change and built-in technological obsolescence have been assaulted by several global thinkers on the ground of ecological unsustainability and resource scarcity. It would also be wrong to think that because man did not have technology as he now does, he was necessarily impoverished. If there is anything the past gives us it is this positive impression of survival in all kinds of environmental scenarios. There is also evidence of more widely dispersed creativity when man was not submerged by technology than there is today. In many areas of human experience, we are yet to match even the technological achievements of the past which were driven by values other than mere complexity for its own sake or profit.

A similar argument may be used against the assumption that humankind is the only tool-making species there is. Several naturalists and ethologists have documented the diversity of nature's schemes at fabrication; most notably, Felix Paturi in his *Nature, Mother of Invention* and Karl von Frisch in *Animal Architecture*. Scholars like Lewis Mumford have gone further in stating quite bluntly that in their expression of certain technical abilities other species have for long been more knowledgeable than man.

> Insects, birds and animals, for example, have made far more radical innovations in the fabrication of containers, with their intricate nests and bowers, their geometric beehives, their urbanoid anthills, and termitaries, their beaver lodges, than man's ancestors had achieved in the making of tools until the emergence of homo sapiens. In short, if technical proficiency alone were sufficient to identify and foster intelligence, man was for long a dullard, compared with many other species.

Niko Tinbergen, another ethologist, after years of close observation of other species, has come to the following conclusion: "It was said that (1) animals cannot learn; (2) animals cannot conceptualize; (3) cannot plan ahead; (4) cannot use, much less make tools; (5) it was said they have no language; (6) they cannot count; (7) they lack artistic sense; and (8) they lack all ethical sense." All of these statements, says Tinbergen, are untrue.

It cannot be said therefore that, in contrast with other species, humankind alone is a tool-maker. Thus the attempt to distinguish man from other living species because of his tool-making capacity is now seen to be a result of limited knowledge and unwarranted assumption of qualitative discontinuities between human beings and other species. It will also be useful to recall here that the ability to fabricate and organize is not a singular human trait – it is an intrinsic feature of nature since nature can exist only in a given form, whether at its most primary constituents at the subatomic level or even at the level of crystalline structures or the multiple tiers of a primary forest.

However, it is the third assumption – concerning the West's genius for technology and the rest of the world's incompetence in the same department – that contains the greatest mythological component of them all.

As we shall presently see, such an assumption has not only no historical basis, it is in fact contrary to historical and even to contemporary evidence. As for the gift of Greek rationality, suffice it to say that for 2,000 years it gave no technological advantage to those who had it over those who did not. On the contrary, major scientific concepts, technological artifacts, tools, and instruments emerged in cultures that had nothing to do with either Greece or Rome.

The other problem with this assumption is it cannot even cope with the long established view that the science and technology traditions of most societies, particularly so of the West, are in significant ways mixed traditions. Even the little that we know about it indicates that the cross-cultural borrowing of technics and technology is impressive. Thus a very large number of critical inventions from both India and China helped fill significant gaps in the technological development of the West. A simple example from Francis Bacon's work will suffice to illustrate this point. He wrote:

> It is well to observe the force and virtue and consequences of discoveries. These are to be seen nowhere more conspicuously than in those three which were unknown to the ancients, and of which the origin, though recent, is obscure and inglorious; namely, printing, gunpowder, and the magnet. For these three have changed the whole face and state of things throughout the world, the first in literature, the second in warfare, and the third in navigation; whence have followed innumerable changes; inasmuch that no empire, no sect, no star, seems to have exerted greater power and influence in human affairs than these mechanical discoveries.

Now all these three mechanical discoveries were Chinese. Yet here again Western scholars have found it hard to acknowledge their origin. Borrowing of techniques from India is easily documented as well.

The documentation of technology in other cultures is only beginning. For example, it was only in 1974 that Sang Woon Jeon's *Science and Technology in Korea* appeared. There is as yet no major record of technology in Africa or South America though there is now available a large volume of documented evidence that both areas were rich in tools and techniques, from metallurgy to textiles.

In India, the other large storehouse of useful and appropriate tools (some still in productive use), the most extensive documentation of technology has only recently commenced, sparked in part by Dharampal's *Indian Science and Technology in the Eighteenth Century* and the work of scholars like Abdur Rahman.

The immediate impact of these reinvigorated investigations, stimulated largely by political independence, is a fresh debate over the issue of technology and culture: the old assumption of one technology and one culture in which others are seen to make a few, presumably inconsequential, contributions, is in tatters. Whatever its own pretensions to be the only viable culture, the West is finally being seen by non-Western societies as only one among several: a certain balance between cultures gets restored even though economic inequality persists. In fact, in some cases the pendulum has swung to the other side with cultures unabashedly resuming their traditions. There has naturally been a reverberation in the climate of ideas.

Changes in perception of this kind have already come about in other academic disciplines. To cite just one example, world histories were once written as if Europe were the center of the planet, if not the cosmos. There has been progress since: Geoffrey Barraclough and Leon Stavrianos, for instance, have both succeeded in producing comprehensive histories which avoid the older Eurocentric perspectives.

But even assuming we are able to produce, culture by culture, a fairly objective and comprehensive record of science, technology, and medicine, we would still be uncomfortably close to the pet obsession and perception of the present epoch. If there is anything the recent past has shown us, it is that we can be all too zealous judges in our own cause. We continue to celebrate uncritically our technological feats even when we know that the principal criterion of success for any species (and the human species is no exception) is primarily its ability to survive.

Therefore, it may be best not to get trapped in the debates on what is basically a subhistory: the history of slave-machines or automation or the recent machine-propensity of some cultures. After all, the *homo faber* concept is itself a distorted reflection of the natural endowments of the human species, an example of reductionist thinking. We know now that reductionism readily distorts knowledge, often pauperizes it, but rarely enhances it.

What is required in the circumstances then is a paradigm shift. I would like to suggest this can be achieved by replacing the heavily loaded term "technology" (too close identified with externalized objects) with the more neutral word, "technique." Technique has a larger ambit than technology and does not necessarily express itself only in the form of tools or artifacts. For the moment, we may define it briefly as every culture's distinct means of achieving its purposes. The natural propensity of human beings is to rely on technique, not technology, for while it has been proven that we can survive without technology, we cannot survive without technique.

Thus there can be no technique without culture, no culture without technique. An investigation into a culture's techniques is bound to be considerably more difficult than the recording of a culture's artifacts. The important gain here would be that we would begin with a more democratic assumption: that there is no culture without a system of techniques. Such a postulate would inoculate us effectively against methodological, ethnocentric, and other fatal flaws the *homo faber* concept was both parent and heir to. It would nip in the bud any undesirable future forays into cultural narcissism or ethnocentric discourse.

If this is indeed so, the more logical assumption would be that every culture has relied on a corresponding system of techniques that has guaranteed survival. Understood in this way, it makes far better sense to talk of Western technique (even though today largely expressed in the form of technology), or African, Indian, Chinese, Maya, or Arabic techniques of survival (in which technology may not be given that importance for fairly valid reasons). But even a relatively low importance given to technology could never mean a poverty of technique. The idea that the human species is technique-natured could be empirically falsified if a human society could be found that lacked technique – and not just machines or artifacts.

Technique, then, is nothing but the permanent but dynamic expression of an individual culture. Cultures can only express themselves or survive through technique: the alternative is chaos. Nonhuman species may be guided in the exercise of technique by inflexible inborn patterns of behavior. But the human world is as rigorously bound by the controls imposed by the symbolic universe that emerged as a substitute for weakened instinctual patterns. Myth, for instance, is technique. Interaction with (or manipulation of) nature may take place either through myth-making, scientific construction, and myriad other ways. All are expressions of the symbolic universe human beings inherit because they are human beings.

Thus we share the necessity of functioning through technique – not just through tools – with other living species – from the mammoth geobiological processes of Gaia to the cross-pollination of the rice plant to species of bird and animals, some of which, like the bower bird, are more prone to technology than others. Thus the so-called potter-wasp is known for its technique in constructing what we human beings culturally recognize as pots: however, the small vessels are the conclusion of technique: without it, there would be no "pot", no propagation and, therefore, no survival.

This will also explain why so-called primitive societies are often more complex in their socio-cultural arrangements – their rich fund of botanical knowledge, slash-and-burn techniques, elaborate myths are as much an expression of technique – than modern societies.

Our new paradigm – based on a thorough-going analysis of technique – will enable us to concentrate more effectively on those aspects of human experience in non-Western societies where there may be appropriate development of technology (as in India and China) but a superabundance yet of technique. A large number of these, particularly in India or in the Islamic cultures, may be located squarely within the domain of the sacred. They would be unintelligible outside such a framework of understanding.

We shall also observe in such societies that even where there is sophisticated technology, it retains an unobtrusive (not invasive) character. This can be seen from the merged outlines of Arab architecture to the irrigation works of South India or Sri Lanka.

An encyclopaedia of non-Western science, technology, and medicine may restrict its scheme to a bare description of the evolution of machines or artifacts incompetently covered by earlier conventional Western works, but it must do so guided by the background of the larger canvas of technique. Here the scholar will eventually examine theories of language in the same detailed manner as he would the culture and preparation of food or the control of breath – all extremely detailed sciences in India and China; he would examine irrigation and animal husbandry techniques, the domestication of cultivars of crop plants, record the elaborate knowledge of plants and of the human body, and seek to understand theories of cosmic phenomena and of the behavior of annual events like the monsoons.

The aim of the historian is to describe the nature of this individual system and not place it within a hierarchical ordering of societies. His task is to document this immense richness, not endeavor to swamp and drive it into oblivion on the questionable assumption that Western technology is the only direction that human technique will take. The growing anxiety over Western technology is closely associated with the threat it is perceived to pose to the fate of the planet and to survival. We may have to examine its history clinically to diagnose why it has generated the kind of problems it poses for humankind. Here, only a proper study of technique and culture within non-Western societies (and not as Forbes hoped, the event of Easter) will bring some balance and provide urgent clues to the origins of what Jamal-ud-din described as the illness of occidentosis, the plague of the West.

See also: ►East and West, ►Colonialism and Science, ►Technology, ►Ethnobotany

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Technology and Environment

Arnold Pacey

The development of technology has usually been socially determined, changing in direction as different social formations have emerged. For example, there are important distinctions to be made between, first, small communities of farmers or dispersed groups of hunters with technologies outstanding chiefly for their adaptation to local *environments*; second, the larger kingdoms and empires, whose technology tended to be *engineering-centred*; and third, trading communities and merchants or entrepreneurs with *production-centred* technologies.

An initial problem in discussing technologies of the first kind is nomenclature. J. S. Weiner, who has discussed the remarkable protective clothing developed by the Inuit for life in the Arctic, has described these people as "the great pioneers of micro-climatological bioengineering". This tribute to the control of body heat loss achieved by Inuit clothing is well deserved but places the skills of Arctic people within the wrong frame of reference. Their technology was environment-centred, not engineering-centred. On the one hand, they were adapting to a very demanding environment; on the other, they were making very efficient use of environmental resources. Thus, the animals hunted for meat were also a source of oil for lamps, bone for making needles and other tools, and the skins, intestines, and fibres from which clothing was made.

Archaeological evidence suggests that the invention of tailored skin clothing adequate to enable people to winter in the Arctic was accomplished in Siberia around 2000 BCE. After that, it was several centuries before oil lamps, houses built of snow, and dog sleds were developed by the people of the Dorset Culture, based on Baffin Island. Later still, improved boats and harpoons were developed by the Alaskan Inuit.

All these inventions, quite clearly, were the work of small, dispersed groups without centralized organization, and all were responses to an exacting environment. Perhaps what we ought also to remember is that for the Inuit, as for most non-Western peoples, the environment was endowed with personal and spiritual meanings and with magical qualities. It was not merely the object of detached, if concerned, analysis that it has become for most Westerners. Thus, their technology was based on an organic worldview.

The same points can be made about peoples inhabiting other environments, such as rainforests, deserts, steppes, or coastal and island situations. The efficiency with which resources were used by such people is illustrated by the estimate that in 1500 CE the Amazon basin supported a somewhat larger population than it did in 1990, yet without the extent of destruction of forest and fishery resources now taking place. Fruits, nuts, leaves, seeds, and roots were gathered for use as food and medicine. Fish and animals were caught, often using poison tipped spears, but with less ecological disturbance.

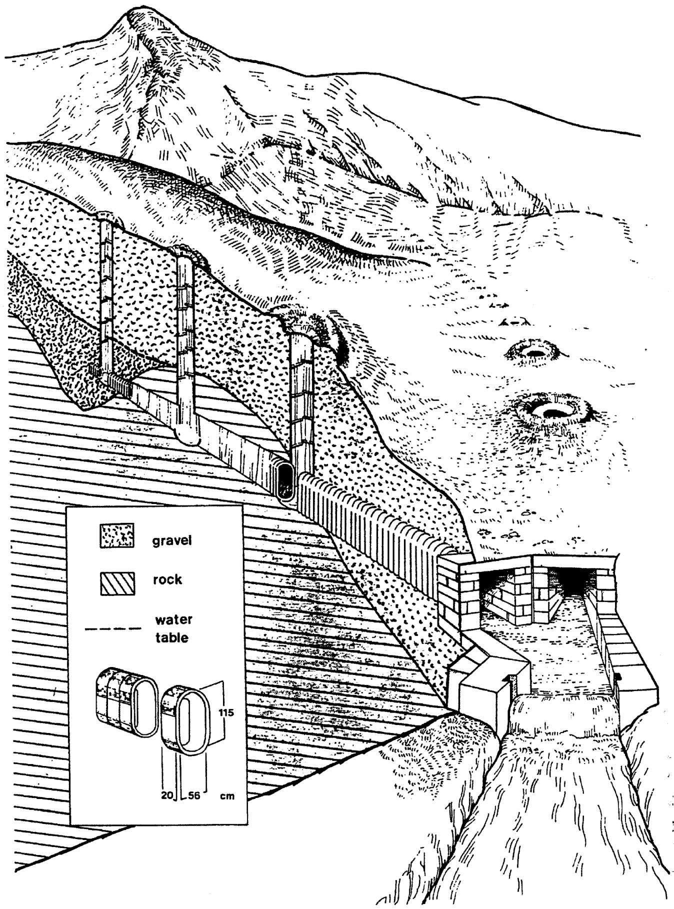
In some rainforests, notably in Central America as well as in Asia and Africa, people developed a form of agriculture in which a great variety of crops was raised while extensive tree cover was retained. Cereals such as corn in the Americas or rice in Southeast Asia were grown in forest glades with shade-tolerant vegetables under trees. Those trees that were left unfelled or were newly planted would be selected according to whether they produced fruit, nuts, timber, fodder, or *materia medica*. Thus, an artificial rainforest was formed in a system often referred to as forest farming, forest interculture, layered gardening or, more recently, agroforestry. The key point – whatever the name – is that there would always be tree cover, and usually other vegetation, to protect the soil from erosion and to retain plant nutrients. By contrast, where rainforest is cleared for conventional western style agriculture, soils become degraded very rapidly.

In Africa, rainforest crop production became widespread only after the banana and Asian yam were introduced on the east coast by Indonesian traders and colonists around 400–500 CE. In quite a short space of time, these crops were adopted by many gardeners across the continent, enabling populations in forested areas to increase considerably. In Central America, archaeologists have now shown that the Maya culture used forest farming with high yielding nut trees and manioc (cassava) as major crops around 600–900 CE.

Other environment-centred technologies were those of people living in hot, dry, and semi-desert conditions who evolved sophisticated water conservation techniques. Some of these made use of small structures, such as check dams in gullies and spreader dikes on flatter ground – for example, in northern Mexico and Arizona – or else stone lines on contours (in the African Sahel). Others practiced the careful planning of fields in relation to rainwater catchment areas, and the construction of bunds (embankments or dikes) to channel water and hold it on the land. Among the most elaborate rainwater harvesting systems of this kind were those of Nabataean farmers in the Negev Desert in Israel from about 200 BCE, and comparable systems in Morocco and elsewhere in North Africa. Small dams, river diversions, and the Persian *qanat* (wells linked by a tunnel; Fig. 1) were other means of providing irrigation water to crops on a small scale.

Consideration of environment-centred techniques such as these offers a distinct perspective on early technology quite unlike the conventional view based on the materials from which tools were made, namely, stone, bronze, and iron. That view seeks to discover a pattern of tool use and metalworking skill common to all human societies, and ignores the environmental particularism emphasized here. It parallels the modern assumption that the principles of technology are independent of cultural values and underestimates the different ways in which human societies explored the varying surroundings in which they lived. By contrast, a perspective based on environmental adaptation allows one to recognize the extraordinary sophistication of some peoples who nominally remained in the "Stone Age" even in the early twentieth century, including the Inuit and some rainforest communities.

Viewed from another angle, however, the Neolithic period in the later Stone Age does seem to have been a time of particularly important innovation, at least for western Asia. It is associated with the first domestication of crops and livestock, and hence the invention of agriculture, probably associated with the earliest used of some of the water conservation techniques previously discussed. Complementing these innovations were



Technology and Environment. Fig. 1 Two *qanat* tunnels in a typical landscape, where rainwater running off mountains replenishes groundwater beneath the sand and gravel of the lower slopes (water-bearing gravel is shown darker than the dry gravel layer above). The ground penetrated by one of the *qanats* is shown in cut-away section to demonstrate how the tunnel gives access to water trapped by impervious rock. The section also shows how the tunnel is lined with earthenware rings when passing through sand or gravel layers which might otherwise cave in. *Qanat* tunnels were excavated from the bottoms of a series of well shafts, with the "mother well" at the upstream end dug first to prove the existence of water. The tunnels were sometimes several kilometres long with their route evident on the surface from the line of well shafts, as on the right of the picture (illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey 1990: 86).

others, such as pottery (and soon after, the potter's wheel), grain milling, tool-making, and textiles (with the looms on which they were woven). Many of these innovations relate to the domestic sphere of life, and it is likely, therefore, that many of the inventors concerned were women.

It would be a mistake, however, to assume that the invention of agriculture, the domestication of plants, and the appearance of pottery or textiles were unique events, each occurring only once in human history, in one part of Asia and then diffusing to other regions. Independent inventions undoubtedly occurred, just as different crops were domesticated in various places and at different times. For example, about 1500 BCE, corn (i.e. maize) and pottery were both known in Mexico, but not in Peru, where beans and peppers were cultivated. Thus, the two cultures may have developed agriculture independently of one another. Moreover, some plants were still being newly domesticated in the twentieth century, for one reaction to deforestation in Africa has been to cultivate a number of fruits and vegetables that people had collected from the wild until the loss of forest cover threatened their existence. Reports from Kenya show how modern gardeners, usually women, have selected from wild varieties and have produced strains adapted for garden conditions.

Engineering-centred technologies developed in a very different context. They were characteristic mainly of kingdoms or empires whose labour resources and administration made large-scale construction works possible. One view of the origins of engineering is that once agriculture was established, irrigation became

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necessary in many of the warm, dry countries of western and southern Asia to produce sufficient food for growing populations. The dams and canal systems necessary for irrigation could not have been constructed, it is argued, without recruiting a large labour force, and that in turn could not have been done except in centrally organized kingdoms. In this view, the need for irrigation canals and other hydraulic works dictated the formation of centralized government administrations with the coercive power and management skills needed to organize large-scale construction works.

This theory about how hydraulic civilizations evolved does not apply everywhere, however, since empirical evidence shows that in many areas where irrigation was practiced, farmers did the essential earth moving and engineering work themselves, or with their neighbours through local systems of cooperation, but without central organization. This seems to be true for rice culture in China, according to Francesca Bray. Some of the biggest centrally organized engineering schemes prior to 605 CE, involving thousands of labourers, were not for irrigation but for construction of transport canals for carrying grain to the capital. However, flood control and irrigation in North China did depend on large-scale works, so the evidence is not clear-cut.

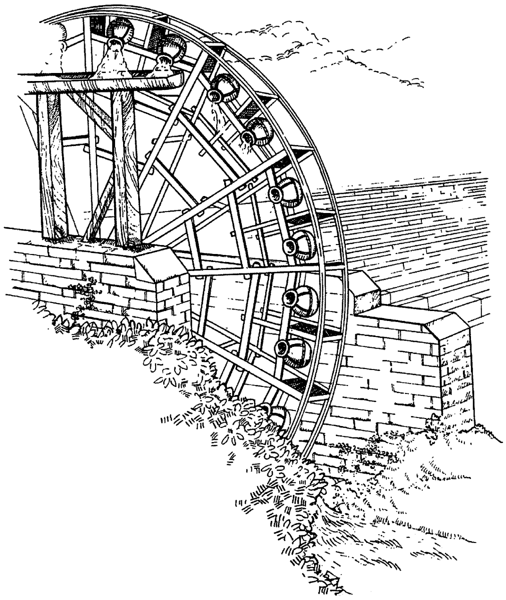
In Mesopotamia and Egypt, much early irrigation was also on a small scale, dependent on manually operated water-raising devices such as the *shaduf* (a device consisting of a long suspended pole weighted at one end and having a bucket at the other end). The type of crops grown and the seasons of cultivation meant that there were fewer water requirements in early agriculture than after the agricultural revolution of the Islamic period (after 700 CE), when crops that demanded more water (including rice) were more widely grown. In Mesopotamia, large-scale works were needed at an early date, but in most places it is hard to argue that the requirements of hydraulic management were sufficiently exacting to determine the development of centrally organized states. On the contrary, the prior existence of centralized political power made possible a wide range of construction programs that included fortifications, monuments, and temples, as well as hydraulic works, and it is impossible to say which kind of engineering came first. One of the earliest sites to provide evidence is Jericho, where defensive walls, but also big water tanks, have been found dating from before 6000 BCE. The pyramids of Egypt were among the largest construction projects ever conceived when they were begun about 2600 BCE. But a comparable amount of labour may have gone into embankments and canals built at about the same time for flood control and irrigation by the Sumerians in Mesopotamia. Thus, the evidence does not give a clear picture of hydraulic requirements, rather than other construction works, forcing the pace in either administration or engineering.

That brings us to a second hypothesis about how engineering-centred technologies evolved, suggested by Lewis Mumford and some like-minded commentators. This is the view that such technologies were related to the invention of warfare, for indeed, organized lethal warfare had to be invented, and this may have happened during the Neolithic age, possibly following the invention of agriculture. The reasoning here is that agriculture made possible denser populations within which social tensions were inevitable and from which large bodies of fighters could be recruited, while at the same time, agriculture produced the economic surplus needed to pay for arms and fortifications. It is suggested, also, that centralized governments and military institutions began to evolve about this time, and provided a model of how large bodies of people could be organized and supervised, not only in combat, but also in constructing fortifications – or dams, canals, and pyramids.

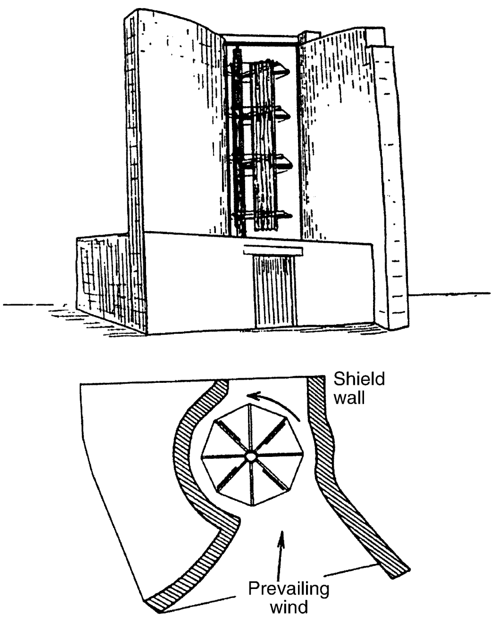
Needless to say, the development of warfare provided other stimuli to engineering-centred technology. Mechanized fighting may be said to have begun with the clumsy, four-wheeled Sumerian chariot of about 2400 BCE. The Hittites, whose empire overlapped Asia Minor and Syria, invented some of the first effective siege engines soon after. Horses were initially used mainly for drawing chariots, their full potential for warfare only emerging much later with the invention of the stirrup and its associated harness. This freed the rider's arms to use weapons while he remained securely in the saddle.

Engineering-centred technologies in ancient civilizations can appear to be focused very largely on large-scale hydraulic works and on military engineering. In addition, one bias in the western understanding of technology is a tendency to focus on the wheel, and on machines using wheels, such as the early chariots just mentioned. But wheels did not always mean progress. Wheeled vehicles were used in the North and West of Africa around 500 BCE, regularly crossing the Sahara Desert. Yet they went out of use later when the camel was introduced, because camels provided much more efficient means of transport in a region with sandy deserts and no paved roads. For parallel reasons, wheeled vehicles were not much used in southern Asia. In Central America, rollers and wheeled toys have been found, but in a region where there were no animals capable of pulling carts, little could be gained by developing such devices.

The potter's wheels (and later, lathes working on similar principles) were probably the first machines to use the wheel, around 3000 BCE. Much later, a basic water-powered corn mill evolved, with a vertical axle



Technology and Environment. Fig. 2 Water-raising wheel of the type known as the *noria*. This is an undershot water wheel, driven by the flow of water in the stream running underneath it. The jars tied to the rim fill from the stream and then empty into the trough at the high level (illustration by Hazel Cotterell; reproduced from Pacey 1990: 11).



Technology and Environment. Fig. 3 Persian-type windmill showing how shield walls were designed to funnel wind onto the sails, which rotated on a vertical shaft. The way the mill worked is most clearly seen from the plan (lower illustration). The perspective view shows how the shield walls of later mills formed a towering open structure built of sun-dried bricks with a small room containing the millstones underneath. The earliest mills seem to have been of different design with the millstones supported by the shield walls at the top of the structure (illustration by Arnold Pacey, based on photographs by Dick Day of a windmill in Afghanistan; reproduced from Pacey 1990: 12).

and propeller-like blades below the millstones. One view is that this was a Greek invention made about the time of Alexander the Great. Another view, however, is that it arose out of the Hittite tradition of engineering which had earlier pioneered so much military equipment. After the Hittite empire collapsed around 1200 BCE, some aspects of its culture survived in Syria, and itinerant craftsmen perhaps reached Mesopotamia and Iran. It was probably in one of these countries that vertical-axle water mills originated. Since the same type of mill appeared in China not long afterwards, one might reasonably look for its origins close to trade routes with China. A related invention of the same period was the water-raising wheel or *noria*, a basic water wheel with a horizontal axle and pots or buckets attached to its rim in which water could be raised (Fig. 2).

Some thousand years later, Iran was certainly where an early type of windmill was invented. It worked in much the same way as the vertical-axle water mill, though mounted in a tower with vents in the walls to catch the wind (Fig. 3).

In both Iran and Iraq extensive use was made of water wheels of several types, and some large dams were erected. Other uses of water power in this region around the year 1000 CE were in sugar cane crushing mills, fulling mills, and mills for preparing the pulp for papermaking. Paper manufacturing had been introduced at Baghdad in 794 CE, probably with the help of Chinese workmen, and water wheels were used to work hammers that made pulp from 950 CE.

Production-centred technologies can be said to include devices such as corn mills, or iron smelting, or the porcelain industry which developed in China. Other evidence of production technologies in China includes several inventions that first appeared there in the three or four centuries prior to 1250. They include spinning wheels, silk-winding machines, and water-powered mills for spinning and winding thread.

Much production of pottery and textiles would be carried on in a domestic context, but there were also instances of large-scale production, of which the most characteristic unit in South Asia was the *karkhana* of Mughal India, or the specialist porcelain factory in China. At one time 4,000 silk workers were employed in karkhanas in Delhi, some of them conscripted.

Production for purposes of trade had to be more flexibly organized and flourished most markedly where merchants could function independently. By 1700, India had become the world's greatest exporter of textiles, sending its cotton cloth to Europe, Africa,

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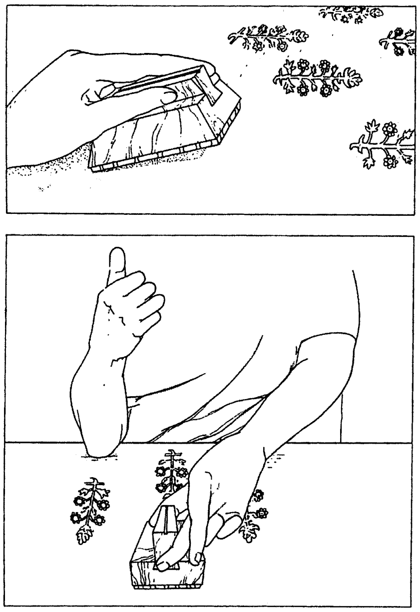

Technology and Environment. Fig. 4 Indian technique for printing designs on cloth using a wooden block, applied by hand to transfer a mordant (rather than the dye itself) to the cloth. Mordants are chemical substances that made the cloth receptive to dye. First the wooden block carved with the flower pattern being printed is carefully placed in position (top), and then it is struck sharply with the right hand to transfer the mordant solution from the block to the cloth (illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey 1990: 85).

Technology and Environment. Fig. 5 Alum production in Rajasthan, India, about the year 1800 CE. Shale tips associated with copper mines provided the raw material and can be seen in the background on the right. Shale was steeped in water in rows of pots on the tips. The liquid was then brought to the boiling house seen to the left where some water was evaporated off and the pots left to stand. Blue crystals of copper sulphate formed and were removed. After decanting the liquid and boiling it again, saltpetre was added. The alum was formed by reaction of the saltpetre with aluminium salts in the solution, and crystallized at the bottom of the pots (illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey 1990: 122).

and many destinations in Asia. Both Indian and foreign merchants were involved, sometimes financed by the many Parsi and Gujarati bankers to be found in ports such as Surat.

It should not be thought, however, that proto-capitalist industrial organization was always favourable to the use of machines, water-powered or otherwise. The high quality of Indian textiles was achieved by painstaking handwork, as in the printing of designs on cloth (Fig. 4), and sometimes by a very fine division of labour. British observers noted that cotton cloth would sometimes be worked on by four people for every one employed on the same tasks in Europe. Thus the remarkably fine muslin produced in Bengal was the result of many detailed processes which would be simplified and reduced to a single operation in the West.

Indian cloth was also noted for the fastness and brilliance of the colours with which it was dyed, mostly using vegetable dyes such as indigo and madder. However, some inorganic substances were also needed as mordants, to help dyes bond with textile fibres and often modifying the colour, and this gave rise to a significant chemical industry. For example, the alum used in madder dyeing was produced in Rajasthan by processing broken shale tipped as waste around copper mines (Fig. 5). These chemical processes were operated on a substantial scale but using labour-intensive methods and minimal equipment. Merchants and banks had ample funds to invest in the textile trade, but because wages were low, there was little advantage in financing more productive equipment.

Technology is too often equated with engineering and hence with structures, machines, or equipment. However, a deeper understanding of technology in non-Western cultures demands awareness of subtleties in responses to the environment by which human survival was guaranteed in very varied conditions, and subtleties in the use of materials (such as dyes and mordants) by which high-quality production was achieved without machinery.

Thus while engineering-centred technologies that are easy to illustrate with pictures of machines are central to most people's image of what technology is about, a more fundamental view of technology must take account of responses to the environment that cannot easily be illustrated, such as rainwater harvesting or agroforestry where there are no machines to illustrate.

See also: ►Ethnobotany, ►Military Technology, ►Gunpowder, ►Paper and Papermaking, ►Colonialism and Science, ►*Qanat*, ►East and West, ►Western Dominance

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Technology in the Islamic World

Donald R. Hill

Hydraulic engineering was the most important technology of medieval Islam. Irrigation schemes supported a thriving agriculture and such schemes involved the construction of canals and *qanats* (see below), dams and water-raising machines. At the other end of the chain, water power was needed to process the raw agricultural products. In this article, we will begin with a survey of hydraulic engineering which will give us an overview of many of the significant aspects of Islamic technology.

Following this, a brief summary of a few other technologies will help us to appreciate the richness and diversity of Islamic material culture. The brevity of this summary is because of limited space and should not mislead readers into thinking that these technologies were insignificant, either in the social life of Islam or in the history of technology.

In Egypt, basin irrigation was in general use. This consists of leveling large plots of land adjacent to a river or canal, and surrounding each plot by dikes. When the river reaches a certain level the dikes are breached, allowing the water to inundate the plots. It remains there until the fertile sediment has settled, whereupon the surplus is drained back into the watercourse.

The regime of the Nile, with the predictable arrival of the flood, made Egypt particularly suitable for basin irrigation. Elsewhere in the Islamic world, however, perennial irrigation was, and is, practiced extensively on all the major river systems. As the name implies, it consists of watering crops regularly throughout the growing season by leading the water into small channels which form a matrix over the field. Water from a main artery – a river or a major canal – is diverted into supply canals, then into smaller irrigation canals, and so on to the fields. In many cases the systems operate entirely by gravity flow, but water-raising machines were used to overcome obstacles such as high banks, whether they were natural or artificial. Perennial irrigation from wells, again using water-raising machines, is also extensively practiced in the Islamic world.

After the advent of Islam a number of existing systems were extended in order to cater for the needs of newly founded cities. Completely new systems were also constructed. In central Iraq the Muslims inherited the network constructed by their predecessors, the Sasānid dynasty of Persia. The major expansion occurred after the foundation of Baghdad in AD 762. The great Nahrawān canal, which left the east bank of the Tigris a short distance below Takrīt, was extended southward.

The rivers ʿUzaym and Diyāla, which discharge into the Nahrawān from the east, were dammed by the Muslim engineers to provide water for a huge irrigated area. Further south, to the west of the Shaṭṭ al-ʿArab, the city of Basra was founded in the seventh century. Originally it was simply an army encampment consisting of reed huts, but soon it grew into a great city which had no rival in Islam before the foundation of Baghdad. Gradually, in the last decades of the seventh and the first decades of the eighth centuries a vast network of canals was constructed to serve the demands of a thriving agriculture.

Other important systems were based upon the rivers in the province of Khurāsān, then much larger than the eastern Iranian province of the same name. Some of the most impressive networks were based upon the river Murghāb, upon which stands the city of Marv. In the tenth century the system was controlled by a specially appointed Amir who had 10,000 men under him, each with an appointed task. This Amir is said to have had more authority than the prefect of Marv. Other important schemes in the east were those centered on the cities of Bukhārā᾽ and Samarqand and on the lower reaches of the Amu Darya (Oxus) river.

In Spain, the Muslims greatly extended the irrigation schemes that had been constructed by the Romans and Visigoths. Syrian irrigation technology – large contingents of the conquering armies were from Syria – was applied in Spain, where the climatic and hydraulic conditions of the rivers of the north were very similar to those in Syria. The irrigation systems, such as those along the Gudalquivir river and those in the province of Valencia, were the basis of the agricultural prosperity of Muslim Spain. Indeed, systems such as that in Valencia, basically unchanged since Islamic times, continue to serve the needs of the province to the present day.

A particular technique, originating in Armenia about the eighth century BCE, and still in widespread use in modern Iran, was the *qanat*, an almost horizontal underground conduit that conducts water from an aquifer to the place where it is needed. For the preparatory work an experienced surveyor carefully examines the alluvial fans, the terrestrial equivalent of a river delta formation, in the general location of the proposed *qanat*, looking for traces of seepage on the surface and often for a barely noticeable change in vegetation, before deciding where the trial well is to be dug. When a successful trial well has been excavated, it is now known as the mother well. The surveyor levels from this point to the outlet of the qanat, marking the positions and levels of the proposed ventilation shafts at 30–50 m intervals. These shafts also provide for excavation of the spoil. A skilled artisan (*muqannī*) then begins work with his assistants by driving the conduit into the alluvial fan, starting at the mouth. At first the conduit is an open channel, but it soon becomes a tunnel. Another team sinks ventilation shafts ahead of the tunnelers, and laborers haul up the spoil to the surface through these shafts by means of a windlass. The tunnel is about 1 m wide by 1.5 m high; in soft soil hoops of baked clay, oval in shape, have to be used as reinforcement. As the work nears the mother well, great care has to be taken in case a muqanni misjudges the distance and strikes the full well, in which case he might be swept away by the sudden flow.

The construction of canals, qanats, and other public works required the assistance of skilled surveyors. The earlier methods of leveling were rather slow and tedious. This involved stretching a string between two staffs divided into graduations and held vertically. A level was suspended to the center of the string. One type, for example, was an inverted isosceles triangular frame suspended by hooks to the string. Fixed to the center of the horizontal leg was a plumb line. One end of the string was moved up or down the staff until the plumb line passed through the inverted apex of the triangle, at which point the string was level. The difference in level between the two staffs was noted. In the eleventh century a level was introduced akin to our modern instrument but without, of course, any telescopic or electronic aids. A thin copper tube rotating on a circular plate that was suspended to a "gallows" was aimed horizontally on to a level staff. The reading gave the difference in level between the two points. The rises and falls along the route of the survey, summed algebraically, gave the level difference required. Triangulation, by which the heights and distances of objects, whether accessible or not, could be determined was usually carried out by the astrolabe. Quantity surveying methods were very similar to those in use today. The amount of excavation for a canal, for instance, was first calculated. Then, by applying known unit rates, the engineer worked out the number of excavators, laborers, foremen, and supervisors. From these results he prepared a Bill of Quantities which was used for measuring progress and paying the contractor.

The main purpose of dams was to divert water from rivers into irrigation systems. Our knowledge of Muslim dams comes from two sources: reports in the works of Muslim geographers, and the examination of Muslim dams which have survived to the present day. In the east, one of the most impressive dams, known as the Band-i-Amir, was built in 960 over the river Kūr in Iran, between Shirāz and Persepolis. As described by the tenth-century geographer al-Muqaddasī, it was used to irrigate 300 villages. At each side of the dam, downstream, were ten water-raising wheels and ten water mills, all given extra power by the head of water impounded behind the dam. The dam was constructed throughout of masonry blocks, and the joints were made of cement mortar strengthened with lead dowels. The dam still exists and it is not surprising, given the solidity of its construction, that it has had such a long and useful life.

Also in Iran, at Kebar, about 15 miles south of Qum, is a dam which is very important in the history of dam construction. Built in the thirteenth century, it is the first known example of the true arch dam. It did not depend for its resistance to water pressure on gravity but was built as an arch, its convexity pointing upstream, and its sides were anchored securely into the rocky sides of the gorge in which it was built. The forces were transferred to the abutments, and it was considerably more slender than a gravity dam across a similar river.

A number of important Muslim dams were built in the Iberian peninsula. These included the dam at Cordoba with an overall length of 1,400 ft. Downstream from the dam were three millhouses that each contained 4 mills, as the geographer al-Idrīsī reported when he saw them in the twelfth century. Also below the dam is a large waterwheel. There are a series of eight dams on the river Turia in the province of Valencia. They are very securely built in order to withstand the sudden dangerous floods to which the river is subjected. They are also provided with desilting sluices, without which the canal intakes would soon become hopelessly choked.

These dams and their associated canals continue to provide for the needs of the province at the present time. It has been shown in modern measurements that the eight dams and their associated canals have a total capacity slightly less than that of the river. This, of course, raises the question whether or not the Muslims were able to gauge a river and then design their dams and canals to match. There seems no reason to doubt that they indeed had that capability.

Given that dam building had been an established practice since the times of the Sumerians and ancient Egyptians, it is not easy to isolate those elements that were Muslim innovations. On present evidence, it seems certain that the introduction of desilting sluices, the arch dam and hydropower were all Muslim inventions. The Muslims also probably perfected the technique of gauging rivers.

All the main water-raising machines were in existence in the Middle East before the advent of Islam. These included the Archimedean screw, the well windlass, the *shādūf*, the *sāqiya* and the *noria*. Because of their survival right up to the present day, and/or their importance in the development of machine technology, the last three of these are the most significant. The *shādūf* is illustrated as early as 2500 BCE in Akkadian reliefs, and it has remained in use throughout the world until now. Its success is due to its simplicity and its efficiency. It can be easily constructed by the village carpenter using local materials, and for low lifts it delivers substantial quantities of water. In consists of a long wooden pole suspended at a fulcrum to a wooden beam supported on columns. At the end of the short arm of the lever is a counterweight made of stone or clay. The bucket is suspended to the other end by a rope. The operator lowers the bucket and allows it to fill. It is then raised by the action of the counterweight and its contents are discharged into an irrigation ditch or a head tank.

The *sāqiya* was invented in Hellenistic Egypt, probably in the third century BCE. It is operated by an animal, usually a donkey, walking in a circle. On its shoulders and neck the animal wears a collar harness that transmits the power through two traces to a doubletree fastened to a drawbar. The drawbar passes through a hole in an upright shaft. This shaft carries the lantern-pinion, which is a type of gear-wheel consisting of two wooden discs separated by pins, the spaces between the pins being entered by the cogs of a vertical gear. This vertical gear has the cogs on one side of its disc and these protrude from the other side to form the wheel that carries the chain-of-pots, or potgarland. The component is therefore known as the potgarland wheel. It is erected on a horizontal axle over a well or other water source. The pots fill with water at the bottom of their travel and discharge at the top, like the shadoof, into a head tank or irrigation ditch. The saqiya was transited by the Muslims from the Middle East to Spain and eventually to the New World. In some areas it has retained its popularity to the present day.

The *noria* is perhaps the most significant, from a technical viewpoint, of the traditional water-raising machines. Being driven by water, it is self-acting and requires the presence of neither man nor animal for its operation. Essentially it is a large wheel constructed of timber. At intervals, paddles project outside the rim of the wheel, which is divided into compartments. The noria is provided with an iron axle and this is housed in bearings that are installed on columns over a running stream. As the wheel is rotated by the impact of the water on its paddles, the compartments fill with water at the bottom of their travel and discharge their contents at the top, usually into an aqueduct.

The point of origin of the noria is unknown, but it was certainly known in the Roman world and in China by the first century BCE. There is a possibility, therefore, that it was invented somewhere in the highlands of southwest Asia. The large noria at Murcia in Spain is still in operation, as are norias in various parts of the world, where they are often able to compete successfully with modern pumps.

Water wheels, as used in mills, were of three types: vertical undershot, vertical overshot, and horizontal. The first type was a paddle wheel mounted directly in a running stream. In the overshot wheel the rim was divided into compartments into which the water was directed from above, usually from an artificial channel or leat. Both vertical wheels required a pair of gears in order to transmit the motion of the water wheel to a vertical axle that led up to the millstones. In the horizontal type a jet of water from a reservoir was directed on to the vanes of the wheel, on the top of whose axle the millstones were installed. Various methods were used to increase the power and hence the output of mills. The wheel could be located in the piers of bridges or on boats moored on rivers, in both cases to take advantage of the increased rate of flow in midstream. In the Basra area in the tenth century there were mills that were operated by the ebb tide – about a century before the first mention of tidal mills in Europe. Apart from the production of flour from grains, water mills were also used for industrial purposes such as papermaking, the fulling of cloth and the crushing of metallic ores.

Bridges of all types were important in the Islamic world not only for communications but also for protecting the banks of canals from damage due to fording people and animals. In the mountains of Central Asia, such as the Tien Shan and Hindu Kush ranges, both cantilever and suspension bridges were used for crossing ravines. The great rivers of Egypt, Iraq, and Transoxiana were usually crossed by bridges of boats. In many cases, however, rivers and other obstacles were crossed by masonry arch bridges built of dressed stone or, sometimes, especially in Iran, of kiln-burnt bricks.

Two bridges in western Iran, built in the tenth century, are constructed with pointed arches. This type of arch, which was to be such an important element in European Gothic architecture from the twelfth century onward, had appeared in Syria and Egypt during the seventh and eighth centuries, but only as a decorative feature. These Iranian bridges are the earliest known occurrence of the pointed arch as a load-bearing component.

Chemical technology was a highly developed profession in medieval Islam. The most important writer on the subject was Muḥammad ibn Zakariyyāʾ al-Rāzī. Although he wrote a number of alchemical books, his major work, *Kitāb al-asrār* (The Book of Secrets), written early in the tenth century, leaves us with the impression of a powerful mind, much more interested in practical chemistry than in theoretical alchemy. *The Book of Secrets* contains a comprehensive list of pieces of equipment, many of which are still in use today. The chemical processes described or mentioned by al-Rāzī include distillation, calcination, solution, evaporation, crystallization, sublimation, filtration, and amalgamation. Arabic works were undoubtedly an important influence upon the development of European chemistry. Evidence for this influence is the abundance of Arabic words in the chemical vocabularies of European languages. Examples in English are alkali, alchemy, alcohol, elixir, naphtha, and many others.

Mining played an important part in the economic life of the Islamic world. Spread throughout this vast area were mines for all the important metals, precious stones and essential commodities such as salt, coal and petroleum. The oilfields at Baku were exploited by the Muslims on a commercial scale by the ninth century. In the thirteenth century Marco Polo reported that a 100 shiploads could be taken from Baku at one time.

Iron and steel were, of course, the most important metals for many industrial and military purposes. Cast iron was described about 1040 by the great scientist al-Bīrūnī – it was exported to many countries as a raw material. There was also an extensive steel industry which produced, among other grades, the famous Damascus steel. As far as we can ascertain at present, this came from a number of Islamic centers in the Middle East and Central Asia. But it was certainly produced in Damascus itself.

We have been able to mention only the more important areas in which Muslim engineers and technologists were pre-eminent for several centuries. In many cases Islamic ideas were transmitted to Europe, but it is important not to evaluate Islamic technologies only with regard to their contribution to their European counterparts. Technologists in the Islamic world were responding to the needs of society and were extremely successful in a number of fields.

See also: ►Qanat, ►Irrigation, ►al-Muqaddasī, ►al-Karajī, ►Surveying, ►Dams

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Technology in the New World

Aaron Segal

The indigenous peoples of the New World were excellent builders. Although their construction tools were limited they managed to produce pyramids, temples, and other public buildings in the Andean Highlands, the lowland jungles of Central America and the Yucatan, and the central highlands of Mexico. There were ceremonial ballcourts built throughout the Caribbean as well as in what is now Mexico, Guatemala, and Belize. Construction in North America included the mound sites of the Midwest and the Southeast and the cliff dwellings of the Southwest. While estimated populations at these sites varied from the hundreds to the thousands these were all urban societies and civilizations.

These master builders relied on their own concepts, designs, craftsmen, and techniques. In spite of claims of trans-Pacific, trans-African and other exogenous contacts, the evidence is sparse and less than convincing. The civilizations of the New World evolved on their own with only limited contacts with one another over space and time. Their achievements as well as their failure are entirely their own, including matters of technology.

The New World societies concentrated on identifying, applying, and improving instrumental technologies, whether for agriculture, irrigation, construction, crafts, or other utilitarian uses. The legacy that has survived is one of warrior-kings, royal courts, artisans cum farmers, priests and scribes, builders and artists.

The peopling of the New World began approximately 15,000 years ago when climatic changes made migration from Siberia and East Asia possible across the Bering Straits. It took another 8,000 years for these small wandering human bands to reach Patagonia and spread throughout most of Middle and South America. Somehow they managed to keep fertility above infant mortality as they diffused on foot throughout the New World. Hunters and gatherers, they relied on stone age worked flint edges to kill, strip, and consume their prey. Their principal weapon, originating in Asia, was the *atlatl* or spear thrower improved with flexible sheets and stone weights. Bows and arrows were introduced later, also perhaps from Asia via the Arctic, and became a favorite weapon for hunting bison on the Great Plains. When the Tainos paddled island by island from Lake Maracaibo up the Caribbean Archipelago (AD 1000–1400) they were armed with an array of bows, arrows, stone, bone, and flint knives, *atlatls* and other weapons.

Those who undertook the Great Journey throughout the New World survived through environmental adaptation as they fanned out across two continents. Those who adapted to the Amazon Basin continued in a hunter–gatherer mode, learning the skills needed to survive in the tropical rain forest. The Arawaks, Tainos, and other voyagers to the Caribbean also relied primarily on hunting and gathering adapted to coastal fishing. Latecomers who remained in the Arctic or sub-Arctic turned to hunting, fishing, shelter, and other technologies to survive harsh winters.

Agriculture probably arose about 3000 BCE simultaneously in the Andean highlands and Central Mexico, first as a supplement to hunting and gathering and as a response to growing populations. Gatherers observed which seeds yielded what plants and began to cultivate on a trial and error basis. Teosinte, a high-protein precursor of corn, was first cultivated in Mexico, while potatoes were an early ecologically suitable cultigen in the colder Andes. The list of cultivated edible plants soon expanded to include manioc, squash, peppers, pineapples, and other New World originals, especially several varieties of beans. The Tainos learned to grow tobacco and to cure it as snuff in their Caribbean islands, which became valuable trade items.

Agricultural technologies evolved to include the use of digging sticks, irrigation canals, terracing and ridging, intercropping, and seed beds. Lacking draught animals fires were set to clear new land. The most sophisticated technique was that of the *milpas* practiced by the Aztecs who built silted mounds of fertile run-off materials.

Food processing and storage technologies were also innovated and widely diffused. The stone *metate*, or mortar and pestle, became the basic Mesoamerican tool for crushing corn. Ethnobotanical experience produced a variety of herbs, spices, and for the Mexicans chocolate to add to largely vegetable diets. As towns and cities grew, especially in the Andes and Mesoamerica, hunting declined in favor of limited domestication of chickens, turkey, pond fish, and small animals. However, animal protein was hard to come by in all the predominantly agricultural societies which relied on trade and food storage to supplement local corn, beans, manioc, and other staples.

Transport was a severe obstacle for all the New World peoples. Dogs were used to pull sleds and traverse with limited loads in the Arctic and on the Great Plains. Alpacas and llamas were semidomesticated and used for limited local transport in the Andes. However, everywhere terrain was rugged, surfaced roads were few and far between, and runners and headloads were the primary mode of transport. Sailing vessels were unknown and the canoes of the Tainos and others had to hug shorelines for safety. Although the concept of the wheel was known, and toy wheels were used in the Andes, the lack of roads and the natural obstacles impeded the development of wheeled vehicles. The Spanish introduction of the horse and the cow revolutionized transport in the New World. Trade previously was confined to what could be carried on men's backs. Thus the Aztec long-distance traders, *pochotes*, specialized in high-value items such as jewelry, ceremonial feathers, and weapons.

Confined to limited home markets, New World societies tended to invest their agricultural surpluses in exquisite crafts. As royal courts developed around ceremonial centers so did specialized artisans capable of meeting quality demands, as well as items for daily use. The oldest discovered textiles date back 3,600 years to the Peruvian coast and were made of cotton with intricate woven designs. Dyed cotton for personal clothing became widely diffused with pendants and ornaments often added. Excavation of Andean and other tombs has revealed the importance attached to clothing and jewelry and the high skills of the artisans. The Olmecs of the Mexican Southeast were the first to work in jade and turquoise as well as to create massive stone carvings. Metallurgy, especially in the form of masks, was highly accomplished in Mexico as well as among the peoples of what is now Costa Rica, Colombia, and Peru.

Ceramics and basket and gourd work were closely associated with the emergence of agriculture. Initial demands were for items used for carrying and storage. However, in the Andes and Mexico, as techniques improved, ceramics became an important ceremonial art form. Funerary jars, urns, water carriers, ceremonial masks, and other items are regularly depicted in sculptures and paintings and found in Aztec, Maya, and other tombs. Pre-Incan and Incan Andean societies also took pride in their varied and elaborate ceramics, baskets, and gourds.

Ceremonials were held largely outdoors, while palaces were for storage purposes. Most common people, including craftsmen, lived, ate, and slept in simple mud and brick dwellings. Their lords and masters lived in larger and more solid enclosures but with similar creature comforts. Building skills were directed at large-scale public constructions to honor the deities and/or fortresses for defense purposes. While kings lived in palaces with a few of their retainers many members of the court had to accept more humble accommodations. The benign tropical climate of the Caribbean contributed to nearly everyone's relying on hammocks and huts made of straw.

The Aztecs alone tackled the sewage and other waste disposal problems of man-made cities. They instituted barges along the canals of their capital at Mexico City, and also made an effort to keep water potable. At the Inca capital of Cuzco public hygiene was minimal as it had been in the Maya city-states. It may have been the scarcity of domesticated animals that reduced disease vectors in these highly crowded urban sites.

As builders the peoples of the New World concentrated their efforts on specific times and places. These included the Olmec (1000–600 BCE), Tectihuacan (AD 0–650), Toltec (1000–1300 BCE), and Aztec (AD 1400–1530) civilizations in Mexico, the Mayas (AD 0–900) in Guatemala and Mexico, and the Moche (AD 0–600), the Nazca (AD 0–600), the Chimu (AD 1300–1420) and the Inca (AD 1400–1530) in Peru. They were able to construct magnificent and lasting buildings in environments as different as lowland jungles and highland mountains. They moved massive amounts of stone and carved and fitted it exactly with simple tools, as well as working with wood. Their architects designed vast open spaces and compelling interiors. Their multistory edifices reached up to the heavens, and served sometimes as astronomical observation sites, while commanding the world below. Their equivalents are neither the medieval cathedrals of Europe nor the Acropolis of Greece. Instead they are the most significant continuing testimony to the uniqueness of the these New World civilizations and peoples.

While we can directly experience and marvel at these sites it is much more difficult to penetrate the intellectual worlds of their builders. The Mayas, prior to their collapse in AD 800–900, had a sophisticated writing system which was lost, as were many of their ideas about astronomy and mathematics. Similarly, the Nazcas of coastal Northern Peru who vanished around AD 600 may have had more advanced ideas about astronomy than their predecessors. The unevenness of historical experience and its inherently nonlinear nature is one of the sobering lessons of the history of science and technology in the New World. The Mayas alone invented a writing system which took nearly 450 years after the European Conquest to decipher. The Incas adapted a system of counting called the *quipu* for purposes of accounts and storage but never extended it into a mathematical base. The Aztecs excelled at urban planning, irrigation, and public health but showed little interest in writing.

The peoples of the New World were builders, agriculturalists, and craftsmen rather than scholars or theologians. The European conquerors came from an age of iron and steel with wooden ships, navigation, steel swords, guns, explosives, and literacy. They brought horses, cattle, and smallpox, measles, diphtheria, trachoma, whooping cough, chicken pox, bubonic plague, typhoid fever, scarlet fever, amoebic dysentery, and influenza.

See also: ►*Quipu*, ►Mathematics, ►Potatoes, ►Crops, ►Technology, ►Sugar, ►Animal Domestication, ►Metallurgy, ►Textiles, ►Nazca Lines, ►Stonemasonry, ►Swidden

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Telescope

Julian A. Smith

The telescope is an optical instrument used to make distant objects appear nearer and larger; it consists of one or more tubes with a series of lenses, mirrors, or both (refracting, reflecting and catadioptric models, respectively), through which light rays are collected, brought to a focus, and magnified. Despite their great variety, all telescopes have two basic parts: the objective, which intercepts and focuses the incoming light, and the mounting, which supports the objective. The telescope, which revolutionized astronomical research in the seventeenth century, is usually considered to be a European invention, though parallel discoveries occurred elsewhere, and some of its elements were developed earlier by other cultures.

The traditional Western account of the telescope's invention is quite complex. The use of hollow sighting tubes without lenses to observe stars had been known to the ancient Greeks, being recorded by Aristotle (384–322 BCE) and the geographer Strabo (ca. 63 BCE–ca. 19 AD). Lenses are mentioned by the playwright Aristophanes (ca. 450–388 BCE), and mirrors were investigated by Heron of Alexandria (ca. 60 AD). The geometer Euclid (ca. 300 BCE) and the engineer Archimedes (ca. 287–212 BCE) studied both. The investigation of lenses, mirrors, and sighting tubes continued throughout the Medieval period. The invention of spectacles, an important telescope precursor, occurred between 1285 and 1300 by an unknown Italian glassmaker, but Alexandro della Spina (d. 1313) and his friend Salvino d'Armati (d. 1317) are most often credited. Meanwhile, English Franciscan friar Roger Bacon (1211–1294) wrote extensively of spectacles and other optical devices, and influenced many later scientists with his research into the laws of reflection and refraction.

An enormous number of sixteenth century figures developed various combinations of perspective glasses and mirrors to enlarge distant objects, including the English father and son surveying team of Leonard (ca. 1520–ca. 1571) and Thomas Digges (1546–1595), mathematician William Bourne (d. 1583), Italian natural philosopher Giambattista della Porta (1534/5–1615), and Dutch mathematician Cornelius Drebbel (1572–1634). But the lack of documentary evidence has thus far left historians divided over whether these instruments were true telescopes or just magnifying glasses.

The first unambiguous accounts of the European telescope come from Holland around 1608. Most credit the Middleburg spectacle maker Hans Lippershey (ca. 1570–1619) with the first refracting telescope; but there are rival claims by Middleburg optician Zacharias Jansen (1580–ca. 1638), and Alkmaar inventor Jacob Metius/Adriaanzoon (1571–1635).

Early telescopes were first applied to military operations. But over the winter of 1609–1610, Italian physicist and astronomer Galileo Galilei (1564–1642) dramatically improved Lippershey's primitive device and turned it to the sky. His announcements of lunar valleys and mountains, sunspots, the phases of Venus, the moons of Jupiter, and much more (published in the March, 1610 *Sidereal Messenger*) thoroughly shook the ancient earth-centered cosmology of Alexandrian astronomer Claudius Ptolemy (ca. 150 AD). Similar observations were made between 1609 and 1612 by English polymath Thomas Harriot (1560–1621). The word "telescope," meanwhile, was coined in 1611, and was first printed in Julius Caesar Lagalla's (1576–1624) *Lunar Phenomena* of 1612.

Early Galilean telescopes, with one biconvex and one biconcave lens, suffered from both chromatic and spherical aberration, which left blurry images. The German astronomer Johannes Kepler (1571–1630) designed the improved Keplerian telescope of two biconvex lenses in 1611, but problems remained. It was not until 1636, when the Minorite friar Marin Mersenne (1588–1648) suggested replacing lenses with mirrors, that real progress could be made. Reflecting telescopes were designed by Scottish mathematician James Gregory (1638–1675) in 1663, and built a few years later by both Isaac Newton (1642–1727) and French physicist Guillame/Nicholas Cassegrain (fl. 1672); these models (Newtonian and Cassegrain) are still widely used today.

During the period 1610–1650, the telescope was carried by European explorers to all regions of the earth; frequently Jesuit missionaries exported it to non-Western cultures. However, there is evidence that other societies developed both the telescope and its various parts independently of Europe. Glass originated in Egypt about 3500 BCE and was first produced on a large scale by the Phoenicians, and lenses dating back to pre-Greek times (2000 BCE) have been discovered in Crete and Asia Minor/Mesopotamia.

Meanwhile, Arabic astronomers played a significant role in paving the way for the telescope. The mathematical laws of optical reflection and refraction in glass and other media were thoroughly investigated and extended by the physicist–astronomer Ibn al-Haytham (Alhazen, 965–ca. 1040). Ibn al-Haytham knew how to use spherical glass segments to magnify objects, and was familiar with spherical aberration and techniques to calculate the focal lengths of lenses and mirrors. Much of this knowledge was subsequently transmitted to Europe through Latin editions of his work, and especially through the texts of his Polish disciple, Witelo of Silesia (ca. 1230–ca. 1275). Bacon also learned much from Ibn al-Haytham.

Sighting tubes were also early employed by Arabic astronomers; al-Battāni (858–929) used them in his Raqqa observatory. Naṣīr al-Dīn al-Ṭusī attached one to a sextant at his Maragha observatory in 1259 to study the sun.

Meanwhile, Needham argues that Chinese opticians may have discovered the elements of the telescope either before, or parallel to, the Europeans. Though glass was developed fairly late (ca. 500 BCE), quartz rock-crystal had been in use since ancient times and lenses of both materials were employed to focus solar rays to start fires. Needham also claims the Chinese used smoky rock-crystal to observe sunspots and eclipses. An important text of Tan Qiao (the *Hua Shu* or Book of Transformations of about AD 940) records the use of planoconcave, planoconvex, biconcave, and biconvex lenses to make objects larger, smaller, upright, and inverted. Spectacles have often been considered a Chinese invention, but this is based on a garbled text; they were brought overland from Europe by 1300. As for catoptrics, Mohist opticians of the fourth century BCE studied both concave and convex mirrors, and were familiar with real and inverted images, focal points and refraction in different media. The use of concave mirrors to ignite tinder by focusing sunlight goes back to the Chinese Bronze Age; one of the earliest citations is dated 672 BCE.

Chinese sighting tubes made of bamboo are similarly old; the most important early reference is the (approximate) sixth century BCE *Shu Jing* (*Historical Classic*). By the *Huia Nan Zi* (*Book of Huai-Nan*) of 120 BCE, they were widely used in land surveying and triangulation; and by the twelfth century, they were standard navigational equipment for taking astronomical observations aboard ships.

Though many of these developments were contemporaneous with European discoveries, there are two parts of the telescope in which Chinese scientists can claim undisputed priority: the invention of equatorial mounting, and the development of clock drives, both of which are standard equipment on today's telescopes.

Astronomer Guo Shoujing (fl. 1270) developed the equatorial mounting now used on all modern telescopes for his "simplified instrument", which was basically a dissected armillary sphere related to the torquetum, an Arabic invention which had been recently imported (ca. 1267) to China from Persia. With an equatorial mounting, a rotation about only one axis (one parallel to the earth's polar axis) was needed to follow the curved paths of the stars.

Chinese physicists and engineers anticipated the fourteenth century mechanical clocks and clock-driven astronomical instruments of Europe by over a 1,000 years. Mathematician, geographer and astronomer Zheng Heng (ca. 78–ca. 142) constructed what Needham calls the "grand ancestor of all clock drives," a rotating bronze armillary sphere powered by a system of gears attached to a waterwheel. This device was used to predict the positions of various stars and planets. The later clock-driven armillary sphere of Su Sung (AD 1090) added a sighting tube to permit direct observation of a star as it moved over prolonged periods, resulting in a true "clock drive" for astronomy.

But despite Chinese priority in clockwork and mounting, just as in Europe, it was not until the seventeenth century that the disparate elements of the telescope were joined together. Though Chinese texts describe European telescopic discoveries from 1615 onwards, and Jesuit Father Terrentius/Johannes Schreck brought a telescope to China in 1618, Needham maintains that enough documentary evidence exists to assert a parallel, independent discovery by Suchow opticians Po You and Sun Yun Qiu. Between about 1620 and 1650, this pair constructed not only early telescopes, but also compound microscopes, magnifying glasses, searchlights, magic lanterns, and other instruments. Meanwhile, Sun Yun Qiu wrote a text on these and other optical devices, entitled *Jingshi* (*History of Optick Glasses*). But the first Chinese book on the telescope specifically was the *Yuan Jing Shuo* (*Far Seeing Optick Glass*) of Tang Ruo-Wang (Adam Schall von Bell) in 1626. *Yuanjing* became the standard term for the telescope, and by 1635 it was being widely used by Chinese artillery in battle.

Telescopes appear to have come to Indian astronomers fairly late. Indian craftsmen made glassware, lenses, and mirrors throughout the ancient and medieval periods. And *gola yantra* or armillary spheres, first mentioned in the *Āryabhaṭīya* of Āryabhaṭa I of Kusumpura (b. 476 AD), had clock-drives (powered by clepsydra) for stellar observation by the *Bhatadipika* of Parameśvara (ca. 1432).

But it was not until the seventeenth century that primitive telescopes were used in India. The celebrated astronomer and instrument-maker Sawai Jai Singh (1686/8–1743) employed telescopes to "show that Mercury and Venus get their light from the Sun as the Moon does" (*Zica-i Muhammad Shahi*); and though they revealed Saturn to be an irregularly shaped "oval," these telescopes were apparently not good enough to resolve the rings, which had already been accomplished by Dutch physicist Christiaan Huygens (1629–1695) several decades previously, in 1659. Indian achievements in this area thus far appear to be rather derivative, but much research still needs to be done in this area.

See also: ►Jai Singh, ►Ibn al-Haytham, ►al-Battāni, ►Naṣīr al-Dīn al-Ṭūsī, ►Maragha, ►Guo Shujing, ►Zhang Heng, ►Clocks and Watches, ►Parameśvara, ►Āryabhaṭa

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Textiles in Africa

GLORIA T. EMEAGWALI

Historians of African textiles now have at their disposal a wide range of oral and written documented sources. These describe significant centers of textile production over time, the raw materials, implements, and techniques used by the various cloth producers, varieties of fabric and techniques of dyeing and coloration, symbolic expression as reflected in the finished products, and the many functions for which the latter were used. The process of technological transfer within various parts of the continent and the elaborate structure of guilds and schools of apprenticeship are also better known to us as a result of the systematic collection of oral history in some areas.

From the Northeast African Nile region to West Africa and elsewhere, travel reports, missionary reports, and even autobiographies have provided details about aspects of the development of cloth making techniques. Herodotus in his travels in Egypt as far as the first cataract obtained specific knowledge about the implements used by the Egyptians and the existing division of labor. Such information has complemented the archaeological evidence brought forward by teams of Egyptologists as they continue to come in contact with numerous reams of cloth in the mummified corpses and burial goods which the Egyptian nobility, like some of their counterparts in West Africa, sent along with the dead to the afterlife.

In the case of Ethiopia, travel reports by missionaries, explorers, and travelers such as Francisco Alvarez, Jerome Lobo, Charles Poncet, James Bruce and Henry Salt, provide direct and indirect information on the variety of textiles in the Axumite and post Axumite realm. For West Africa in the eighteenth and nineteenth centuries, Mungo Park, Barth, and Baikie complement the perspectives diffused in the missionary reports of Trotter, Allen, and Crowther, who emphasized that the people of Onitsha, Eastern Nigeria, like their counterparts elsewhere, "manufacture their own clothes generally plain or fanciful with cotton grown in their farms" (Crowther 1968).

Archaeological reports have been no less useful than the eyewitness travel and missionary accounts cited. Reams of linen and cotton have been found in Egyptian tombs, and the Sudan, also one of the Nile Valley kingdoms, has yielded cloth and looms dating back to 500 BCE. The Igbo-Ukwu finds of Eastern Nigeria included thousands of artifacts, among which was cloth dated to the ninth century. The Bandiagara cliffs of Mali have yielded textile products dated to the eleventh century. The evidence from the excavated pits complements the various collective recollections reflected in poetry, song, and narrative accounts no less than the honorific codes and titles and range of linguistic terms accorded textile specialists and their products. Some city states and towns in the African continent gave their names to a product line, as was the case of Akwete and Okenne in Eastern and Central Nigeria, West Africa.

Whether in renowned Nigerian textile centers such as Kano, Iseyin, Bida or Akwete and Okenne, or in the Wolof empire of Senegal, the Bambara kingdoms of Mali, the Mossi Empire of Burkina Faso, or the Baule polities of the Ivory Coast, we can identify some basic raw materials, production instruments and techniques, as well as common tendencies relevant to textile not only in West Africa, where the latter regions were located, but also in Central, East, and Southern Africa. Raw materials were derived from vegetable or animal products and generally involved wool, camel hair, flax, cotton, the leaves of the raffia palm (*Raphia rufia* or *Raphia vinifera*), silk from cocoons, and bark from the baobab tree. In all the above cases, with the exception of bark, which was hammered into shape, there developed over time sophisticated spinning, weaving, and dyeing techniques which included the gradual invention and improvement over time of vertical and horizontal frames, lower and upper beams, beaters, shed sticks, hecklers, shuttles, and templars, all various components of the horizontal and vertical looms produced across the continent.

African textiles, by the nineteenth century, included a wide range of fabrics, each influenced by the base material from which the thread was made, the texture of the thread, the width of the strip woven cloth, the alignment of the thread, and the intensity of inlays and the dyeing procedure, whether starch resist or not. Indigo, guinea corn stalk, the bark of the locust tree, the leaves of the tombolo tree, combined with ash potash and any of a long list of colorants were used to produce blue, red, buff, rust, or brown and other colors. Dyes were derived from experimentation with vegetable and other products. The famous *Kente* cloth of strip woven silk (sometimes interlaced with threads of gold and very often confined to the Ashanti nobility), *Sanyan*, Western Nigeria's silk derived fabric, *Adrinkra*, the hand-printed cloth of the Ivory Coast, and *Sotiba* of Senegal, are some of the various types of textile products which have become household names in the continent.

A wide range of symbols was reflected in cloth through the representation of motifs of special shapes, figures, dimensions, and sizes. These were either impressionistically done by the use of geometrical shapes and symbols or were made to reflect naturalistic images derived from African cosmologies and indigenous belief systems. It was common for Dahomean quilts to portray images of the founding fathers of particular dynasties. A lion represented King Gelele and a buffalo King Gezo, whilst a representation of a ship was the symbol of King Agaza – all historic figures in the making of the Dahomean (Beninois) state. More recently, worldly events ranging from the American soap opera Dallas to statements about the prevailing economic reform programs have been coded into fabric. A study of African textile over the centuries yields information not only about changes in technical expertise and accretional gains made from the intraregional and interregional exchange of ideas, but also the prevailing lifestyles, philosophies, and world views of Africans in various parts of the continent. Textiles in themselves provide a rich source of historical information. They were associated with many activities and had many uses. They were a medium of exchange in barter, or units of currency in a wide range of commercial transactions. Tax payment was collected in the form of textiles and so too tribute. Since fabric differed in cost and the degree of technical expertise associated with various types, it was easy for it to become a symbol of wealth, extravagance, and conspicuous consumption. Cloth very often was a symbol of class affiliation. Saddle cloth and the overall accoutrements of the horse included specialized fabric, as did the panoply associated with Ashanti royalty. Cloth had special burial functions. Specialized fabric was associated with shrines of the dead. Marital gifts, whether prenuptial or not, tended to include cloth as part of the expected dowry. Decorative and symbolic objectives were matched by functional and practical ones. Cloth was used for protective purposes against the elements, as sheets and covers, and also to make rice bags, purses, or tents.

The reproduction of knowledge systems was done through institutionalized apprentice systems of guilds, each of which adhered to strict codes of conduct and behavior. Fees in cash or kind were paid by the apprentice who was expected to "gain freedom" after periods agreed to in the context of elaborate ceremonies. These guilds themselves had a hierarchy of officials who in many cases were of significant political clout. The teaching and training of spinners, weavers, and dyers was therefore organized in the context of established custom and practice, even though there was a general tendency for specialization to be restricted to specific lineages within various regions.

There is evidence that Africans imported cloth in the context of the trans-Saharan trade as well as the trans-Atlantic, but these importations were complementary to a wide range of indigenous textile products. It was not unusual for various political elites to flaunt some of the imported textiles along with indigenous products, or for textile specialists to unravel an epic of imported fabric with the objective of isolating particular reams of thread. The British industrial revolution had specific implications for African textiles, given the fact that factory produced cloth was cheaper with the mechanization of spinning and weaving. The successful transfer of textile technology from India to Britain by the nineteenth century meant that the British factory system was able to churn out some relatively attractive textile products for the African consumer. This, however, did not lead to the destruction of the indigenous textile sector which continued to be a dominant component of the informal sector well into the twentieth century, despite some ill-intentioned legislation and policies during the period of colonial rule.

Contemporary Africa is home to a wide variety of indigenous textiles. Local factory-produced cloth has had to compete with Taiwanese, Indonesian, and Dutch imports, most of which are imitations of indigenous African fabric. IMF and World Bank conditionalities tend to call for the removal of duties on imports and therefore undermine those local textile centers, some of which lack the productive capability to compete on the open market. In spite of these trends, however, there is every indication that African textile producers will continue to have a large share in the market and continue to experiment, innovate and produce the high quality textiles historically associated with the continent.

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Textiles in China

DIETER KUHN

A textile is here understood as a woven fabric made from a wide range of raw materials. Some of these were silk, cotton, wool, and the bast fibers ramie (*Boehmeria nivea L.*), hemp (*Cannabis sativa L.*), and the bean- or vine-creeper (*Pueraria thunbergiana*), which possessed the greatest economic and cultural importance in pre-Mongol (prior to AD 1279) China. The development of textiles is described here on the basis of archaeological evidence and from the view of its cultural importance.

The origin of weaving can be traced back to basketry and matting techniques from the Neolithic. Impressions on ceramic sherds and fragments from the archaeological sites of Banpocun near Xi'an in Shaanxi and from Hemudu in Yuyao county in Zhejiang prove that they existed in China as early as the fifth millennium BCE. The earliest finds of textiles are from southeast China. There is a complicated fragment of fabric, made of *Pueraria thunbergiana*, found at Caoxieshan in Jiangsu province and dated to the fourth millennium BCE. Its structure features a combination of hand twining and loom weaving techniques. A number of silk belts, a piece of silk, and a scrap of ramie cloth were discovered in a bamboo box excavated from the site of Qianshanyang in Wuxing in northern Zhejiang, dated to ca. 2750 BCE.

Small stone-cut and jade figures were found in various Anyang sites from the the Shang period (sixteenth–eleventh centuries BCE). They clearly show "textile ornaments" which give an impression of Shang clothing and fashion. Apart from furs and leather, especially suitable as winter clothing and used for ceremonial occasions, hemp and silk were tailored. Tailoring does not mean cutting pieces of fabric so as to make them fit but simply sewing pieces of fabric together, only allowing a few corrections. It was probably the Shang people who introduced right side fastening and a hair-dressing style which could be distinguished from the barbarians. Most garments including lined garments were buttoned on the right side under the right arm. Very often the overlap of a robe was unbuttoned. *Obi*-like waist-belts kept the coat and the undergarments in position. Women's dress included a skirt. Women had their hair styled in a cylindrical shape, and flat rather high round caps were common. Upperclass people wore gaiters and shoes that curled upwards to the toe. Geometrically patterned fabrics (*T-, hui* and *lozenge*-patterns) were exclusively used as borders of garments, at the openings of the sleeves, at the collar, and along the overlap, for girdles and waist-belts, caps and hats. Colorful painted and embroidered silk was available to the higher echelons of Shang society. Certain important weaving techniques were applied to produce silk fabrics as early as Shang times:

1. Tabby weaves with threads of almost identical diameter and a thread-count of warp and weft between 8 : 7 and 75 : 50 cm^{-1};
2. Warp-faced tabby, also called rep or rib, where the number of warp-threads is roughly double the number of weft-threads per centimeter;
3. Monochrome tabby patterned with twill (3/1), very often named twill damask (*wenqi*). The ground weave is a tabby weave, and the pattern is woven in twill weave with the warp-threads forming the pattern;
4. Tabby crêpe (*zhou* or *hu*) with a thread-count of ca. 30 : 30 cm^{-1}. The warp-threads show a twist with 2,500–3,000 twists per meter. The weft-threads are twisted together from several threads in an *S*-twist showing 2,100–2,500 twists per meter. The strong twisting of the threads causes the crêpe effect;
5. crossed-warp weave technology was known and used.

The most important and spectacular textiles of the Zhou period (1045–221 BCE) discovered so far are from central and southern China, especially from Jingzhou in Hubei and from the region of Changsha in Hunan. In Western Zhou times (1045–771 BCE) the *jin* brocade appeared, an outstanding weave which on the one hand was produced on a rather complicated loom and on the other hand asked for expert craftsmanship. This so-called brocade was a new type of warp-faced compound weave with the warp divided into at least two series, normally of different colors. Even picks of weft interlace with the warp either in tabby or twill. Although this weaving method produced polychrome silk fabrics with a colorful shiny and mostly geometric pattern on the surface, its repertoire was still limited by the weaving technology at the time. Weavers exhausted the technical possibilities of their looms and composed scenes and figures which were evidently intended to be pictorial descriptions, but they are still symmetric with straight lines and cornered outlines. Embroidery helped to make the patterns of tigers, phoenix, dragons, birds, and blossoms appear more lively. The patterns were arranged in various ways adorning the silk robes of the fourth and third centuries BCE.

In 1972 outstanding textile fabrics and garments totalling more than 100 objects were unearthed at tomb no. 1 at Mawangdui in Changsha. The tomb belonged most probably to the Lady Dai (d. 168 BCE). Among the well preserved fabrics and garments there were more than a dozen robes of various make, such as 11 floss-wadded robes, one lined robe, three unlined robes, several blouses and skirts, two pairs of socks, four pairs of shoes, three pairs of gloves, pillow covers, 46 rolls of single-width silk fabrics, and many more items of daily life. The textiles exhibit an unrivaled excellence in weaving skills, the mastering of pattern design, and imagination in applying all sorts of patterning techniques. Favorite weaves were thin and loosely structered gauzes (*sha*) and lozenge-patterned leno (*luo*), a fabric of open structure which is made by crossing warp yarns.

The most sophisticated weaving techniques and looms were used to produce brocade with small geometric patterns. A new technical dimension of weaving becomes obvious with the pile-loop brocade, a velvet-like fabric with geometric patterns of different sizes. Forty silk garments are embroidered with the colorful and curvilinear designs of *xin qi* (abiding faith), *changshou* (longevity), *cheng yun* (riding on the clouds), and various plants and cloud patterns. Embroidery as a patterning technique lost some of its importance when by Eastern Han times (AD 25–220) the variety of weaving patterns was finally extended to include mythological beasts, birds, fishes, flowers, all sorts of four-legged creatures, and Chinese characters.

The brocade manufactured from Han to early Tang times (seventh century) was woven with warp-faced patterns. The colors of the previously dyed warp threads mounted on the looms dominated the patterns. The patterns could be as wide as the width of the fabric (ca. 50 cm) but their length was rather limited. Probably during the eighth century of the Tang dynasty a dramatic innovation took place. The weft-faced patterning method as it had already been practiced in a few woollen textiles from Han times was now widely applied to silk weaving. The advantage of weft-patterning was that the colors of the pattern produced by the weft could easily be changed, which resulted in larger and more vivid pattern units. Furthermore the dressing of the loom was facilitated. After the Tang dynasty, the weft-faced patterning method gained predominance in brocades and in other weaves. At the same time the cultural influence of Central Asia became evident in textile patterns. Apart from several hundred fragments of silks unearthed in 1987 from the underground palace of Famen Temple near Xi'an, most textile finds from the Tang period were discovered in the dry desert region of Turfan (Xinjiang province) and in the cave temples of Dunhuang.

If satin weave (*duanwen*) is classified as an irregular twill (*xiewen*), then satin could have been created as early as Tang times. Whereas the interlacing points of warp and weft in twill weaves are arranged in a continuous oblique line, those points in satin do not form a line but are evenly distributed, thus allowing long floats of the threads which give the fabric a glittering and at the same time smooth appearance. The French name *satin* was derived from the word *zaituni* which was used by Persian merchants to name the city of Citong at the coast of Fujian, another name for the famous commercial center of Quanzhou in the Song period (AD 960–1279). Several well preserved complete sets of official robes, garments of various types, underwear, and other textile items were found in three Song tombs. The tomb of Huang Sheng (1226–1243) in Fuzhou in Fujian province, who was the daughter of an official and married to an imperial clansman, contained 354 textile items, of which 201 were articles of clothing. The textiles are of top quality. The weavers and textile printers made use of the most advanced techniques of their time in producing figured leno (*hualuo*), gauze (*sha*), crêpe (*zhou*), and figured twill silks (*ling*). Even a few satin weaves (*duan*) are described. More than 30 textile items were discovered in the tomb of the student of the Imperial College Zhou Yu (1222–1261) in Jiangsu province, and the recently excavated tomb of Mme. Zhou (1240–1274) in Jiangxi province yielded 329 items of textiles. Among the many regional brocades produced, the pure red brocade from Sichuan (*Shu jin*), with a formidable array of realistically depicted designs, was most famous.

In northern China, where the Liao dynasty reigned from AD 916 until 1125, and in the Song empire, the use of various types of tapestry (*kesi*) became highly fashionable. Among the textiles recovered from the Liao tomb of Yemaotai, dated between 959 and 986, there was a shroud made of silk tapestry in gold threads with a powerful design of dragons. The forerunners of this *kesi* tapestry technique can be traced back to the *zhicheng* technique of Han times, an intricate inlaid pattern produced by the weft yarn employing the swivel weaving method. During the Yuan and the Ming dynasties the use of various types of weaves with gold threads (*jinjin*) increased. The weavers of Ming times, especially the craftsmen of the cloud pattern brocade (*yunjin*) from Nanjing mastered a swivel weaving method (*zhuanghua*) making use of colored wefts to form a pattern on a fabric of various weaves. In many cases a glossy satin served as ground for the colorful swivel weave.

Three types of pile fabrics were produced on a large scale in Ming and Qing dynasties. The *Zhang* satin, originally from Zhangzhou in Fujian, was a figured warp pile fabric. From early Qing times until the end of the eighteenth century its main centers of production were Nanjing and Suzhou. The *Zhang rong* was a velvet where in order to produce a pattern the loops in the pattern area were cut. Thus the velvet pattern stood out on a ground of loops. The *Jian rong* was a cut pile fabric made of black silk threads produced on looms in Nanjing.

For the dragon robes (*longpao*) of the imperial Ming and Qing courts, the formal Manchu court robes (*chaofu*), and the semiformal coats (*qifu*) all patterning techniques known at the time were employed. This applies especially to the robes manufactured during the reign of the Qianlong emperor after 1759. Many of the old weaving techniques were handed down from generation to generation and can still be found in China.

See also: ►Silk and the Loom

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Textiles in Egypt

Gregg De Young

Egyptian textiles during the Dynastic Era (3100 BCE–300 BCE) were almost exclusively linen, although wool was not unknown. (Cotton and silk were introduced only later.) Linen was produced in three basic grades: royal linen, thin cloth, and smooth cloth. Production of royal linen, the highest grade, was a palace monopoly. Its manufacture took place both in the royal palace and in workshops associated with state temples. These workshops were supervised from the royal harem and were obligated to provide specific amounts of linen annually for use of the royal household and in temple rituals.

The Egyptians did not ordinarily color their linen because most of the dyes known to them were not colorfast. When one desired to dye either a piece of linen cloth or the thread used in embroidery, it was generally necessary to treat the fabric first with a mordant (one of several substances, such as alum, that would adhere to the fibers of the linen and allow the chemical bonding of the dyestuff) then with the dye itself. Thus, the typical color of Egyptian linen ranged from near white (from young, immature, flax plants) to golden brown (from fully mature flax).

Tomb paintings show that when Egyptians harvested flax, they pulled it up by the roots, rather than cut the stalks. Presumably this was to obtain the longest fibers possible. The stalks were first drawn through a comb-like devise to remove the seeds. The stalks were soaked, then beaten and sometimes scraped in order to separate the woody parts from the long, flexible fibers. A final combing prepared the fibers to be spun into thread.

Once dried, the flax fibers were rolled together, usually between the palm and the left thigh, forming a loosely twisted strand. These were wound into loose balls on a pottery reel, then stored in clay or basketry containers until ready for spinning. Based on artistic representations, the Egyptians used three different techniques to rotate the spindles while twisting the thread together. The supported spindle was rotated by being rolled between the palm and the thigh of the spinner. The grasped spindle was rotated between the palms. The suspended spindle was set spinning and allowed to drop and swing freely, its rotary motion being maintained by the weight of the whorl, the drum-shaped or dome-shaped stone or ceramic attachment near the top of the thin shaft of the spindle, which acted as a kind of miniature fly-wheel. The dropped spindle produced the most constant tension on the thread, permitting a finer and more homogeneous thread to be produced.

The earliest looms were simple ground looms in which the two beams supporting the warp threads were placed on the ground and held firmly in place with pegs. At about the beginning of the New Kingdom (ca. 1550–1085 BCE) we also begin to find examples of the vertical-framed loom in which the two beams were incorporated into a less portable rectangular wooden frame. Some have speculated that this innovation may have been introduced when Egypt was dominated by the "Sea People" or Hyksos (ca. 1700–1550 BCE).

When thread was ready for weaving, the warp threads were attached parallel to one another between the two main beams of the loom. In the simplest weaving, the weft thread was passed over and under alternate warp threads. On its return, the path of the weft thread was reversed, so that it passed on the opposite side of each warp thread. A stick or comb was often used to beat down and press the weft threads together. There are, of course, many variations on this basic tabby weave, some of them of considerable complexity. Various weaving patterns were used to provide some form of decoration in the fabric.

Based on artistic evidence, it appears that men were most frequently involved in the cultivation and harvesting of flax and in the preparation of the fibers for spinning. Both men and women (and even children) are shown involved in the spinning of the fibers into linen threads. Women, however, seem to be the ones who work at ground looms, while men more often are shown working at vertical looms. Whether this represents a true division of labor or only an artistic convention is unclear.

Woven cloth was cut either with a metal shears or a knife when the ancient Egyptian wished to fashion a piece of clothing. The pieces were sewn together using a fine linen thread and a needle of polished wood, bone, or metal (usually copper or bronze, but occasionally gold or silver). The pieces were held together during sewing with pins of the same composition. Both needles and pins tended to have larger dimensions than modern examples. Pins were frequently capped with a looped head, which may have served a decorative purpose. Seams and hems were frequently rolled and secured by a rather crude whipping stitch. Garments that might experience greater stress or wear might be joined instead with flat seams. There were, as today, many experiments with decorative sewing in order to produce an aesthetic effect.

Fine linen was apparently quite valuable. Considerable effort was often expended to repair damaged garments. Usually repairs were in the form of darning (reweaving), rather than patching. The more ordinary grades of linen, however, were repaired with considerably less effort. A frayed edge might be bound carefully with a whipping stitch, but more serious damage often led to the object being discarded and replaced. Sometimes outworn garments were torn into strips to use in wrapping mummies.

From as early as the Old Kingdom (ca. 3000–2700 BCE), there are indications that laundering was done for wealthy households and temples. Washermen often formed a kind of guild. In the New Kingdom, the Superintendent of the Washermen seems to have enjoyed nearly as much prestige as the Sandal Bearer within the royal household. (Of course, in most households, the task would have fallen to the women or slaves.) Clothing was picked up regularly from subscribing households, identified with specific markings and listed on *ostraca* (pottery shards or flakes of limestone), and taken to the riverside laundry. There it would be treated with natron or other types of surfactants, beaten with sticks or stones, rinsed, wrung out, and spread to dry and bleach in the hot Egyptian sun. When fully dry, it would be folded, bundled, and returned to its owners.

As is often the case, much of our knowledge of the processes for textile production, use, and care is derived from scenes portrayed in the funerary art of the social elite, coupled with study of surviving examples (and Egypt's dry climate has helped to preserve many pieces of textile). These reveal a remarkably sophisticated industry for production of cloth and clothing. Modern archaeology increasingly realizes the importance of textile evidence in dating artifacts, as well as in offering invaluable evidence of the daily life of all classes of ancient Egypt society.

See also: ►Dyes

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Textiles in India

Vijaya Ramaswamy

India may be described as one of the ancient centers of the cotton textile industry, since early evidence of cloth has been found in prehistoric archaeological sites. The spinning and weaving of cloth was very much a part of everyday life in ancient India. The loom is used as poetic imagery in several ancient texts. The *Atharvaveda* says that day and night spread light and darkness over the earth as the weavers throw a shuttle over the loom. The Hindu God Vishnu is called *tantuvardhan* or "weaver" because he is said to have woven the rays of the sun into a garment for himself.

It is interesting to note that in the third or second century BCE, when the cotton industry in India was in a flourishing state, in Europe cotton was still virtually unknown. The Greek scholar Herodotus thought that cotton was a kind of animal hair like sheep's hair. At the beginning of the Christian era, Indian textiles figure prominently in the trade with Rome. Arrian, the Roman historian, testifies to the export of dyed cloth from Masulia (Masulipatnam on the Coromandel coast), Poduca (Pondicherry), Argaru (Uraiyūr in Tanjavūr district, Tamil Nāḍu) and other places in south India. Legend has it that Indian cloth was purchased in Rome for its weight in gold. The quality of Indian dyeing too was proverbial in the ancient world, and in St Jerome's bible, Job says that wisdom is more enduring than the dyed colors of India. Indian textiles even passed into Roman vocabulary as is seen by the use as early as 200 BCE of a Latin word for cotton, Carbasina, derived from the Sanskrit *kārpasa*.

The history of Indian textiles constitutes one of the most fascinating and at the same time tragic chapters in Indian history. In the sixteenth century the Portuguese first set foot on Indian shores and were followed in quick succession by the Dutch, English, and French. For the next hundred years "Indian cotton was king" and Europe was in the grip of what economic historians describe as "the calico craze." Indian textiles were used in the Middle East, Africa, and Europe not merely as dress material but also as coverlets, bed spreads, and wall hangings. The joint English sovereigns William and Mary are described as having landed in England in 1689, resplendent in Indian calico. Daniel Defoe, the author of *Robinson Crusoe*, commented that Indian calico, which at one time was thought fit to be used only as doormats, was now being used to adorn royalty.

However, there was a dramatic reversal of fortune in the eighteenth century. The cotton revolution in England rendered redundant the products of Indian handlooms. The first ban on Indian textiles was imposed by the British crown in 1700 and repeatedly after that. By the end of the century, instead of Indian cloth being exported abroad, the Indian market was flooded by the machine-made cloth of Manchester and Lancashire. Around the same period, India was hit by one of the worst famines beginning in the late seventeenth century and continuing through the eighteenth century. The words attributed to Lord Bentinck, the Governor of India in the 1830s, that "the bones of the weavers are bleaching the plains of India" are a dramatic but apt description of the fate of the Indian weavers.

The eclipse suffered by the Indian textile industry lasted until the early twentieth century until its grand revival under Gandhi, who initiated the *khādi* movement. The *charkhā*, or Indian spinning wheel, and *khādi*, or homespun cloth, became symbolic of the Indian struggle for independence. Foreign cloth was burnt in the public squares and the Indian spinning wheel became a part of the home of every Indian patriot.

Since Independence, a sea change has occurred in the traditional Indian textile industry. The changeover to power looms and jet looms and the introduction of computer designs is setting new traditions in Indian textiles. In the course of its historical vicissitudes, the Indian textile industry has gone through a process of change as well as cultural assimilation.

Indian Textile Technology

The first process in the weaving of a cloth is warping and sizing, and in India this is done in the open. Bamboo sticks, about one hundred and twenty in number, are fixed upright in the street or what is called the warping grove, at a distance of a cubit from one another. Rows of women walk up and down the line, each carrying a wooden spindle in the left hand and a bamboo wand in the right. As they walk, they intertwine the threads between the split bamboos. These threads are then stretched horizontally from tree to tree, evenly washed with rice starch and carefully brushed. The right amount of tension in the warp in required to prevent the yarn from breaking while on the loom.

In India spinning was and still is almost exclusively the occupation of women. More specifically, this was the sole occupation of destitute women and widows. It is interesting that this corresponds to the English notion of the ‘spinster’ as one who has to spin for her livelihood since she has no one to support her.

The earliest looms in use in India were either the pit loom or the vertical loom. The *Atharvaveda*, probably compiled in the early pre-Christian era, says, “A man weaves it, ties it up; a man hath borne it upon the firmament. These pegs propped up the sky; the chants, they made shuttles for weaving… (sic).” However, the most common type of loom in use was the horizontal pit loom in which the loom is placed inside an earthen pit and is operated with foot treadles. By depressing the pedal with one foot and raising the other, one set of threads get depressed and the weaving shed is formed through which the throw shuttle is shot across by hand. References to such looms are scattered throughout ancient and medieval inscriptions. Around the fifteenth century one begins to get reference to the draw loom. This would consist of several levers and so enable the weaving of complex patterns. The introduction of the fly shuttle in the 1930s toward the end of British rule in India resulted in the partial mechanization of loom technology and in another three decades this was followed by the introduction of the jacquard. Nowadays, partially mechanized looms, power looms, and jet looms are displacing the traditional Indian handloom.

Traditional Indian Costumes

Different types of cloth are worn and woven in the different parts of India, since this is a vast land with varying climates. Generally, men tend to wear a longish lower cloth of about one and a half yards in length, called *dhōti* or *lungi* in the north and *veshti* in south India, while the traditional upper cloth consists of a single piece of cloth called *aṅgavastra*. However, in hot weather, men generally go without the upper cloth. In many parts of northern India, men also wear a head gear against the dust and heat. This is especially true of desert regions like Rajasthān. The Indian women wear large skirts or loose trousers called *salwār* and longish or short jackets. Alternately, they wear a six-yard piece called a *sāri* and a blouse for the upper part. In the colder parts of India, such as the Himalayan mountain ranges and Kushmir, the garments are thicker and more elaborate, including warm woolen shawls and heavy jackets. It is noteworthy that in antiquity, stitched garments such as shirts, trousers, and blouses were hardly ever worn in India. In the ancient sculptures and paintings such as the ones at Amarāvati or Brahadīśvaram, it is only the menials, palace attendants, common soldiers, and dancing girls, all of them belonging to the lower echelons of society, who are depicted wearing stitched garments. Such garments are never depicted on the upper classes or royalty nor on the images of gods and goddesses. A plausible reason may be the association of impurity and pollution with stitched cloth.

Colors and Designs in Textiles

Traditional Indian textiles reflect the Indian ethos. There is an aura of religion and romance around Indian weaving. Everything is significant – the colors chosen, the motifs, and the wearing occasion. Crimson or shades of red are very auspicious and worn by women on the occasion of their marriage as well as by ceremonial priests in certain parts of India, such as the Madhvā Brāhmins of Karnātaka. White represents purity and ochre, renunciation, and these are the colors worn by Hindu widows as well as ascetics. Yellow and green denote fertility and prosperity and are worn in the spring. Black is considered inauspicious, although pregnant women in south India wear black, perhaps to ward off the evil eye. As late as the eighteenth century, coloring was done entirely through vegetable dyes such as madder and indigo, although now dyers have almost entirely switched over to chemical dyes except in the case of highly specialized textiles like the *kalamkāris*.

The earliest designs on Indian textiles seem to have been geometrical. A twelfth century Sanskrit text called the *Mānasōllāsa* described textiles designed with dots, circles, squares, and triangles. The depiction of flora and fauna was related to religion and popular beliefs. The lotus, which has great spiritual significance in Hinduism, and the mango design are among the most popular Indian motifs. Swan, peacock, parrot, and elephant are also commonly depicted. The tree of life, which symbolizes fertility and prosperity, is another auspicious motif. All these designs are patterned on the loom itself and it may take a handloom weaver working on an ordinary frame loom as long as 30 days to weave an elaborate six-yard *sāri* with designs and gold lace. As the weaver weaves, he also sings the special loom songs, a tradition which has now almost entirely died out except perhaps in some interior weaving villages in Uttar Pradesh or the remote south. These loom songs tell of the glory of particular weaving castes or they are full of esoteric religious metaphors describing god as the eternal weaver, weaving the web of life, and the human body as the cloth he has woven.

Textile Varieties

Traditional Indian textiles are unique and unparalleled for their beauty. The *jāmdāni* is an elaborate textile which is woven with multiple shuttles and resembles tapestry work. Floral motifs called *bootis* in gold or silver lace are scattered over the body with heavy gold lace on the borders. The most striking of these designs is the *pannā hazāra*, literally a thousand emeralds, in which the flowers shimmer and gleam all over the sari. The Benarsi sāris called *Kiṁkhābs* woven in Uttar Pradesh are legendary for their loveliness, although Benaras in the north and Kāñchipuram in the south were traditionally associated with pure cotton rather than silk. It was the British who introduced sericulture in Kanchipuram in the nineteenth century. Gadhwāl and Venkaṭagiri saris of Andhra and the Īrkal saris of Karnataka specialize in rich gold borders and heavy panel-like *pallūs* (that portion of the sāri which is draped over the shoulder). Another variety is the tie and dye (called variously *bandini, ikāt,* or *chungdi*) produced in Rajasthān, Orissa, Andhra Pradesh, and Madurai where the fiber is tie-dyed before weaving. A unique Andhra textile is the *telia*, which was soaked in oil before weaving and catered exclusively to the West Asian market because it was woven to suit desert conditions. This textile appeared in the sixteenth century with Muslim rule and died out with the collapse of the Islamic empires. Another textile which became popular in the mughal period was the *mashroo* (also the *himroo*) in which cotton was used in the warp and silk in the weft. Initially these were used as Islamic prayer mats by the Mughal nobility who were forbidden by Islamic tenets to use any animal product. They therefore contrived the mashroo which enabled them to have their comfort without violating the religious tenet against the use of pure silk.

Textiles also form an important part of temple ceremonials such as the flag cloth hoisted in temples, the garments put on the deity, the cloth covering the chariots in which the deities are taken out on a procession and the ritual dance costumes. The *kalamkāri* cloth of Andhra, in which mythological stories are sketched minutely on cloth with a fine pen as well as the *Nādhadwāra pichwāis* of Rajasthan, are of this genre. In India it is also the practice among wandering groups of minstrels to render dramatic narrations of mythological stories, and the elaborately painted screens used on these occasions form an important aspect of traditional Indian textiles.

See also: ►Colonialism and Science

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Textiles in Mesoamerica

Carolyn Jones and Tom Jones

Because textiles are rare among the artifacts of cultures known to us only archaeologically, any analysis of them, or of the technology of their production, must be pieced together from indirect sources. In Mesoamerica, while archeological finds attest to the existence of various textile technologies at specific dates, much of our understanding of the subject comes from ancient Maya, Mixtec, and Aztec books, stone sculpture, painted pottery, murals, clay figurines, European documents from the time of the Conquest, and modern textile traditions.

Though the physical environment of Mesoamerica generally precludes the survival of perishable artifacts, textiles have none the less survived from certain areas. The majority, mostly small fragments, have been found in dry caves in the arid regions of Mexico. In the humid southern lowlands very little has survived, some 2,500 carbonized fragments dredged from protecting mud at the bottom of the Sacred Well at Chichen Itza are the most important single find.

The oldest textiles to survive in Mesoamerica are cordage, netting, and basketry, worked in vegetal fibers other than cotton, with early examples dating to at least 7000 BCE in Oaxaca and to 5000 BCE in central and northern Mexico. Such textiles are fashioned from the leaves and stems of various plants worked without the benefit of a loom. In instances where fibers were extracted from their plant sources, they were probably spun by rolling them together between the hand and thigh, as no tools for spinning have been found. Spindle whorls and evidence of loom woven textiles appear much later.

The earliest evidence for loom weaving in Mesoamerica consists of fabric-impressed ceramics datable to 1500 BCE, at which time spindle whorls also begin to appear. Woven cotton fragments follow soon after. These early woven textiles are worked in plain weave and almost certainly were created on a backstrap loom. From these simple beginnings, a sophisticated textile industry developed.

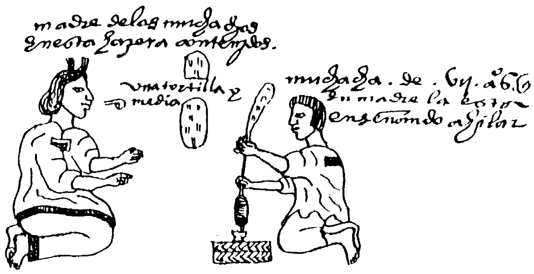
The weaving process begins with the selection and preparation of suitable materials. The predominant fiber of woven Mesoamerican textiles was cotton, *Gossypium* spp., with both annual and perennial varieties reported at the time of the Conquest. Cotton was cultivated in at least two colors, white and brown, and traded throughout ancient Mesoamerica. Other fibers, generically termed istle (from the Nahuatl *ixtli*), were drawn from the leaves and stems of many plants of more local distribution, including *Agave* spp. and *Apocynum* spp. Both cotton and istle required much preparation prior to spinning and weaving. Cotton was carefully picked over, its numerous small seeds and other vegetal debris removed by hand and the mass of fiber then fluffed or beaten to produce a uniform, smooth mass. Istle, on the other hand, was toasted, split, and scraped to remove the plant flesh from fibers which were then washed, dried, and combed. No animal fibers are known to have been used in ancient Mesoamerica. Textile headdresses incorporating human hair, however, have been found.

Both cotton and istle were spun on the spindle, a simple device consisting of a "whorl" wedged onto the end of a straight-tapered shaft. A mass of fiber was attached to the shaft, which was then twirled, imparting twist. The whorl helped the device to spin easily and for an extended time, and provided weight against which the fiber could be drawn out and twisted into thread. Different fibers required different types of spindles and sizes of whorls. Cotton, because of its very short fibers, was spun on a small spindle, the lower end of which was supported in a bowl or on the ground. The longer istle fibers required a larger, heavier spindle. Yarns of any size could be created and some as fine as 0.005 mm in diameter have been recovered. Yarns could be used singly, or two or more individually spun strands could be retwisted ("plied") together. A mixture of cornmeal and water was likely applied to some yarn to smooth and strengthen it for weaving.

While there is little archeological evidence for the use of dyes, Post-Classic pictorial codices and reports of the *conquistadores* both attest to the vivid colors of Mesoamerican textiles. Plant dyes probably included indigo (*Indigofera anil*) for blue, brazilwood (*Caesalpinia* spp.) for red, logwood (*Haematoxylon campechianum*) for black or blue, annatto (*Bixa orellana*) for orange, and many other leaves, seeds, roots, barks, and fruits. Two animal dyes were important: on the Pacific coast, purple was extracted from small mollusks of the genera *Thais*, *Murex*, and especially *Purpura*, while in arid regions, cochineal (*Coccus cacti*, a scale insect of the order Hemiptera) was cultivated on the prickly pear cacti (*Opuntia* spp.). The beautiful red produced by cochineal was much admired by the Spanish, and the dyestuff became a major export to Europe following the Conquest. Mineral pigments, such as ochre, iron pyrite, cinnabar, carbon, copper sulfate, and "Maya blue" clay were known, and there is some evidence for the use of mordants which make dyes more permanent. Dyes and pigments were applied by painting, by stamping or rolling with figured clay implements, and by immersion dyeing. Patterns were produced during dyeing through the application of resists and through tying-off of sections to create undyed areas of yarn or fabric. Fabric incorporating tie-dyed warp, called *jaspe*, is still produced in Guatemala today.

Once suitable yarns were spun and dyed, the process of setting up the loom began. The *Florentine Codex*, a documentary of Aztec life and custom written by the Spanish friar Sahagún just after the Conquest, illustrates the weaver's equipment, including spindle, warpboard, loom sticks, backstrap, and batten. It also describes the training of weavers, from the presentation of the newborn girl with miniature weaving equipment, to the day of a woman's death when her loom and spindle were burned in the funeral pyre awaiting her in the afterworld. In the *Mendoza Codex*, created by Aztec scribes at the order of the first Viceroy of New Spain, there is a section devoted to a mother's training of her daughter in domestic chores. It portrays the child's instruction in spinning (Fig. 1) and weaving, from ages 3 to 14, her food rations, and punishments for unacceptable work.

Information about weaving is also contained in Maya books, whose almanacs provide endlessly repeating prognostications for the timing of certain quotidian activities. One almanac in the *Madrid Codex* depicts the process of preparing the warp for the loom (Fig. 2). The weaving goddess, named *Sak Na* in the accompanying hieroglyphic text, is shown seated cross-legged with her left hand against a horizontal frame supported by at least two vertical posts and with lines stretched between their projecting upper parts. Her raised right hand holds an inverted spindle from which thread reaches to the frame before her. While there have been varying interpretations of the activity portrayed in this illustration, the overhead texts clearly read: *Sinah u chuch Sak Na*, or "She strings her warpboard, *Sak Na*," describing in ancient Mayan the process depicted. This manner of preparing the warp yarn, by measuring and stretching it

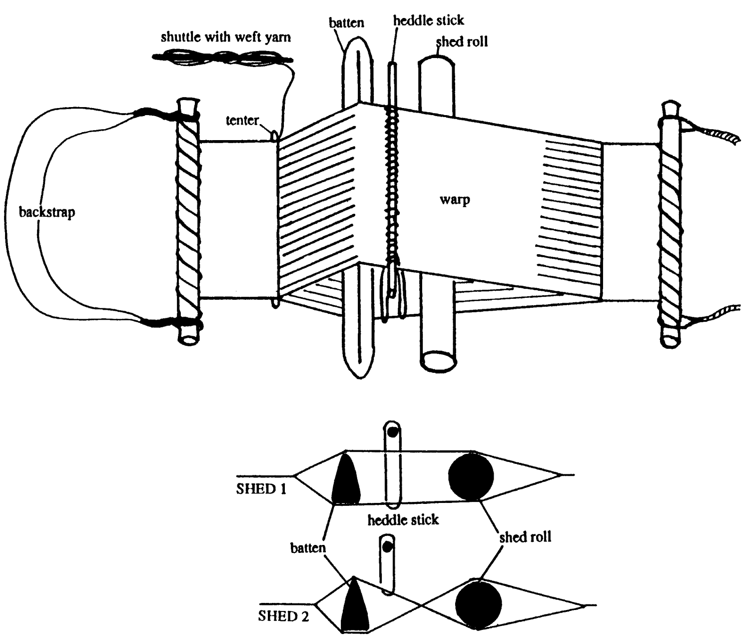


Textiles in Mesoamerica. Fig. 1 An Aztec woman instructs her 7-year-old daughter in the art of spinning cotton on a supported spindle. The child's ration of one-and-a-half tortillas is shown between them (from *Mendoza Codex*, page 59; from a photo of the codex).

Textiles in Mesoamerica. Fig. 2 A Maya almanac illustrating the goddess *Sak Na* preparing her warp (from *Madrid Codex*, page 102; drawing after Villacorta).

between vertical posts on a warping frame, was in use at the time of the Conquest and survives to this day. It is the initial phase of preparing a backstrap loom (Fig. 3) for weaving.

As the warp yarns are measured, they are wound alternately to one side and the other of a pair of vertical posts, thus creating a lease which maintains their order and allows the easy selection of alternate threads. Once wound, the opposite ends of the warp are secured to bars which form the ends of the loom, and a large, smooth, rounded stick (the shed roll) is placed through one side of the lease. The shed roll allows for the lifting of those threads which travel over it, one half of the



Textiles in Mesoamerica. Fig. 3 The structure of a backstrap loom, showing component parts and how they are used to create two sheds for weaving (drawing by Carolyn Jones).

total warp threads in alternating order, creating the first opening or shed. The remaining threads, which travel under the shed roll, are individually secured to a second stick (the heddle). By pushing the shed roll back and lifting the heddle, the other half of the warp threads are raised, creating the second shed. This is the mechanism by which Mesoamerican weavers created plain woven fabric.

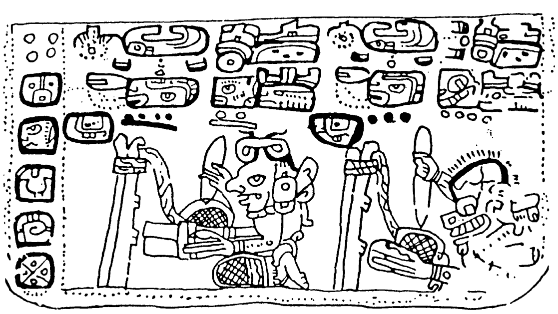
Before the loom is ready for weaving, additional implements are required. A long, heavy, straight-sided wooden stick (the batten) which can be turned on its side to enlarge the shed through which yarn (the weft, carried on a shuttle) will pass, and which is used to beat that weft into place, is employed continuously during weaving. A thin stick (the tenter) is usually attached to the fore-edge of the weaving to regulate the fabric width. Finally, the far end of the loom is tied to a tree or post, while the close end is attached to a strap which travels around the weaver's hips as she sits on the ground. By adjusting the position of her body, the weaver controls the tension of the warp of her loom.

This action is illustrated in the *Florentine*, *Mendoza*, *Matritense*, *Dresden*, and *Madrid Codices*, and in clay figurines from Maya burials on the island of Jaina. The *Madrid Codex* contains an almanac comprised of two episodes (Fig. 4). The first is illustrated with a crude drawing of a skirted female on her knees, her left hand supporting a backstrap loom, her raised right hand inserting the batten. Over the scene is an explanatory text that reads: *Och-i ti te' Ch'ul Na Che'el*, or "Divine *Na Che'el* (another name for the Maya weaving goddess) weaves at the post."

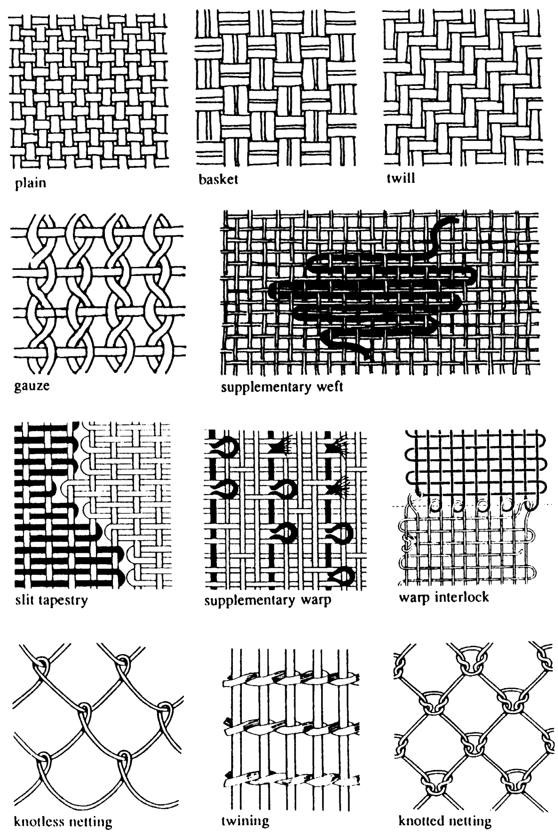
Simple in construction, the backstrap loom was well suited to the Mesoamerican woman's environment. Spinning and weaving were but two of her many daily chores, and the easy portability of the backstrap loom allowed its being rolled up for safekeeping when not in use, or set up when and where convenient. The simplicity of the equipment, however, did not preclude complex weaving. Extant fabric fragments display a wide variety of techniques. Among the simple weaves are plain, semibasket, basket, twill, and gauze. More complex weaves include supplementary weft brocade, tapestry, inlay, supplementary warp patterning and pile, warp interlock, and layer exchange double cloth (Fig. 5).

The structure of the backstrap loom determined several qualities of the fabric to be woven. The size of the finished cloth was determined when the loom was set up, and was limited in both width (by the weaver's armspan and her need to position herself at the center of the loom for proper tensioning), and length (the longer the warp, the more cumbersome and difficult it was to weave). When a large fabric was required, it was woven in small rectangles and pieced together, usually without cutting. Mesoamerican fabrics could include four finished edges and tended to show more warp than weft, with warp counts as high as 78 threads to the inch recorded.

In addition to weaving, ancient Mesoamericans were familiar with twining, braiding, plaiting, knotted and knotless netting, sewing, and embroidery. Methods for making leather, felt, bark cloth, and paper were known.



Textiles in Mesoamerica. Fig. 4 A Maya almanac illustrating the goddess *Na Che'el* weaving at her backstrap loom (from *Madrid Codex*, page 102; drawing after Villacorta).



Textiles in Mesoamerica. Fig. 5 Some structures known from ancient Mesoamerican textiles. The bottom row provides nonwoven techniques for comparison with the loom-woven structures shown above (drawing by Carolyn Jones).

At the time of the Conquest, new materials and techniques were introduced, including needle knitting and the use of sheep wool and silk. In some areas, the treadle loom came into use, and men entered the field of textile production. These different technologies survive side-by-side with backstrap weaving today.

The importance of textiles, and particularly of weaving, to the ancient cultures of Mesoamerica must not be underestimated. Weaving was not simply a means of producing necessities of daily life, but was an expression of the Mesoamerican world view. The act of weaving was seen as a basic creative force, analogous to the original creation of the world in Mesoamerican myth. The symbolic significance of the act of weaving lives on in the complex patterns of the modern Maya woman's *huipil* (or traditional poncho-like garment), each of which is a cosmogram that places the weaver at the center of the universe. Many designs used today are notably similar to symbols depicted in carved stone representations of textiles from the ninth century, thus displaying remarkable continuity with a lengthy and rich Mesoamerican textile tradition.

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Textiles in South America

Amy Oakland Rodman

Unlike most parts of the world where discoveries of ancient textiles are unusual, the Pacific desert coast and dry western Andean slopes have preserved enormous quantities of textiles, wood, feathers, plant material, and other usually perishable artifacts. Most of the best preserved textiles were originally part of burial furnishings left in ancient cemeteries stretching from central Peru to northern Chile. The far north Andean coast (modern Colombia, Ecuador, and northern Peru) encounters periodic torrential showers which have destroyed most ancient remains. Few textiles have survived from the highland wet and dry climate or the rainforest regions of the eastern Andean slopes stretching to the Atlantic ocean.

It is apparent that desert conditions and the careful preparation of tombs are the two elements most responsible for the preservation of ancient Andean textiles. Beginning around 3200 BCE and continuing until the conquest of the Andes in AD 1532, it is possible to reconstruct textile technology in coastal regions and occasionally to witness highland development through textiles preserved in coastal sites.

Archaeologists have designated the Cotton Preceramic (3200–1800 BCE) as a period when a variety of coastal cultures developed cotton twining, looping, and other nonloomed textiles before the use of the heddle loom or ceramics. Major discoveries at Huaca Prieta, La Galgada (a highland site with remarkable preservation), and in Asia have determined that not only were large quantities of cotton textiles used, but that some were elaborately patterned. Images on Preceramic cotton textiles include condors with outstretched wings, two-headed snakes, and humans or deities with splayed feet, all subjects with similar presentation to images which continue in the art of many subsequent Andean cultures. Designs are created through transposing twined elements, often combining a change in regular yarn movement with alternating colored yarns. Cotton dyes include indigo for blue and unidentified, red, yellow, and brown colors. Thicker plant fibers were twisted into sturdy twined mats, while cotton was used for looped caps and twined mantles.

Beginning in the Initial Period (1800–800 BCE) and the following Early Horizon (800–0 BCE), Peruvian textiles developed through the use of the heddle loom. Hundreds of painted Early Horizon cotton plain-weave textiles discovered near Karwa on the Peruvian south coast identified fabrics with designs very similar to stone carvings from the north highland pilgrimage site of Chavin de Huantar. This important and well-preserved painted ritual cloth provided evidence of the ways in which textiles were used to transport religious imagery throughout the Andes beginning in very early periods.

Camelid fibers, sometimes termed "wool" yarn, from the hair of the nondomesticated guanaco and vicuna or the domesticated llama and alpaca, were introduced into coastal weaving during the Early Horizon. Camelid hair is more easily dyed than cotton and its introduction into coastal technology is usually based in its application in brilliant colors for weft-patterned structures. The first all-wool tapestry textiles appear in coastal cemeteries during this period and it is likely that these identify an ancient highland wool technology rarely preserved in the highland regions of natural camelid habitat.

The famous Paracas textiles were woven and embroidered on the southern Peruvian coast during the Early Horizon. On the Paracas Peninsula, elite individuals were buried with hundreds of embroidered shirts, skirts, mantles, feather fans, and golden objects all wrapped inside enormous plain woven cotton winding cloth. The multicolored wool embroideries depicted repeating human, deity, and animal images and were executed in stem stitch on plain-woven fabric. Paracas textiles also included a unique type of three-dimensional embroidery using the crossknit loop stitch to embellish borders with polychrome images. The technique was created with a single cactus spine needle as a continuous form of crossed looping.

The Nazca culture, which followed the Paracas on the south coast in the following Early Intermediate Period (AD 0–500), continued one of the most elaborate weaving technologies ever known, with textiles in double and triple cloth, warp and weft patterning, oblique interlacing, and fine garments woven with both discontinuous warp and weft. Andean loomed textiles are characterized in their tradition of four finished selvedges. Individual finished cloth webs were sewn together to complete a garment and were rarely cut.

Very little is known of north coast weaving during the Early Intermediate Period, the time of Moche cultural development. The few surviving Moche textiles identify a technology principally based in the use of cotton and a narrow backstrap loom like that employed on the south coast. But structurally, Moche textiles are distinguished through the use of fine un-plied cotton yarns in twilled and weft-brocaded structures. Moche tapestry is woven with both cotton and dyed camelid fiber weft over a cotton warp using a noninterlocking weft which creates vertical slits between different color areas. Apparently slit-tapestry was common to coastal cultures both north and south.

Although known for only a handful of large weft-interlocked tapestries or tapestry fragments and triple-cloth narrow bands, the Early Intermediate Recuay culture of the Peruvian north highlands developed a distinctive textile tradition. Recuay tapestries were woven on a wide loom of more than seven feet with a short warp of no more than two feet. Brilliantly dyed red and yellow wool yarns are characteristic of Recuay textiles, and tapestries use the highland weft-interlocked structure which leaves no openings between areas of different color. In the south central Andes, weft-interlocked tapestries uncovered on the Chilean north coast have been attributed to the Alto Ramirez culture of the southern highlands. Alto Ramirez textiles exhibit a decided preference for the use of blue and red dyed yarns almost certainly identifying an ancient source and knowledge of indigo dyeing in the southern highlands.

The following Middle Horizon (AD 500–1000) marks a break with previous cultural development. The Peruvian Huari culture located near the modern city of Ayacucho appears to have controlled the central Andean highlands and coast, while the south central Andes was allied to the site of Tiwanaku. Tapestry was the distinctive Middle Horizon medium woven in slit techniques with cotton on the coast and with interlocking camelid fiber wefts in the highlands. Local, coastal tapestry continued to be woven on the narrow backstrap loom. Highland Tiwanaku and Huari tapestries preserved in coastal desert burials identify the use of the wide loom with narrow warp like that used in Recuay tapestry. Huari shirts were woven in two parts and seamed down the center leaving an opening for the head and neck. The few Tiwanaku shirts discovered in northern Chilean desert cemeteries were patterned with similar images but were woven in a single panel with a neck opening woven through discontinuous wefts. Headgear was always used as an important Andean badge of identity. Huari and Tiwanaku officials wore a knotted hat with four peaks or points on the top. Tiwanaku four pointed or cornered hats created polychrome designs in lark's head knots while similar Huari hats were patterned with knots with tufts of wool pile in each knot.

By AD 1000 the highland centers of Huari and Tiwanaku had collapsed and individual cultures began clearly to establish local identities noted in regional textile styles. Warp-patterned structures such as complementary and supplementary-warp weaves were commonly woven in the following Late Intermediate Period (AD 1000–1450). Textiles are often characterized as having repetitive, small-scale imagery in gauze, painted cotton, weft-brocades, and double-woven fabrics. South coast weavers shaped bags and shirts through the selective addition of warp yarns during the construction process. North coast weavers often wove exotic bird feathers into the cloth, creating shirts and other garments with one face completely covered with feather patterns. During this period coastal weaving especially exploited the full potential of natural native colored cottons which were woven in contrasts of white and natural red-brown, beige, and grey.

The highland Aymara weaving tradition was consolidated in the south central Andes during the Late Intermediate Period after the fall of Tiwanaku. Aymara textiles are characterized by elegantly striped warp-faced shirts, woman's dresses, head cloths, and mantles in natural colored camelid fiber yarns often dyed blue, green, and red.

The Late Horizon (AD 1450–1534) again marks the period when local cultures were brought under highland control, this time that of the monolithic Inca state with its capital at Cuzco in the southern Andes. Inca textile patterns are strictly geometric and nonfigurative and the most valued cloth was weft-interlocked tapestry woven on the wide tapestry loom with a short warp. Some of the best preserved Inca textiles have been discovered as miniature offerings covering gold and silver male and female figurines and left on the tops of Andean mountain peaks from Ecuador to Argentina. Male garments include a tapestry tunic, a mantle, a bag with a carrying strap, and a large feather headdress. Female garments include a large wrap-around dress and a narrow, highly patterned belt. Most of these garments are woven entirely in camelid fiber and are colored with red and yellow dyes.

Following the conquest of the Inca state by European conquerors, European methods of textile manufacture were introduced throughout the Andes. The spinning wheel was adopted for workshop production, and the treadle loom was constructed for the manufacture of yardage to be sewn into non-Andean style tailored clothing. Needle knitting was introduced and is now regularly used for sweaters and knitted caps in local communities. Felting was introduced for wide-brimmed hats which have now become part of indigenous community dress in many regions.

While foreign clothing styles and techniques replaced local garment manufacture in coastal regions, European methods never replaced highland traditions in many indigenous communities in Colombia, Ecuador, Peru, and Bolivia. Today, some areas have maintained camelid-fiber spinning practices using the drop spindle and the backstrap loom or the staked ground loom to produce native four-selvedge garments. Men are the principal weavers in indigenous communities in Colombia and Ecuador, and women weave in Peru and Bolivia. In the southern Andes men weave on the European treadle loom. All community members spin, but spinning is generally considered women's work. Many communities continue to express local identities through handwoven patterns and specific color combinations which are worn daily or for community rituals. Traditional four-selvedged handwoven garments are also worn with European-style vests, pants, sweaters, or skirts in many areas. Some communities have specialized in the decoration of textiles with sewing machine embroidery.

Outside of the Andean region, a few Brazilian tribes and groups living in the Amazonian areas of Ecuador, Peru, and Bolivia, have continued lowland traditions using barkcloth, elaborate feather headdresses, and oblique-interlaced bags and narrow bands, textile traditions which may reflect ancient lowland origins never preserved in these wet regions.

South America continues as the native home to herds of guanaco, vicuna, llamas, and alpacas with an export industry in camelid fiber and manufactured textiles. Peruvian cotton is valued for its luster and is enjoying a revival in interest in native natural-colored cotton yarns.

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Thābit ibn Qurra

Boris Rosenfeld

Abū'l-Ḥasan Thābit ibn Qurra ibn Marwān al-Ḥarrānī al-Ṣābi᾽ (836–901) was a Syrian mathematician, astronomer, physicist, physician, geographer, philosopher, historian, and translator from Greek and Syriac into Arabic. His scientific treatises were written primarily in Arabic and partly in Syriac. He was born in Kafartūtha near Ḥarrān (now Altinbaşak in Southern Turkey) and was a student in Ḥarrān. Ḥarrānians, the descendants of the ancient nation Mitanni in the Hellenistic age, were hellenized, and their ancient religion of star-worship was deeply connected to Greek philosophy. In the Arab caliphate Ḥarrānians called themselves Ṣābians since the Ṣābians religion was one permitted by the *Qur᾽ān*. Ḥarrān University was founded in the fifth century in Alexandria as a school of philosophy and medicine. After the Arab conquest it was moved to Antiochia and later to Ḥarrān where, under the influence of Ḥarrānian traditions, astronomy and mathematics were taught, and it became a university.

At first Thābit ibn Qurra worked in Kafartūtha as a money-changer. Here the Baghdad mathematician Muḥammad ibn Mūsā ibn Shākir met him and invited him to Baghdad, where Muḥammad and his brothers Aḥmad and al-Ḥasan, the Banū Mūsā, became his teachers. Later he worked at the court of the caliphs in Baghdad and in Surra man ra'a (Samarra) as a physician and astronomer. His position as caliph's physician allowed him to keep his heathen religion. His son Sinān ibn Thābit and grandson Ibrāhīm ibn Sinān also were mathematicians, astronomers, and physicians in Baghdad.

Thābit ibn Qurra's contributions to science covered many different disciplines, from mathematics to philosophy. In mathematics, he was a translator or editor of translations of many works of Euclid, Archimedes, Apollonius, Theodosius, and Menelaus. Many of these are extant only in these translations. These translations, together with the geometric treatise of Thābit's teachers, the brothers Banū Mūsa, and his *Kitāb al-mafrūḍāt* (Book of Assumptions) constituted the so-called "middle books" which were studied between Euclid's *Elements* and Ptolemy's *Almagest*.

Two of Thābit's treatises on parallel lines were first written in Syriac, the first under the title *Ktovo al-hay da-tren surte trishe kad mettapkin al bshir men tarten gonowoto dagᶜin bahdode* (Book [in which is proved] that Two Lines Produced Under Angles Which are Less Than Two Right Angles Will Meet). The second is called "the second book on the same topic." Both these treatises are extant only in the Arabic translations made by Thābit himself. The ideas of these treatises were further developed by Ibn al-Haytham (965–ca. 1050), ᶜUmar al-Khayyām (1048–1131), and Naṣīr al-Dīn al-Ṭūsī (1201–1274) and later led to the discovery of non-Euclidean geometry.

Thābit's *Kitāb fī taᶜlīf al-nusub* (Book on Composition of Ratios) was devoted to the theory of compound ratios. This theory later led to the notion of real numbers and to the discovery of differential calculus.

Other work covered such subjects as a simple proof of the Menelaus theorem (the first theorem of spherical trigonometry), mensuration of plane and solid figures, and solutions of different problems of integral calculus. His books contained some proofs of the Pythagorean theorem and its generalization, and dealt with the subject of amicable numbers, in which each number is equal to the sum of the divisors of the other.

In the field of astronomy, Thābit was the editor of the translation of Ptolemy's *Almagest* and the author of many treatises on the movement of the sun and moon, sundials, visibility of the new moon, and celestial spheres. In his treatise "On the Motion of the Eighth Sphere," extant only in Latin translation (*De motu octave sphere*), he added the ninth to Ptolemy's eight spheres and proposed the theory of "trepidation" to explain the precession of equinoxes. The fragments of Thābit's Syriac *Ktovo d'pulog d'yumoto d'shoboᶜo al koukbe shabᶜe* (Book on the Subdivision of Seven Days of the Week According to Seven Planets) are extant in Bar Hebraeus' *Chronography*. In this book the planets are designated by their Babylonian and Greek names; this subdivision was known to Romans and Indians and is the source of the names of the days of the week in many European and Asian languages.

Thābit also wrote books on mechanics and physics. His *Kitāb al-qarasṭūn* (Book on Lever Balance) discusses the conditions for equilibrium of different kinds of levers. In his *Kitāb fī masā'il al-mushawwiqa* (Book on Interesting Questions) Thābit tries to explain the phenomenon of the camera obscura. This attempt was erroneous, but it led Ibn al-Haytham in the *Book on Forms of Eclipses* and al-Bīrūnī (973–1048) in *The Exhaustive Treatise on Shadows* to the solution of this problem. He also studied the problems of acoustics in *Mas'ala fī'l-mūsīqā* (Question on Music) which is an extant fragment of his great *Book on Music*.

In geography and medicine, Thābit revised works of Ptolemy (*Kitāb ṣūra al-arḍ*, Book of the Picture of Earth) and Galen. He was the author of the fundamental *Kitāb al-dhakhīra fī ᶜilm al-ṭibb* (Book of Treasure in the Science of Medicine).

In philosophy, Thābit emphasized that integer numbers were abstractions of objects of counting and criticized Aristotle who rejected actual infinity. In his commentaries to Aristotle's *Metaphysics* he considered the problem of the "first motor" and argued with Aristotle's opinion that the essence is immobile. Many of Thābit's treatises are devoted to problems of religion, in which he is critical of both Christianity and Islam.

See also: ►Banū Mūsā, ►Sinān ibn Thābit, ►Ibrāhīm ibn Sinān, ►*Elements*, ►*Almagest*, ►Ibn al-Haytham, ►al-Bīrūnī, ►ᶜUmar al-Khayyām, ►Naṣīr al-Dīn al-Ṭūsī

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Timber-Handling Technology in Japan

Conrad Totman

Japan has long been known for the ability of its artisans to construct gigantic, durable wooden structures, lesser wooden buildings of graceful design, and small objects of meticulous craftsmanship. One wonders how they were able to use the trees of their archipelago for these purposes when its topography made logging and timber transport so exceedingly difficult.

Preindustrial Timber Handling

Japan's earliest wood-handling technology was predictably simple. Stone – and later metal – hand axes, adzes, and chisels were used to fell and process tree trunks and bamboo to create rafts, dugout canoes, and plank-walled boats; diverse hand tools, weapons, and other small objects; and post-and-beam buildings lashed together with vine and enclosed with thatch or wattle.

During the seventh century, however, major new architectural forms – grand wooden palaces and Buddhist temples that utilized stone foundations, mortis-and-tenon framing, board walls, and tile roofs – arrived from the adjacent continent. These new forms vastly increased the demand for timber and, as a consequence, produced changes in all stages of wood handling, from felling and transporting to final fashioning into the devices of daily life. In following centuries that technology was elaborated and refined, and its usage spread across the islands.

In the first stage, loggers used slender-hafted, narrow-bladed axes to fell and limb trees and cut them to length. By the sixteenth century blacksmiths were producing large saws with sufficient temper and consistency of thickness for use as crosscut saws, and for several decades woodsmen employed them in felling trees. During the seventeenth century, however, their use for felling was outlawed, evidently to prevent timber theft: the sound of an axe thwack carries much farther than does the swish of a saw, helping guide warden to miscreant. From then until the late nineteenth century felling was handled by professional axmen. To facilitate the felling of especially large trees, choppers gouged holes around the base, stuffed the wood chips back into them, and set them to burning, guiding the burn through the base so as to fell the tree in the desired direction.

Turning to transportation, in early centuries, when adequate timber was available within reasonable proximity of a construction site, logs could be carried to it on two-wheeled oxcarts. Or they could be floated downriver (or hauled upstream by man or animal power), snared and pulled ashore at a landing, and then loaded onto carts for overland transport.

Later, as lowlands were cleared and more and more timber came from steeply mountainous regions, the transport system became more complex. Skidding crews at the felling site used long-handled hooking tools, vine or woven rope, and, where the situation required them, winches and sleds to role, skid, and sled pieces down to a log-assembly point. There (or sometimes at the felling site) axmen hewed the logs to form roughly rectangular pieces. This hewing reduced log weight, rendering sticks more manageable, and it made them more stable for the journey to town. In particular, when used to form rafts, hewn pieces were far less likely to twist and tear apart as raftsmen were negotiating rapids and turns in the river.

Depending on the terrain, workmen might use some of their squared sticks to form log trestles or trough-shaped chutes down which they could slide pieces to streamside. Or in the case of assembly beside a small mountain stream, they could construct splash dams and elevated chutes as needed to propel sticks on the flood down to where normal stream flow would float them freely.

Where felled trees were being converted to shingling or other small pieces, they commonly were split to portable size at the felling or assembly site or at a river landing. And material for conversion to charcoal was processed in kilns and the cooled charcoal bagged for transport. Both split pieces and charcoal were then carried overland to market by packhorse or floated out of the forest aboard log rafts.

The trip by water could be complicated. Most of Japan's rivers rush from mountains down to the sea, and given the frequency and unpredictability of downpours, freely floating logs risked doing damage to riverbanks or facilities, being stranded by high water at inaccessible sites, or even of floating out to sea and being lost. At convenient locations, therefore, river transporters constructed floating booms by lashing bamboo or logs together with vine and anchoring them to rock outcroppings, trees, or huge posts as the site allowed. These booms captured floating sticks, enabling workmen to beach them for temporary storage or processing or to assemble and bind them into rafts for the remainder of their journey.

On the largest rivers, the short initial rafts were beached at a midway point and several then joined end-to-end for the journey's final leg to a landing near the coast. At seaside, especially large logs could be lashed to shipside or hauled astern to a port of destination. But most pieces were taken aboard for the trip.

At the lumberyard or work site, squared logs were left floating in the water until needed, or they were stacked on land for curing and sale or processing and use. To convert a log to boards or planking, sawyers positioned one end on a high A-frame and used wide-bladed saws to rip it to the specified dimensions. The saw teeth were shaped to cut on the draw stroke rather than the push stroke, which reduced the risk of kinking the blade. That design lowered the required level of temper and hence the cost of the saw, but it increased the frequency of sharpening.

Other workmen used regular axes or broadaxes to split sticks into staves, shingles, or fuel wood. And carpenters and craftsmen employed a handsome array of hammers, small saws, adzes, planes, chisels, rasps, and drills to shape pieces for final use, whether as building parts, cabinetry, tools, weapons, *objets d'art*, or whatever.

By the nineteenth century, then, Japan had a well-developed and complex system of wood provisioning. It was operated by an array of professionals – axmen, skidders, raftsmen, other rivermen, sawyers, and carpenters – most of whom were organized in guilds that protected their fields of expertise and employment. And timber merchants, who arranged and financed many of the logging and transport operations, also managed the lumberyards and handled most of the wholesaling, jobbing, and venture capitalization that the timber business entailed (Figs. 1–3).

Timber-Handling Technology in Japan. Fig. 1 Stacking wood at a lumberyard on Tatekawa Canal in a harbor side section of Edo (today's Tokyo). Men on the left stack split pieces of fuel wood; bales of charcoal are stored under thatch cover at their feet; sawyer on right rips a timber to form planks; poles are stacked vertically to his right, partially obscuring Mt Fuji; planking, boards, squared timbers, and long green bamboo poles are below him. (Katsushika Hokusai, *Thirty Six Views of Mt. Fuji* (ca. 1820), in the author's possession.)

Timber-Handling Technology in Japan. Fig. 2 Sawyers rip a squared timber at Yamanaka in Tōtōmi Province, southwest of Mt Fuji, while another workman, seated before their temporary mountain hut, sharpens his saw, as family members look on. (Katsushika Hokusai, *Thirty Six Views of Mt Fuji* (ca. 1820), in the author's possession).

Industrial-Age Timber Handling

The world of preindustrial timber provisioning was thrown into turmoil during the 1860s when the established political order collapsed in the face of foreign encroachments. The new rulers set out to achieve rapid national self-strengthening, and that project entailed, among other things, sharply intensified exploitation of domestic resources, woodland included. Those developments altered radically the techniques of felling, transporting, and milling timber.

Until around 1900 the organized guilds of axmen, raftsmen, and others were able to slow appreciably the inflow of new technology. But by then the use of crosscut saws – no longer forbidden after 1868 – had become common, and they prevailed into the 1950s, until being displaced by chain saws. And in those areas, mainly in Hokkaido, where tractor-mounted mechanical saws are able to function, they and other similarly "high tech" devices – feller-bunchers, skidders, processors, harvesters, forwarders, and tower yarders – have been introduced during recent decades in unsuccessful attempts to reduce labor costs enough so that the domestic timber harvest can compete with imports.

Timber-Handling Technology in Japan.
Fig. 3 Surrounded by his mallets and bamboo for hooping, a barrel maker smoothes the inner surface of his staves at Fujimigahara in Owari Province, west of Mt Fuji. (Katsushika Hokusai, *Thirty Six Views of Mt. Fuji* (ca. 1820), in the author's possession).

Rather similarly, raftsmen and rivermen retained their roles until around 1900, when timber began leaving the forest by tramway and railroad. By the 1930s nearly all flotation and rafting had ceased. But starting then, and especially after 1950, rails in turn gave way to roads as trucks and "Caterpillar" type tractors and sleds took over. In some interior valleys, moreover, highlines have come into use for carrying logs airborne from felling site down to assembly point, where they are yarded and loaded onto trucks or otherwise moved along for processing.

Sawmills had appeared in Japan by the 1870s, initially sash saws (vertically mounted, mechanically powered crosscut saws), subsequently circular saws, and eventually band saws (continuous ribbons of teethed steel driven at high speed by sheaves mounted above and below the saw carriage). The earliest were water and steam powered, but electric power, whether purchased or produced on site, came to prevail during the early 1900s. And internal-combustion engines later powered some portable mills. (Pulp, plywood, and chip mills, technologies that are not discussed here, were introduced to Japan, respectively, in 1886, 1907, and 1957.)

The scale of Japan's sawmill technology has differed greatly from that found elsewhere. During the years ca. 1860–1920 the productivity of mills in Euro-America rose dramatically, tenfold or more. That rise was made possible by myriad technical improvements in saw types, power sources, and other aspects of mill equipment. But it also was premised on two conditions not found in Japan.

First, it presumed the existence of sprawling, richly stocked, flatland forests cut by leisurely flowing rivers that could float vast quantities of large, same-species logs to a sprawling sawmill site, flatland that would, a few decades later, provide easy terrain for the construction and use of roads and railways. Second, it presumed a system of woodland ownership that would allow a mill to obtain vast quantities of logs from large, more-or-less contiguous areas. In Japan, however, nearly all forests were on steep mountainsides, and possession was highly fragmented, about half being owned by smallholders with a few acres apiece, the other widely scattered half by government. Almost nowhere could a mill operator expect to obtain substantial quantities of large-scale timber from his immediate environs for any extended period. In consequence, before World War II the most efficient technology did not fit Japan's circumstances, and the newest devices, band saws most importantly, were used in only a small portion of the country's sawmills.

During the first two decades after that war, great effort was made to introduce and refine the most up-to-date mill technology. However, from about 1970 onward, imported wood undermined the profitability of domestic milling, and the enthusiasm for technological change largely evaporated. Instead, sawmills gradually developed in two directions. Today large, highly integrated mills, which are set up at coastal sites near major markets expressly to handle imported logs, use elaborate, efficient, high-speed equipment to produce great volumes of lumber. Domestic timber, meanwhile, is mostly sawn at small mills set up in major timber-producing areas, where they use much simpler equipment to turn out high-grade, specialty lumber, but at rates comparable to those of American sawmills of the 1860s.

So today the timber-processing technology of Japan is used primarily to handle imported wood. And that situation seems likely to prevail for a few more decades, until destruction of the world's woodland drives global timber prices up enough to make Japan's mountain forests again competitive in the marketplace.

See also: ►Forestry in Japan

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Time

Henry J. Rutz

The dual classification of cultural systems of time as Western or non-Western is an oversimplification that limits our understanding of how time is created, represented, measured, and practiced in different cultures. The premises underlying dualistic thinking about time reveal its limitations.

First, dualistic thinking adopts the premise that Western time is linear (irreversible), abstract, quantitative, and homogeneous. In contrast, non-Western time is cyclical (reversible), concrete, qualitative, and heterogeneous. There is a tendency to draw too sharp distinctions based on characteristics presumed to be in opposition. Underlying these are further distinctions between *them* (Oriental, primitive, oral, preindustrial) and *us* (Occidental, modern, literate, industrial). Embedded in these implicit distinctions is the assumption that non-Western time is to be thought about within a conceptual frame that implicitly adopts Western time as a standard for perception and evaluation of non-Western time. In a word, dualistic thinking about time has been Eurocentric.

Second, dualistic thinking rests on the premise that Western and non-Western cultures are different and unrelated totalities, and that time is unitary within each. The Unitarian premise leads to generalizations such as believing that non-Western cultures have a cyclical as opposed to a linear concept of time. The result is that diversity is underreported and undertheorized.

Third, dual systems of culture and time suffer from an ahistorical and overly formal foundation to knowledge. Western societies have "history" and a consciousness of being in time, in contrast to non-Western societies which have "myth" and a sense only of relational time that renders events mere epiphenomena of structure. Myth is not about the causation of before and after but about a formal means for making all the elements and characters ever-present.

Fourth, the ahistoricist premise also leads to the view that non-Western societies have an awareness of themselves in time only to the extent that westerners bring such awareness to them, either in the form of historical consciousness or as a practical matter of the efficient and productive use of time as a resource.

Fifth, dualistic thinking rests on the premise that time is a thing that is either present or absent in a culture. A dichotomy between western *linear* time and non-Western *cyclical* time appears as real and coerces people to behave and think in a particular way. But the terms of this dualism are highly abstract and refer to no particular period, bounded space, social organization, or real people. The dichotomy bears little relation to the cultural construction of time in the everyday lives of people in a specific region, a particular period, or known conditions of migration, diffusion, and contact.

The situation is complex. While no cultural constructions of time have remained unaffected by European expansion, it is presumptuous to think that we know what aspects of European time (which varied in different periods and places) influenced a bewildering variety of religious communities, empires, and kin-ordered societies, each with its own historically constituted temporal rhythms. Indeed, examining the real complexities of culture and history raises important issues about temporal dynamics only to the extent that we abandon dualistic thinking.

An alternative perspective, one that anthropologists, historians, and archaeologists increasingly embrace, pays attention to multiple constructions of time in single social formations, the extent to which different times are articulated, and the temporal dynamics of development and change in the rhythms of everyday life.

While some languages lack a generic word for time, there is abundant evidence for the universality of concepts of duration and succession in the linguistic and cultural practices of every person. The French sociologist Émile Durkheim expressed the opinion that it is hardly possible to think about time "... without the processes by which we divide it, measure it or express it with objective signs." These processes, he concluded, are social in origin. The anthropologist Edmund Leach, following Durkheim's lead, noted that "We talk of measuring time, as if it were a concrete thing waiting to be measured; but in fact we create time by creating intervals in social life. Until we have done this there is no time to be measured." To these ideas about time we need to add those of another French sociologist, Georges Gurvitch, who pointed out that every social formation has a multiplicity of times. Not only are there different collective representations of time among different cultures, but different time systems coexist within a single social formation.

These ideas, that time is culturally constructed, socially embedded, and multiple, have become guiding principles in cultural studies of time. The other articles on time in this encyclopedia illustrate the complexity and diversity of time systems from the multiplicity of time perspective. A brief comment on a number of issues will clarify the present direction in cultural studies of time systems.

1. Acceptance of the multiplicity of time within single social formations has led to the rejection of attempts to classify whole societies, not to mention a whole class of societies such as "Western" or "non-Western" by any single subsystem of time. Comparison remains important, but comparativists now

recognize that they must seek out similar subsystems in different cultures. Leopold Howe, for example, disputes Clifford Geertz's conclusion that the Balinese calendrical system does not represent a flow by which the passage of time can be measured, that the calendar represents a concept of time that is nondurational, and that Balinese experience of time is of "islands" or points that are unconnected (an extreme form of discontinuity, imprecision, and noncountability). Geertz asserts that the particulate nature of days implies a nondurational concept of time. Such a description of Balinese time carries an implicit comparison with our own, based on dualistic assumptions that go unexamined in both. Howe provides evidence that Balinese count days and are forever referring to past and future in terms of such counts. Geertz confused an attribute of members of a class with the class itself—each day is qualitatively different from others, but days fit into a succession that is endlessly repeated. Each name day partakes of being a day that *qua* day has the attribute of countability. The Maya had no such confusion. They viewed time as a flow that could be measured and also endowed days with qualities dependent upon the work of gods and men.

2. Recognition of the multiplicity of time shifts attention away from gross comparisons of presumed-to-be-different systems of time toward contextualized descriptions and similarities of subsystems in apparently different cultures. There has been a concomitant shift from classification to process, raising questions about temporal dynamics. How *does* time get constructed? What *are* the processes of development and change that account for the multiplicity of time and the degree of articulation among subsystems? Cultural studies of time have taken several directions, none of which is mutually exclusive. Nancy Munn challenges, from a phenomenological perspective, Evans-Pritchard's conclusion that Nuer time amounts to a creation of a static and nondevelopmental experience of time. His structural models of Nuer time overlook Nuer accounts of their bodily activity of procreation, their own subjective experience of time in terms of layers of ash on the fires, their ability to plan for events in the future, and other evidence of developmental constructs of time in their projects and practices. Peter Rigby, who has researched the age-set system of the pastoral Ilparakuyo Maasai in Kenya, challenges, from a historical materialist perspective, Evans-Pritchard's failure to address the degree of articulation of Nuer multiplicity of time. Had Evans-Pritchard taken into account the historical consciousness of Nuer, he would have found that all the elements of time-reckoning can be placed in a single conceptual frame arising from the historical development of Nuer within a specific social formation. Rigby, drawing on his own work and that of others, attempts such a synthesis for the Ilaparakuyo Maasai.
3. Cultural studies of time that explore the underlying temporal dynamics of how a multiplicity of time is constructed have paid increasing attention to the politics of time. Cultural constructions of time are part of the political economy of development. The creation of time requires agents and agencies temporalizing their respective projects in struggles for power and legitimacy. Farriss' attempt to reconcile cyclical and linear concepts within the same calendrical system in Maya culture rests on an interpretation of Maya political transformation from city-states to rule by dynastic lineages. With the demise of Maya elites, subsystems of time wither and die.
4. The attention paid to the politics of time has raised anew issues about the reflexive study of time in different cultures. Johannes Fabian has criticized anthropologists for failing to recognize that theories which distance "other" cultures by placing them in an-other time unwittingly use time as an instrument of political domination. Apparently disinterested studies of difference are revealed to be interested studies of "the other", a form of cultural politics. The solution is to recognize that people of different cultures are contemporaries and use that as a point of departure for all conceptual frames concerning the politics of time. A reflexive approach to cultural construction of time would overcome Rigby's concern that most descriptions of time in "different" cultures are really implicit comparisons using hegemonic bourgeois time as a standard. Most of us reckon time in our daily lives by systems other than the formal-mathematical or chronological ones deployed by an army of scientists, historians, and anthropologists. Such reflexivity, or self-awareness, of our own multiple concepts of time would be salutary for advancing our understanding of the cultural construction of time in different cultures.

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Time in Africa

Henry J. Rutz

In every society, one source by which time is divided, measured, and expressed by objective signs is the mutual obligations and principles that structure social relations between persons and groups. Among the most important is kinship. In those societies in which kin communities encompass the widest range of social relations, time is expressed as duration and succession of kin-ordered activity. Perhaps the best-known case is that of the Nuer, a Nilotic pastoral people who live in villages of the upper reaches of the Nile in Sudan.

E.E. Evans-Pritchard has given us a rich account of ways in which village kin communities conceptualize and reckon time as an aspect of social structure. Among the multiplicity of times apprehended by Nuer, three of the most important subsystems are (1) a series of social activities articulated with a series of ecological events by which one is used to measure the duration and succession of the other; (2) a series of age-sets that measures intervals and succession in the life cycle; and (3) a hierarchy of segmented kin groups that measures lapsed time, i.e. a form of collective memory of the "past" that constitutes the conceptual frame of Nuer history.

Nuer livelihood is based primarily on cattle herding and the cultivation of millet, a dual adaptation to vast stretches of marsh and savannah in a climate that necessitates a transhumant existence between village settlements on knolls during the rainy season and dry season cattle camps near rivers. A change of season is the objective sign for a change in settlement pattern, accompanied by changes in ceremonial and social activities. Most collective rituals, such as marriage and male initiation, take place in wet season villages, but the dry season cattle camps, when youth disperse to small camps in search of pasturage near sources of water, are viewed as a time of freedom and courting. In a rare comment on the experience of seasonal rhythms, Evans-Pritchard states that the pace of time speeded up during the wet season and slowed down during the dry season, an effect of the density of social activities and the significance the Nuer attributed to them.

Although the Nuer have no word for a generic "year", they reckon cycles of wet and dry seasons, giving names to each, and divide the cycle into twelve named "moons" of unequal duration that mark the succession from wet to dry season and back again. The duration of months depends less upon lunar observance (though they are familiar with phases of the moon) than the agricultural and pastoral activities associated with ecological phases within seasons. Nuer adjust the series of ecological activities to fit social contingencies. If the Nuer were still in their dry camps, waiting for rain, then they would say that they were still in the named "moon" prior to the onset of rains. If they were still engaged in rituals associated with the wet season villages, then they would reckon the name of the moon by the social activities appropriate to it. The result is an annual calendar embedded in a coordinated parallel series of ecological and social rhythms, the durations of which vary within and between cycles. Working one series against the other, Nuer rename months, skip months altogether, or even omit "years" in their recounting of socially significant events over a number of seasonal cycles.

Nuer can count seasonal cycles, months, and days (there is no "week"), but they tend not to. Chronology or a sense of lapsed time with respect to livelihood is culturally suppressed, giving the illusion of endless recurrence. Days, months, and seasons remain socially embedded and unarticulated as an abstract and numerical system independent of the concrete activities that lend the system meaning. The Nuer have no generic word for time.

Biological facts of individual maturation and aging, like ecological and physical facts, are given social significance in every society. But their division, measurement, and expression in objective signs are contingent and vary from one society to another.

Among Nuer, the reproduction of cattle, or cattle genealogies, is the basis of a concept of male personhood. Individual Nuer men are fiercely egalitarian and quick to defend themselves against perceived affronts to their manhood. The natural reproduction of cattle, combined with a culturally constituted series in the life cycle of male individuals—for example the transition from boyhood to manhood marked by the gift of a first cow, the transition to husband marked by a gift of cattle at marriage (a transfer from the groom's to the wife's kin), and a further transfer of cattle marking the transition to "fatherhood" with the birth of each successive child — regulate the rhythms of interpersonal kinship, articulating the pedigree of specific cows with the genealogy and life history of individuals.

Cattle genealogies mark the passage of time in the lives of individual male Nuer, a process that in its very nature is directional and irreversible. But Nuer also have organized individual male maturation as a collective problem of social significance. Village boys of comparable age (between 14–16 years) are initiated into a named age-set during an open period. A "Man of the Cattle" is responsible for closing a period, "thereby dividing the sets." The initiation consists of a painful ritual whereby each boy is cut to the bone across the forehead six times, producing deep scars called *gar*. His reward is a gift of his first cow and a taboo on milking. The only point of articulation between the seasonal and age-set time systems is the timing of the initiation, which occurs at the end of the wet season when food is plentiful. Proximate villages tend to coordinate periods despite independent declarations in each. Regions tend to share at least some age-set names (but vary the sequence), which differ from one part of Nuerland to another.

In pastoral Kenya and parts of Bantu East Africa, the age-set/generation-set system consists of age-sets organized into three distinct generation-sets of boys, warriors, and elders, with a pronounced taboo on warriors marrying. It is hard to avoid the conclusion that Nuer age-sets have something to do with the collective control of elders over young men. The military and administrative functions of Nuer age-sets, however, are attenuated and appear to have more to do with regulating the domestic obligations of manhood.

Nuer conceive of the age-set system as fixed at six living sets. Using a kinship idiom, they break the sets down into "brothers" who are equals, "fathers" who are elders in authority, and "sons" over whom they have authority. But age-set names are not repeated and Nuer do not perceive the age-set system as cyclical (some Bantu groups do). Age-sets whose members have died are not remembered or recounted. Even when a few old men of the most senior age-sets are still alive, junior age-sets are merging them with members of adjacent age-sets. The system is designed for the living, intended to mark lapsed time by the intervals between open and closed periods that define the age of one group of males relative to another in a weak form of gerontocracy. Like individual biography inscribed in cattle gifts and their genealogies, a sense of an irreversible flow of time is given in the fact that a named age-set "changes its position in relation to the whole system, passing through points of relative juniority and seniority."

All human communities develop collective representations of a past that embody a historical consciousness of the community *qua* community. Nuer have embedded their sense of historical consciousness in a model of a lineage system that creates the illusion of a fixed temporal horizon to events such as migration, tribal war, and territorial expansion that might otherwise be perceived as a succession of unique events in an irreversible "before and after" construction of past and future. The correct view of Nuer history is that it is ever-present and performative in the reciprocal rituals of lineage segments.

The segmentary principle of membership in a Nuer lineage is common descent through males from a recognized ancestor. The way Nuer think about tribal history is structured by how they think about the hierarchical relations between lineages, which also form the basis for claims to a division of territory. Reckoning political relations by lineages is relative because it depends on the particular person who is selected as the point of departure in tracing descent. The largest lineages, those which incorporate the widest latitude of members connected by descent from a common ancestor, are termed clans, and they in turn are comprised of lineages with several lines, each of which is a smaller lineage tracing descent through less distant ancestors to incorporate a narrower range of members.

The lineage system is employed by living Nuer to reckon their common past. Although every man is a potential founding ancestor, the social fiction is that the living are organized into segments in such a way that there are only ten to twelve ancestors at the maximum social distance, and three to four at the minimum. This fixed system of reckoning is in contrast to the real events of Nuer history, which is one of human propagation inscribed in Nuer genealogical reckoning, expansion and contraction of territory, and the actual bifurcation and amalgamation of lineage segments. But the Nuer fit such events into a structure of lineages with a time depth of 10–12 generations when there is no reason to presume that they have existed for so short a time. The Nuer express their political history as a fixed structure of relations between lineage segments. They prefer a stylization of history to a record of the endless march of unique events in an irreversible flow of time. The absence of writing and the strength of oral culture no doubt have something to do with it. The content of relations changes and is irreversible, no matter who the ancestors are or where a particular named unit fits into the hierarchy, but the structure remains constant. Eternal returns, with their prophecies of foretelling and fulfilment, or dynastic genealogies that record the unfolding succession of heroic deeds from some fixed starting point into a receding time horizon, are not the stuff of Nuer social history.

The Nuer are a tribal state without centralized authority. Their kin-ordering and genealogical reckoning are the key to their construction of time, which contrasts greatly with that of empires. In those states where imperial elites (military and religious) ruled over vast areas and innumerable village communities from imperial centres, there developed an awareness of time itself as an objective instrument of power and legitimation.

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Time in China

Jean DeBernardi

Chinese methods of calculating time are of great antiquity. According to the *Shi Ji* (Book of Records), as early as 2254 BCE Emperor Yao employed astronomers to calculate solstices and equinoxes and predict seasonal change so that farmers would know when to plant crops. Oracle bones dating to ca. 1200–1181 BCE attest to the fact that Shang Dynasty Chinese calculated time using a 60-day divinatory calendar that still is in widespread use. The early development of methods of measuring time was not entirely endogenous to China; cultures throughout the ancient world exchanged astronomical ideas and data.

Striking similarities exist between calendrical systems in widely separated regions, including parallels between the form and names of the Chinese and Maya divinatory calendars. At least as early as the first century BCE the Chinese used a luni-solar calendar resembling the standardized Babylonian calendar developed in the fourth century BCE. The similarities suggest borrowing, and it is possible that the Babylonians were the original inspiration for the Chinese soli-lunar calendar. In the Sui and Tang dynasties (589–960), Indian astronomers resided in China, and during the Yuan dynasty (1280–1368) Chinese collaborated with Persian and Arab astronomers. The technology of observation and measurement included an observatory built in Beijing during the Yuan dynasty. Contrasting with the astronomical system developed in Greek and medieval European astronomy, Chinese astronomy was polar and equatorial rather than ecliptic.

Although at times the Chinese borrowed astronomical ideas and technologies, these became incorporated into a system of time reckoning rooted in Chinese society. Sociologists have observed that time is a symbolic structure that represents a society's collective rhythms. In the Chinese calendar, some elements are based on astronomical cycles, while others have been shaped by the temporal rhythms of social life.

Chinese notions of the seasonal cycle are integrated into a system of classification based on the dualism of *yang* and *yin*. While *yang* and *yin* are often defined in terms of the complementary dualism of male and female, in Chinese they originally referred to sun and shadow, the very elements used to measure the changing seasons. For Chinese metaphysicians, *yang* and *yin* came to denote primal cosmic forces that interacted to generate a cycle of five phases (*wuxing*) which were identified with five primary elements (wood, fire, metal, water, and earth). These phases and their associated elements were in turn identified with the seasons. Thus Chinese classified spring with wood, summer with fire, autumn with metal, and winter with water, while earth was associated with the midpoint of the year.

This model of cyclical process associated the five phases with five colors (green, red, yellow, white, and black), directions (east, south, the center, west, and north), organs of the body, tastes, planets, virtues, passions, etc. Chinese elaborated rituals designed to control this cyclical process. Throughout the yearly cycle, the Emperor performed rites to inaugurate the seasons, and his performance gave concrete expression to the association of season, direction, color, and ritual. Chinese thought that by means of these ritual performances, the emperor could ensure harmony in the universe, and interpreted natural calamities as evidence of his loss of the "mandate of heaven" (Granet 1934). The cosmological framework of *yin* and *yang* and the five phases also informed Daoist alchemy, and still is fundamental to the Daoist rituals of popular religious culture.

Chinese philosophers and scientists appreciated the importance of natural cycles, and also linked the cycles of time with the cycles of human life. Not only they did link cyclic ideas of time to the liturgical calendar that regulated rites performed in the imperial court and its temples, but also they linked it to the microcosm of the body. In contrast with the taxonomic thinking that informs much Western science, Chinese explored patterns of function *through* time to make sense of various experiences, including ones related to health and illness. The associations of the five phases applied not only to the yearly cycle, but also to the cycle of the month and the day. For example, Chinese medical practitioners thought that the "seasons of the day" could predict crisis periods for physical disorders affecting different parts of the body.

While cyclical time had key significance, Chinese also had a well-developed concept of continuous time.

This concept found expression in “continuity history-writing,” in which historians sought to chronicle causal sequences of events in history. While official historians recorded the objective facts of history, they also critiqued the past in a form of “praise and blame” historiography that sought to discern the logic of a *Dao* (path or way) that had its origins in Heaven. Thus the rulers of China employed history, like divination, as a means to gain insight into the logic of events, and as a guide to appropriate action.

In an agricultural society, charting seasonal change was crucial, and one responsibility of the emperor was promulgation of the luni-solar calendar. Since promulgation of a calendar was a political responsibility and privilege, astronomy was an orthodox Confucian science. Every year a Board of Mathematicians led by an Imperial Astronomer (who was a Minister of State) prepared the calendar. After the Emperor approved the new almanac, high-ranking officials received it with great ceremony. The Emperor, who had exclusive rights to promulgate the calendar, also bestowed the almanac upon China’s vassal states as a mark of favor. During the Qing Dynasty (1644–1911) over two million almanacs were officially printed each year, and excess copies were available for sale. Despite this imperial monopoly, pirated editions circulated widely. Rebellious feudal lords sometimes expressed their withdrawal of allegiance by issuing a new calendar.

The Chinese used the calendar as an instrument to predict not only the best time for planting, but also the best time to initiate action. As a consequence, astronomy was interwoven with astrology and divination. Details of the zodiac are still published in the almanac, and the Chinese may consult this source to predict dates that are propitious or unpropitious for human undertakings such as weddings.

The most ancient method of timekeeping is the 60-day divinatory calendar, evidence for which appears on oracle bones in the late Shang dynasty (ca. 2300–1181 BCE). The cycle is composed of two interlocking sets of cyclical characters that are combined to form 60 unique two-syllable names. The “Ten Heavenly Stems” (*tian gan*) revolve in concert with the “Twelve Earthly Branches” (*di zhi*), and their combination generated 60 cyclical names. These 60 combinations were arranged in six 10-day groupings called *xun*. Since the first century BCE, years have been named after the consecutive days of the divinatory calendar, producing a repeating 60-year cycle. In the late Shang dynasty, the *xun* of the dyadic divinatory cycle was the basis for ordering sacrifices to royal ancestors. A full ritual cycle was completed in 360 days, increased to 370 by the addition of an intercalary *xun* every second cycle. This arrangement created a calendar that approximated the length of a solar year.

The Twelve Earthly Branches correspond to the 12 signs of the Chinese Solar Zodiac, which also name 12 constellations used to calculate the position of the sun every month. The zodiac animals (six wild or mythical and six domestic) are the rat, ox, tiger, rabbit, dragon, snake, horse, sheep, monkey, cock, dog, and pig. They are divided between passive *yin* and active *yang* symbols, and name the years in a repeating 12-year cycle. Chinese popular wisdom has it that persons who are born in a particular year have personalities shaped by the associated zodiac animal. Individuals should avoid marriage with persons born in the zodiac years of antagonistic animals, and also seek to avoid having children during such years.

The task facing early astronomers who sought to invent a calendar for use in predicting the seasons involved reconciling lunar and solar cycles. The regular cycle of the moon provided a readily observed celestial clock, but the lunar year does not correspond with the seasons, since 12 lunar months produces a cycle of only 354 days. The yearly cycle of the sun produces a cycle of 365 1/4 days, but it does not predict the full moon. The 365-day Gregorian calendar follows the solar year alone, with an extra day added every leap year to adjust for the fraction. The Chinese, however, sought to reconcile solar and lunar calendars.

By the eighth century BCE, Chinese could calculate and record eclipses, and they knew of the Metonic Cycle. This was a 19-year cycle at whose beginning and end the sun and moon are in the same relative position to each other. Discovery of this cycle led to a system of coordination of lunar and solar cycles that resembles the Babylonian standardized calendar, and some authors have suggested that this system was perhaps borrowed rather than invented (for details of debates, see Needham 1959: 171–177).

During 19 solar years, there were 235 lunar months, and Chinese astronomers divided these into 12 years that were 12 lunar months long, and 7 years that were 13 lunar months long. The 13-month years were produced by duplicating 1 month. The inventor of this calendar introduced that intercalary month in such a way as to ensure that the winter solstice always occurred in the eleventh lunar month, the summer solstice in the fifth, the spring equinox in the second, and the autumn equinox in the eighth. In addition, the introduction of an intercalary month ensured that the Chinese New Year always fell on the second new moon after the winter solstice, between January 20th and February 19th.

Before the adoption of the luni-solar calendar, Chinese dynasties inaugurated their reign by adopting a different month as the beginning of the civil year. The Manchus are said to have followed this tradition when Emperor Kang Xi in 1669 adopted the revised calendar proposed to him by the Jesuit Father Verbiest. The Republican Government expressed its break with imperial rule by adopting the Gregorian calendar, which was favored because of its universality. Its adoption also eliminated a powerful source of imperial authority, since monopolistic control of the calendar contributed to a mystification of Manchu power. None the less, the traditional luni-solar almanac still regulates the cycle of community festivals and the rituals of ancestor worship.

See also: ►*Yin–yang*, ►Five Phases, ►Geomancy in China, ►Astrology, ►Lunar Mansions, ►Calendars, ►Stars in Chinese Science, ►Divination in China

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Time in Islam

M. S. Stern

Islam is now a major global religion. It has its roots, however, in the Arabian Peninsula of the early seventh century. Its core elements were implanted in the early years and all later developments relate, one way or another, to that core.

In pre-Islamic Arabia some elements seem to have related to time (*dahr*) as fate, an underlying force directing human and natural destiny. It was conceived as a power existing eternally and responsible for the happiness or agony of humanity. Thus the *Qurʾān* refers to those who "say… 'nothing but time can destroy us'." [45:24/23]

While time was generally seen as an impersonal force, some people sought to identify God with time or, worse still by Islamic standards, to use this concept to deny God's existence. The Apostolic Tradition (*ḥadīth*) records Muḥammad's saying that Allah commanded men not to blame *dahr* "for I [God] am *dahr*." Later there were various groups of radical thinkers, often only vaguely defined and known primarily from polemic references, who asserted "the eternity of the course of time." Accordingly, because they denied both Creation and Judgment, the beginning and end of time, they were considered atheists. The term *dahrīya*, therefore, came to encompass a broad spectrum of dissenters advocating some form of atheism and/or hedonistic materialism.

Islam universally views time as created. It is God's handiwork which, like all Creation, is under God's command. God acts in and through history but, being eternal, time does not encompass him. Nature is also his Creation but, while it manifests his greatness, it in no way encompasses Allah.

According to al-Bayḍāwī (d. 1282) in the *Anwār at-tanzil wa-asrār at-taʾwīl* (The Lights of the Revelation and the Secrets of the Interpretation), time consists of *mudda*, the period of revolution of the sphere from beginning to end (i.e., the totality of time); *az-Zamān*, a gross subdivision of *mudda* into long periods of time (e.g., specific historical eras such as dynastic reigns); and *al-Waqt*, a fine subdivision of *zamān* into definite points of time or short intervals (e.g., precise times of the five obligatory prayers).

There are some within the Islamic tradition who assert that time, begun at Creation, has no necessary end. Al-Ghazālī (1058–1111), speaking in the *Tahāfut al-falāsifah* (Inconsistency of the Philosophers) for the mainstream tradition, teaches that religious dogma, for example the Day of Judgment, points to a finite end to time.

Measurement of Time

The two most significant historical eras, in the consciousness of Muslims, are the Age of Ignorance (*al-Jāhilīya*), the Dark Age in Arabia before the revelation of the *Qurʾān*, and the Islamic age stretching from the formation of the Islamic community in AD 622 until the end of history at Judgment.

There is evidence which suggests that most ancient Arabs followed a pure lunar calendar. About two centuries before the Prophet, apparently under the influence of Jewish civilization, many in Arabia adopted a lunisolar calendar. After Muḥammad's transfer to Medina (the *hijra*), an absolute lunar calculation was mandated.

The *hijrī* year consists, in theory, of 12 months of 29 days, 12 h, 44 min, and 3 s. In fact, for various practical reasons, the lunar months are computed variously as having either 29 or 30 days. The *hijrī* year is about 11 days shorter than the solar year. There is no intercalation to the solar. Any particular *hijrī* date, over a period of approximately 33 years, will move through all four solar seasons.

A number of Islamic societies have introduced a solar or lunisolar calendar (e.g., pre-revolutionary Iran, Kemalist Turkey). None of these has achieved any universal acceptance among the world's Muslims. It is accepted, further, that such a calendar has no support in the *Qurʾān* or the prophetic *Sunnah*.

Specific points in the yearly cycle are sanctified and celebrated in various ways. There are many local holidays and celebrations, and certain times are acknowledged as primary Muslim holy times. The first is the month of Ramaḍān during which the Muḥammad's prophetic career was begun. For the entire month Muslims abstain from food, drink, smoking, and sexual contact. The fast begins each day at the moment that there is sufficient light to distinguish white from black threads. It ends each night after the sun has completely set. Islam's "lesser feast," *ʿId al-Fiṭr* (breakfast), brings release from the month-long abstention.

The "greater feast" is the *ʿId al-Aḍḥā* (Feast of Sacrifice) on the tenth of Dhū 'l-Hijjah. It celebrates the end of the Holy Pilgrimage (*Hajj*) and reenacts Abraham's sacrifice of a ram in place of his son (*Qurʾān* 37:102). The primary sacrifice is made by the pilgrims in the valley of Minā, near Mecca. Muslims all over the world also offer such a sacrifice.

In Muḥammad's time the Arabs counted a 7-day week. There is evidence that this is a relatively late practice imported from Babylonia (or, perhaps, by way of resident Jewish communities who observed the weekly Sabbath). Earlier time flow was divided according to weather and similar seasonal changes. Under Islam the week was given significance by assigning a special status to Friday. It is not a day of rest but rather a day of communal prayer.

Time as a Moral Dimension

> By [the token of] Time [through the Ages].
> Verily Man is in loss.
> Except such as have faith and do righteous deeds and
> [join together]
> in the mutual teaching of truth and of patience and constancy. (*Qurʾān* 103: 1–3)

There are numerous Quranic references to man's time and God's time. "He rules [all] affairs from the heavens to the earth: in the end will [all affairs] go up to Him, on a Day, the space whereof will be [as] a thousand years of your reckoning [32:5]." Creation, as well, is said to have been effected in 6 days [32:4]. Exegetes often emphasize that the days of Creation, before the placement of the sun, refer to God's days reckoned as a thousand man years (and, in 70:4, to 50,000 years). Muslim scholars reiterate that Allah is in no way bound by time; he is totally transcendent.

The point is that throughout the course of human history God maintains full control over his Creation. In his mercy Allah provided man with a window to his will and commanded him in the straight path. When time ends, at Judgment, man will face his time compacted to God's scale. "… In the immense future all affairs will go up to Him, for He will be the Judge, and His restoration of all values will be as a day or an hour or the twinkling of an eye; and yet to our idea it will be a thousand years" (Yūsuf Alī).

There is an implicit ambivalence as regards the pursuit of scientific and technological knowledge. In so far as the Muslim centers his consciousness on God, his greatness and omnipotence, he can easily succumb to a fatalistic acceptance of what comes to him. He then asserts God's absolute will and denies causality in nature. Without cause and effect there is no necessary natural order. In so far as man sees time as his sphere of action, he can hear the Quranic command to perceive God in his Creation. Exploration of the world becomes an act of moral compliance.

Time's purpose is to serve as an arena of moral action. It is the place which God has established for the exercise of will. Judgment and consequent assignment to paradise or hellfire will mean the end of time, its sole purpose being the setting for man's surrender.

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Time in Korea

Nam Moon-Hyon

Timekeeping was both a royal duty and a royal prerogative in Korea since the period of the Three Kingdoms (三國時代, ca. 37 BCE to 668 AD) of Silla, Baekje, and Goguryeo. Although sundials and clepsydras (water clocks) were the main timekeepers, there were also fire clocks such as incense sticks at temples. Chinese calendrical systems, instruments for astronomy, and timekeeping systems were introduced to the Korean peninsula in antiquity, while from 554 AD Baekje sent calendrical scientists to Japan to supervise calendar- and clock-making there. Among the achievements of such missions was the water clock of the Japanese emperor Tenji (r. 661–671) which was made in 671. In Gyeongju, the capital of Silla, a royal observatory known as the Cheomseongdae (瞻星臺) was built in 647 and a water clock was constructed at the temple Hwangryongsa in 718; the latter was used to announce time by striking large bells in the bell tower, as was the case also with the bell shown in Fig. 1.

Time in Korea. Fig. 1 King Seongdeok’s God Bell at Bongdeok Temple, cast in 771. It announced dawn and dusk in Gyeongju, the capital city of the unified Kingdom of Silla (Korean National Treasure Number 29, restored at the National Museum in Gyeongju).

Late in the fourteenth century, the rulers of the Goryeo dynasty (918–1392) adopted Guo Shoujing’s *Shoushili* (授時曆, Time-Giving Calendar) that was compiled during the 1270s in Yuan China. They also introduced Su Sung’s astronomical clock tower powered by water and described in the *Xinyixiangfayao* (新儀象法要, The Appearance, Methods, and Importance of New Instruments, 1092), the Daming Hall lantern clock and Emperor Shunji’s elaborate clock with jacks (figurines) to announce the time automatically as described in the *Yuan Shi* (元史, History of the Yuan [Dynasty], 1369–1370), and various books from the Sino-Islamic tradition of striking clepsydras. Toward the end of the Goryeo dynasty and throughout the Joseon dynasty (1392–1910) astronomical, calendrical, meteorological, and clepsydral affairs were entrusted to the royal observatory known first as the Seoungwan (書雲觀) and then the Gwansanggam (觀象□). King Taejo (r. 1392–1398), the founder of the Joseon dynasty, built in central Seoul a Bell Tower (鐘樓, *Jongnu*) which announced the time provided by a newly cast night-watch[1] clepsydra (更漏, *gyeongnu*) in 1398. The third Joseon king, Taejong (r. 1400–1418), was a scientifically inclined ruler who worked with his son, the future King Sejong (r. 1418–1450), to improve printing Palace Guard technology and clock-making. Assisting them was the Chief Court Engineer Jang Yeong-Shil who cast a new night-watch clepsydra (更點之□, *gyeongjeomgi*, instrument with night-watches and [their] points) in 1424. Sejong became particularly interested in astronomy and, in 1432, initiated a project to reequip the royal observatory Ganeuidae (簡儀臺) using calendrical corrections in the *Shoushili* and the *Datongli* (大統曆, Calendar of the Great System) from Ming China. While the project was underway, 15 kinds of astronomical instruments and clocks were made, including two monumental water clocks by Jang and four kinds of sundials (see “Astronomical Instruments in Korea”). How the clocks were made is recorded in the *Sejong*

[1] “Night-watch” and “night-watch point” are technical terms from ancient Chinese timekeeping. The expression “night-watch” is used for the Korean word *gyeong* (更, *geng* in Chinese), about a 2-h period in the nighttime. There were five *gyeong* each night, corresponding with the 2-h blocks or “double-hours” from around 6 p.m. to 6 a.m., and each *gyeong* was divided into five *jeom* (點, *dian* in Chinese), an expression translated as (night-watch) “point.”

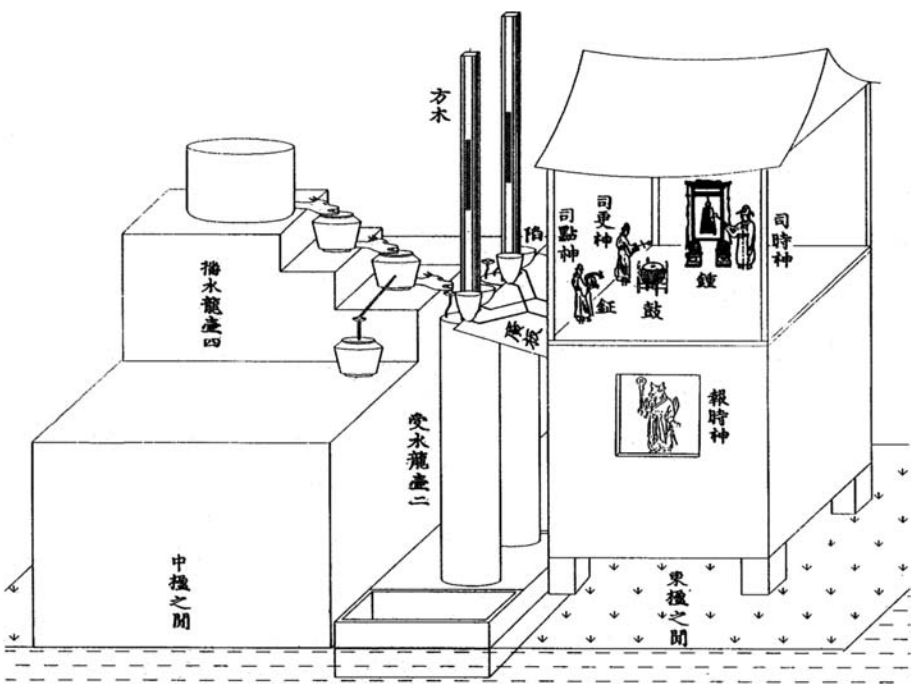
Sillok (世宗實錄, Factual Record of Sejong), which is supplemented in the *Cheungbo Munheon Bigo* (□□□□□□, Enlarged [Edition of] Documents and Notes, 1903–1908), a comprehensive study of civilization.

After the Japanese invasion of Korea late in the sixteenth century and during the emergence of the Qing dynasty in China during the middle of the seventeenth century, a Western-style calendrical system called the *Shixianli* (時憲曆, Calendar of the Constitution of Time) was adopted and several mechanical clocks were introduced through China and Japan in the 1630s and 1660s. In 1669 the horologist Lee Min-Chul and the Professor of Astronomy Song I-Yeong respectively made a traditional water-operated clock and a Western-style armillary clock driven by weights.

The *Jagyeongnu* (Self-Striking Water Clock)

The *Jagyeongnu* (自擊漏) is an elaborate timekeeper which announced the 12 "double-hours" (2-h blocks) that corresponded to the animals of the Chinese zodiac – the rat (which straddled midnight), ox, tiger, rabbit, dragon, snake, horse, sheep, monkey, rooster, dog, and pig – as well as the five night-watches (*gyeong*) that covered the hours from around 6 p.m. to 6 a.m. (and corresponded with the rooster, dog, pig, rat, ox, rabbit, and tiger) and their five "points" (*jeom*). Details about the *Jagyeongnu* are recorded in the *Sejong Sillok*, under the first day of the 7 month of the 16th year of Sejong's reign (1434), in the memoir *Borugakki* (報漏閣記, Description of the Announcement of the Clepsydra Pavilion) that was written by the court official Kim Don. Having been completed in 1434 under the commission of Sejong, it was an improvement on the clepsydra of 1424 and is divided into three parts (Fig. 2).

The inflow part of the clepsydra has four water-supplying vessels and two measuring vessels for everyday changeover. A floating indicator rod, graduated for the 12 double-hours and the points of the five night-watches, was in the measuring vessels, while above these vessels were wooden vertical ball racks with 12 (for the double-hours) and 25 (for the five points of the five night-watches) small bronze balls. The rod would rise and release horizontal latches that let the bronze balls out; the balls then fell and ran along an inclined channel to cause a set of 12 and 25 iron balls about as big as a hen's egg to trigger the time-announcing mechanisms. These mechanisms consisted of two ball-relays and an audible time signal for the double-hours and the night-watches, a visible time-indicator for the double-hours, three wooden jacks which sounded a bell for the double-hours, a drum for



Time in Korea. Fig. 2 The *Jagyeongnu*, "Self-Striking Water Clock." *Left*: The inflow part of the clepsydra consists of a reservoir, compensator, regulator, and overflow receptacle; two measuring vessels are on the floor bed. *Middle*: Two ball racks are implanted on the measuring vessels, which release small bronze balls through the holes that correspond to the 12 double-hours and the five night-watches. *Right*: Devices to announce the time are in the box, and the three jacks on the box strike a bell, drum, or gong; the jack in the middle of the box displays the time by showing the double-hour through the window as the bell is stricken.

the night-watches, and a gong for the night-watch points.

The ball-relaying mechanisms were separated by two large channels for the balls to move along. One channel allowed the balls to cause a jack in the form of a god to ring its bell for the double-hours; it also caused a horizontal wheel with 12 small gods to turn so that the appropriate god would display its double-hour tablet, an example having the character 午 for the hours of the horse (11 a.m. to 1 p.m.). The second channel caused another jack in the form of a god to announce the night-watches by striking a drum the appropriate number of times (e.g., three for the third night-watch), while a third god sounded a gong once for the beginning of a night-watch as well as the appropriate number for each night-watch point (e.g., five strikes of the gong for a fifth *jeom*).

During the Japanese invasion of Korea in 1592, this clepsydra was destroyed, but details about how this ingenious combination of balls and levers operated the mechanisms for announcing time are in the above-mentioned literature and in Joseph Needham's monograph *The Hall of Heavenly Records* (1986: 27–30). Figure 3 is a reconstruction of the *Jagyeongnu* made by the present author and his associates at the National Palace Museum of Korea, and details are in the author's monograph *Jang Yeong-Shil and Jagyeongnu*: *Reconstruction of Time Measuring History of Choseon Period* (2002).

In 1536, by order of King Jungjong (r. 1506–1544), the horologist Park Se-Ryong made a new striking clepsydra for the Changgyeong Palace in Seoul. Similar to the water clock made at the time of King Sejong, the new clepsydra had however an independent time calibrator. Although it had broken down at the time of the Japanese invasion, parts of it that included the major vessels for supplying water survived and were restored, and under King Gwanghae the time-announcing mechanisms were back to work in 1608 in the rebuilt clock house near the former place. After the Jesuit-designed *Shixianli* was adopted late in the seventeenth century, the clock operated on a system of 12 double-hours and 96 intervals; this new system also replaced that of the 12 double-hours and 100 intervals (each interval corresponding to 14 min, 24 s), both of which comprised one full day according to the *Datongli*, with the 24 h and 15-m quarter hours of the Western tradition. The clepsydra operated automatic sounding devices to announce the time, but this came to be done by manually striking a bell, drum, and gong after the building with the clock fell into disrepair in the early nineteenth century. Until the end of the traditional curfew system late in the nineteenth century, this clepsydra had operated as a timekeeper for roughly 350 years. In 1938, what remained of it was moved to the Deoksu Palace in Seoul, and in 1985 the parts were collectively entered as "National Treasure Number 229" (Fig. 4).

The *Heumgyeonggaknu* (Water Clock with the Pavilion of Prudence and Respect)

In 1438, Jang Yeong-Shil made the *Heumgyeonggaknu* (欽敬閣漏), another striking clepsydra. Besides announcing hours automatically by mechanisms known as jade-clepsydra mechanical wheels that were rotated by trickling water, it also displayed celestial movements. The armillary part of this machine had a golden

Time in Korea. Fig. 3 The *Jagyeongnu* made by the present author (NAM M-H) and his associates in 2005 restored at the National Palace Museum of Korea.

Time in Korea. Fig. 4 Relics of the self-striking clepsydra made in 1536 after that commissioned under King Sejong in the 1430s (Fig. 2). Shown here, from the *upper left*, are the reservoir for supplying water, compensator, and regulator vessels, and the two measuring vessels on the floor bed stand two meters high. The parts which announced time have been dismantled. (Korean National Treasure Number 229, the *Jagyeongnu* of the *Borugak*, preserved at the Deoksu Palace since 1938).

model of the sun which moved daily along the peaks of a mountain that was surrounded by five-colored clouds. The clepsydra part had three mechanisms for announcing time: (1) a set of four female jacks in the form of goddesses standing at the four cardinal directions on the mountain peaks and holding wooden mallets to strike at the double-hours, (2) similar to the clepsydra in the previous section, a bell was struck by a jack at the beginning and middle of the double-hours, a drum for the night-watches, and a gong for the night-watch points; and (3) at the base of the mountain, 12 gods represented the animals for the double-hours (rat, ox, tiger, etc.), and each would descend into a hole during its time period as a jack came out of a slot with a tablet bearing the double-hour time. Besides these mechanisms for announcing time, an inclined vessel on another platform automatically was filled by and emptied water which overflowed from the clepsydra. Because the mountain was surrounded by rural scenes from the four seasons and wooden carvings of men, birds, and plants that express labor and difficulties in agriculture, this timekeeper emphasizes the importance of measuring time and making calendars in Neo-Confucian ideology. Ideas from traditional Chinese armillary clocks, such as that of Su Sung in the *Xinyixiangfayao*, and Arabian water clocks were combined to make this automatic armillary clock, which Korean kings had reproduced several times as a symbol of the political ideology of the state. Fig. 5 is an artist's rendition of what this interesting clock looked like.

The *Honcheoneui* (Instrument About the Entire Heavens) and *Jamyeongjong* (Self-Ringing Bell)

In 1669 King Hyeonjong ordered the jade clepsydra system of the *Heumgyeonggaknu* from the time of King Sejong to be rebuilt, and this led to two new armillary clocks being made. One was a relatively traditional water-operated instrument by Lee Min-Chul, which had driving and time-announcing mechanisms like those in the striking clepsydra, jade clepsydra, and King Sejong's armillary sphere from the 1430s. It was a late survivor of the ancient Sino-Korean tradition of water-operated clocks that represented the universe and were operated in completely traditional ways (Needham et al. 1986: 110). Except for not having a compact weight drive, Lee's armillary clock was quite similar to the other made at this time.

Based on a Chinese clock which had been presented to King Injo in the 1630s by a Western missionary stationed in Beijing, Song I-Yeong produced a Western-style, weight-driven apparatus called the *Honcheoneui* (渾天儀) and a self-sounding clock known as, after the Chinese name, the *Jamyeongjong* (自鳴鐘). Song's clock combined Sino-Arabian wheels with jacks, a traditional armillary sphere that represented a rotating-earth system, and a weight-driven clockwork mechanism that had reached Korea via Japan. While making repairs in 1687, Lee Jin replaced a telescopic mechanism with a terrestrial globe and a clockwork mechanism, which was converted into state-of-the-art technology that Christian Huygens had developed in 1672 in Paris. Although it is not known for sure, Huygens' clock probably had been imported from Japan during the reign of King Sukjong (1674–1720). Lee's clock came to be known in the West through studies by Carl Rufus in the 1930s, and in the 1970s Joseph Needham and others did a detailed study on Lee's clock and armillary sphere (Needham et al. 1986: 115–152). From the eighteenth century onwards, royal clock-makers in Korea made weight drives of the sort used by Song in his clock, and parts of Song's clock itself have survived (Fig. 6). They were donated by Kim Seong-Su (a former Vice President of the Republic of Korea) in the 1950s to the Korea University Museum, where they have been restored and, in 1985, became "National Treasure Number 230."

Time in Korea. Fig. 5 Artist's impression of the *Heumgyeonggaknu*, showing the model of the golden sun revolving around the mountain. Standing on the multicolored cloud and facing each of the cardinal directions are four jade girls who strike golden bells with wooden mallets to announce the double-hours; as they do this, the four tutelary spirits (Black Warrior, Blue Dragon, Red Bird, and White Tiger) also face in their respective cardinal directions. At the southern foot of the mountain a jack and three warriors strike the double-hours, night-watches, and night-watch points with their instruments in a similar fashion as that for the *Jagyeongnu* (Fig. 3). At ground level are the 12 animals of the Chinese zodiac which correspond to the double-hours. At midnight (11 p.m. to 1 a.m.), for example, the hole behind the Rat opens, an hour god with a tablet announcing the time comes out, and the Rat stands still. South of the mountain, a man with a vase pours water into an inclined vessel which lies on its side when empty, stands upright when half full with water, and falls over when it has been completely filled. The rural scenery, from the four seasons, depicts various types of labor performed around the mountain by peasants. The design for this impression was made by Prof. Hahn Young-Ho, the author of "Astronomical Instruments in Korea."

Time in Korea. Fig. 6 What remains of Song I-Yeong's armillary clock. At the left is the armillary sphere, in the center a striking train and weights to strike the clock and bell, and at the right a time-announcer, gong train, and striking-release mechanism. The measurements are 120 (length) × 98 (height) × 52 (breadth) cm; courtesy of the Korea University Museum.

See also: ►Time in China, ►Astronomical Instruments in Korea

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Time in Maya Culture

Henry J. Rutz

Classic Maya culture developed from the second to the tenth centuries AD and expanded to encompass all of the Yucatan peninsula including the modern countries of Guatemala, Belize, and portions of El Salvador and Honduras. Unlike the Aztec and Inca states, which developed highly centralized imperial cities, the Maya developed city-states. Elites intermarried, formed alliances, and shared a complex calendar.

While all empires have created multiple times to connect village community to imperial center, and earthly city to heavenly city, the historian Nancy Farriss has noted that "from their earliest recorded history, the Maya displayed an intense interest, bordering on obsession, in measuring and recording the passage of time." Anthony Aveni (1989) observes, "The first bits of information in any Maya inscription are about time. What sets the Maya apart is not the number of time units they devised, or even their complexity; rather, it is their preoccupation with 'commensurateness' – perfecting the way time cycles interlock or fit together." Over a millennium since the climax of classic Maya culture and five centuries after the Spanish conquest, Maya continue to practice their own time, albeit in modified form.

The Maya had a military state with a literate elite. Our information about their multiplicity of time comes from their own writings. Although Maya hieroglyphic writing died out, Maya elites were able to maintain an unbroken continuity from their system of writing to that of Spanish script. The language survived in many colonial documents from the sixteenth century on. Today two million people still speak more than a dozen dialects of the Mayan language.

The Maya calendar is the centerpiece of Maya concepts of time and its measurement. It consists of the conjunction of cycles upon cycles of time of long duration. Like the Gregorian calendar we use today, the Maya calendrical system was the culmination of many different cultural influences over millennia. The conception of time underlying the calendar is one of movement. Maya referred to time as a flow and perceived a need for both human and divine intervention in maintaining it. In Maya culture, people actively construct their sense of time, a point to which I return below with reference to daykeepers and their role in the regulation of everyday life.

The flow of time is incorporated into an all-encompassing cyclical pattern. Conjunction of complex forces mark cycles of different duration. The Body Count of twenty is the basic unit of Mesoamerican counting (ten fingers plus ten toes). The classic Maya week consists of twenty named days, each propitious or unpropitious for particular activities. The twenty-day week was combined with a separate series of thirteen numbered days to create the Sacred Round of 260 days. Later, a Solar Year was calculated consisting of eighteen twenty-day months plus five days. The solar year was articulated with the sacred round to create the Calendar Round of 52 years. The Maya also developed a Katun Round consisting of thirteen twenty-year periods for a duration of 260 years. Despite an obsession with commensurability that led Maya priests into astronomy and cosmology, not all the cycles were articulated with each other. Late in the political development of pre-Conquest Maya culture a Long Count of five millennia appeared. Today, Maya daykeepers reckon the rhythms of everyday life by interpreting the solar and divinatory calendars.

Although Maya viewed time as a flow, it is also time with a content. Each day was named after a god and was qualitatively different from every other. Furthermore, the content of time was regulated by a conjunction of forces. Those days that were at the conjunction of different cycles had a greater force than other days. The larger the cycle, the greater the number of forces intermeshing from different subcycles. The Maya depicted time on stone carvings or drawings as weighty numbers carried by gods.

Intermeshing cycles produce a succession of days whose events are linear, unique, and irreversible. But this apparent linearity is an illusion because "no matter how unique a pattern of events may seem, no matter how long the sequence, it will eventually be repeated, when the governing forces of all the cycles of different dimensions coincide in one huge cycle" (Farriss 1987).

Why these cycles? Maya observers were not disinterested observers of the heavens. Cosmic time links common people to rulers through the latters' association with the cosmos. The construction of cycles appears to be associated with the problems of legitimacy and political order. Returning to the same point, at least logically, is the ultimate form of reassurance against the reality of present conflict, chaos, and events that seem to be getting out of hand. As Farris says, "Accounts of the famine in the books of Chilam Balam show less concern with starvation than with the fact that people flee into the forest to eat roots and other wild food… In other words, people cease to live in their customary fashion... Political conflicts are condemned because they disrupt the established hierarchy, and upstarts and invaders are vilified for breaking the rules." Encompassing cycles provide a cosmic charter of legitimacy of a magnitude rarely conceived in the history of cultures.

The predictable order of cosmic time reckoning, unfortunately, depended upon human agency for execution. "It is unlikely that the Maya priests claimed to comprehend all the possible combinations of divine forces governing the subordinate movements of so immense a projection." Past, present, and future are written in a single bound book, but one that admits of many interpretations.

How did the dual conception of cyclical and linear time work out in practice? Both serve as charters for sociopolitical arrangements, but each in its own way. It appears that classic Maya elites confined linear concepts to relatively short term duration out of choice (they possessed the literary or numeracy skills to create historical memory). Among the most important were the katun round and the chronicles written by members of Maya royal lineages during the colonial period.

The katun round, consisting of a recurring wheel (time is often depicted as a wheel in Maya stone carvings) of thirteen twenty-year counts for a total of 260 years, recorded the important events of royal lineages. The interesting aspect of the katun round is its duality of both history and prophecy. Each year has its own name together with characteristic and appropriate events. The future is contained in the past, and therefore Maya could look to a record of the past as a guide to the future. The same pattern of events for a given year recurs every 260 years. In Chilam Balam texts, logically associated events always occur in the same katun regardless of their inner chronology. It is as if all invasions were taken out of their chronological sequence and placed in their cosmological reckoning. Even references to the most recent "descent" – the Spanish conquest – are woven into the pre-Hispanic mix.

In addition to general reference to recurrent patterns of events there is also remarkable specificity to katun accounts, which name specific people and places, details of real famines, invasions, migrations, exiles, and rivalries. The specific content is about unique and irreversible events. The chronicles appeal to secular principles as the basis for claims to legitimacy, for example descent from previous rulers. The twenty-year katun cycle may have served as a calendar for rotation and succession of ruling families in post-Classic Maya. In contrast, books of Chilam Balam that record cycles stress quality of time – joy, misery, abundance, and the place of cosmic and divine forces in their production. The sacred personages of the calendar rounds merge with their worldly actors.

There is some evidence that the Maya calendar evolved toward a dominance of linear over cyclical concepts of time during the post-Classic period as a consequence of the emergence of dynastic rule and its dominance over the more autonomous city-states of the Classic period. Unlike the calendrical system of cycles and their conjunction, which have no particular starting date, the Long Count system measured elapsed time from a starting point that would extend to a time horizon of 5,200 years before its repetition. This new calendar represented a radical shift from the dominance of cyclical time over linear time because its duration was long enough to encompass the ancient Calendar Round of 52 years and more recent katun round of 260 years. Specific details of human affairs accompany the Long Count and a new emphasis on written genealogies supports the hypothesis of a shift to dynastic rule.

If it is unlikely that ancient Maya priests could comprehend all the divine forces converging on particular days or years, how much less likely is it that ordinary people could use the Maya calendar to take control of their own lives? A partial answer appears in the guise of Maya daykeepers. Barbara Tedlock (1982) has given us an account of time among Quiche Maya in the town of Momostenango, highland Guatemala. There daykeepers use an integrated solar year and the sacred round to divine whether a day is good or bad for particular activities. The appropriate determination of qualities to a day are specific to a particular client and require active participation on the part of both daykeeper and client.

Daykeepers use a set of practices referred to as "the speaking of the day" and "the speaking of the blood." The qualities of the twenty name days are based on stipulated but vague mnemonic phrases that require interpretation by the daykeeper. Other factors specific to a client enter the picture, including the client's character, part of which is determined by the particular day on which a child is born.

The daykeeper achieves understanding by sortilege or divination by lots. She or he mixes, grabs, and arranges piles of seeds and crystals into a pattern, all the while counting and interpreting the 260 days of the divinatory calendar. The blood is considered to be an active substance that sends signals or "speaks" to the daykeeper. The rapport between daykeeper and client is also thought to affect the divining of a day as good or bad for a particular activity. Clients come to a chosen daykeeper with a specific question about such probable occurrences as illness, accident, land disputes, building houses, inheritance, business transactions, travel, marriage, adultery, quarrels, dreams, births, deaths, and interpretation of omens. The divination is performed for the specific question posed by a particular client.

See also: ►Calendars, ►Long Count, ►Writing, ►Mathematics

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Time in Native North America

Michael Zeilik

The Pueblo people of the United States Southwest believe in a cosmos in which nature functions with the active cooperation of humankind. The proper ceremonies must be carried out at the proper time so that the cosmic order is sustained. Traditional doctrines held that there were correct times for planting, harvesting, hunting, ceremonies, and many other activities – all embedded in a sense of sacred time. The right times for these crucial undertakings are established by astronomical observations to regulate the ritual calendar. The cycles of the sun and moon set the rhythm of Pueblo time.

Sacred time is ordered with different levels of periodicities. The longest appears to be the seasonal year. We have very little evidence – almost all ambiguous – that the Pueblos kept long counts or tallies greater than a year. Until the twentieth century, with the intrusion of European concepts of time, no indigenous interest appears in tracking cycles over many years. The yearly cycle is all important; after its end, a new, equally unique one begins. Within the seasonal span, ceremonies occur in a fixed sequence, in which the completion of one sets the stage for the next. The observation of the phases of the moon marked the subdivision of the year. Within a night, the start and end of some ceremonies are flagged by observations of the positions of certain stars, especially the Pleiades as seen from the smokehole of a *kiva*, a structure used as a ceremonial room.

The shortest unit of time reckoned by the Pueblos is the day, which begins with sunrise. The day has vague subdivisions into loose "hours," most of which are noted near sunrise and sunset by the color of the sky. About the only time of day noticed with any care is that of noon, which is typically observed by the length and directions of shadows cast by the edges of walls, buildings, trees, or sticks embedded in the ground.

A religious official has the responsibility and the authority to set the ceremonial dates within the ritual cycle. The crucial task entrusted to this official is the forecasting of the correct date by making anticipatory astronomical observations. The dates are announced ahead of time so that the people of the pueblo can enter into proper preparations (abstinence, practicing songs and dances, preparing costumes and special foods) so that the ceremony may be carried out with "good heart" and be effective.

Typically, one official – the Sun Priest – performs the sun-watching for the seasonal cycle, which includes the planting schedule. He does so from a sun-watching station that is usually located within or close to the pueblo. From this fixed spot, the Sun Priest keeps a horizon calendar (usually at sunrise using an observation of the first gleam) against the horizon profile. He knows from experience that when the sun rises (or sets) against a certain horizon feature, so many days will elapse until, say, the winter solstice. Then he uses tally markers (such as a knotted cord) to count down to that day, with an announcement made to the pueblo a few days ahead of the celebratory date. This anticipatory technique allows the Sun Priests to forecast the dates of the solstices to within 1 day of the astronomically correct date when the sun appears to “stand still” at its sunrise point. The observations made about two weeks in advance catch the sun when the angular speed of its sunrise position is large enough to be discerned by the naked eye on a day-to-day basis. Hence, this practice neatly solves both a cultural and astronomical problem.

Moon watching regulates timings between the seasonal and daily ones. The official responsible for tracking the phases of the moon generally is not the one who watches the sun. A Pueblo month begins with the observation of the first visible crescent and ends with the last. The days of invisibility are not typically counted. Calendar sticks were used to tally the observed months.

The months of the year are counted starting with the first before the winter solstice ceremony. The first five (or six) are named (usually after seasonal characteristics); then these names are repeated for the next five or six. The lunar calendar needs to be synchronized with the solar one, which is accomplished by adding an intercalary month (which can be as short as four days!) at the end of the regular count or after the winter solstice.

Although Pueblo people feared eclipses of the sun and the moon, they had no way to forecast them. In part, this lack was related to their disinterest in keeping counts longer than a year. We also find no evidence for knowledge of the 18.6-year lunar standstill cycle, even though the moon certainly was observed rising and setting. The historic Pueblo culture did not seem to attach any importance to this astronomical cycle so it was ignored.

The ancestors of the Pueblo people were the Anasazi, who inhabited what is now the greater Four Corners area of the US Southwest as a settled agricultural people. During the height of the classic Anasazi culture some thousand years ago, two major sites developed: Mesa Verde and Chaco Canyon. A regional center developed in the San Juan basin around Chaco by AD 1110; as many as 70 communities dispersed among 50,000 km^2 were integrated into a socioeconomic and ritual network connected by a road system.

How did the Anasazi regulate and track time? By using ethnographic analogy, we can generate hypotheses about Anasazi astronomy that can be checked against the archaeological record. The most important cycle of time for the Pueblos is the seasonal year, which is typically tracked by horizon calendars. Anticipatory observations are made about two weeks prior to the solstices. Of the Anasazi sites field-tested so far, about one-third have reasonable horizon calendars.

A secondary strategy employed in the historic Pueblos used a special opening or window to cast sunlight on an opposing wall. The best Anasazi analogs to this type of interior observational technique occur in Hovenweep National Monument at Hovenweep Castle, Unit Type House, and the Cajon Group ruins with small portals. Hovenweep Castle and Cajon ruins work at sunset, Unit Type House just after sunrise. In all three locations, the horizon profiles lack the relief for tracking horizon calendars. For all, the throw from the shadow-casting edges is large enough so that the linear motion on the receiving wall is typically a few centimeters per day from the sun’s angular positional change at sunrise or sunset. The evidence so far hints that interior light and shadow casting played an important role in Anasazi seasonal time keeping.

Exterior light and shadow casting was not an important time keeping technique in historic times. It may have been used more extensively by the Anasazi though perhaps more for ritual than calendric purposes. The three-slab site atop Fajada Butte in Chaco Canyon has been much investigated; so has the Holly site at Hovenweep. In both these cases, light and shadow cast by rock edges fall onto panels of rock art at important seasonal times of the year. These exterior sites generally suffer from a lack of resolving power for reliable calendric forecasting, if we apply the standard achieved by the historic Pueblo Sun Priests – within a day of the astronomical date of the solstices. Hence, these sites may have served as sun shrines for offerings to the sun with a light and shadow display that served a commemorative rather than a calendric function.

We have no firm evidence so far of prehistoric monthly lunar calendars, though such a count of days would have a unique sequence tied to the phases of the moon. No rock art in the Anasazi region has been demonstrated to display the measure of a lunar tally.

Occasional claims have been made that the Anasazi noted the 18.6-year standstill cycle of the moon. The hypothesis of attention to this interval has been put forth for the Fajada three-slab site and for Chimney Rock Archaeological Area in Colorado (among a few others). The most convincing case is made for Chimney Rock, where the natural rock pillars (after which the site is named) act as a natural foresight when viewed from the site of Chimney Rock Pueblo, a Chacoan outlier, which was occupied from about 1075 to 1175.

The orientation allows a spectacular anticipation and forecasting of the major lunar standstills. For about two and a half years prior to the standstill, the moon rises between the pillars for 1 or 2 days per month. Starting after the summer solstice, the moon appears as a waxing crescent. Finally, near the winter solstice, the full moon stands between the pillars at around sunset. Hence, the priest in charge of the moon watching could forecast the date of the standstill and also the full moon nearest the winter solstice – an important conjunction among the historic Pueblos.

See also: ►Long Count, ►Astronomy

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Time: Non-Western Views

C. K. Raju

Time is a difficult notion, since time beliefs underlie a variety of seemingly unrelated areas like (1) scientific theory, (2) philosophy of science, (3) religious beliefs about the nature of life after death, and consequently about the soul (4) human values and the (5) nature of language and logic, etc. These various time beliefs may or may not cohere with each other.

The structure of the English language, unlike that of the Hopi (American Indian) language, presupposes that time and space are entirely separate entities, and this makes it hard to understand the intermingling of time and space in relativity theory. As another example, the Buddhist Dhamma (ethics, way of life) is closely connected to the Buddha's concept of *paticca samuppāda*, or conditioned coorigination, the proper understanding of which requires the concept of a structured time, in which the instants of time are not featureless geometrical points. This notion of a structured time is incompatible with the two-valued logic assumed in Western philosophical discourse. In Buddhist thought, seemingly contradictory properties may coexist, as in the quantum-mechanical Schrödinger's cat who is both alive and dead at a single instant of time. Thus, the attempt to understand one aspect of a non-Western view of time, such as the Buddhist notion of *paticca samuppāda*, can force us to reconsider fundamental issues like the logic underlying Western thought.

Any attempt to provide an account of non-Western views of time is a very difficult enterprise, involving complex relationships across widely different areas of knowledge, and potential conflicts at a deep level with stock metaphysical assumptions underlying even the language and logic of Western discourse. This entire gamut of relationships between different pictures of time has been covered in the books *Time: Towards a Consistent Theory*, and *The Eleven Pictures of Time*, by this author, but it is too complex to be covered in the span of this one article, which will focus on only a single aspect related to the Western stereotype of non-Western beliefs about time.

The Western stereotype: "linear" time versus "cyclic" time

Non-Western views of time have typically been represented in Western literature and scholarship by contrasting Western "linear" time with non-Western "cyclic" time. Linear time is endowed with a variety of positive properties: rationality, progress, free will, etc. while cyclic time is attached to a variety of negative properties: spirituality, stasis, fatalism.

The first step needed to understand non-Western views of time is to get rid of this stereotype.

For example, the time beliefs underlying scientific theory are not the same as those underlying the philosophy of science, and the two do not cohere, but both can be classified as linear time. Thus, scientific theory is today presented in the form of differential equations, such as Newton's laws of motion, or the Hilbert-Einstein equations, or Schrödinger's equation. These equations fix the state of the cosmos at any time, once its initial state is known. However, all these equations involve the mathematical notion of a derivative with respect to time – for example, velocity, or the rate of change of position, is the time derivative of position, and acceleration is the rate of change of velocity or the time derivative of velocity. On the existing Western mathematical understanding of the calculus, these derivatives with respect to time force us to suppose that time is a continuum, which can be represented using real numbers. That is, current scientific theory necessarily presupposes that time is like the real line, or that time is "superlinear".

On the other hand, our reasons for believing in this or that scientific theory are (or ought to be) based on experiments, and this presupposes the belief that one can perform various experiments, the outcomes of which were not all determined beforehand, by the state of the cosmos at some moment in the remote past. That is, the philosophy of science presupposes a different belief about time: that the future of the cosmos is a consequence of human choices and actions, and not merely of its past state. One does not normally stop to think about such presuppositions because everyday human actions are premised on the same belief that human actions are powerless to change the past ("no use crying over spilt milk") but that they do bring about the future in some small way ("if I don't watch the milk it will boil over"). Thus, the philosophy of science subscribes to the belief in "mundane time".

These two types of time, superlinear and mundane, are both linear, but they are nevertheless incompatible and in conflict with each other. This conflict is a serious matter, for it pits scientific theory against the reasons for regarding it as valid. How is this conflict to be resolved? This would naturally seem to require a correction in one or the other picture of time.

However, the slightest alteration in one's time beliefs can have profound consequences. Changing the picture of time in scientific theory fundamentally changes the type of equations used to formulate the models of physics. On the other hand, if one were to believe that the future of the cosmos has already been rigidly determined by its past, there would be little point to human action, and life itself would become meaningless, as in the theory of the Stoics, or in Nietzsche's thought.

Since there are different notions of linear time, such as superlinear time and mundane time, which do not cohere with each other, so the very category of linear time is not meaningful. The category of cyclic time is not meaningful for similar reasons.

On the other hand, there need not be any particular conflict between a locally superlinear time and a globally recurrent cosmos. If the cosmos is restricted to a finite region, like a gas in a box, and evolves deterministically – according to Newtonian mechanics, say – then the Poincaré recurrence theorem tells us that, with probability one every state of the cosmos must repeat to an arbitrary degree of precision, infinitely often. Recurrence would similarly take place even if the cosmos evolves probabilistically rather than deterministically, so long as the future state of the cosmos depends only on its present state, an assumption more precisely formulated in current mathematics as the Markovian assumption for the evolution of a stochastic process. These recurrence theorems assure us that a recurrent cosmos, instead of being in conflict with superlinear time, is a logical consequence of it, under some rather general conditions, such as finiteness. In the above situations of cosmic recurrence, it could be argued that time only seems superlinear because the time scale of cyclicity – the recurrence time – may be very large, just as the earth seems flat, although it is round, since it is very large. Thus, a linear picture of time, need not be in conflict with a cyclic picture of time.

This meaningless dichotomy of linear versus cyclic time has nevertheless been persistently used in the West to characterize non-Western thought about time. A non-Western historical perspective on the development of Western time beliefs is helpful in understanding the origins of this incorrect (but widespread) stereotype about time and its linkage to religious ideology.

Quasi-Cyclic Time and the Soul

Early notions of the soul (in India, for example) were based on the belief that the cosmos went through recurrent cycles, or, equivalently, that time was quasi-cyclic. It was believed that each cycle of the cosmos lasted for an enormous duration of time – billions of years – and that each cycle of the cosmos was approximately like the preceding one. Events repeated in approximately similar ways in successive cycles of the cosmos. Roughly the same people were reborn in successive cycles of the cosmos, and lived roughly the same lives, and died roughly the same death repeatedly, across cosmic cycles. This perceived state of affairs was described by saying that each individual has a soul, which persisted beyond death, and was repeatedly reborn (in successive cycles of the cosmos), until such time as it achieved deliverance.

The duration of a cycle of the cosmos is reckoned in the *Viṣṇu Purāṇa* as a day and night of Brahma, and amounted to 8.64 billion years. (An ordinary day and night amount to 86400 seconds.)

This notion of a soul which persists across vast cosmic cycles is not a metaphysical notion, since it presupposes a cosmic state of affairs, which may or may not be the case. That is, this notion of the soul is a physical notion, since it involves a refutable or falsifiable picture of the cosmos.

It is a common error to confound quasi-cyclic time with eternal recurrence. It was not generally believed that these cosmic cycles were exact or eternal. The whole possibility of deliverance – *mokṣa*, *nirvāṇa* – was premised on the idea that these cycles were neither exact nor eternal. (However, the category of cyclic time encourages such an error by suggesting that various types of cyclic time are the same.)

In India, this was the traditional view of time and life after death held from before the time of the Buddha. The Lokāyata denied the belief in life after death as a fraud. An interesting feature of this denial is how Pāyāsi sought to establish the non-existence of the soul by performing some 37 experiments with dying men, and condemned felons. It is unlikely that such experiments were ever performed anywhere else.

The Buddhists did not deny this cosmic state of affairs. Indeed, popular stories like the *Jātaka* tales clearly accepted what was then the prevalent common belief about the world. What Buddhists denied was only the significance of cosmic recurrence, for they denied the existence of a soul or any continuity between two similar individuals across two cycles of the cosmos. In fact, they also denied that anything essential persisted between two similar individuals across even two instants of time: they maintained that the seed in the granary is a distinct entity from the seed in the ground, which is bloated. The seed in the granary cannot be the cause of a plant, because the seed in the granary remains a seed at the next instant. There is a similarity between the two seeds, and hence, due to the paucity of names, one gives the same name to both seeds. Therefore, in the Buddhist view it would not be proper to say that there is some essential sameness in an individual which persists from birth to death: in the Buddhist view, an individual exists (unchanged) only for a single instant.

This notion of quasi-cyclic time is incorporated in artistic or mythical representations, like the Wheel of Time, the Phoenix, or the Plumed Serpent of Central America, that are found from across the world, and certainly existed in Egypt. And, as Herodotus informs us, numerous ideas, customs, and religious beliefs were transmitted from the Egyptians to the early Greeks. Therefore, it is not surprising that a similar notion of the soul is found in the works of Plato, and was subsequently developed by the Alexandrian Neoplatonic philosophers.

Indeed, it is little known that this belief in quasi-cyclic time was the anchor of early Christianity, as enunciated by one of its greatest real (as opposed to mythical) teachers, Origen of Alexandria (3rd–4th century CE). This early Christian notion of cyclic time was remarkably similar to what is today known as the Hindu doctrine of *karma-samskāra*. According to this doctrine, the actions (*karma*) in one cycle determine the dispositions (*samskāra*) in the next cycle, and the objective of life is taken to be deliverance (*mokṣa*) from these repeated births and deaths.

Quasi-Cyclic Time, Immanence and Equity

Curiously, while cyclic time and *karma-samskāra* are today associated with casteism and inequity, in early Christianity, Origen argued in his *De Principis* that this notion demonstrated both equity and justice: equity, since God had created all souls equal, and justice, since souls were rewarded and punished in each cycle of the cosmos according to the merits or demerits they had earned from their good or bad actions in the preceding cycle. Origen's argument was not an isolated curiosity.

Thus, the notion of equity was related to immanence or the idea of divinity with in man, and hence the importance of deep introspection. The discipline of Yoga (union) is not a physical exercise, but a technique of meditation or introspection to bring about the union of ātman with Brahman, inside man, and thence lead to deliverance. Mathematics (geometry) was perceived by early Greeks to be a technique, exactly like Yoga, to achieve the same goal. Thus, in Plato's *Meno*, Socrates demonstrated the slave boy's prior knowledge of mathematics, in support of his theory that all learning was but reminiscence of the prior knowledge of the soul. Likewise, Proclus explained the etymology of mathematics (from *mathesiz* or learning) as the science of learning, or the science of the soul, since he thought mathematics related to eternal truths, and forced one into an introspective state, which then aroused the immortal soul and induced it to recollect its past knowledge, which it had forgotten since birth.

Immanence related to equity, since all souls were regarded as being part of one God. This relation is well brought out by the following story. Śankara was the founder of Advaita Vedanta, a philosophical system which asserts that ātman and Brahman are "not two" (but one). Śankara was returning from his bath in the river, when he was accosted by a *candāla* (outcaste). By force of habit, Sankara shrank back. After this the *candāla* taunted him, asking how Śankara could maintain this distinction when both had an ātman one with Brahman, hence equal to each other. Realizing his mistake, Śankara prostrated himself before the *candāla*. Almost every theorem of Euclid's *Elements* is about equality (not congruence), and this was unambiguously related to political equality as in the mystery story that there is "no royal road to geometry". The connection to political equality was made quite explicit in subsequent Islamic rational theology (*aql-i-kalam*). The lasting impact this had on Islam is obvious from the fact that religious-minded emperors like Aurangazeb, even though they ruled vast empires, worked to earn their livelihood – something observed with great astonishment by Europeans who had never known any ruler of this sort. In the early Christian version, Origen argued that not only were all souls created equal, but they would again become equal at the end of time, since all would ultimately achieve deliverance, as in *karma-samskāra*, and there would be a time when God would be all *in* all.

This notion of an immanent God was also essentially a celebration of the creativity of life. Man creates the future cosmos (at least a tiny part of it), just because God is in Man (and also other living creatures). All people are equal, just because all people are equally parts of one God. Since these notions involved a celebration of creativity, they were associated with what have been called "fertility cults", such as the worship of Bacchus or Dionysius. In India, various Tantric schools have many similar practices. The relation of equity to creativity is well brought out by the Lokayata festival, today known as Holi. On the one hand it is related to the harvest and is thus a celebration of creativity. The custom of throwing color on people was intended to erase the social distinctions that are displayed by means of clothes, and in fact to erase all individuality. The custom of taking bhang (marijuana) was intended to further creativity by heightening sexual passion.

Inequity as the Basis of Linear Time

After Constantine, this belief in the equity of all souls stood in the way of the political goals of the church, which now viewed the world from the imperial perspective of the Roman state: if all souls would be saved anyway what was the advantage to be gained by turning Christian? If God was within man, where was the need to fear God, and be obedient to the priest? Hence, theologians like Augustine proposed to erase equity and erect a transcendent God who would judge people and establish a simplistic moral division between good (Christians) and bad (non-Christians). In the revised picture proposed by state Christianity, all souls were NOT equal, so not all souls were eventually saved. Instead God established a permanent inequity in the world, sending some souls (those of good Christians) to heaven (forever), and other souls (non-Christians) to hell, as described in gory detail by Dante, for example. Reincarnation was accordingly changed to resurrection – life after death, just once.

Because the earlier notion of soul depended upon a view of life after death deriving from the belief in quasi-cyclic time, time beliefs were also compelled to change with this changed notion of the soul and of life after death. Time beliefs changed from qausi-cyclic time to linear apocalyptic time: the world, as conceived by Augustine, began a few thousand years ago, and would soon come to an end. The notion of the soul became metaphysical.

Thus, the question of linear versus cyclic time is an issue that lies at the very foundation of Christianity (and the related historical notion of the West, as in Toynbee's classification, used more recently by Huntington). Rejection of that view of (apocalyptic) linear time would amount to a denial of the entire religious ideology of state Christianity, as it is understood today. This explains the significance and importance to the West of the competitive stereotype of linear time versus cyclic, directed as much against early Christianity as it is directed against non-Western views of time.

The Western Misrepresentation of Quasi-Cyclic Time as Supercyclic

Augustine argued against Origen's view, by misrepresenting "cyclic" time as eternal recurrence or a state of affairs where deliverance was available to none. He asserted that the cosmos would recur exactly, so that even Jesus Christ would be repeatedly reborn and repeatedly crucified, so that no one could be saved. "Heaven forbid that we believe this, for Christ having died once for our sins, rising again, dies no more". Augustine then rejected this state of affairs on the grounds of "fatalism" (which, he quibbled, was different from "determinism").

This was certainly a misrepresentation of non-Western views, where deliverance from the cycle of birth-death-rebirth was not only held to be possible, it was regarded as the ultimate aim of life. This was also a misrepresentation of Origen who explicitly stated:

> And now I do not understand by what proofs they can maintain their position, who assert that worlds sometimes come into existence which are…in all respects equal. For…then it will come to pass that Adam and Eve will do the same things which they did before: there will be a second time the same deluge…. So therefore it seems to me…that a diversity of worlds may exist with changes of no unimportant kind…in that age [world] which preceded this, Christ did not suffer…. (*De Principis*, Book II, chapter III.4-5)

Augustine's misrepresentation of "cyclic" time may be presented thus: time was thought to be quasi-cyclic, whether in *karma-samskāra* or in Origen's teachings; however, Augustine misrepresented quasi-cyclic time as supercyclic time – a situation (of "eternal and exact recurrence") where no change is possible in the cosmos, which repeats mindlessly like a stuck record (this "repetition" being in some implicitly assumed notion of increasing time, external to the cosmos, perhaps in the mind of God). Most Western thinkers have fallen into the same Augustinian trap of confounding "cyclic" time with "eternal recurrence" because they lacked even the words required to make a distinction between different varieties of cyclic time.

Therefore, Augustine's misrepresentation of Origen's notion of "cyclic" time has confused a long line of Western thinkers like Nietzsche, who founded an entire philosophy on this misunderstanding of "cyclic" time as supercyclic time or "eternal recurrence of the same". The same confusion between quasi-cyclic time and eternal recurrence can be found in T. S. Eliot, or in Mircea Eliade's *The Myth of the Eternal Return*.

Starting from Newton, the same confusion about "cyclic" time persists in scientific theory to this day. For example, Stephen Hawking and G. F. R. Ellis, in their *Large Scale Structure of Spacetime,* argue against closed time loops (a third variety of partially cyclic time, distinct from quasi-cyclic time and super-cyclic time) repeating exactly Augustine's mistaken arguments. The first step of the argument confounds any sort of cyclicity with eternal recurrence, and the second step rejects eternal recurrence on grounds of fatalism. More recently, arguments in the scientific literature related to the Grandfather paradox of time travel, which involves a loop in time, have again endlessly repeated Augustine's wrong arguments. The confusion between quasi-cyclic time and eternal recurrence seems to reverberate eternally in Western thought: "cyclic" time represents "eternal recurrence" hence fatalism, and should be rejected. On the contrary, as this author has pointed out, such closed loops in time, being causally inexplicable from the past, are the way to have spontaneity, or creativity, within the frame of current physical theory.

Thus, the Western stereotype of non-Western views of time involves involves a very deep-seated and long-standing confusion about the nature of time within Western thought, starting from Augustine and stretching down to people like Newton, Einstein, and Hawking.

There are a few other aspects of non-Western views of time that deserve at least a brief mention.

Discrete Versus Continuous Time

First, consider the issue of discrete versus continuous time. The belief that time is a continuum is forced in present-day physics, as we have seen, only by the Western understanding of the calculus, based on an idealistic understanding of mathematics. However, the calculus that developed in India incorporated a different understanding of mathematics, that could be called a realistic understanding. The difference between the two may be explained with reference to the Buddhist denial of the existence of the soul. The Buddhists (especially followers of Nāgārjuna's *śūnyavāda*) maintain that between two instants of time, an individual changes, and there is nothing "essential" in the individual that remains the same. In common parlance, and for practical purposes, we neglect or zero the differences as inconsequential, or non-representable, due to a paucity of names.

Let us now apply this understanding to a number like π, which denotes the ratio of the circumference of a circle to its diameter. No matter how we try to express this number, it cannot be specified – that would require a supertask. In idealistic (formal) mathematics, it is asserted that there really is such a number, although any actual representation of it will always only be approximate or erroneous. In realistic mathematics it would be asserted that calculations can only be done with an actual representation and not an idealized one. There is a paucity of names, and therefore we use a representation appropriate for a given practical purpose, zeroing certain things treated as non-representable. The subtle difference between the two positions is brought out very clearly in the representation of such numbers on a computer; the actual numbers (floating point numbers) do not follow the same rules or "laws", such as the associative law for addition that the ideal "real" numbers are supposed to obey.

This leads to a fundamentally different understanding of "infinitesimals" (as non-representable quantities discarded in a calculation), which presented such a problem for Newton and Leibniz. However, all practical conclusions drawn from the calculus use realistic mathematics and computation, rather than idealistic mathematics. Therefore, the idealistic point of view, which forces time to be a continuum in physics, involves the superposition of "extra baggage" from Western metaphysics, and there is no real need to believe that: time may well be regarded as discrete or atomic, provided one does the calculus with a different philosophy of mathematics. The point here is not to argue that time is, in fact, discrete, but rather that the discreteness or continuity of time should not be fixed purely from mathematical and metaphysical considerations, since these metaphysical considerations could be fundamentally different in the non-West.

Atomically Structured Time and Quasi Truth-Functional Logic

The second question concerns the link between time beliefs and logic. Time may be related to logic through Wittgenstein's notion of logical worlds: the state of the physical world at an instant of time can be specified by specifying all the statements that are true at that instant of time. In the West it has been believed that if A is true at an instant of time, then its negation $\sim$A cannot be true at that very instant. Certainly there are schools of thought in the non-West which also subscribe to this belief, but it is not universal. Buddhist and Jaina logics permit both A and $\sim$A to be true at an instant of time. This involves the concept of an atomically structured time. The classical way to explain this would be to think of an instant of time as a microcosm. A modern explanation for this state of affairs can be provided using microphysical loops in time.

Imagine that one has a time machine, and that one puts Schrödinger's cat (now dead) on board the time machine and sends it back to the time of Schrödinger. The events here described from a future perspective would actually have been observed by Schrödinger somewhat differently: for Schrödinger, the "observed" sequence of events would have been that time spontaneously and inexplicably split into two streams (both part of this world), in one of which the cat is alive, and in the other it is dead. (At the microphysical level, one can actually "see" a somewhat analogous phenomenon of a photon or a particle of light splitting into an electron-positron pair, which may later recombine to produce back a photon. The positron has exactly the properties of an electron travelling back in time, so the process can also be described as an electron executing a closed circuit in time.) These two streams of time, witnessed (or rather inferred) by Schrödinger, are NOT "parallel" worlds, for the two worlds do meet, and the two cats would coalesce back into a single cat at the time we put the cat into the time machine.

In place of imaginary time machines, one can construct a more realistic desktop model involving parallel computing, although understanding this requires a little more technical knowledge. In parallel computing, a single process executing on parallel processors may be in multiple states at a "single instant" of time. Needless to say, "parallel" is a bit of a misnomer, since it is an essential feature of parallel computing that the processors (logical worlds, in the Wittgensteinian sense) and processes communicate with each other, and that they branch and collapse. Time, so to say, acquires a structure, and it is necessary to take into account this structure to understand the semantics of formal parallel computing languages.

Microphysical closed time loops enable us to understand how an atom of time can nevertheless have a structure, in the sense that multiple logical worlds are attached to a single instant of time. This structure is manifested not by further subdivision of the atomic instant, but by a change of logic. In such a situation of an atomically structured time, it is perfectly possible to have both A and not-A valid at a single instant of time that cannot be further decomposed.

This notion of an atomically structured time or a structured instant is the basic unit of reality in Buddhism. It leads to the alternative notion of "causality" in Buddhism, called *paticca samuppāda*, or "conditioned co-origination". The present is not the cause of the future, but the future cooriginates, conditioned by the past. *Paticca samuppāda* is identified by the Buddha as the key to his Dhamma. Thus, the use of a logic of four alternatives in Buddhism is not incidental to Buddhism but is integrally linked to its worldview, for it is only through an understanding of the causes of *dukha* that one can remove it.

Ontically Broken Time

The common terminology of the laws of physics – for example, Newton's laws of motion – is related to the theological idea that creation was a one-time process and that subsequent states of the cosmos were controlled by God using laws. This idea of a clockwork cosmos is denied in many non-Western systems of thought. Al-Ghazālī, argued from a different perspective, where the world is continuously created by God. In this situation, any causal connection becomes a restraint on the powers of God; al-Ghazālī denied the existence of causal connections. He conceded that there are observed regularities in the cosmos, but he explained them as arising from force of habit. God habitually creates smoke with fire; he is not obliged to do so. Of course, one does not know on what time scale God changes habits, but it could be imagined that the cosmos is such that not only would physical theories change, but physics itself would change, over a time scale of, say, a thousand years.

More to the point, this helps us to see the historical evolution of the idea of the laws of God. Thus, al-Ghazālī was speaking about an immanent God, the apparent restrictions on whose powers were all too obvious. When this was taken over in the West, as by John Scotus Duns, it created a problem, because it was supposed (at least by the opponents of this point of view) that this description concerned a transcendent God. Under those circumstances, God would become a terrible tyrant, since one would never know what to expect next. Accordingly, God's intervention was toned down, and his role limited to instituting laws. This led eventually to superlinear time.

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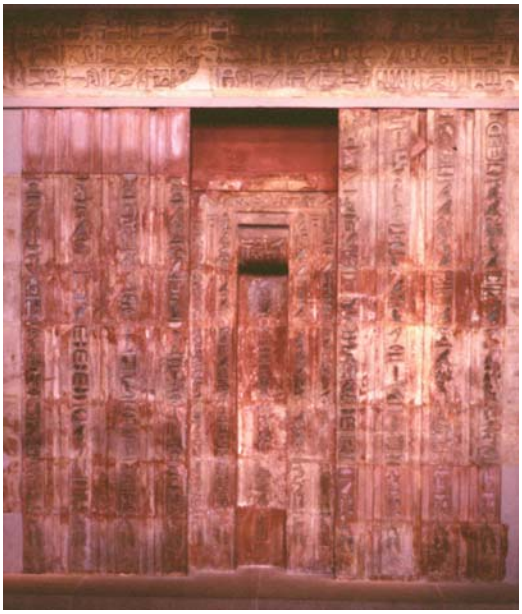
Tombs in Ancient Egypt

Aidan Dodson

An Egyptian tomb ideally comprised two basic parts. One was intended to house the body for eternity; the other was to act as the interface between this world and the next. These two elements could lie close to one another or could be separated by some considerable distance; they could also be of various constructional types and materials. However, the fundamental distinction remained between the mortuary chapel, or offering place, open to the public, and the burial chamber, intended to be sealed for eternity.

The public element usually focused on a stela, an inscribed slab that provided a point at which the two worlds met. It might be of simple form, bearing a depiction of the deceased (and perhaps his or her spouse) receiving offerings of food and drink, together with a ritual formula that guaranteed their eternal provision. On the other hand it might be an elaborately panelled 'false door' (Fig. 1), making explicit the stela's role as a portal between the worlds. In certain cases a statue of the dead person might replace or supplement the stela.

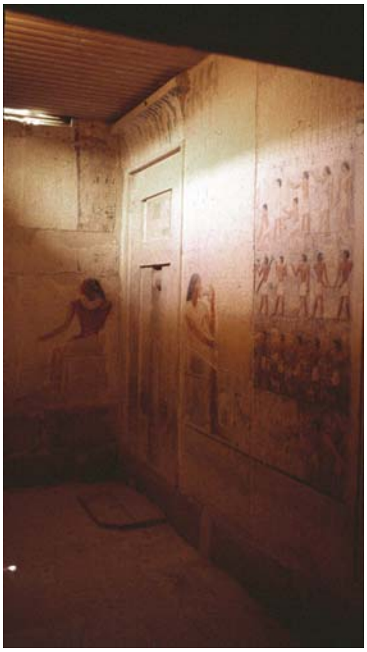


Tombs in Ancient Egypt. Fig. 1 A typical false door stela of the Old Kingdom (British Museum EA682) belonging to Ptahshepses (ca. 2425 BCE) Photo by author.

In many tombs the offering place comprised simply the stela, standing exposed, or with a very basic shelter carved out of the rock or built in brick or stone. However, in other cases the offering place was housed in a far larger structure, which could in turn be extensively decorated (Fig. 2). This structure may be referred to as a mortuary chapel or a mortuary temple, the latter term being generally used for royal examples.

For much of Egypt's history, the decoration of such structures was concerned with food production, other motifs taken from the agrarian world and the experiences of the deceased. In royal cases, this could include scenes of the gods and events of the reign. Tableaux in private chapels are often referred to as 'daily life' scenes and provide an important source for our understanding of life in ancient Egypt. Their primary role was clearly to recreate magically the world the deceased had once enjoyed, as well as providing a further source of eternal sustenance. It seems likely, however, that they had other more esoteric significance, linked with concepts of regeneration and rebirth in the next world. From around 1250 BCE, these 'daily life' scenes tend to be replaced by others of purely ritual type, with images of the gods and extracts from the various Egyptian funerary 'books' that aided the dead person in his or her posthumous destiny.

As already noted, the form of the offering place varied. At one extreme, those of kings could be huge temples, either freestanding or, prior to the middle of the second millennium BCE, attached to a pyramid. Prior to the appearance of the pyramid, royal tombs seem to have had a simple offering place adjacent to the burial chamber, and a large rectangular enclosure up to 1.5 km away. A mound of rubble or some other structure may have topped the burial place itself. At the beginning of the Old Kingdom (ca. 2650 BCE), these separate elements were united in a single location, in the Step Pyramid complex of King Djoser at Saqqara. For perhaps the first time, all parts were built of stone, and a low square structure over the burial place was soon extended to form the basis of a six-stepped pyramid, the first of its kind (Fig. 3).



Tombs in Ancient Egypt. Fig. 2 The false door of Ptahhotep at Saqqara (ca. 2350 BCE) lies within a highly decorated chapel. Photo by author.

Only the very earliest pyramids were stepped, perhaps to provide a stairway to heaven for the dead king. They were soon replaced by smooth-sided structures ('true pyramids'), apparently intended as a recreation of the sun's rays, along which the monarch might make his way to join with the sun god (Fig. 4). The very first step pyramids were surrounded by large rectangular enclosures holding ritual buildings (Fig. 5). However, these were soon superseded by a smaller enclosure with a mortuary temple on the east side of the pyramid. From this a causeway led to a 'valley temple' on the edge of the desert (Figs. 6 and 7).

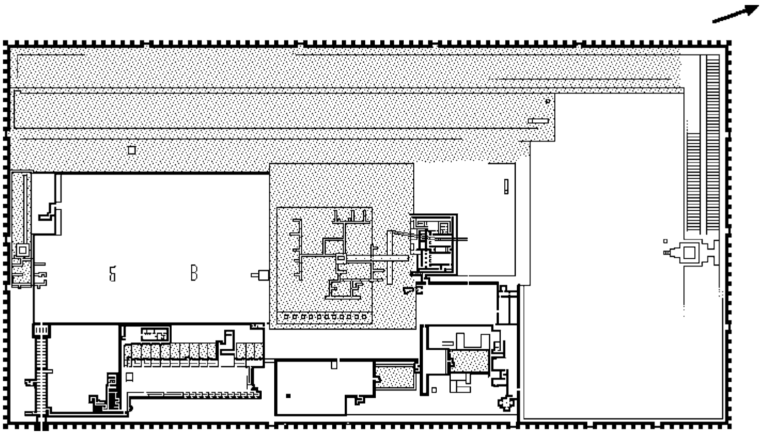
The free-standing temples that were adopted by the kings of the New Kingdom (1550–1070 BCE) after the royal abandonment of pyramids were all but indistinguishable from contemporary temples of the gods, the differences being in detail only (Figs. 8 and 9). Unlike earlier mortuary temples, the king's spirit now shared the temple with Amun, the King of the Gods, and the sun god, Re, each of whom had his own separate sanctuary within the temple.

Private individuals' mortuary chapels fall broadly under three headings. One type is built against or within *mastabas*, stone or brick structures shaped like low benches ('mastaba' means 'bench' in Arabic). They are used throughout Egyptian history at sites with a flat basic topography, although the best-known date to the Early Dynastic Period and Old and Middle Kingdoms (ca. 3000–1700 BCE).

Mastabas of the earliest times usually had a panelled exterior, but from the Old Kingdom onwards they tended to have flat, slightly sloping, sides, although panelling is occasionally found down into the Middle Kingdom (2100–1700 BCE). Chapels range from a simple niche at the southern end of the eastern face, holding the stela, to a complex of a dozen or more decorated rooms occupying much of the interior of the mastaba. Most usual is an offering place with one or two rooms (Figs. 10–12, 15).

Tombs in Ancient Egypt. Fig. 3 The first pyramid – the Step Pyramid at Saqqara. Photo by author.

Tombs in Ancient Egypt. Fig. 4 The finest examples of the true pyramid lie at Giza, belonging (left to right) to Kings Menkaure, Khaefre and Khufu (ca. 2550–2475 BCE). Photo by author.

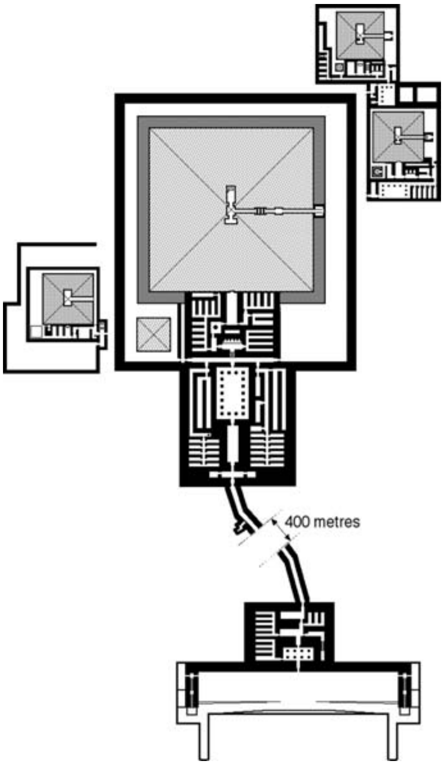


Tombs in Ancient Egypt. Fig. 5 Plan of the Step Pyramid complex, showing the great expanse of ritual buildings. Plan by author.

Tombs in Ancient Egypt. Fig. 6 Typical of later pyramids is that of Sahure (ca. 2465–2450 BCE), with a mortuary temple on the east side. Photo by author.

The next type of mortuary chapel is also employed on flat sites, but comprises a freestanding building without an associated mastaba. Once again, these can vary considerably in size and elaboration, from little more than a shed around the stela to a miniature temple. The latter seem to appear first late in the Eighteenth Dynasty and are referred to as 'temple-tombs' (Fig. 13).

The final form of mortuary chapel is that which is cut into a rock face (Fig. 14). Such offering places first appear around 2500 BCE at Giza, and are found throughout the rest of Egyptian history. Plans are almost infinitely variable, although a number of fairly standardised plans are to be seen at Thebes during the New Kingdom (1550–1070 BCE). In particular there is the T-shaped tomb, with a broad but shallow hall running across the axis, and a long corridor running from the middle of its back wall to the offering place, deep in the rock. This basic form could be greatly elaborated by the addition of columns and further chambers – one had no fewer than 70 columns.



Tombs in Ancient Egypt. Fig. 7 This shows the layout of the whole complex of Pepy II (ca. 2290–2180 BCE); the small pyramids belonged to his wives. Plan by author.

Of course, this division is purely for convenience, and many tombs exist that are a combination of more than one category. In particular, rock-cut mortuary chapels could have freestanding courtyards built in front of them (Figs 17 and 18). Particularly elaborate examples date to the Saite Period (663–525 BCE). In addition, after the abandonment of pyramids by kings, miniature examples often appeared above private sepulchres, of both built and rock-cut designs.

The burial chamber and its associated elements are collectively known as the 'substructure'. The two key types are those approached via a vertical shaft and those accessed by sloping passage or stairway. A further consideration is whether the substructure has been tunnelled out of the living rock, or whether it has been constructed out of stone or brick in a cutting in the desert surface and subsequently covered over. There are, however, tombs that use more than one approach to various elements of their substructures.

In the vast majority of Egyptian tombs the substructure lay close to, or directly under, the offering place. Many Old Kingdom mastabas had shafts descending from their roofs to burial chambers in the rock below (Fig. 15), while royal pyramids usually had their burial chamber under the centre of the monument, approached via a sloping corridor from the centre of the north face of the pyramid. In rock-cut mortuary chapels, sloping passages are found in the earliest examples, but later shafts are used as well.

Tombs in Ancient Egypt. Fig. 8 The earliest surviving New Kingdom royal mortuary temple is that of Queen Hatshepsut (ca. 1472–1457) at Deir el-Bahari. Photo by author.

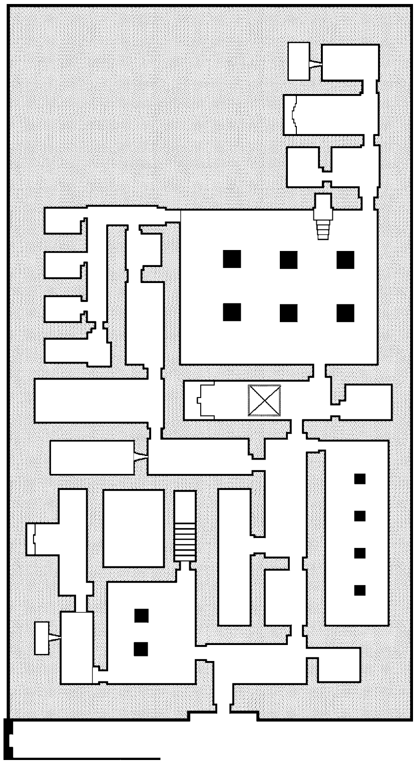
Tombs in Ancient Egypt. Fig. 9 Of rather different appearance, but with the same purpose is the temple of Ramesses III (ca. 1185–1153 BCE) at Medinet Habu. Photo by author.

Tombs in Ancient Egypt. Fig. 10 The entrance to the now-ruined chapel of the panelled brick mastaba of Nefermaat at Meidum (ca. 2550 BCE). Photo by author.

Tombs in Ancient Egypt. Fig. 11 A group of stone mastabas at Giza (ca. 2430 BCE). Photo by author.

Occasionally, the substructure lies some way from the offering place. The best examples of this are the royal tombs of the New Kingdom at Thebes, where the mortuary temples lay on the edge of the desert, but the tomb chambers were up to 2 km away in a desert valley. This is now known as the Valley of the Kings, and also held the burial chambers of a handful of highly placed nobles, whose rock-cut mortuary chapels lay a similar distance away.

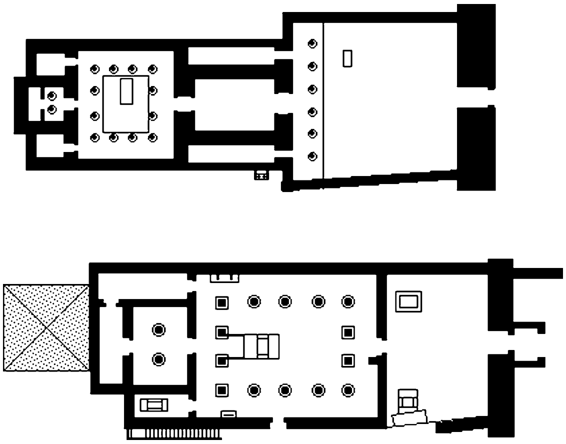
Substructures took a variety of forms, ranging from a single chamber and approach shaft/corridor, to a long sequence of corridors, pits and halls. Some included special security features, with sliding trap doors, hidden entrances, and/or burial chambers cut from single blocks of stone, closed with the aid of a 'hydraulic' system using sand. Such features were first employed during the late Twelfth Dynasty (ca. 1800 BCE), and then revived over a millennium later, during the Saite Period.



Tombs in Ancient Egypt. Fig. 12 The most elaborate chapel within a mastaba is that of Mereruka (ca. 2340 BCE) at Saqqara. Plan by author.

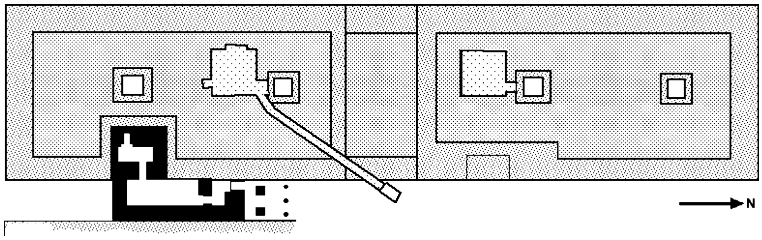
Royal tombs were not surprisingly amongst the sepulchres with the most elaborate substructures, although certain private examples, particularly of the Saite Period, exceeded even them. Many earlier pyramids had a standardised substructure, built of stone in a shallow cutting, with a group of three chambers reached by a long corridor. This was blocked by three vertical portcullis slabs of granite (Fig. 7). From the middle of the Middle Kingdom, however, changes were brought in to increase security. Entrance locations became random, and the aforementioned security arrangements introduced.

The security imperative probably also lay behind the separation of the royal burial chamber from the mortuary chapel early in the New Kingdom. The Valley of the Kings tombs generally take the form of a set of

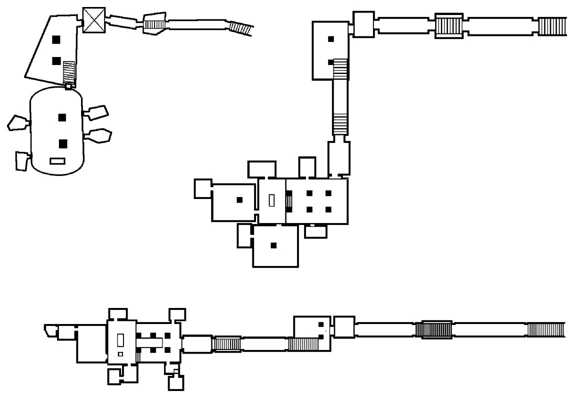


Tombs in Ancient Egypt. Fig. 13 Plans of the 'temple-tombs' of Maya and Tjia at Saqqara, ca. 1340–1240 BCE. Note the pyramid attached to the rear of the lower sepulchre. Plan by author.

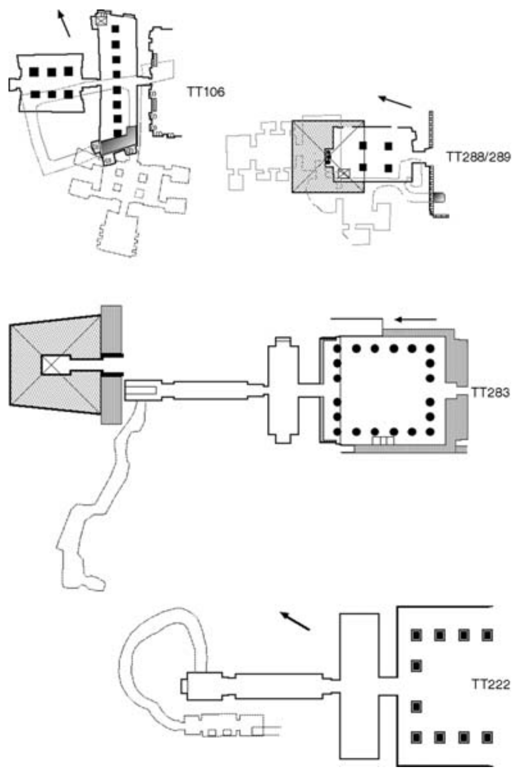
Tombs in Ancient Egypt. Fig. 14 A classic group of rock-cut mortuary chapels are at Aswan, dating between ca. 2400 and 1850 BCE. Photo by author.



Tombs in Ancient Egypt. Fig. 15 Plan of the tomb of Kawab at Giza (ca. 2530 BCE), showing the burial shafts descending through the superstructure and the chapel built partly within and partly outside the mastaba. Plan by author.



Tombs in Ancient Egypt. Fig. 16 Plans of the tombs of Kings Thutmose III, Amenhotep III and Horemheb in the Valley of the Kings, showing the evolution from a 'bent' to a straight plan between ca. 1450 and 1300 BCE. Plans by author.



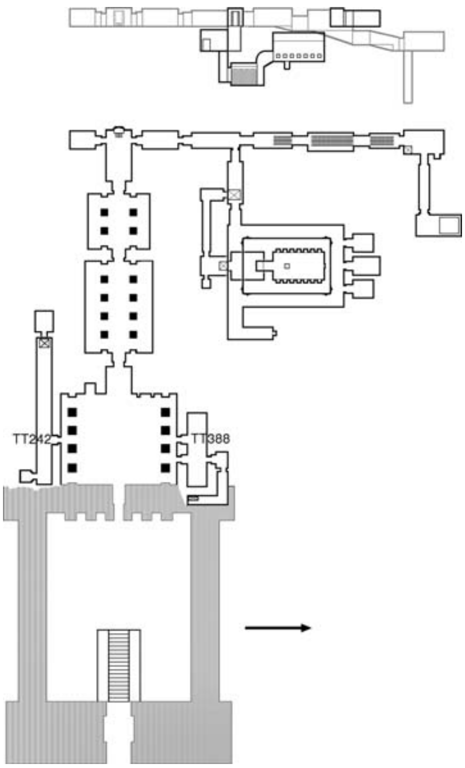
Tombs in Ancient Egypt. Fig. 17 Plans of the private tombs of Paser, Setau, Roma-Roy and Heqamaatrenakhte at Thebes during the middle of New Kingdom (ca. 1300–1150 BCE), showing the relationship between the mortuary chapel, in some cases pyramid, and the substructure. Plans by author.

passages and stairways, leading to a pillared antechamber, and finally to a pillared burial chamber. A shaft in the floor interrupted progress down the tomb, probably with a dual role of hindering thieves and preventing storm water's penetrating the inner rooms (Fig. 16).

In contrast to the mortuary chapel or temple, which almost always had some form of decoration, the substructure was usually completely plain. The principal exceptions were the royal tombs of the late Old Kingdom and the New Kingdom onwards, and a handful of private sepulchres of the Sixth Dynasty, Middle Kingdom, New Kingdom and Saite Period. In the late Old Kingdom, royal burial apartments were adorned with the *Pyramid Texts*, magic formulae intended to aid the king in the next world. They are the ancestors of a whole series of 'books' that formed the basis for all later substructure decorations.

Royal tombs of the New Kingdom and later were principally adorned with various heavily illustrated compositions relating to the sun god's nocturnal journey through the underworld, in which the dead king would participate (Fig. 19). At first these works were a royal prerogative, but by Saite times they could also be found in private tombs as well, which also revived the ancient *Pyramid Texts*.

The rare Old Kingdom decorated private burial chambers generally had illustrated lists of offerings on their walls. This was also the case in the Middle Kingdom, but in the New Kingdom the main decorative composition was the *Book of Coming Forth by Day* – better known as the *Book of the Dead*. This was essentially a guidebook to the next world, and was more usually found on a papyrus placed alongside the mummy. Extracts are also found in mortuary chapels of the Nineteenth Dynasty and later.



Tombs in Ancient Egypt. Fig. 18 One of the largest and most elaborate tombs in Egypt belonged to the priest Pedamenopet (ca. 600 BCE). It was partly built of brick and partly rock-cut, with an extremely elaborate substructure. The burial chamber was carefully concealed, and was approached from below. Plan by author.

Following the Macedonian and Roman takeovers of the country, Egyptian-form tombs were supplemented by those in the Classical tradition, in particular at Alexandria and in other areas with high levels of European settlement. However, even these sepulchres often included Egyptian features, especially in their decoration, where the native gods often appeared. A key difference between the two mortuary traditions was the blurring of the previous rigid distinctions between the chapel and the burial place. In Classical tombs the body was placed in a sealed loculus in the wall of a generally accessible catacomb that might include both a chapel and a room for funerary feasts.

See also: ►Mummies

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Tombs in Ancient Egypt. Fig. 19 The Book of the Earth, one of the numerous compositions found on the walls of New Kingdom royal tombs. Here it is seen in the burial chamber of Ramesses VI (ca. 1141–1133 BCE).

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Tongren Zhenjiu Shuxue Tujing

Richard Bertschinger

The *Tongren Zhenjiu Shuxue Tujing* (Illustrated Canon of Acupuncture Points based upon the Bronze Figure) was written by Wang Weiji, and published in AD 1026. It has been a baseline in the identification of acupuncture points ever since. It is used not only in Chinese medicine, but also in acupressure as developed recently in the West, in *shiatsu* (pressure point massage) in Japan during this century, and in all acupuncture-related disciplines.

By the Song Dynasty (AD 960–1126), after much copying and recopying, the locations of the points and channels had become confused. Because of this and the greater stability brought about by the Song reunification of the empire, the medical scholar Wang Weiji reorganized and collated all the then available material in order to locate and define the points precisely.

He produced a book which very quickly became the authoritative text throughout the country. It gave very detailed and accurate information concerning the points, the channels, the depths and effects of needling. The total number of points named in the *Huangdi Neijing* (Yellow Emperor's Canon of Medicine) had been 160; in the *Zhenjiu Jiayi Jing* (A–Z of Acupuncture and Moxibustion) it was 349. But now it was raised to 354. Not long afterwards, the full text of this

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book was cut onto two stone tablets, each some 2 m high and 7 m in length, which were erected in the Song capital, Kaifeng, where they could be read by everyone, or where ink-impressions could be made from them.

At the same time Wang Weiji directed the casting of two life-size bronze figures – hence the title of his book – which were completed in 1027.

These bronze figures are the very earliest of their kind. They were hollow and had the exact locations and names of the acupuncture points marked on their surface. It is noted in the Song histories that the purpose of the figures was for them to be covered in beeswax and then filled with water. When a student palpated and punctured a point correctly, a stream of water would flow out, reminiscent of the energy stream (or *qi*) tapped by that particular point.

The later history of these figures and tablets is also revealing. After two hundred years, when the Yuan Dynasty moved the capital to what is now Beijing, the bronze figures and tablets were also moved, to take pride of place in the temple at the new Imperial Medical College. However, much use had been made of the figures, and the tablets were so worn that they were indecipherable. Reproductions were therefore made again. During excavations from 1965 to 1971 in Beijing, fragments of the original Song tablets were discovered, and their texts shows that the tradition has been faithfully and accurately preserved to the present day. This book is used as the foundation text for the listing of points in the *Essentials of Chinese Acupuncture* (Beijing 1980) and other texts which have all been recently produced in China and which are aimed at the interested acupuncture audience in the West.

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Tools Used in Ancient Egyptian Construction

James A. Harrell

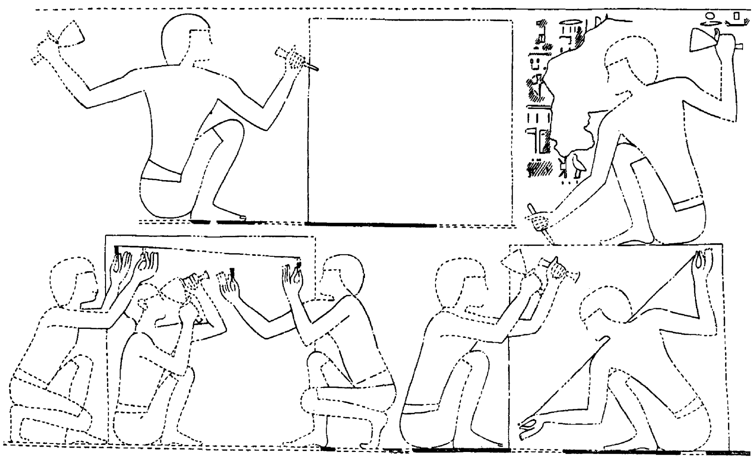
Building Materials

Most ancient Egyptian buildings were constructed of either mud bricks with wood elements or waddle-and-daub walls of intertwined poles packed with mud. These include all the houses and even the royal palaces. In the better-built structures, mud bricks were used for the foundations and walls with wood planks and poles employed for most everything else, including door and window frames, doors, window shutters, vertical supports (pillars) for roofs and upper floors, and horizontal supports for the mud-brick walls. Stone was also sometimes used in these buildings wherever extra strength and durability were required, such as for door thresholds and pillar bases. The only buildings constructed largely or entirely of stone were the temples and freestanding tombs (pyramids and mastabas [tombs]), although some of these were also built of mud brick, and many stone temples were surrounded by massive mud-brick walls.

The construction tools considered here were in use during Egypt's Dynastic period (Dynasties 1–30), which ranged from about 3000 to 332 BCE (Table 1). The subsequent Greco-Roman period is excluded because many of the tool designs (and construction practices) were imported from the Greeks and Romans. Although there are no ancient Egyptian texts describing the use of construction tools, many of the tools themselves have survived, and there are also numerous carved reliefs and painted scenes on the walls of tombs showing the tools in use (Petrie 1917; Clarke and Engelbach 1930; Arnold 1991; Gale et al. 2000; Kemp 2000). Two such tombs are especially noteworthy in this regard, those of (1) Ti, an overseer of pyramids and temples under three 5th Dynasty kings (late Old Kingdom) at Saqqara near Cairo (Epron 1939; Wild 1966) and (2) Rekhmira, a vizier under two 18th Dynasty kings (early New Kingdom) at Qurna near Luxor (Davies 1943). It is the art in these tombs that supplied the representations of tool use in Figs. 1–17. Another source of information

Tools Used in Ancient Egyptian Construction. Table 1 Ancient Egyptian chronology

Late Predynastic Period (3200–3000 BCE): Dynasty 0
Dynastic or Pharaonic Period (3000–332 BCE): Dynasties 1 to 30
Early Dynastic Period (3000–2686 BCE): Dynasties 1 and 2
Old Kingdom (2686–2160 BCE): Dynasties 3 to 8
First Intermediate Period (2160–2055 BCE): Dynasties 9 to early 11
Middle Kingdom (2055–1650 BCE): Dynasties late 11 to 14
Second Intermediate Period (1650–1550 BCE): Dynasties 15 to 17
New Kingdom (1550–1069 BCE): Dynasties 18 to 20
Third Intermediate Period (1069–664 BCE): Dynasties 21 to 25
Late Period (664–332 BCE): Dynasties 26 to 30
Greco-Roman Period (332 BCE–395 AD)
Ptolemaic Period (332–30 BCE)
Roman Period (30 BCE–395 AD)

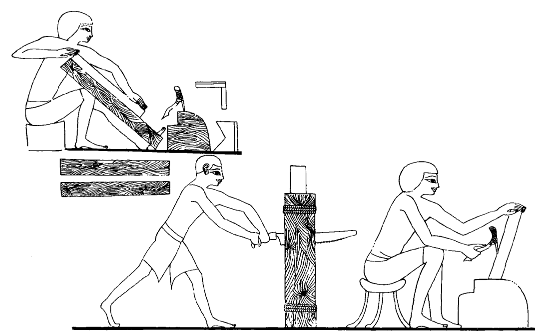


Tools Used in Ancient Egyptian Construction. Fig. 1 Stoneworkers using mallet-struck chisels, leveling rods (lower left), and a measuring cord (lower right). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 52).

comes from experimental archaeology, where facsimiles of ancient tools are made and then used to test their efficacy in various applications and materials (Stocks 2003; Solenhofen website).

Measuring Tools

Construction, especially of the more elaborate stone structures, required the use of a variety of measuring tools, including ones for determining distance, slope, and flatness. For distance, the Egyptians had "cubit rods" and "measuring cords." The "cubit" was a standard unit of distance that varied slightly during the Dynastic period but averaged 52.5 cm. It was divided into seven "palms," each of which was further subdivided into four "fingers." The working cubit rods were carved from wood, and some could even be folded along hinges. Measuring cords were used to mark off both short and especially longer distances, and these were subdivided by knots tied at fixed multiples of cubits (Fig. 1).



Tools Used in Ancient Egyptian Construction. Fig. 2 Woodworkers using a saw (center), adzes (lower right and upper left), and a straightedge (or perhaps a cubit rod; upper left). Note the builder's square just to the right of the adze (upper left). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 55).

Squared edges and corners were achieved through the use of a "builder's square," which consisted of two straight lengths of wood joined at their ends to form a right (90°) angle (Figs. 2 and 7). The "square level" combined a builder's square with a "plumb bob." It had two perpendicular sides of equal length that were joined by a crosspiece. At the apex, where the two joined sides met, there was an attached cord with a plumb bob suspended from the other end. The conical plumb bob was typically carved from stone. In use, the square level was placed upright on (vertical and perpendicular to) a surface, resting on the free ends of its two sides. By noting where the cord with the plumb bob lay on the crosspiece, the slope of the surface could be ascertained. Plumb bobs suspended from long cords were used to mark straight lines on vertical surfaces, check the verticality of walls, and measure vertical distances. A tool called a "plumb rule" was also employed to determine verticality. This consisted of a flat wood plank with two short shelves of equal depth at one end. A cord was attached to the end of the plank, just above the shelves, and this was threaded through a hole in the top shelf, exiting at its outer edge. A plumb bob was suspended from the cord's other end. To use the plumb rule, the back of the plank was pressed against a surface with the end bearing the attached cord and shelves oriented upward. The cord with the plumb bob was draped over the bottom shelf, and if the surface was vertical then the cord would just touch the shelf's outer edge.

"Marking cords" were employed to draw straight lines on a surface. The cord was first dipped in a colored paint or powder (usually made from red ochre) and then pulled taunt across the surface. By flicking the cord against the surface, a straight line was marked off.

A set of "leveling (or boning) rods" was used to ascertain the flatness of a stone surface (Fig. 1). The set's three or four short wood rods were of identical length, and two of these were joined at their tops by a cord with the others left unattached. Two workers, each holding one of the joined rods, would place their rods upright (perpendicular to) the surface and then pull the cord taunt. With their free hands, or with the assistance of a third worker, the loose rods were placed upright on the surface and moved along the stretched cord. Wherever one of these rods fell below or rose above the cord, a departure from flatness was indicated. Areas that were too high were probably marked with colored paint or powder to show where additional dressing of the surface was needed. The degree of flatness of a small surface could also be determined with a "straightedge," which was a long piece of wood with a straight edge (Fig. 2).

Cutting Tools

Stone vs. Metal

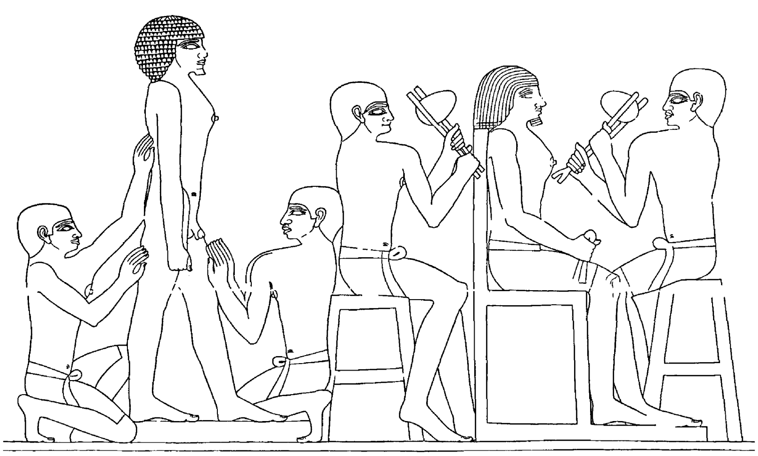
The first tools used in ancient Egypt, and volumetrically the most common ones employed throughout the Dynastic period, were made of stone. Tools requiring a hard, sharp edge or point were fashioned from chert (also known as flint), a rock consisting of microcrystalline quartz. These were used to cut soft stones (limestone, sandstone, travertine, and rock gypsum) as well as wood. Hard stones with good impact-fracture resistance (notably anorthosite gneiss, dolerite, and siliceous [quartz-cemented] sandstone or "quartzite") were employed for pulverizing and grinding the hard stones, including anorthosite gneiss, basalt, granite, granodiorite, metagraywacke, and siliceous sandstone among a few others.

Copper tools, like those of stone, predated the Dynastic period. Because copper is a very soft metal, it could only be used to cut wood and soft stones, and being much costlier than stone, it was used sparingly for tools and then just for the more important projects. The much harder bronze metal (copper alloyed with tin) was first introduced during the Middle Kingdom and became the predominant material for metal tools beginning in the New Kingdom. Even though much harder than copper, bronze was still too soft to use on hard stones. Iron-bearing tools first appeared toward the end of the New Kingdom and came into common use during the Late period. Although usually described as consisting of "iron," these tools were actually made from either a primitive kind of steel (iron alloyed with carbon) or case-carburized wrought iron. Iron tools were strong enough to work the hardest materials and quickly replaced the stone tools formerly employed.

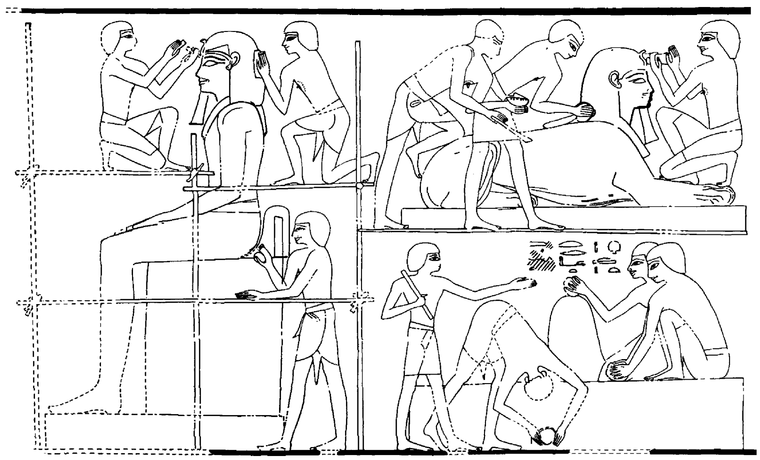
Stone Tools

"Stone mauls" were elongated, generally roughly shaped pieces of hard stone with a blunt tip and a pinched waist where a wood handle was attached (Fig. 3). In contrast to this hammer-like tool, "stone pounders" were compact, generally well rounded and often nearly spherical, pieces of hard stone that were handheld (Fig. 4). Both tools cut stone by pulverizing it. They were used to work soft as well as hard stones, but saw their greatest application with the latter.

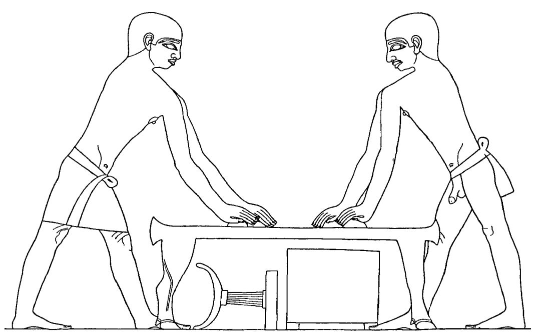
"Grinding stones" were employed for smoothing both stone and wood surfaces (Figs. 4–7). The same hard stones used for mauls and pounders were utilized



Tools Used in Ancient Egyptian Construction. Fig. 3 Stoneworkers using stone mauls (right) and possibly abrasive sand for polishing (left). Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 173).



Tools Used in Ancient Egyptian Construction. Fig. 4 Stoneworkers using grinding stones (left and upper right), a chisel struck with perhaps a small piece of wood or stone (upper left corner), stone pounders (lower right), and possibly abrasive sand for polishing (upper right – man with cup and ladle). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 60).



Tools Used in Ancient Egyptian Construction. Fig. 5 Woodworkers using grinding stones. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 174).

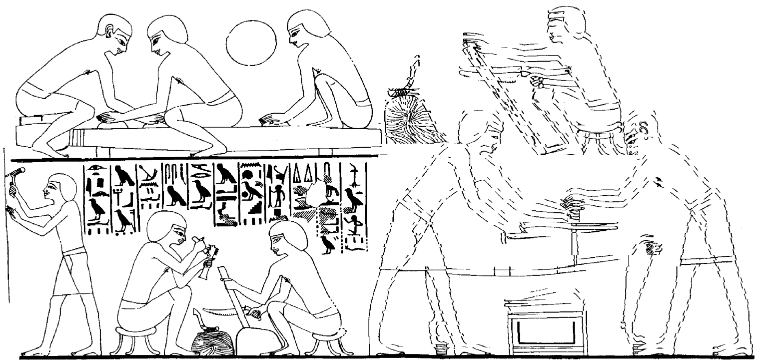
for grinders, but siliceous sandstone was especially favored for this application. Only the harder stones can take a polish, and smoothing with grinders was the first step. Producing a good, reflective polished surface required rubbing with an abrasive paste. Quartz sand was almost certainly the abrasive used, and this would have been applied with either a piece of leather or cloth (Figs. 3 and 4). Using progressively finer-grained sands would produce an increasing degree of polish.

"Hand-cranked stone drills" were used to hollow out the interiors of stone vessels, and may have had some construction applications as well (Figs. 8 and 9). The drill consisted of a wood shaft with a forked end into which was lashed either a siliceous sandstone or, more often, a chert bit. The other end of the shaft was bent to form a handle, and suspended just below this were stone weights that served to increase the downward cutting force of the bit. By cranking the handle back and forth, a worker could drill a cylindrical hole.

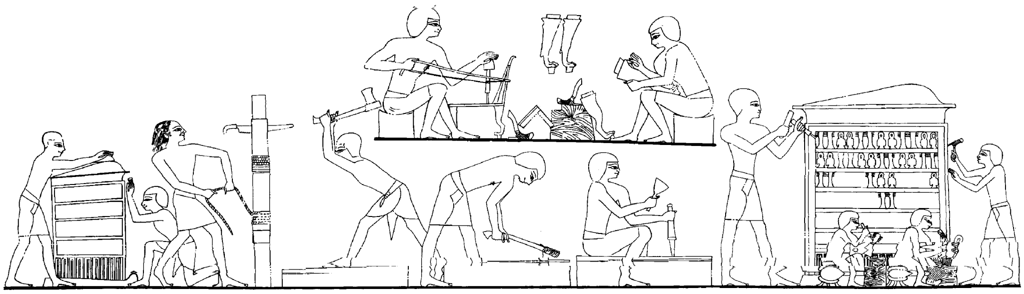
Chert is the only native Egyptian stone that can be shaped into a tool with hard, sharp points and edges. It was consequently widely utilized for a wide variety of nonconstruction applications, such as arrow and spear points, and knife and sickle blades. In woodworking, chert was used for axe and adze blades, but it is unclear whether this stone was also used in stoneworking. It has been shown experimentally that chert pick heads, adze blades and chisels can easily cut the softer stones (limestone and sandstone), and chert gravers (sharp-pointed inscribing tools) can be used to incise both soft and hard stones. Although there is no direct archaeological evidence for such applications, it seems likely that chert was employed for stoneworking tools.

Metal Tools

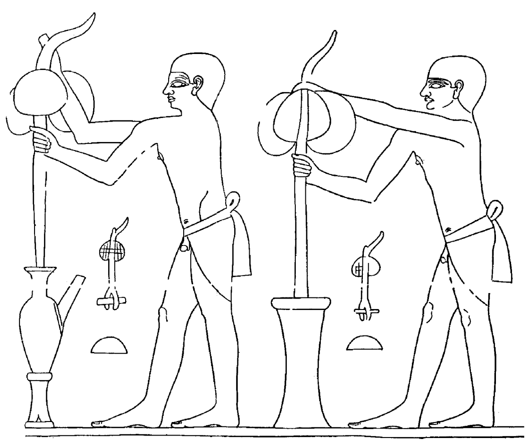
The principal metal tool used for stoneworking during the Dynastic period was the "chisel" (Figs. 1 and 4). Copper and bronze chisels were formed from stout cylindrical bars with either a pointed or flat-edged tip, and were struck with a wood mallet. Some, especially for woodworking, were fitted with a wood handle (Figs. 7 and 10). The chisels were used to dress soft stones, and to cut holes and grooves in wood. Even for such soft materials, the tips needed frequent sharpening. It was not until the advent of iron chisels (and the first metal hammers) during the Late period that the hard stones were worked with metal tools. Copper and bronze "gads" resemble chisels but were not used for cutting. They were instead hammered into existing cracks and fractures within wood or stone in order to split these materials. The woodworkers also used a



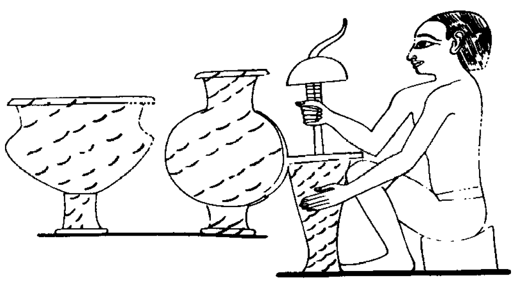
Tools Used in Ancient Egyptian Construction. Fig. 6 Woodworkers using grinding stones (upper left), an adze (far lower left), a gouge (lower left), saws (lower left and upper right), and a bow drill (lower right). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 53).



Tools Used in Ancient Egyptian Construction. Fig. 7 Woodworkers using grinding stones (far left), a saw and axes (lower center left), mallet-struck chisels and adzes (lower center right and far right), a gouge (lower right), and a bow drill (upper



Tools Used in Ancient Egyptian Construction. Fig. 8 Stoneworkers using hand-cranked drills with stone weights just below the handles. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 173).

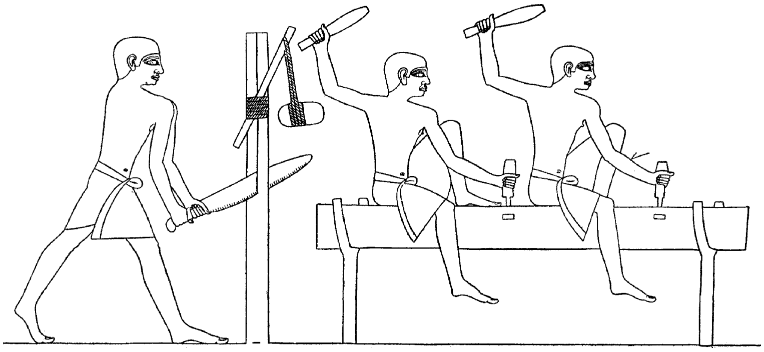


Tools Used in Ancient Egyptian Construction. Fig. 9 Stoneworker using a hand-cranked drill with a stone weight just below the handle. Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 54).

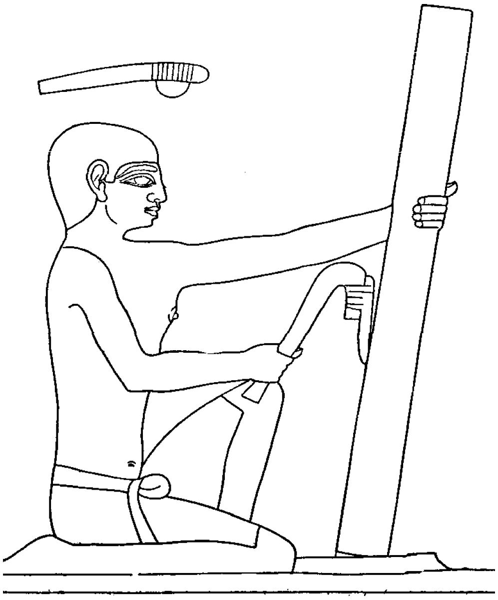
"gouge," which was a small hand-held, chisel-like tool for cutting grooves (Fig. 6).

"Adzes" are essentially flat chisels with a broad, straight cutting edge that were mounted on the end of a hooked wood handle (Figs. 2, 6, 7, 11, and 12). Blades of both metal and chert were employed. Adzes were used for trimming and smoothing soft stone surfaces, and were especially effective for stripping wood.

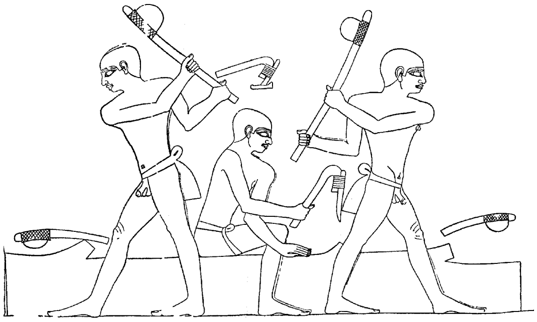
Copper and bronze "saws" were employed for cutting wood and stone (Figs. 2, 6, 7, 10, and 13). Those with a serrated blade cut both wood and soft



Tools Used in Ancient Egyptian Construction. Fig. 10 Woodworkers using a saw (left; note the stone weight keeping the saw cut open) and mallet-struck, wood-hafted chisels (right). Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 129).

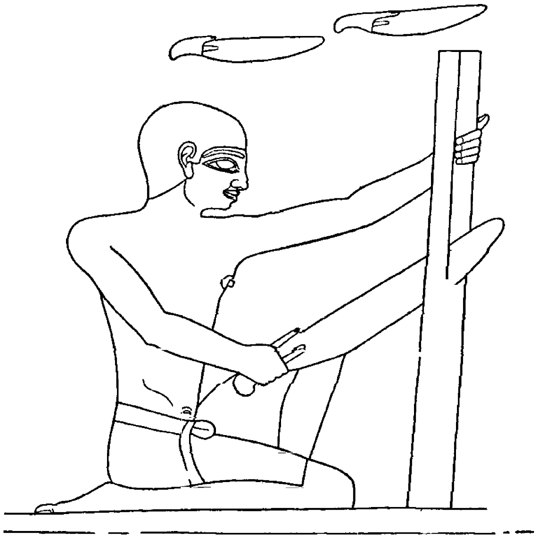


Tools Used in Ancient Egyptian Construction. Fig. 11 Woodworker using an adze. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). Note the axe at top. From Wild (1966: pl. 174).



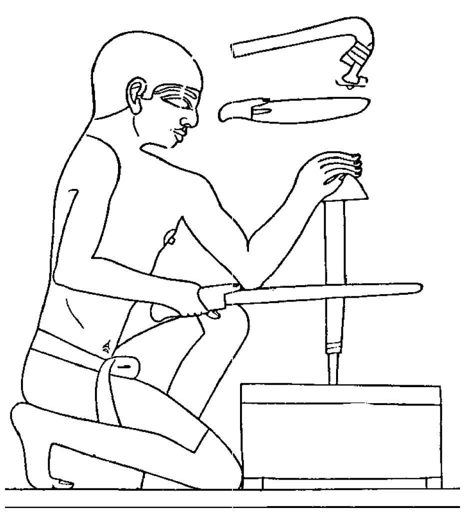
Tools Used in Ancient Egyptian Construction. Fig. 12 Woodworkers using axes (left and right) and an adze (center). Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 129).

stone, whereas saws with smooth, nonserrated blades were used to cut the hard stones. In the latter case, the cutting was not done by the metal blade itself (unlike the serrated blades used for softer materials) but rather by a quartz sand abrasive that was fed into the saw cut and over which the metal blade moved. Weights were normally attached to the ends of the longer saws of both types in order to increase the downward cutting force. Although iron saws eventually replaced those of copper and bronze, the basic designs did not change: serrated blades for soft materials, and nonserrated blades for hard stones.



Tools Used in Ancient Egyptian Construction. Fig. 13 Woodworker using a saw. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 174).

"Bow drills" with a metal bit ("bit drills") were used to cut holes through wood and soft stones (Figs. 6, 7, and 14). The drill consisted of a wood shaft into one end of which was fitted a solid metal bit. A bow strung with cord (similar to those wielded by archers) was used to rotate the drill shaft. This was accomplished by tightly looping the bow cord around the shaft and then moving the bow back and forth. While operating the bow with one hand, the worker used his other hand to hold onto a loosely fitting, hemispherical wood or stone cap on top of the drill shaft. In place of the solid metal bit, other bow drills were fitted with a hollow metal tube ("tube drills"). Unlike the bit drill, where the bit itself does the cutting, the tube drill used a quartz sand abrasive fed into the bottom of the hole. As with the nonserrated saw, it was the quartz sand that did the actual cutting, thus making the tube drill suitable for hard stones. As a by-product of the use of this kind of drilling, a cylindrical core was extracted from the hole. Both types of drills originally had copper or bronze fittings; later ones were made of iron. Both were also much used in woodworking to produce the holes for doweled joints and lashings.



Tools Used in Ancient Egyptian Construction.
Fig. 14 Woodworker using a bow drill. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). Note the adze and saw at top. From Wild (1966: pl. 174).

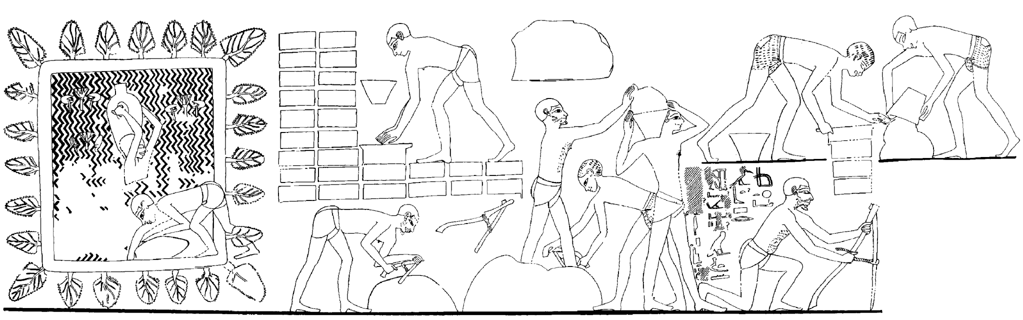
An especially important tool for woodworking was the "axe," which was used to chop and cleave wood (Figs. 7 and 12). Axes had either a subcircular or subrectangular metal blade that flared out into lugs on the dull side and were used in lashing the blade onto a wood handle.

Tools for Mud Brick Manufacturing

Mud bricks were made from a mixture of fine-grained sediment (especially clay-rich mud), sand, chopped straw or other plant chaff, and perhaps also, as in modern-day Egyptian mud bricks, animal manure (Fig. 15). Excavation of the sediment and mixing the ingredients was done with the same "hoe" used by the ancient farmers. The wood blade of this tool had a narrow extension or "tang" on one side and this was fitted into a hole cut through one end of a short wood handle, with the two parts lashed together. The mud mixture was typically packed into wood "moulds" to produce bricks of uniform size. After drying and hardening in the sun, the bricks were ready for use.

Moving Tools

The construction of stone buildings required the lateral movement and lifting of stone blocks weighing anywhere from a few tons to tens (and exceptionally hundreds) of tons. Nearly all of this work was done with ropes, levers, and sledges combined with a large measure of human muscle. The ancient Egyptians had ropes made from a variety of materials, including palm fibers, grasses, and papyrus and other reeds. Ropes up to several centimeters thick have been found and would have been strong enough for the heaviest loads. These

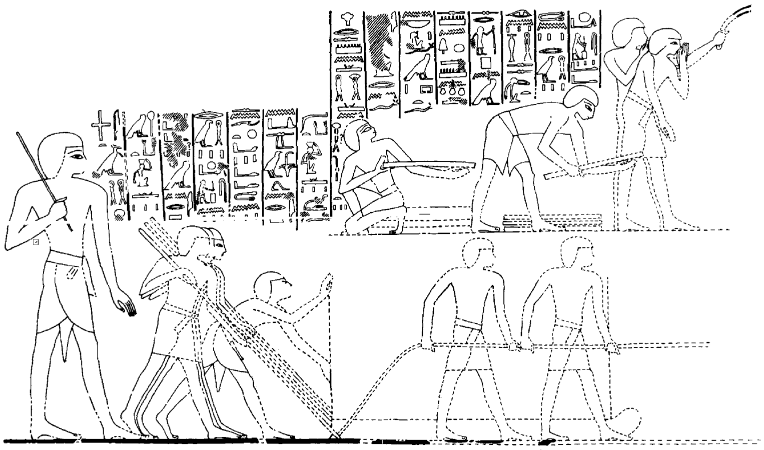


Tools Used in Ancient Egyptian Construction. Fig. 15 Workers making mud bricks: obtaining water from a pond (far left), mixing the wet mud with hoes (lower center), placing the mud in brick moulds (upper center and upper right). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 58).

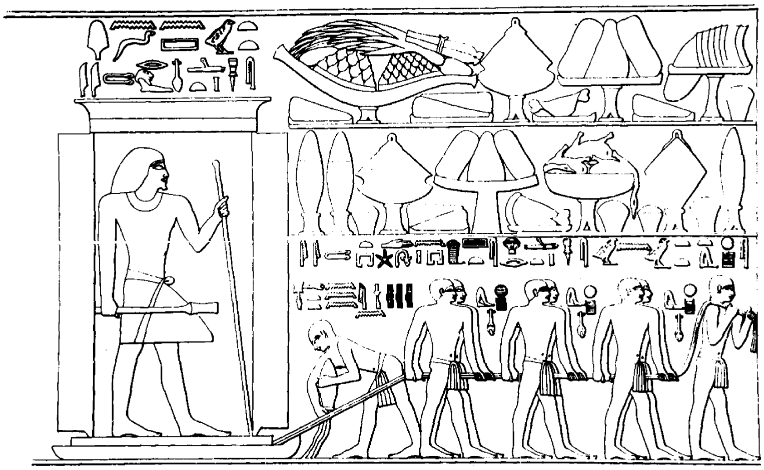
were sometimes used in conjunction with grooved "bearing blocks," which were carved from wood or stone and served as rope guides. By draping a rope around this device, the workers were able to pull from an angle.

Stout wood poles or beams were employed as "levers" for shifting stone blocks (Fig. 16). The largest were operated by teams of workers who would pull down on the elevated end with attached ropes. Stone blocks sometimes had small recesses ("lever sockets or holes") cut along their sides where the lower ends of levers could be inserted. Wood or stone "fulcrums" were placed under the lower end of these levers, and wedge-shaped pieces of wood were pushed under the levered-up edge of a block to allow deeper insertion of the lever.

"Sledges" made from wood were employed for moving heavy loads around the construction site (Figs. 16 and 17). This conveyance consisted of two parallel runners joined by a series of crossbeams. Along the sides, on top of the runners, wood stakes or other attachments would have been present to restrain the load or anchor tie-down ropes. The front ends of the runners were rounded and angled upward to allow the sledge to ride up and over irregularities in the ground. The back ends of the runners were often



Tools Used in Ancient Egyptian Construction. Fig. 16 Workers with a sledge using levers behind it (lower left), pulling on a rope (lower right), and handling sleepers (or rollers?; upper right). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 58).



Tools Used in Ancient Egyptian Construction. Fig. 17 Workers pulling a sledge with ropes while another worker pours water on the ground in front of the sledge. Note the rounded front and chamfered rear of the sledge runner. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Epron (1939: pl. 52).

T

chamfered (beveled) with a cut angling downward toward the front of the sledge (as in Fig. 17), and these allowed the insertion of levers to help move the sledge forward or adjust its direction. Using attached ropes, the sledges were pulled by teams of men or, less often, draft animals.

In order to reduce ground friction, the sledges were pulled over either wetted ground or wood beams ("sleepers") laid crosswise along the sledge's path (Fig. 16). It has been suggested that the sledges were also sometimes pulled over wood "rollers," but this is unlikely as rollers would only be effective on ground that was hard, smooth, and relatively flat. Even though the Egyptians knew about the wheel from earliest Dynastic times, they had no wheeled wagons until the early New Kingdom. From this time onward, wagons may have been used for hauling stone blocks, especially the smaller ones, but sledges almost certainly remained the main conveyance for moving blocks around the construction site.

Wood "rollers" were apparently sometimes placed directly under stone blocks when these were being moved across hard, flat pavements. Another tool thought to also assist in moving stone blocks is the so-called "rocker." Made from wood, this device had two parallel, vertical sides that were joined by cross-beams as in the sledges. The tops of the sides were flat and level, and their bottoms were rounded into a half circle or ellipse. There is much speculation on how the rockers were used, but it is generally agreed that a block of stone was placed on top of the sides, and then by rocking it back and forth, the block could be "walked" across a hard surface or pivoted to assist in its placement.

Extra: Wood or Iron Wedges?

In hard stone quarries dating to the Late period and especially the subsequent Greco-Roman periods, one sees lines of wedge-shaped holes on quarry faces and extracted blocks. It is a common misconception that these holes were cut to hold wedges of wood, which when wetted would swell and so split the rock along the line of wedge holes. In actuality, however, these holes were cut to hold iron wedges, which were struck with an iron sledgehammer to split the stone. This same method of splitting stone was also used in stone construction work toward the end of the Dynastic period.

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Trephination

Ruben G. Mendoza

Perhaps one of the least understood surgical practices performed in ancient America concerns cranial trephination (also spelled "trepanation"), or the surgical modification of the skull. While much of the prevailing literature is largely dated, an older generation of theories tended to ascribe the practice to primitive wonderment and notions of spirit release and possession. This is despite a substantial body of technical evidence available from trephined specimens and a large and specialized body of surgical instruments and procedures documented in archaeological and contact-period historical contexts. According to medical historian Guido Majno, trephination was used as a cure for a number of ailments including skull fractures and related trauma, epileptic seizures, and insanity. In fact, many of those skulls examined to date bear evidence of blunt trauma or pathology that may provide a more direct indicator of why the practice was carried out in the first place.

While ancient Peru provides the largest body of trephined specimens available for study, and the clearest evidence of an established medical tradition in skull surgery, other important specimens have been reported from throughout the Americas. Documented examples, with evidence of osteitis, have been reported from the Mexican states of Chihuahua and Oaxaca, and archaeological sites in Lamy, New Mexico, and Accokeek, Maryland, in the United States, where trephined surgical openings are often no more than 2 cm in diameter. Reported trephined specimens from Columbia County, Georgia, archaeological zones along the Skeena River, and in the sites of Eburne and Lytton, British Columbia and Kodiak Island, Alaska, range between 3.8 and 6.0 cm in diameter. If all the putative cases of trephination reported in these examples are a reliable indication of areas in which the practice was known, then cranial trephination was quite widespread.

Majno has identified five primary techniques of trephination in specimens from both Peru and Mesoamerica. These include the most ancient method on record – the scraping-away of that bone just underlying the scalp – as well as other techniques such as grooving, boring, cutting, sawing, and rectangular intersection incision, the most predominant method employed, in which cut, sawed, or abraded grooves were used to perforate the skull in a rectangular pattern. Once the intersection incisions were connected to each other, a rectangular or octagonally shaped plate of bone remaining within the intersection was removed with a spatula-like device. Schendel (1968) notes that "the trepanning technique used in Mexico was to punch a series of small holes in the skull outlining the fracture, or the area to be removed, then to cut between those holes and lift off the depressed section of cranial bone." After this initial procedure, the exposed brain was protected with a thin plate of hardwood and cotton pads. When trephination was not deemed suitable because of the extent of skull trauma, the damaged portion of skull was encased in a protective plaster cast. There were two types of plaster cast. The first was a mixture of feathers, egg whites, and resin, and the second was prepared from a mixture of animal ash, blood, and egg whites.

Specialized tools and instruments employed by Inca physicians in the trephination of the skull included *tumi* knives crafted from alloyed and annealed, or metalurgically hardened, copper and bronze metals. The *tumi* knife consisted of a crescent-shaped blade, at the midpoint of which was attached a cylindrical metal handle or other appendage. *Tumi* knives used in trephination included razor sharp, serrated, or other sawtooth-edged crescent-shaped scalpels. Additional instruments included bronze perforators, drills, and chisels. The basic surgical instrumentation utilized in cranial trephination long predated the rise of the Inca state, whose government came to sponsor and control this specialized field of medical endeavor (Burland 1967). Cranial trephination, and both *tumi* knives and bronze perforators, are frequently depicted on the carved and painted surfaces of vessels of the Mochica civilization of the north coast of Peru (ca. AD 500).

In one collection of 273 skulls from Peru, 47 bore evidence of having been trephined between one and five times. According to Majno, the skulls studied thus far suggest that the survival rate was near 100%. Only a few cases of osteomyelitis, or bone deterioration, were documented in the cranial collection he examined. Those cases appear to have been associated primarily with the size of the original injury, and whether or not the trauma was located at the base of the skull. Apparently, patients suffering blunt trauma over the cerebral cortex or brain stem were least likely to benefit from treatment by trephination. In other recent studies, projected survival rates, based on the examination of the presence of osteitis, range from 62.5% in one study that found healing or evidence of osteitis in 250 of 400 skulls examined, to between 23.4% and 55.3% in other studies (Froeschner 1992). These latter figures are questionable in that the studies cited by Froeschner do not distinguish postmortem trephination from that performed on severely traumatized patients. Froeschner's review also fails to acknowledge the existence of even the most basic metal instruments and surgical kits documented for the practice of trephination in ancient Peru, claiming instead that "primitive tools" were the mainstay of the art of Inca trephining.

It is clear that specialized techniques and treatments contributed to the diversity and variation in surgical localities known from trephined specimens alone. In one analysis of a trephined skull collection consisting of 112 specimens (the Tello collection housed at the Peabody Museum of Harvard), 53.6% of the skulls, or 60 specimens, bore trephined areas in the frontal area of the skull (26 of which were situated in the frontal bone, 12 in the region of the bregma, and another 12 crossing over the left coronal suture); 33%, or 37 specimens, were trephined in the parietal area (18 of which bore surgical openings over the left parietal, while 15 crossed the sagital suture), and 13.4%, or 15 specimens, were trephined over the occipital area (with seven in the region of the lambda, and four in the occipital bone). Most trephined specimens from the Harvard collection bear surgical openings within the frontal areas of the cranium, and again, trephined openings are most highly correlated with blunt trauma and other pathologies. The incidence of epileptic seizures among Inca era peoples was documented by both European-contact chroniclers and contact-era Inca scribes. This fact may provide directions for future inquiry into the origins of specific types of trephination among Inca and related peoples.

Based on a worldwide survey of ancient skull surgery, Majno has concluded that the Inca were the "Masters of the Art of Trepanning." He also noted that the survival rate for patients in Inca times was better than for such rates in modern times. He says that modern survival rates are the inverse of what they had been in earlier Inca times, and concludes that modern humans complicated the task of skull surgery by introducing new sources of infection and disease. In turn, modern physicians were trained to perpetuate otherwise antiquated traditions of skull surgery based on flawed nineteenth century assumptions and beliefs.

European medical belief systems regarding infection, surgical procedure, anesthetics, and basic hygiene necessitated a constantly expanding and contracting repertoire of experimental procedures which further complicated survival rates. As a result, the fledgling early twentieth century version of modern skull surgery suffered many casualties.

See also: ►Medicine in Mesoamerica; ►Surgery in India

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Tribology

Lu Jing-Yan

Tribology, the study of the phenomena and mechanisms of friction, lubrication, and wear of surfaces in relative motion, can be traced back to remote antiquity in China, where it developed significantly.

Sliding bearings were discovered in ancient mechanisms, especially in carts which operated at high speeds and carried great loads. In order to reduce friction and damage, Chinese mechanics lubricated bearings on their carts. This was recorded in the earliest poetry collection entitled *Bei Fen Quan Shu* (The Bei Wind and Spring Water) as follows:

The grease used is sufficient to lubricate the axle shaft.
On the shaft end, we carefully check the pin bolt.
Quickly, send me home driving the cart.
Quickly, send me back to my Wei country town.

It proves that before the book *Shi Jing* (Poems and Odes) appeared – before 1100–600 BCE – lubricant was widely applied in China. Owing to their rhythmic quality, the verses were repeatedly quoted and talked about, and often appeared in later books as well.

By the time of the Chun Qui (Spring–Autumn) period (500 BCE) in the Lu and Qi states, there was a group of special officers called *Jinche*, whose duty was to check the pin bolts on the shaft ends. They were probably the earliest tribology supervisors. This demonstrates that the ancient Chinese already knew well that the better the lubrication, the faster and easier ran the cart.

Early lubricant was called *zhi* or *gao*. According to research on ancient characters, *zhi* was the fat of horned animals, and that of hornless animals was called *gao*. The lubricant used might be sheep oil, which was easier to get. Since *zhi* or *gao* is in a solid state at normal temperature, it had to be heated and melted before it was used. In 300 BCE petroleum began to be used.

Metal bushes appeared in China quite early. There were relevant records about their use in *Wuzi Yebing* (Wuzi casting), which shows that they appeared not later than 400 BCE. The metal bush was made of two layers: outside and inside. The outer one was called *gong*, which turned together with the wheel, and the inside one was *jian*, which turned together with the shaft. Between them a kind of lubricant was provided, and the cart ran quickly and easily. In addition to carts, the metal bushes were applied in other mechanisms of antiquity, and they appeared in a variety of forms. In the Han Dynasty, they were already used quite widely. This is illustrated by the discovery of hundreds of mold sets of metal bushes in county Wen in Henan province.

Most of them were still undamaged. They reflect the level of manufacturing as well as the scale of their production and application in the Han Dynasty.

The ancients took other measures to reduce friction and damage. Most mechanisms were made of wood. In the *Kao Gongji* (The Artificer's Record), three principles of wood selection were listed (1) the wood must be smooth, without joints; (2) it must be tough and wear-resistant; and (3) it must be thick enough and easy to revolve. In the sixteenth century a book entitled *Tian Gong Kaiwu* (Exploitation of the Works of Nature) was written, in which a further summary on the basis of experience was made. It analyzed the advantages and shortcomings of various woods, and provided an example: if wood works for too long, it gives out heat. In the field of structural design, the *Kao Gongji* and other books analyzed the relationship between the axis path and the length of the shaft, and pointed out that when the cart and load were different, the interior axis of the wheel must keep a fixed proportion to the length of the shaft.

There was one other achievement of note in this field. In the Yuan Dynasty (thirteenth century) a ball bearing, which was circle-formed and consisted of four balls, was successfully applied to an astronomical instrument made by Guo Shoujing.

Trigonometry in Indian Mathematics. Table 1 Hipparchus' chord table reconstructed

Number	α	R crd α
1	7; 30	450
2	15	897
3	22; 30	1,341
4	30	1,779
5	37; 30	2,210
6	45	2,631
7	52; 30	3,041
8	60	3,438
9	67; 30	3,820
10	75	4,185
11	82; 30	4,533
12	90	4,862
13	97; 30	5,169
14	105	5,455
15	112; 30	5,717
16	120	5,954
17	127; 30	6,166
18	135	6,352
19	142; 30	6,510
20	150	6,641
21	157; 30	6,743
22	165	6,817
23	172; 30	6,861
24	180	6,875

Trigonometry in Indian Mathematics

Michio Yano

Trigonometry offers one of the most remarkable examples of transmission of the exact sciences in antiquity and the Middle Ages. Originating in Greece, it was transmitted to India and, with several modifications, passed into the Islamic world. After further development it found its way to medieval Europe.

The very term "sine" illustrates the process of transmission. The Greek word for "chord" (εὐθεῖα, literally "a straight line [subtending an arc]") was translated into Sanskrit as *jīva* or *jyā* ("string of a bow") from the similarity of its appearance. The former word was phonetically translated into Arabic as *jyb*, which was vocalized as *jayb* (meaning "fold" in Arabic), and this was again translated into Latin as *sinus*, an equivalent to the English sine.

It was by tracking back along this stream of transmission that the first chord table ascribed to Hipparchus (fl. 150 BCE) was recovered by Toomer (1973) from an Indian sine table (compare Tables 1 and 2). Toomer showed that some numerical values ascribed to Hipparchus in the *Almagest* of Ptolemy (fl. AD 150) could be explained by hypothesizing the use of this reconstructed table.

According to this reconstruction, Hipparchus used 6,875′ as the length of the diameter (1) of the base circle, in other words, as the greatest chord subtending the half circle($= R\,\mathrm{crd}\,180^{\circ} = 6{,}875$). This number is the result of rounding after dividing 21,600′ (360°) by the value of π = 3; 8, 30. (In this article we follow the convention: integer and fraction are separated by a semicolon, the former is in decimal form and the latter is in sexagesimal form with commas to separate the places.) In India 3,438′, namely, the rounded half of D, was used as the length of the radius (R), which is the largest "half chord" (*jyārdha* or *ardhajyā*).

Thus the relation between the Greek chord and the Indian sine can be expressed as:

$$AB = 2AH, \quad R\,\mathrm{crd}\,2\alpha = 2\mathrm{R}\sin\alpha. \tag{1}$$

Plane trigonometry was the essential tool for mathematical astronomy in India. All the astronomical texts in Sanskrit either give a kind of sine table or presuppose one. On the other hand, trigonometry was studied only as a part of astronomy and it was never an independent subject of mathematics. Furthermore since they were not aware of spherical trigonometry, Indian astronomers developed the method called *chedyaka* in which the sphere was projected on to a plane.

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Trigonometry in Indian Mathematics. Table 2 Indian sine table with R = 3,438

Number	α	$R \sin \alpha$	Δ
1	3; 45	225	225
2	7; 30	449	224
3	11; 15	671	222
4	15	890	219
5	18; 45	1,105	215
6	22; 30	1,315	210
7	26; 15	1,520	205
8	30	1,719	199
9	33; 45	1,910	191
10	37; 30	2,093	183
11	41; 15	2,267	174
12	45	2,431	164
13	48; 45	2,585	154
14	52; 30	2,728	143
15	56; 15	2,859	131
16	60	2,978	119
17	63; 45	3,084	106
18	67; 30	3,177	93
19	71; 15	3,256	79
20	75	3,321	65
21	78; 45	3,372	51
22	82; 30	3,409	37
23	86; 15	3,431	22
24	90	3,438	7

Sine Table with R = 3,438

The earliest Indian sine table with R = 3,438 is found in Āryabhaṭa's book on astronomy, *Āryabhaṭīya* (AD 499). It should be remembered that "table" here does not mean that the numbers are actually arranged in a tabular form, i.e., in lines and columns. As is usually the case with Sanskrit scientific texts, all the numbers are expressed verbally in verse. For brevity's sake, Āryabhaṭa gives only the tabular differences (Δ, the fourth column of Table 2). This is the standard sine table in ancient India. Exactly the same table is found in the *jiuzhili*, a Chinese text on the Indian calendar written in AD 718 by an astronomer of Indian descent, but it did not have any influence on Chinese mathematics.

The values of sines were geometrically derived from R sin 90° (=R) and R sin 30° (=R) by two formulas:

$$R\ \sin(90^{\circ} - \alpha) = \sqrt{R^2 - (R\ \sin\ \alpha)^2}, \qquad (2)$$

$$R\sin\frac{\alpha}{2} = \sqrt{\left\{\frac{R - R\sin(90^{\circ} - \alpha)}{2}\right\}^2 + \left(\frac{R\sin\alpha}{2}\right)^2}. \qquad (3)$$

It is worth noting here that the first tabular sine was equated with the arc (3; 45° = 225′) which it subtends. This means that, when α' is small enough, the approximationsin $\alpha' \approx \alpha'$ can be applied.

What is more remarkable in Āryabhaṭa is that he gives an alternative method for computing tabular differences by means of the formula:

$$\Delta_{n+1} = \Delta_n - (\Delta_1 - \Delta_2)\frac{J_n}{J_1},$$

where $J_n = R\ \sin\ n(3;45^{\circ})$. The formula, after several centuries of misunderstanding, was correctly interpreted by a South Indian astronomer Nīlakaṇṭha (born in 1444), one of the most distinguished scholars belonging to the Mādhava school (see below). When suitable values of $(\Delta_1 - \Delta_2)$ and J_1 are used, this formula produces very good values for the rest of R sins. It seems that Āryabhaṭa's sine values were computed by this second method rather than by the geometrical method. This means that the table with R = 3,438 is not a mere copy of the Hipparchan table, if ever existed.

Sine Table with R = 120

There is another kind of Indian sine table which uses R = 120. The table is found in the *Pañcasiddhāntikā* of Varāhamihira, a younger contemporary of Āryabhaṭa. This table is closely related to the Greek chord table with R = 60 which is offered in Ptolemy's *Almagest*. Because of the relation (1) given above, all the numerical values in the chord table with R = 60 can be transferred directly to the sine table with R = 120. Table 3 compares the first four and the last four values in the *Pañcasiddhāntikā* with Ptolemy's corresponding ones. The fractional parts after the semicolon in both tables are expressed sexagesimally. It seems that Varāhamihira's values were the results of rounding the numbers in the second fractional place of a chord table similar to that of Ptolemy.

In these earlier Indian sine tables, only the 24 values in the first quadrant are given, with the interval of 3°45′. Although Indians knew and used cosines (*koṭijyā*), they had no need of tabulating them because they knew that cosines could be derived from sines by the relation (2) above. On the other hand they were interested in the versed sine (*śara* in Sanskrit, meaning "arrow" or *utkramajyā*, "sine of the reversed order," CH in Fig. 1) which is defined as:

$$R\,\text{vers}\,\alpha' = R - R\ \sin(90^{\circ} - \alpha).$$

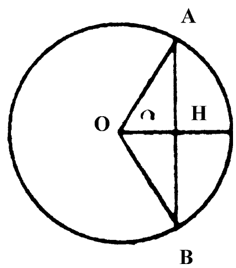
Using this relation, Brahmagupta (seventh century) simplified some formulas. For instance, formula (3) was rewritten as:

$$R\ \sin\frac{\alpha}{2} = \sqrt{\frac{D \times R\,\text{vers}\,\alpha}{4}}. \qquad (3')$$

A table of versed sines can be easily obtained by adding Δs in Table 2 successively from the bottom upward (namely, in the "reversed order").

Trigonometry in Indian Mathematics. Table 3 Comparison of the first four and last four values in the *Pañcasiddhāntikā* with those of Ptolemy

Number	α (°)	Varāhamihira with R = 120	Ptolemy with R = 60
		$R \sin \alpha$	R crd 2α
1	3; 45	7; 51	7; 50, 54
2	7; 30	15; 40	15; 39, 47
3	11; 15	23; 25	23; 24, 39
4	15	31; 4	31; 3, 30
…	…	…	…
21	78; 45	117; 42	117; 41, 40
22	82; 30	118; 59	118; 58, 25
23	86; 15	119; 44	119; 44, 36
24	90	120	120



Trigonometry in Indian Mathematics. Fig. 1 Sine of the reversed order.

Brahmagupta computed anew 24 sines with R = 3,270 in the *Brāhmasphuṭasiddhānta*. Elsewhere in this book and in the *Khaṇḍakhādyaka*, he offers a sine table with R = 150 and with the interval of 15°. This small table generates remarkably correct sine values when his ingenious method of second order interpolation is applied.

Bhāskara II

An improved version of the traditional sine table was prepared by Bhāskara II (b. 1114). In the chapter "Derivation of Sines" (*Jyotpatti*) of his *Siddhāntaśiromaṇi* he introduces two new values:

$$R \sin 36^{\circ} = \sqrt{\frac{5-\sqrt{5}}{8}}R,$$

$$R \sin 18^{\circ} = \sqrt{\frac{\sqrt{5}-1}{4}}R.$$

With these two values and formulas (2) and (3) above, he obtains $R \sin 3n°$ (where n = 1, 2, 3,…, 30). Further he combines them with the approximate value

$$R \sin 1^{\circ} \approx 60'$$

using the new formula

$$R\sin(\alpha \pm \beta) = \frac{R\sin\alpha R\cos\beta \pm R\cos\alpha R\sin\beta}{R}, \quad (4)$$

which is equivalent to the modern formula:

$$\sin(\alpha \pm \beta) = \sin\alpha \cos\beta \pm \cos\alpha \sin\beta.$$

Thus he could obtain sines for all the integer degrees of a quadrant. Formula (4) was unknown to Indians before Bhāskara II, while a chord version of the same formula was known to Ptolemy.

Trigonometry underwent a remarkable development in the early fifteenth century on the western coast of South India (the modern state of Kerala). The person who initiated this development was Mādhava (fl. ca. 1380/1420) of Saṅgamagrāma (near modern Cochin). His important works on astronomy and mathematics are now lost, but we know his achievements from the books of his successors. A sine table ascribed to him is quoted in Nīlakaṇṭha's commentary on the *Āryabhaṭīya* (Table 4).

A couple of verses, which are often quoted by the students of the Mādhava school and which are ascribed to Mādhava himself by Nīlakaṇṭha, give the method of computing sines. The method can be expressed as

$$R \sin\theta = \theta - \frac{\theta^3}{3!R^2} + \frac{\theta^5}{5!R^4} - \frac{\theta^7}{7!R^6} + \frac{\theta^9}{9!R^8} - \cdots$$

with R = 1 this is equivalent to Newton's

$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \frac{\theta^9}{9!} - \cdots.$$

Similar power series for cosine and versed sine are ascribed to Mādhava.

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Trigonometry in Indian Mathematics. Table 4 Mādhava's sine table

Number	α (°)	$R \sin \alpha$
1	3; 45	0224; 50, 22
2	7; 30	0448; 42, 58
3	11; 15	0670; 40, 16
4	15	0889; 45, 15
5	18; 45	1,105; 01, 39
6	22; 30	1,315; 34, 07
7	26; 15	1,520; 28, 35
8	30	1,718; 52, 24
9	33; 45	1,909; 54, 35
10	37; 30	2,092; 46, 03
11	41; 15	2,266; 39, 50
12	45	2,430; 51, 15
13	48; 45	2,548; 38, 06
14	52; 30	2,727; 20, 52
15	56; 15	2,858; 22, 55
16	60	2,977; 10, 34
17	63; 45	3,038; 13, 17
18	67; 30	3,176; 03, 50
19	71; 15	3,255; 18, 22
20	75	3,320; 36, 30
21	78; 45	3,321; 41, 29
22	82; 30	3,408; 20, 11
23	86; 15	3,430; 23, 11
24	90	3,437; 44, 48

See also: ►*Almagest*, ►Sexagesimal System, ►Āryabhaṭa, ►Mādhava, ►Varāhamihira, ►Brahmagupta, ►Śrīpati, ►Nīlakaṇṭha

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Trigonometry in Islamic Mathematics

Sami Chalhoub, Boris A. Rosenfeld

Trigonometry is the connecting link between mathematics and astronomy, between the way calendars are calculated, the gnomon, and the sundial. In the Islamic world, the calculation of spherical triangles was necessary to carry out ritual customs. The *qibla*, the direction to Mecca, was indicated next to the hour lines on all public sundials.

The first trigonometric problems appeared in the field of spherical astronomy. Around the year 773 one of the Indian *siddhāntas* (astronomy books) was made known in Baghdad. The Indian astronomers Varāhamihira (fifth century) and Brahmagupta (sixth century) solved different problems in spherical astronomy by means of rules equivalent to a general sine theorem for a spherical triangle ABC with sides a, b, c and angles A, B, C (where angle A is opposite to side a, etc.), namely $(\sin A/\sin a) = (\sin B/\sin b) = (\sin C/\sin c)$ and to the cosine theorem for the same triangle $\cos a = \cos b \cos c + \sin b \sin c \cos A$.

In the ninth century Ptolemy's *Almagest* and Menelaus' *Spherics* were also translated, and commentaries were written to these works. Many trigonometrical problems were solved in Ptolemy's *Almagest*, in which Menelaus' theorem on the spherical complete quadrilateral was used. The cases of this theorem used by Ptolemy are equivalent to the sine and tangent theorems for a right-angled spherical triangle. The *Almagest*, the *Spherics*, and the Indian *siddhāntas* formed the basis on which Arab mathematicians built their trigonometry.

The ancient Greek astronomers only used one trigonometric function, the chord of an arc. The "theorem of Ptolemy," which is equivalent to the formula for the sine of the sum of the angles, forms, together with the formula for the chord of the half arc, the basis for the chord table in the *Almagest*. The Indian people replaced the chord with the sine, introduced the cosine and the versed sine, and compiled a small table of sine values. The Arabic mathematicians progressively made trigonometry into a science independent of its (astronomical) context.

Applications of trigonometry analogous to those in the Indian *siddhāntas* are found in the astronomical works of al-Khwārizmī. An analogous geometric construction for finding the azimuth according to the rule formulated in al-Khwārizmī's third treatise was provided by al-Māhānī (ca. 825–888) in his *Treatise on the Determination of the Azimuth at Any Time and in Any Place*. The rules equivalent to the spherical sine and cosine theorems were also used by Thābit ibn Qurra in his *Book on Horary Instruments Called Sundials*. With Ḥabash the applications of the tangent and cotangent functions went beyond the usual applications in the theory of sundials. The introduction of the tangent and cotangent and their application in astronomy was a novelty. The names *zill* (shadow) and *zill maʿqus* (reversed shadow) apparently are translations from Sanskrit. In the case of a vertical gnomon, al-Ḥabas expressed the cosecant as the "diameter of the shadow" for a given height of the sun, i.e., as a hypotenuse. He computed a table for the cosecant with steps of 1°.

For a long time, the chord was used along with the sine. A theory of these magnitudes is found in the work of al-Battānī (ca. 858–929). In his astronomical work *Islaḥ al-Majisṭī* (The Perfection of the Almagest), he systematically employed the trigonometric functions sine and versed sine with arguments between 0° and 180°. Since the cosine is defined as the sine of the complement of the angle, and since no negative numbers are used, the versed sine is defined in the second quadrant as a sum of two quantities. The elements of trigonometry are set forth in an even more systematic way in the *Kitāb al-Kāmil* (Perfect Book) of Abū'l-Wafāʾ (940–997/998). He defined several trigonometric functions in the circle with radius 1. The trigonometrical tangent function is defined as a line on a tangent to the circle.

The proof of the general spherical sine theorem was given by Abū'l-Wafāʾ in his *al-Majisṭī* (Almagest), by his pupil Abū Naṣr ibn ʿIrāq (d. 1036) in the *Risāla fī maʿrifa al-qisī al-falakiyya* (Treatise on the Determination of Celestial Arcs), and by al-Khujandī (d. ca. 1000) in the *Kitāb fī al-sāʿāt al-māḍiyya fī al-layl* (Book on Past Hours in the Night). The history of the discovery of this theorem was described by al-Bīrūnī, the pupil of Ibn ʿIrāq and al-Khujandī, in the *Kitāb maqālīd ʿilm al-hay'a* (Book on the Keys of Astronomy).

The use of trigonometry was expanded through al-Bīrūnī (973–1048). He is the author of the *Masʿūdic Canon*, which is a summary of the results from the works of many predecessors and of personal observations and calculations. It comprises 11 books. Book 3 is dedicated to trigonometry. It has calculations equivalent to the formulas for the sine of the sum of two angles, the sine of the differences between two angles, and the sine of the double angle. It also includes the solution of cubic equations and the division of angles into three parts, and the sine rule of plane trigonometry: $(\sin A/a) = (\sin B/b) = (\sin C/c)$. (The plane cosine theorem $a^2 = b^2 + c^2 - 2bc \cos A$ is equivalent to two of Euclid's theorems.)

Another important scholar in the area of trigonometry was Naṣīr al-Dīn al-Ṭūsī (1201–1274). His principal work was *Kitāb al-shakl al-qaṭṭāʿ* (Book on the Secant Figure, also known as Treatise on the Complete Quadrilateral). It was written in Persian and translated by the author into Arabic in 1260, possibly for the needs of the observatory of Maragha. In five books, it contains a full system of trigonometrical formulas for plane and spherical triangles. If any three elements of such a triangle are given, the other three elements can be found by the theory explained in this work, which also contains the notion of the polar triangle $A'B'C'$ of a spherical triangle $ABC(A' = 180° - a,\ B' = 180° - b,\ C' = 180° - c)$. This work played an important role in the development of mathematics in Europe.

See also: ►*Qibla*, ►Varāhamihira, ►Brahmagupta, ►al-Khwārizmī, ►al-Māhānī, ►Thābit ibn Qurra, ►al-Battāni, ►Abū'l-Wafāʾ, ►al-Khujandī, ►al-Bīrūnī, ►Naṣīr al-Dīn al-Ṭūsī

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Ulugh Bēg

Boris Rosenfeld

Ulugh Bēg, Mīrzā Muḥammad ibn Shārhrukh ibn Tīmūr Ulugh Bēg Guragān, 1394–1449, was the ruler of Samarqand (now in Uzbekistan) and an astronomer, mathematician, and poet. His nickname, Ulugh Bēg, means "great prince". He was the grandson of the great conqueror Tīmūr. In 1417, as a pupil of Qāḍī Zādeh al-Rūmī of Bursa (Turkey), he opened in Samarqand the *madrasa* (school) where al-Rūmī was the teacher. In 1425 he founded an astronomical observatory and invited Jamshīd al-Kāshī to be its director. After al-Kāshī's death, the head of the observatory became ʿAlī al-Qūshjī. Ulugh Bēg was killed by enemies of enlightenment. After his death his observatory was destroyed, and al-Qūshjī fled to Turkey.

The main work of Ulugh Bēg was a book of astronomical tables known as the *Zīj-i Ulugh Bēg* or *Zīj-i jadīd-i Guragānī* (New Zīj of Guragan) written together with al-Kāshī, al-Rūmī, and al-Qūshjī. The tables are written in Persian and are extant in many manuscripts in Persian and Arabic translations. The work consists of four books of trigonometrical, astronomical, geographical, and astrological tables.

Book I covered the subject of calendars, including the Muslim lunar calendar, the pre-Islamic Persian solar calendar, and the Chinese–Uyghur calendar. Book II dealt with spherical astronomy, covering sine and versed sine, shadows (tangents and cotangents), spherical coordinates on the celestial sphere (equatorial, ecliptical, and horizontal coordinates), geographical coordinates, as well as spherical distances between stars and the direction of *qibla* (to Mecca). In Book III Ulugh Bēg considered planetary and stellar astronomy, such as the motion of the sun, moon, and planets, the distances of the sun and the moon from the center of the world, and the equalization of astrological houses. Finally, Book IV dealt with astronomical calculations.

Ulugh Bēg also was the author of the mathematical *Risāla fī istikhrāj jayb daraja wāḥida* (Treatise on the Determination of Sine of One Degree). Originally the treatise was wrongly ascribed to al-Rūmī; Ulugh Bēg's authorship was established on the basis of the information in al-Birjandī's commentaries to the *Zīj* of Ulugh Bēg.

See also: ►al-Kāshī, ►Observatories in Islam, ►*Zīj*, ►*Qibla*

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Umar al-Khayyām

Boris A. Rosenfeld

ʿUmar al-Khayyām (Ghiyāth al-Dīn Abū'1-Fatḥ ʿUmar ibn Ibrāhīm Khayyām (al-Khayyāmmī) al-Naysābūrī (Nīshāpurī), 1048–1131) was a Persian mathematician, astronomer, philosopher, and poet. His scientific treatises were written primarily in Arabic; his poems were mostly written in Persian. The name Khayyām means "the tentmaker" – probably it was the profession of his father or grandfather. He was born and died in Nīshāpūr. Khayyām was a student in Balkh (now in Afghanistan), and worked at first in Bukhārā and Samarqand (now in Uzbekistan). In 1074 he was invited by Saljūq Sultan Mālikshāh Jalāl al-Dīn to the capital Iṣfahān to participate in the reform of the solar Persian calendar and to organize an astronomical observatory. The calendar reform was completed in 1079; the new calendar era was named according to the names of the sultan Māliki or Jalālī. In 1092, after Mālikshāh's death Khayyām fell into disgrace, and his observatory was closed. This was because of suspicions that some of his verses were anti-Islamic. To allay these suspicions, he made a pilgrimage to Mecca. Later he worked in Marw (now Marv in Turkmenistan) which was the new capital of the Saljūq sultans.

Two of Khayyām's treatises are very important for the history of mathematics. One is the *Risāla fī'l-barāhīn ͨala masā'il al-jabr wa'l-muqābala* (Treatise of Demonstrations of Problems of Algebra), written in Samarqand and dedicated to the judge Abū Ṭāhir who had given him the opportunity to devote himself to the science. The topic of this work was the theory of cubic equations. Here the complete classification of cubic equations with positive roots was given, and for every type of equation the solution by means of the intersection of circumferences, equilateral hyperbolas, and parabolas was also given.

The second work is the *Sharḥ mā ashkala min muṣādarāt kitāb Uqlīdis* (Commentaries on Difficulties in Introductions of Euclid's book). It was written in Iṣfahān in 1077 and contains the commentaries to Euclid's *Elements*. The treatise consists of three *maqālas*: (1) on the theory of parallels, (2) on the theory of ratios, and (3) on the theory of compound ratios. The ideas of this work were developed further by Naṣīr al-Dīn al-Ṭūsī (1201–1274), John Wallis (1616–1703), and Girolamo Saccheri (1667–1733) (Khayyām's quadrangle is also called Saccheri's quadrangle).

Before the *Risāla fī'l-barāhīn*, Khayyām wrote the *Risāla fī taqsīm rubͨ al-dāʾira* (Treatise on Division of a Quarter of a Circle) and *Mushkilāt al-ḥisāb* (Problems of Arithmetic). In the first, a geometric problem is considered. It is reduced to a cubic equation whose solution by means of the intersection of the circumference and equilateral hyperbola and an approximate numerical solution are found. Here the problem of classifications of cubic equations is formulated. The second work is not extant, but is mentioned in the former as "the treatise on the demonstration of methods of Indians of extraction of square and cube roots and on generalization of these methods for determination of bases of square-squares, square-cubes, cube-cubes and so on as many as you like, what was not earlier." These words show that this work was devoted to the extraction of roots of *n*th degree, which was explained later in the arithmetic treatise of Naṣīr al-Dīn al-Ṭūsī. Probably in this work, as in al-Ṭūsī's treatise, "Newton's binomial formula" for $(a + b)^n$ for an arbitrary natural n was explained.

Khayyām also made many contributions to the study of astronomy and the calendar. His *al-Zīj Mālikshāhī* (Malikshah Astronomical Tables) is not extant, except for the catalog of fixed stars from this work. In Khayyām's calendar there were 8 intercalary days in 33 years. The error is 1 day in 5,000 years (in the Gregorian calendar the error is 1 day in 3,330 years). After the closing of his observatory Khayyām wrote the Persian historical treatise *Nowrūz-nāmeh* (Book on the New Year) on reforms of the solar Persian calendar and on the Persian New Year holiday Nowrūz in pre-Islamic Iran.

In the field of physics, Khayyām wrote *Fī ikhtiyāl maʾrifa miqdāray al-dhahab wa'l-fiḍḍa fī jism murakkab minhumā* (On the Art of Determination of Quantities of Gold and Silver in a Body Consisting of Them) and *Fī'l-qustāṣ al-mustaqīm* (On the Right Balance). Both of these works are included in the *Kitāb mīzān al-ḥikma* (Book of the Balance of Wisdom) of Khayyām's student ͨAbd al-Raḥmān al-Khāzinī, who worked in Marv. In this he explains a method to determine specific gravity.

Khayyām also made significant contributions to music and philosophy. He wrote a *Qaul ͨalā ajnās allatī bi'l-arbaͨa* (Speech on Genera Which are [formed] by a Quarter) on the division of a quarter into three intervals in accordance with three genera of tonality – diatonic, chromatic, and enharmonic.

In philosophy, Khayyām was a follower of Aristotle and Ibn Sīnā (Avicenna). On the question of universalia he was near to Peter Abelard. Many philosophical questions were considered in Khayyām's poetry, particularly in his well-known *Rubāͨīyāt* (Quatrains).

See also: ►Elements, ►Naṣīr al-Dīn al-Ṭūsī

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Vāgbhaṭa

Guy Mazars

In the history of medicine in India, Vāgbhaṭa is the most celebrated author after Caraka and Suśruta. It is not known at what period Vāgbhaṭa lived. We usually place him in the sixth century; he is in any case earlier than the tenth century. His identity has been the subject of unending discussion, and Indian critics hold that there was an "elder Vāgbhaṭa" in addition to "Vāgbhaṭa", grandson of the former and son of Siṃhagupta.

Several treatises of Āyurveda (Indian medicine; see article in the encyclopaedia) are ascribed to him. The most interesting are the *Aṣṭāṅgasaṃgraha* and the *Aṣṭāṅgahṛdayasaṃhitā* which are probably two different versions of the same medical text whose teachings agree generally with those of Caraka and Suśruta. However the more commonly used text of Vāgbhaṭa is the *Aṣṭāṅgahṛdayasaṃhitā* or "Compendium on the Heart of Medicine" which is considered the greatest synthesis on Āyurveda ever produced. The Chinese pilgrim Yi Jing, who stayed in India from AD 673 to 688, spoke, without mentioning its name, of a work that was then recent and that summarised the eight branches of medicine. It is thought that he was referring to the work of Vāgbhaṭa, but he may also have been referring to the *Yogaśataka*, "The Hundred Formulas", which fits Yi Jing's description perfectly. This work consists, as its name indicates, of a series of 100 therapeutic formulas distributed according to the eight theoretical divisions of Āyurveda. Its author is a certain Nāgārjuna, perhaps the same author who is reputed to have revised the *Suśrutasaṃhitā* but who is not necessarily the Buddhist patriarch of that name with whom he is nevertheless identified by the tradition.

The *Aṣṭāṅgahṛdayasaṃhitā* gives full expression to the richness and detail of the ancient tradition of Āyurveda. Numerous manuscripts of the work are extant in Indian libraries and the first printed edition appeared in 1874–1878 in Calicut. Since then, countless editions of the whole or of parts of the treatise have been published.

Vāgbhaṭa enjoyed early and widespread recognition. The *Aṣṭāṅgahṛdayasaṃhitā* was the object of numerous commentaries. The work is quoted in the *Firḍaws al-Ḥikma* or "Paradise of Wisdom" composed in AD 850 by the Persian physician 'Alī Ibn Sahl Rabban aṭ-Ṭabarī who gives a very complete summary of the āyurvedic doctrines. The *Aṣṭāṅgahṛdayasaṃhitā* was also translated into Tibetan and incorporated into the immense Buddhist Encyclopaedia of the *Tanjur* between the years 1013 and 1055.

See also: ►Medicine in India: Āyurveda

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Vākyakaraṇa

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Vākyakaraṇa, apocryphally ascribed to Vararuci, is an astronomical manual produced in about AD 1300 which was very popular in South India, especially in Tamil Nadu and the adjoining regions. The work is so called because it was a *karaṇa* (astronomical manual) which used computational tables where the numbers are expressed in mnemonic sentences (*vākyas*), phrases, and words. It is also called *Vākyapañcādhyāyī*, because it contains *pañca adhyāyas* (five chapters). Until recently, when the *Nautical Almanac* came to be used in South India for the computation of the Hindu almanac with its "five limbs" (*pañcaṅga*): the lunar day, weekday, asterism, *yoga* and *karaṇa*, the *Vākyakaraṇa* was widely used for that purpose.

The author of the *Vākyakaraṇa* hailed from Kariśaila or Kānchī in Tamil Nadu, as he himself states in his work. He also states that he based his work on the writings of Bhāskara I (AD 629), the exponent of the school of astronomy promulgated by Āryabhaṭa (b. AD 476), and the works of Haridatta (AD 683), author of *Grahacāranibandhana* and *Mahāmārganibandhana*. The *Vākyakaraṇa* was elaborately expounded by Śundararāja (AD 1500) who had contacts with the Kerala astronomer Nīlakaṇṭha Śomayāji. The date of *Vākyakaraṇa* is determined as ca. AD 1300, on the basis of epochs which the author gives for the computation of the planets.

In five chapters, the *Vākyakaraṇa* deals with all aspects of astronomy required for the preparation of the Hindu almanac. Chapter I is concerned with the computation of the sun, the moon, and the moon's nodes, and Chapter II with that of the planets. Chapter III is devoted to problems involving time, position, and direction, and other preliminaries like the precession of the equinoxes. The computation of the lunar and solar eclipses is the concern of Chapter IV. Chapter V is devoted to the computation of the conjunction of the planets, and of planets and stars.

For the computation of the moon, the *Vākyakaraṇa* employs the 248 moon sentences of the ancient astronomer Vararuci. But for the five planets, Mars, Mercury, Jupiter, Venus, and Saturn, the author himself computed 82 tables devoted to the different planetary cycles, containing, in all, 2,075 mnemonic sentences (*Kujādi-pañca-graha-mahāvākyas*).

The results obtained through the computations enunciated in the *Vākyakaraṇa* are not very accurate, going by modern standards, but they were accurate enough for the determination of auspicious times and other matters required in the routine life of orthodox Hindus. Besides, there was the saving of much time and labor in working with the simple methods advocated in the work.

See also: ►Bhāskara I, ►Haridatta, ►Āryabhaṭa, ►Nīlakaṇṭha Śomayāji, ►Precession of the Equinoxes

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Values and Science

Ziauddin Sardar

Is science value free? If "science," as Lord Rutherford is reported to have said, "is what scientists do" then scientists would have to be superhuman to keep their values out of what they do in their laboratories. We cannot clinically isolate our cultural and ethical (and through them our historical) baggage from our human activities. Values play an important part in what we select to do or not do and how we actually do it. In as far as science is a human activity, it is subject to the strengths and weaknesses of all human activities.

However, in Western tradition, up to quite recently, scientists were seen as quasireligious supermen, heroically battling against all odds to discover the truth. Also, the truths they wrestled out of nature were said to be absolute, objective, value-free, and universal. The idea of scientists as dedicated hermit-like lone researchers is now obsolete. Nowadays, science is an organized, institutionalized, and industrialized venture. The days when individual scientists, working on their own, and often in their garden sheds, made original discoveries are really history. Virtually all science today is big science requiring huge funding, large, sophisticated, and expensive equipment, and hundreds of scientists working on minute problems. As such, science has become a unified system of research and application, with funding at one end and the end-product of science, often technology, at the other.

Values enter this system in a number of ways. The first point of entry is the selection of the problem to be investigated. The choice of the problem, who makes the choice and on what grounds, is the principle point of influence of society, political realities of power, prejudice, and value systems on even the "purest" science. Often, it is the source of funding that defines what problem is to be investigated. If the funding is coming from government sources then it will reflect the priorities of the government – whether space exploration is more important than health problems of the inner city poor, or nuclear power or solar energy should be developed further. Private sector funding, mainly from multinationals, is naturally geared toward research that would eventually bring dividends in terms of hard cash. Some 80% of research in the United States is funded by what is called the "military–industrial complex" and is geared toward producing both military and industrial applications.

Subjectivity thus enters science in terms of what is selected for research which itself depends on where the funding is coming from. But values also play an important part in what is actually seen as a problem, what questions are asked and how they are answered. For example, cancer rather than diabetes may be seen as a problem even though they may both claim the same number of victims. Here both political and ideological concerns, as well as public pressure, can make one problem invisible while focusing attention on another. Moreover, if, for example, the problem of cancer is defined as finding a cure then the benefits of the scientific research accrue to certain groups, particularly the pharmaceutical companies. But if the function of scientific research is seen as eliminating the problems of cancer from society, then another group benefits from the efforts of research: the emphasis here shifts to investigating diet, smoking, polluting industries, and the like. Similarly, if the problems of the developing countries are seen in terms of population, then research is focused on reproductive systems of Third World women, methods of sterilization, and new methods of contraceptives. However, if poverty is identified as the main cause of the population explosion then research would take a totally different direction: the emphasis would have to shift to investigating ways and means of eliminating poverty, developing low cost housing, basic and cheap health delivery systems, and producing employment generating (rather than profit producing) technologies. The benefits of scientific research would go to the Third World poor rather than Western institutions working on developing new methods of contraceptives and companies selling these contraceptives to developing countries. Thus both the selection of problems and also their framing in a particular way are based on value criteria.

It can be legitimately argued that these factors are external to science, that within science, the scientific method ensures neutrality and objectivity by following a strict logic – observation, experimentation, deduction, and value-free conclusion. But scientists do not make observations in isolation. All observations take place within a well defined theory. The observations, and the data collection that goes with them, are designed either to refute a theory or provide support for it, and theories themselves are not plucked out of the air. Theories exist within paradigms – that is a set of beliefs and dogmas. The paradigms provide a grand framework within which theories are developed and make sense, and observations themselves have validity only within specific theories. Thus, all observations are theory laden, and theories themselves are based on paradigms which in turn are burdened with cultural baggage. All of which raises the question: can there ever be such things as value-neutral "objective facts"? Studies of scientists working in laboratories have shown that the scientific method, by and large, is a myth. Researchers seldom follow it in the linear fashion that exists in the text books. Neither do they ascertain new "facts" suddenly out of the blue. And the same holds true of the laws of nature they are supposed to be discovering. It appears that scientists do not actually "discover" laws of nature; they manufacture them. Scientific knowledge advances by a process of manufacturing which involves thousands and thousands of workers assembling "facts" which through peer review and other procedures end as description or laws of nature.

Value judgments are also at the very heart of a common element of scientific technique: statistical inference. When it comes to measuring risks, scientists can never give a firm answer. Statistical inferences cannot be stated in terms of "true" or "false" statements. When statisticians test a scientific hypothesis they have to go for a level of "confidence". Different problems are conventionally investigated to different confidence-limits. Whether the limit is 95 or 99.9 per cent depends on the values defining the investigations, the costs, and weight placed on social, environmental, or cultural consequences. In most cases, the importance given to social and environmental factors determines the limits of confidence and the risks involved in a hazardous scientific endeavor. For example, when a chemical plant is placed in an area with an aware and politically active citizenry the risks are worked out to a high level of confidence. However, when one is located in an area where the citizens themselves are ignorant of the dangers and do not command political power, the confidence levels are much more relaxed. The people of Bhopal and Chernobyl know this to their cost.

But it is not just in its institutions and method that science is value laden. The very assumptions of science about nature, universe, time, and logic are ethnocentric. In modern science, nature is seen as hostile, something to be dominated. The Western "disenchantment of nature" was a crucial element in the shift from the medieval to the modern mentality, from feudalism to capitalism, from Ptolemaic to Galilean astronomy, and from Aristotelian to Newtonian physics. In this picture, "Men" stand apart from nature, on a higher level, ready to subjugate and "torture" her, as Francis Bacon declared, in order to wrestle out her secrets. This view of nature contrasts sharply with how nature is seen in other cultures and civilizations. In Chinese culture, for example, nature is seen as an autonomous self-organizing entity which includes humanity as an integral part. In Islam, nature is a trust, something to be respected and cultivated and people and environment are a continuum – an integrated whole. The conception of laws of nature in modern science drew on both Judeo-Christian religious beliefs and the increasing familiarity in early modern Europe with centralized royal authority, with royal absolutism. The idea that the universe is a great empire, ruled by a divine logos, is, for example, quite incomprehensible both to the Chinese and the Hindus. In these traditions the universe is a cosmos to which humans relate directly and which echoes their concerns. Similarly, while modern science sees time as linear, other cultures view it as cyclic as in Hinduism or as a tapestry weaving the present with eternal time in the Hereafter as in Islam. While modern science operates on the basis of either/or Aristotelian logic (X is either A or non-A), in Hinduism logic can be fourfold or even sevenfold. The fourfold Hindu logic (X is neither A, nor non-A, nor both A and non-A, nor neither A nor non-A) is both symbolic as well as a logic of cognition and can achieve a precise and unambiguous formulation of universal statements without quantification. Thus the metaphysical assumptions of modern science make it specifically Western in its main characteristics.

The metaphysical assumptions of modern science are also reflected in its contents. For example, certain laws of science, as Indian physicists have began to demonstrate, are formulated in an ethnocentric and racist way. The Second Law of Thermodynamics, so central to classical physics, is a case in point: due to its industrial origins the Second Law presents a definition of efficiency that favors high temperatures and the allocation of resources to big industry. Work done at ordinary temperature is by definition inefficient. Both nature and the non-Western world become losers in this new definition. For example, the monsoon, transporting millions of tons of water across a subcontinent is "inefficient" since it does its work at ordinary temperatures. Similarly, traditional crafts and technologies are designated as inefficient and marginalized. In biology, social Darwinism is a direct product of the laws of evolutionary theories. Genetic research appears to be obsessed with how variations in genes account for differences among people. Although we share between 99.7 (unrelated people) and 100 per cent (monozygotic twins) of our genes, genetic research has been targeted toward the minute percentage of genes that are different in order to discover correlations between genes and skin color, sex, or "troublesome" behavior. Enlightened societal pressures often push the racist elements of science to the sidelines. But the inherent metaphysics of science ensures that they reappear in new disguise. Witness how eugenics keeps reappearing with persistent regularity. The rise of IQ tests, behavioral conditioning, fetal research, and sociobiology are all indications of the racial bias inherent in modern science.

Given the Eurocentric assumptions of modern science, it is not surprising that the way in which its benefits are distributed and its consequences are accounted for are themselves ethnocentric. The benefits are distributed disproportionally to already over-advantaged groups in the West and their allies elsewhere, and the costs disproportional to everyone else. When scientific research improves the military, agriculture, manufacturing, health, or even the environment, the benefits and expanded opportunities science makes possible are distributed predominantly to already privileged people of European descent, while the costs are dumped on the poor, racial and ethnic minorities, women, and people located at the periphery of global economic and political networks. Science in developing countries has persistently reflected the priorities of the West, emphasizing the needs and requirements of middle class western society, rather than the wants and conditions of their own society. In over six decades of science development, most of the Third World countries have nothing to show for it. The benefits of science just refuse to trickle down to the poor.

But modern science is not only culturally biased toward the West: it represents the values of a particular class and gender in Western societies. As feminist scholars have shown, science in the West has systematically marginalized women. Women, on the whole, are not interested in research geared toward military ends, or torturing animals in the name of progress, or working on machines that put one's sisters out of work. But more than that, even the least likely fields and aspects of science bear the fingerprints of androcentric projects. Physics and logic, the prioritizing of mathematics and abstract thought, the so-called standards of objectivity, good method and rationality – feminist critique has revealed androcentric fingerprints in all. This is the case, for example, in the mechanistic model of early modern astronomy and physics, in modern particle physics, and in the coding of reason as part of ideal masculinity. The focus on quantitative measurements, variable analysis, impersonal and excessively abstract conceptual schemes is both a distinctively masculine tendency and one that serves to hide its own gendered character. Science has tried to hide its own masculine nature in other ways, by, for example, making women themselves objects in scientific investigation. It was not entirely accidental that sexology became a major science at the same time as women in the West were fighting for the vote and equal rights in education and employment. A number of studies have shown that scientific work done by women is invisible to men even when it is objectively indistinguishable from men's work. Thus, it appears that neither social status within science nor the results of research are actually meant to be neutral or socially impartial. Instead, the discourse of value-neutrality, objectivity, and social impartiality appears to serve projects of domination and control.

The history of science bears this out. The evolution of Western science can be traced back to the period when Europe began its imperial adventure. Science and empire developed and grew together, each enhancing and sustaining the other. In India, for example, European science served as a handmaiden to colonialism. The British needed better navigation so they built observatories and kept systematic records of their voyages. The first sciences to be established in India were, not surprisingly, geography, and botany. Western science progressed primarily because of the military, economic, and political power of Europe, focusing on describing and explaining those aspects of nature that promoted European power, particularly the power of the upper classes. The disinterested commitment of European scientists to the pursuit of truths had little to do with the development of science. The subordination of the blacks in the ideology of the black "child/savage" and the confinement of the white women in the cult of "true womanhood" emerged in this period and are both by-products of the Empire. While the blacks were assigned animal and brutish qualities the white women were elevated and praised for their morality. While the blacks were segregated and enslaved, the women were placed in narrow circles of domestic life and in conditions of dependency. Racist and androcentric evolutionary theories were developed to explain human behavior and canonized in the history of human evolution. The origins of Western, middle class social life, where men go out to do what men have to do, and women tend the babies and look after the kitchen, are to be found in the bonding of "man-the-hunter"; in the early phases of evolution women were the gatherers and men went out to bring in the beef. Now this theory is based on little more than the discovery of chipped stones that are said to provide evidence for the male invention of tools for use in the hunting and preparation of animals. However, if one looks at the same stones with different cultural perceptions, say one where women are seen as the main providers of the group – and we know that such cultures exist even today – you can argue that these stones were used by women to kill animals, cut corpses, dig up roots, break down seed pods, or hammer and soften tough roots to prepare them for consumption. A totally different hypothesis emerges and the course of the whole evolutionary theory changes.

Thus the cultural, racial, and gender bias of modern science can be easily distinguished when it is seen from the perspective of non-Western cultures, marginalized minorities, and women. The kinds of questions science asks when seeking to explain nature's regularities and underlying causal tendencies, the kinds of data it generates and appeals to as evidence for different types of questions, the hypotheses that it offers as answers to these questions, the distance between evidence and the hypothesis in each category, and how these distances are traversed – all have the values of white middle class men embedded in them. Put simply, this implies a relativism in science as in any other sphere of human knowledge. However, most scientists do not look kindly toward criticism, or sociological, philosophical, historical, and anthropological studies which highlight science's value laden nature. Relativism is anathema to scientists: many believe that they are engaged in revealing nature's absolute truths. Science, they argue, is special and different from any other body of knowledge: it is counter-intuitive and rarely a matter of common sense. Some propagandists for science have even suggested that the entire discipline of the sociology of knowledge is a conspiracy of the academic left against science.

The idolization and mystification of science, the insistence on its value neutrality and objectivity, is an attempt not only to direct our attention away from its subjective nature but also from the social and hierarchical structure of science. Whenever we think of "the scientists" we imagine white men in white coats: the sort of chaps we see in advertisements for washing power and skin care preparations, standing in a busy laboratory behind a Bunsen burner and distillation equipment telling us how the application of science has led to a new and improved soap or cold cream. This view of scientists is not far from reality. True power in science belongs to white, middle-aged men of upper classes. Everyone else working in science – women, minorities, black men, white men of lower classes, and third world researchers – are actually basically rank and file laboratory workers. The social hierarchy within science by and large preserves absolute social status, the social status scientific workers hold in the larger society. The people who make decisions in science, who decide what research is to be done, what questions are going to be asked, and how the research is going to be done are a highly selective, tiny minority. These people have the right background, the contacts to get the necessary appointments, and then further contacts to secure funding for their research projects. The actual execution of scientific research, the grinding and repetitive laboratory work, is rarely done by the same person who conceptualizes that research; even the knowledge of how to conduct research is rarely possessed by those who actually do it. This is why the dominant (Western) social policy agendas and the conception of what is significant among scientific problems are so similar. This is why the values and agendas important to white, middle class men pass through the scientific process to emerge intact in the results of research as implicit and explicit policy recommendations. This is why modern science has become an instrument of control and manipulation of non-Western cultures, marginalized minorities, and women.

Even if we were to ignore all other arguments and evidence, the very claim of modern science to be value-free and neutral would itself mark it as an ethnocentric and a distinctively Western enterprise. Both claiming and maximizing cultural neutrality is itself a specific western cultural value: non-Western cultures do not value neutrality for its own sake but emphasize and encourage the connection between knowledge and values. By deliberately trying to hide its values under the carpet, by pretending to be neutral, by attempting to monopolize the notion of absolute truth, Western science has transformed itself into a dominant and dominating ideology.

See also: ►Colonialism and Science, ►Technology and Culture, ►Western Dominance

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Varāhamihira

K. V. Sarma

Varāhamihira, who flourished in Ujjain, in Central India, during the sixth century, was perhaps the greatest exponent of the twin disciplines of astronomy and astrology in India. A master of all three branches of the disciplines astronomy, natural astrology, and horoscopic astrology, he was a prolific writer whose works number more than a dozen, some of which are extensive.

Varāhamihira was born in Kāpitthaka, present-day Kapitha, in Uttar Pradesh, known also as Saṇkāśya and mentioned as a great center of learning by the Chinese pilgrim Yuan Chwang as Kah-pi-t'a. He was the son of Ādityadāsa, and a Śakadvīpī brāhmaṇa of the Maga sect who were sun worshippers. His renown has caused several legends, both Hindu and Jain, being woven round his birth, growth, and predictive propensity. A legend has it that he was one of the nine luminaries of the court of King Chandragupta II Vikramāditya, but the definitively known date of Varāhamihira goes against this identification. Varāhamihira's patron has now been identified as King Mahārājādhirāja Dravyavardhana who ruled over Ujjain during the middle of the sixth century. Varāhamihira also possessed great poetic talents, so that some of the later rhetoricians have extracted verses from his writings to illustrate poetic qualities. Indeed, the fame of Varāhamihira has even induced several places in India to be named after him.

It is a characteristic of Varāhamihira that he produced larger and shorter versions of most of his works. His only work on astronomy is *Pañcasiddhāntikā* (The Five Basic Texts), being a redaction of select topics from the basic texts of five earlier astronomical schools: *Vāsiṣṭha, Paitāmaha, Romaka, Pauliśa*, and *Saura*, in 443 verses, in the form of a work manual.

Varāhamihira wrote several astrological works. In his *Bṛhajjātaka* (Large Horoscopy), also called *Horāśāstra* (Science of Hours), in 25 chapters, containing about 400 verses, he treated all conceivable topics on the subject. This work has been a model for later works and is highly popular even today. In this work, Varāhamihira exhibits his understanding of Greek astrology and employs the Sanskritized forms of a number of Greek terms. His *Laghujātaka* (Shorter Horoscopy) is an abridged form of the previous work. On marriage and the prediction of auspicious times to marry, Varāhamihira composed two works: the *Bṛhadvivāha-paṭala* (Larger Treatise on Marriage), and its abridgement, the *Svalpa-vivāha-paṭala*. Prognostication on military marches and domestic journeys was treated in three works: *Bṛhad-Yoga-Yātrā* (Larger Course on Expedition), in 34 chapters, *Yoga-yātrā* (Course on Expedition), and *Svalpa-yātrā* (Shorter Course on Expedition).

On natural astrology, Varāhamihira's major work is the *Bṛhatsaṃhitā* (Large Compendium), the *Svalpa-saṃhitā* (Shorter Compendium), and *Vaṭakaṇikā* (Short Text), the last two known only through profuse quotations in later works. The *Bṛhatsaṃhitā*, in 106 chapters, is an encyclopedic compendium on numerous subjects relating to life and nature, such as physical astronomy, geography, calendar, meteorology, flora, portents, agriculture, economics, politics, physiognomy, engineering, botany, industry, zoology, erotica, gemology, hygiene, omens, and prognostication on the basis of asterisms, lunar days, etc. A fund of material on applied science, physical observation, and deduction on the basis of statistics and experimentation went into the production of this work which is perhaps unparalleled in the early literature of the world. Varāhamihira's works, set in precise terminology and in graceful language, have been models for writers of later times, not only in astronomy and astrology, but in other disciplines as well.

See also: ►Astronomy in India, ►Astrology in India

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Vaṭeśvara

K. V. Sarma

Vaṭeśvara (b. AD 880), son of Mahadatta, hailed from Ānandapura or Vaḍanagar, in Gujarat in Western India, a great center of learning of the time. The *Vaṭeśvara-siddhānta*, composed by Vaṭeśvara in AD 904, is one of the largest and most comprehensive works on astronomy, a work which throws much light on the theories, methodologies, and processes of Indian astronomers until the tenth century AD. It was one of the standard works for the study of the discipline, and several of the rules enunciated by Vaṭeśvara were adopted by later astronomers like Śrīpati (eleventh century) and Bhāskara II (b. 1114). It is also noteworthy that the Persian scholar and polymath al-Bīrūnī, who came to India early in the eleventh century, referred to

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Vaṭeśvara and cited some of his views in his own writings. Vaṭeśvara also wrote a *Karaṇasāra*, known only through references, and a *Gola* (Treatise on Spherics), which is available only in part, the existing portion dealing with a graphical demonstration of planetary motion, construction of the armillary sphere, spherical rationale, and the nature of the terrestrial globe.

The *Vaṭeśvara-siddhānta*, in 1326 verses set out in eight chapters, deals exhaustively with all aspects of Indian astronomy, besides bringing in a number of methodologies, short-cuts, and interpretations. Chapter I, on mean motion, depicts the astronomical parameters, time-measures, calculation of the aeonary days, and computation of the mean planet in three ways: using parameters, using a cut-off date, and by the orbital method. The longitude corrections to be applied to mean longitude are also dealt with here. Chapter II, on true motion, deals with the corrections to be applied to the mean planet by the epicyclic theory, by the eccentric theory, and by the use of the R sine table. Different items relevant to the almanac are also set out here. Chapter III treats in detail the three problems in diurnal motion. Chapters IV and V deal with the computation of lunar and solar eclipses. Chapter VI treats of heliacal rising, chapter VII with elevation of lunar horns, and chapter VIII with the conjunction of celestial bodies.

Again, a unique feature of the work, found in no other work, consists in Vaṭeśvara's dividing each chapter into small sections earmarked for different topics. Unlike other works, rules are formulated for all possible alternatives of a theory or practice. It is interesting that sets of problems are posted at the ends of chapters for the student to solve, as in textbooks of modern days. The work is also characterized by the depiction of novel interpretations and methodologies practised by early Indian astronomers. In fact, the invaluable service done by Vaṭeśvara through his *Siddhānta* lies in his presenting the achievements of the Indian astronomers from the sixth century to the tenth century and methodically documenting the astronomical knowledge of the Hindus during those centuries.

See also: ►Śrīpati, ►Bhāskara, ►Astronomy in India, ►al-Bīrūnī

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Veterinary Medicine in India

Guy Mazars

A tradition of veterinary therapy developed very early in India. Modelled on Āyurveda,[1] this veterinary medicine is known through a specialised literature which tells us about the ancient methods of prevention and treatment of animal diseases in India before the advent of modern medicine (Mazars 1994, 1999). Some of these treatments, as yet little known outside India, are still practised today.

The surviving texts are concerned mainly with the treatment of horses and elephants. The legends incorporated in these texts present knowledge regarding the medical treatment of horses and elephants as being directly revealed by the gods. This may be explained partly by the need to provide veterinary medicine with an origin similar to that of the Āyurveda, which is also presented as 'divinely inspired' knowledge. In fact, veterinary medicine developed from the ayurvedic model over the seven or eight centuries which preceded the Christian era. It is also known, from the inscriptions of Aśoka in the middle of the third century BCE, that this Buddhist sovereign opened hospitals for animals (Schneider 1978). Unfortunately, no actual veterinary records exist from this period.

The oldest Sanskrit text of veterinary medicine that has come down to us is a treatise entitled *Aśvāyurvedasiddhānta* (Complete System of Āyurveda for Horses) attributed to a certain Śalihotra (Mukhopadhyaya 1926: 356–99). This text is probably dated before the tenth century. There also exists a Tibetan version written at the beginning of the eleventh century, and the text was translated into Persian in the fourteenth century. Subsequently, various treatises on horses and diseases of horses were composed. The principal surviving ancient text dealing with elephant medicine is a treatise which tradition ascribes to Pālakāpya, a legendary person, also known as Dhanvantari, the father of Indian surgery (Mukhopadhyaya 1926: 400–24). The text, entitled *Hastyāyurveda* (The Āyurveda of Elephants), is divided into four parts. The first part is devoted to general diseases, the second to localised and minor ailments, the third to surgery and anatomy, and the last to the feeding of elephants and medicinal preparations. The text cannot be earlier than the Middle Ages, but it contains medical concepts and veterinary practices of long standing.

Specialised treatises are not the only source of existing information. The treatises of the Āyurveda sometimes refer to veterinary treatments. Thus, a passage

[1] Āyurveda is a holistic medical system that is explained in detail in an article in the encyclopaedia.

in *Carakasaṃhitā* (Siddhisthāna, XI, 20–26) contains a list of ingredients for preparing enemas for elephants, camels, cattle, horses, and sheep (Sharma 1983: 665–6). There is also information on animal-borne human diseases. For example, rabies is described under the name *jalatrāsa* (hydrophobia) in the *Suśrutasaṃhitā* (from the beginning of the Christian era) (Bhishagratna 1963: 733–734). A small collection of therapeutic formulae from the eleventh century, the *Rājamārtaṇḍa,* contains a chapter devoted to the treatment of domestic animals (Misra 1966: 108–112). In addition, certain nonmedical texts contain information on the veterinary art. Some information regarding veterinarians is contained in the *Arthaśāstra* (Kangle 1960–1963), a treatise of government traditionally attributed to Kauṭilya, possibly an adviser to Chandra Gupta (313–289 BCE), founder of the Maurya dynasty.

In the field of anatomy the knowledge of the ancient Indian veterinarians seems to have been quite extensive and is more accurate than that concerning the human body. Observations on animal carcasses were favoured by sacrifices, wars and other events. As regards the physiopathological conceptions in the Sanskrit texts of veterinary medicine, they are those of classical Āyurveda. According to these conceptions the health of both animals and human beings depended on the normal balance and proper functioning of the three vital principles: wind (*vāyu*), bile (*pitta*) and phlegm (*kapha* or *śleṣman).* Generalised diseases and localised ailments were linked to imbalance in these principles, or disturbances in the secondary forms of a single principle. Consequently, the name *tri-doṣa* (three troubles) was given to this triad of elements. Disorders in the functions governed by the three principles were themselves the outcome of multiple causes related to behaviour, character, feeding, mode of life, season, habitat, etc. In particular, equestrian texts often invoked a nutritional cause: food poisoning or unbalanced feeding.

Classification of diseases was broadly similar to the principles applied to human diseases but differed in detail, except in certain cases such as the diseases common to horses and human beings. The various conditions were classified according to their supposed origin, their apparent seat, or the nature of the symptoms. In the first category were diseases attributed to a disorder of wind, bile, etc. Diseases of wind were the most numerous, totalling 76 in the case of elephants. In the second category were diseases of the skin and the head, chest pains, etc. The last category notably included fevers, which were differentiated into many types according to the involvement of wind, bile or phlegm, and according to the other symptoms which accompany hyperthermia. One of the most detailed classifications is that of the *Hastyāyurveda*, which placed diseases of elephants in two broad groups. The first group was endogenous diseases, including diseases attributable to disturbance of the vital principles. The second group was exogenous diseases, mainly traumatic injuries: accidental wounds and those caused by weapons, bites of wild animals, etc. However, identification of the diseases listed in the texts is often uncertain, and sometimes even impossible, due to a lack of information. The passage in the *Suśrutasaṃhitā* (Kalpasthāna, VII, 43–50) concerning rabies was translated as follows: ‘The bodily Vāyu in conjunction with the (aggravated) Kapha of a jackal, dog, wolf, bear, tiger, or any other such ferocious beast affects the sensory nerves of these animals and overwhelms their instinct and consciousness. The tails, jaw-bones and shoulders of such infuriated animals naturally droop down, attended with a copious flow of saliva from their mouths. The beasts in such a state of frenzy, blinded and deafened by rage, roam about and bite each other’. The text states further: ‘A person bitten by a rabid animal barks and howls like the animal by which he is bitten, imitates it in many other ways and, bereft of the specific functions and faculties of a human subject, ultimately dies…’ (Bhishagratna 1963: 733–734).

As in Ayurvedic medicine, prevention occupies an important place. It is based on general and dietary hygiene. The texts lay stress on the layout and maintenance of cowsheds and stables, the different sorts of foods with their qualities and their drawbacks, as well as on the dietary rules to be observed. They underline the importance of moderation in food for domestic animals and enumerate the undesirable consequences of an excess of food. Furthermore, like Āyurveda, the veterinary tradition of India emphasises methods aimed at strengthening the general state of health, notably by the use of tonics and stimulants (*rasāyana*), and aphrodisiacs (*vājīkaraṇa*). The latter, containing various constituents, which have been the object of little study to date, augmented the strength of enfeebled animals and those of poor virility. Sanskrit texts provide various recipes for potions enabling a stallion to mate repeatedly. The *rasāyana* (elixirs of long life) were prescribed to strengthen animals and were recommended for preventing all sorts of illnesses. For example, a mixture based on aconite and three sorts of peppers was recommended for extending the life span of horses. The following plants were main constituents of such elixirs: *Asparagus racemosus* Willd., *Emblica officinalis* Gaertn., *Terminalia bellerica* Roxb., *Terminalia chebula* Retz., *Tinospora cordifolia* (Willd.) Miers and *Zingiber officinale* Rosc. Buffalo horn was also a valued ingredient.

Veterinary medicine is theoretically divisible into eight branches, corresponding to the eight divisions set out in the Āyurveda. Thus, hippiatry was divided into general surgery, general therapeutics, ophthalmology and otorhinolaryngology, care of foals (corresponding to

Ayurvedic paediatrics), toxicology, fortifying treatments, demonology, and the use of aphrodisiacs. Apart from surgical operations, therapy consists most often in the administration of medicinal preparations by different routes and under different forms: mixtures of powders, decoctions, electuaries, ointments… The texts lay stress quite particularly on the benefits of using medicinal oils and butters in food, in external applications and in enemas. We find also various procedures intended to make horses sweat, techniques of cauterisation, bloodletting and several kind of enemas. Procedures of inducing sweating, eight in number, are indicated for treating the sicknesses due to wind and to phlegm. The texts of hippiatry distinguish between violent and mild sudorifics. They specify the method of use of each by indicating the most favourable periods for this type of treatment. Cauterisations with red-hot irons are reserved for the treatment of diseases which neither dietary regimes, nor errhines, nor enemas have been able to cure. The sites to be cauterised and the form and the number of the cauterisations vary according to the case to be treated. We are well informed also on the post-operative care and the precautions to be taken in the days that follow the operations. We note also the use of caustics. As far as bloodletting is concerned, the treatises on hippiatry tell us also about the contra-indications and indicate the food for 'reconstituting' the blood and the remedies to be administered if the bloodletting is substantial.

Since India gained its independence in 1947, the Indian Government, recognising the services rendered by traditional medicine, has given a new impetus to these practices. The study and practice of traditional medicine has been regulated, and training is provided at present by a large number of schools with associated hospitals and care centres. This movement has also benefited traditional veterinary medicine, which has undergone a revival.

Several Indian laboratories now produce preparations from ancestral recipes, which are packed under modern conditions and sold throughout India for the treatment of domestic animals. Traditional formulations produced on a large scale include tonics, fortifiers and digestives, as well as antiparasitic and antifungal products. Many of these medicaments are polyvalent, due to the multiplicity of ingredients used in their preparation. For example, a company in Bangalore produces a stomachic and tonic containing 59 ingredients. This preparation is recommended for treating digestive disorders (anorexia, dyspepsia, constipation, etc.) in cattle, sheep, goats, horses and dogs, in doses proportional to the size of these animals. The principal ingredients of vegetable origin include the following: *Aegle marmelos* Corr., *Aquilaria agallocha* Roxb., *Butea monosperma* (Lam.) Kuntze, *Centratherum anthelminticum* Kuntze, *Curcuma longa* L., *Ferula narthex* Boiss., *Moringa oleifera* Lam., *Piper longum L.*, *Punica granatum* L., *Terminalia bellerica* Roxb., *Terminalia chebula* Retz., *Tinospora cordifolia* (Willd.) Miers, *Trachyspermum ammi* (L.) Sprague and *Zingiber officinale* Rosc. These ingredients were prescribed in Ayurvedic medicine for their aperitive, digestive, stomachic, carminative or anthelmintic properties. Another example is provided by an ointment against sprains and sores, prepared from the following plants: *Abrus precatorius* L., *Acorus calamus* L., *Celastrus paniculatus* Willd., *Hyoscyamus niger* L., *Moringa oleifera* Lam., *Nardostachys jatamansi* D.C., *Ocimum sanctum* L., *Saussurea lappa* C.B. Clarke and *Vitex negundo* L. To these oils are added extracts of seven other plants: *Anacyclus pyrethrum* D.C., *Colchicum luteum* Baker, *Curcuma amada Roxb*., *Gloriosa superba* L., *Litsea sebifera Pers*., *Myrica nagi* Thunb. and *Nerium odorum* Sol. All these plants have been investigated and their active principles are known. *Nardostachys jatamansi* is often combined with oil of henbane (*Hyoscyamus niger*) as an antineuritic. *Ocimum sanctum* and *Vitex negundo* are used as wound dressing. In traditional medicine, the root of *Curcuma amada* is applied to contusions and sprains. Extract of *Colchicum luteum* is applied externally as an analgesic (Mazars 1994: 449).

Many plants of the Ayurvedic pharmacopoeia have been shown to be effective. Listing and identification of the many plant species used in preparing remedies described in the ancient medical literature was accomplished during the 1970s. Veterinary applications of these medicines were also taken into account. Despite the increase in chemical and pharmacological studies in recent years, there is still much to be done in evaluating the resources of India with regard to medicinal plants, which may be useful in veterinary medicine.

Long before the development of veterinary medicine in the West, the veterinary tradition of India had already originated a large body of theoretical and practical knowledge. Before the advent of modern medicine and the discovery of antibiotics, the knowledge of veterinarians in the West was not much further advanced than that of their Indian predecessors. Certain aspects of ancient veterinary medicine in India, neglected or unknown in the West, merit deeper study. These include the ideas regarding the feeding of animals, preventive methods and cauterisation techniques. Also of interest are the medicines derived from plants which are still in use, as well as those medicines which are no longer used but are fully described (together with indications, and mode of preparation and administration) in ancient texts.

See also: ▶Medicine In India : Ayurveda

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Veterinary Medicine in Iran

H. Tadjbakhsh

Veterinary medicine was known in Iran from the time of the Sassanids (212–652 AD). They treated useful animals with drugs or surgical operations. Veterinarians received wages and each animal had a tariff of its own. General practice was the same in human and veterinary medicine, but the duties of physicians and veterinarians have been separate since the Sassanid reign. Administration of a vast country like Iran with so many poor roads required the transport of army equipment to meet public demands. Domesticated draught animals, such as horses, mules, and camels, received special attention. This called for a disciplined veterinary organization. Veterinarians, especially army veterinarians, were celebrated figures in the country. In ancient Iran there were more veterinary clinics than in other countries of the world at that time (Elgood 1974).

There were almost 70 important offices in the Sassanid government. One of the important offices related to horses and other domesticated animals and was administered by the head equerry (*Akhvarbadh* = *Hwrpt*). This head equerry was one of the key figures responsible for animal husbandry and veterinary organization. Another senior official was *Nhcyrpt* (master of the hunt) who was responsible for hunting affairs, breeding and treating hunter animals and birds or wildlife in modern-day terminology. The head equerry and master of the hunt had other responsibilities that sometimes were nonveterinary, but they were aware of veterinary affairs and sometimes they were veterinarians. There were also second-class equerries who offered veterinary services especially to the horses. Ruminants were not paid equal attention. Experienced shepherds or rustic veterinary technicians treated them.

In the Sassanid reign, Becheshk Sotur (Quadruped Doctor) was the one in charge of treating army horses. He was an important figure. According to *Mafatih al-Olum* (Keys to Sciences) of Kharazmi, there were almost seven forms of writing for registering accounts and provisions. *Dad Dafira* was used for writing justice rules and *Ahur Hamar Dafira* was used for keeping the accounts of stables and horses. These forms of writings belonged to seven secretariats or ministries, and one of them was the Ministry of Stables that dealt with livestock affairs.

During the Sassanid era, veterinary medicine was separated from human medicine as a specialized art and profession, although it shared its roots with medicine. These two fields were unified to some extent in post-Islam Iran and some of the celebrated physicians of the time wrote independent treatises on veterinary medicine or allocated chapters of their medical collections to this field. Meanwhile, some of these people researched animal diseases and treated horses and birds of prey. However, there were certain people who practiced solely in the veterinary field during all the centuries since Islam. They had their own special clinics or offices and did not practice human medicine.

In Iran of the Islamic period and in other Muslim countries, they recognized the similarities between medicine and veterinary medicine, but at the same time they believed in their independence from each other. The most important duty of veterinarians was in treating and preventing equine diseases, because this animal was important to them in war and in performing the Hajj.

The Iranian state-run veterinary system was divided between the head equerry organization and the Investigation Department. The head equerry's organization was a well-organized department that took care of the health of animals in state studs and stables. In addition to these, the investigating departments inspected the affairs of the stables, and cookery inspectors were busy with food hygiene inspection. Documents suggest that veterinarians headed all these practices.

Private veterinarians had their own special veterinary associations and veterinary regulations. They treated horses, mules, asses, and camels in their clinics or in their cottages. When there were disputes between the animal owner and veterinarian, the master of veterinarians or chief of the veterinary association intervened and reported the result to the market inspector for a final ruling. The final arbiter was the market inspector who also administered tests and issued certificates for veterinarians.

In the ancient Iranian and eastern world, people attached special significance to breeding and treating horses and birds of prey but not to ruminants. Perhaps one reason was the abundance of these animals, as there were vast ranges and low population densities. There was little need for treating ruminants, because these animals were religiously permitted meat, and so people slew them at times of probable danger and ate them if they were not rotten. But there was a dire need for horses, for protecting state borders, consolidating the ruler's power, and carrying food and ammunitions. People did not eat the flesh of these animals; they had to cure them.

The places and routes for keeping or trafficking horses, mules, asses, and camels, was chiefly in the cities, suburbs or probably in the studs, but the ruminants were kept in villages and suburban areas. Veterinarians and educated physicians depended on urban life and tended to work in developed areas. This is why, until the early twentieth century, rustic eastern communities had little access to physicians and veterinarians. People had to learn medicine, veterinary medicine, and midwifery through their own experiences.

Iranian Veterinarians and Hippologists

Fakhr Modabber, in his *Adab al-Harb*, alludes to a hippologist and horse master named Muhammad Marzban, who visited Hadjaj, the ruler of Iraq, in the company of Ibn Qerryah (d. 703) a great man-of-letters and horse master in Iraq. He said, "Marzban is the mother and father of this profession." That means that he is a master in hippology (the study of the horse). Ibn Qerryah was himself a student of Marzban. Marzban thought there was a direct link between the color and efficiency and physiological properties of horses. "A dark bay horse is good for war, a gray or white horse is good for plains, a piebald horse is good for hunting, a dun horse is good for visiting friends and walking, a colored horse is suitable for playing polo and a grass-green blond horse is the best for escaping." He then gave anatomical characters of the horse in great detail and in beautiful words. Marzban is a famous Iranian name meaning chief. According to the *Adab al-Harb* the title of horse master was attributed to a veterinarian skilled in raising horses.

The most renowned and best learned of the veterinarians of the first three centuries was Ibn Akhi Hozam, the chief of veterinary medicine and stock-breeding affairs of Motavakkel of Abbasids (d. 861). He was Iranian by birth and his father and uncles were all skilled veterinarians. His magnum opus lists the names of some notable veterinarians such as Abu Qoreh and Muhammad ibn Suleyman ibn Ghaleb, who was apparently a relative of Hozam.

Pre-Mongolian Veterinary Organization of Iran

In the administrative chart of Iran, the grand vizier or prime minister was second in administrative rank to the Sultan. The viziership was for some time hereditary in some families such as Jeyhani, Balami, and Nezam al-Mulk. There were almost ten tribunal courts in the office of the grand vizier, such as the Inspector's Court (*Divan Moshref*), *Mohtasseb*, *Saheb-e Barid* (which was responsible for mounted couriers), and the equerry office. This last was responsible for breeding horses, news dispatches, taking care of the pony express, veterinary medicine and inspecting livestock and food.

Breeding horses and training them for war were the chief responsibilities of the head equerry. The Moshref was in charge of animal health, administering veterinarians' affairs and other affairs related to animals. The inspectors' organizations and a number of other Seljukids administrative systems were in force until the end of the nineteenth century but changes occurred in the course of time in the nature and sometimes in the names and terms.

Any business, including medicine and veterinary medicine, had a chief of its own. These people, in addition to observing professional rules and regulations, were in charge of collecting taxes from the businessmen and industrialists. In some cases they defended the rights of their guild members against the government.

During the Ghaznavid dynasty, the head equerry was a distinguished title in the administrative system and army. It was the same during the Seljukid's reign. Ibn Abi Toba Nassir al-Din Kharazmi (killed 1135), the Shafiite vizier of Sultan Sanjar, was born in Merv and entered the court of the sultan upon learning the sciences of the time. He was skilled in inspecting the stables and food hygiene service and in veterinary medicine and stockbreeding. He served for a short time in the beginning. Twice he was appointed minister of Sultan Sanjar but was jailed following a conspiracy of one of the emirs of the Sultan and died in prison. He was a patron of scientists and authors. Ekhtiar al-Din Kushli was one of the head equerries at the court of Kharazmshah who fought in the Mongolian raid on Bukhara and was killed.

Veterinarians and Their Activities (10–13th Centuries)

Veterinarians carried out their duties in the state veterinary service or as private practitioners. Some had veterinary offices. Veterinarian masters and sometimes master physicians, skilled in both medicine and veterinary medicine, wrote books on horses and their diseases. Abū Rayḥān Bīrūnī in his *Al-Tafhīm*, writing about of astrology from a Persian point of view, cited various professions such as veterinary medicine and its relation with the stars. Fakhr al Din Rāzī in his *Djama al-Olum* in the *Treatise on Al-Baytara* wrote about the activities of the veterinarians.

Physicians Writing About Veterinary Medicine

Many physicians of Iran and the world of Islam have written about veterinary medicine and zoology. Ibn Baytar belonged to a family of veterinarians living in Andalusia. He wrote a book entitled *Kashf al-Vayl fi Marefat al-Amraz al-Khayl* (Detection of Afflictions in Horse Diseases) that showed his thorough knowledge of veterinary.

Veterinary Organization in the Mongolian and Timurid Periods

Veterinary medicine was a common profession during the 13–15th centuries. Many books were written on veterinary medicine and zoology in Persian or in Arabic, either independently or as chapters of general books. Some of these books are extant. They provide solid evidence about the education of veterinarians during this period.

In *Rozat al-Djannat*, falconers' treating birds of prey was explained. It says that Shams al-Din Kart, king of Herat who fell captive to Abaqa Khan, cured his beloved falcon in 1277. According to Shah-Qoli, the head equerry, Tamerlane was so skilled in veterinary medicine that he performed necropsy to find out reasons for the horse's death. Ibn Arabshah (1436) writes that Tamerlane, in his military march to Damascus, sent a number of veterinarians, physicians, industrialists, and scientists to Samarkand. Veterinary medicine was also a profession of high value in other states of the world of Islam. Ibn Monzer wrote the book *Kamel al-Sanaatayn* at the request of Nasser al-Din Qalavoon, King of Egypt (fourteenth century). Al-Malek al-Mujahed, King of Yemen and Arabia, wrote *Al-Aqval al-Kafia* on veterinary medicine.

Veterinary Organization in the Safavid Era (16–18th Centuries)

Like previous periods, veterinary and animal husbandry affairs in the reigns of the Safavids, Afsharids, and Zands were a chief responsibility of the head equerry, hunt master and inspectors' court. A number of veterinarians cured sick animals in clinics or in the field. The head equerry was an army commander and the third most important person in the nation. According to Mirza Sami'a, he had thousands of men working under him, ranging in rank from second-class head equerry, *Baytar* (veterinarian), inspector of technical and financial affairs, horseshoe maker, cattle breeder, horse groom, technicians, and saddle keepers and setters. There were many organizations related to animal husbandry and wildlife organizations such as organizations for grooms (*Mehtarbashi*), head of cattle or horses (*Ramedarbashi*), head of herd of cows and sheep, grooms of mules and camels, grooms of lions, grooms of dogs, snake handlers, etc.

Investigation Department (*Eshraf*) or Veterinary Organization of the Safavids

There was an organization called *Eshraf* that supervised all governmental affairs both before and after the time of the Safavid reign. Part of their responsibility concerned the supervisors of the quadrupeds, camels, kitchens, etc. They also inspected the stables and studs of the horses and other animals producing food and dairy, and checked on taxes levied on animals. According to Chardin and Mirza Sami'a, the inspectors paid attention to the health of the camels and horses. Special officers studied animal corpses to identify causes of death.

There was a ministry called the head equerry organization that administered the affairs and inspected the health of the horses and other animals. Another organization called Eshraf, coequal with a modern-day veterinary organization, was responsible for treating and supervising the technical and financial affairs of the animal breeding sector of the monarchy. The chief of this organization in the time of the Shah Abbas II was Nezam al-Din Ahmad.

The Veterinary Profession in the Time of the Safavids

Medicine and veterinary medicine in the Safavid reign inherited the traditions and knowledge of the Timurid dynasty.

Amin Ahmad Razi in *Haft Eqlim* (Seven Continents), written in 1601, mentions Romia or Constantinople, where there was a bazaar of veterinarians. There were special bazaars or marketplaces of veterinarians in other Muslim nations. Safavid kings, especially Shah Abbas I and II, paid special attention to breeding horses. At the order of Shah Abbas II, many veterinary books were written. Shah Abbas I used to go to the stables and inspect horseshoes; he knew about horse diseases and means of treatment.

Some of the great veterinarians of the period, as mentioned in the available manuscripts, treatises of falconry and hippology, are Hashemi, Saffi, Nezam al-Din Ahmad, Mohebali Khan Khas, Majd al-Din bin Muhammad Shafi, Abdullah Khan Bahador, Arab Najafi and a few others.

Department of Veterinary Medicine in the Time of Qajars

In the time of Qajarids (until almost 1921), the department of veterinary medicine was part of the head equerry organization. The head of this department was the deputy chief of the head equerry organization.

Veterinary medicine was an independent job, and although many people contributed to it, as they did with humans, the veterinarians only were responsible for treating animals, especially horses. Another veterinarian and hippologist of the time of Nasser al-Din Shah was Haji Muhammad Qoli Beyq Turkman.

Since the middle of the Qajarid reign, Iranian veterinary medicine gradually lost prestige compared with Western veterinary science. Unfortunately Iranian ancient veterinary medicine completely fell into oblivion, as did medicine. They could still use bleeding medicine, which is similar to Chinese acupuncture in some of its aspects, and use medicinal herbs observing rules of sanitation.

The political and social instability of Iran in the nineteenth century affected veterinary medicine. "Almost all of the veterinarians and the majority of the peddler physicians are Turkman. Veterinary is confined to a few diseases of horse and mule, and after cauterization and drainage they use purgatives. Since there are no sanitary police, sanitation measures, or veterinary establishments, deadly diseases have killed a greater number of animals making the tribal people poor" (Polak 1865).

Comte de Gobineau, in his trips to Iran in 1855–1856, mentioned peddler veterinarians but did not attach significance to them. The fact that they said Iranian horses and sheep were the best of these animals in the world, shows that Iranian veterinary medicine must have been well developed.

The first faculty of veterinary medicine in Iran was founded in 1933 in Tehran and the German Dr. Damon, the French Le Louet and seven other German and Hungarian professors plus Iranian army veterinarians who had graduated from France, taught in this faculty.

In between the years 1926 and 1931, 15 civil students left Iran for France to study veterinary medicine. They studied at various schools of veterinary medicine and some of them passed specialized courses. On their return they taught at the Tehran Veterinary Faculty and they replaced foreign professors.

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Veterinary Practice in Nepal

Krishna Kaphle

Nepal is a landlocked country lying between 80°04′ and 88°12′ East longitude, and 26° 22″ and 30° 22′ North latitude. It extends over an area of 147,181 sq. Km with an average east to west length of about 885 kms. The north–south width is not uniform and it varies from a maximum of 245 kms to a minimum of 145 kms. Politically and geographically Nepal is located between two giant nations, China on the North and India on the South. The country has three patterns of landscape: the mountains, mid hills and the plains. The plains and hills with valleys are the major sites of human settlement and major cities are located here. Nepal has a population of slightly over 23.15 million. Though the political boundary of Nepal was restructured by the British colonial era occupation in the Indian subcontinent, isolation from the world was almost total until the mid twentieth century. This isolation affected Nepal both in positive and negative ways. On the positive side, when ancient cultures and traditions were safeguarded, progress made elsewhere was slow to be. This has happened with veterinary medicine in Nepal. The tradition of ethno-veterinary medicine awaits revival, while the copied concept of western veterinary system has limited use. This short article describes the historical and contemporary situation of organized veterinary services in Nepal.

Agriculture, the only source of livelihood for most of the Nepalese people, is not only an occupation but also a way of life. About 85.80% of the population live in rural areas and earn their living from farming, whereas only 6% live in cities and are involved in non-farming occupations. Livestock is an indispensable part of agriculture, which provides employment to over 80% of the country's population. Livestock is now looked upon with great expectations as playing a great part for the development of the nation, and attempts are made to boost production. The efforts are seeing results, with farmers turning to commercial livestock farming which in the past was just a satellite component of agriculture, basically intended for manure production and domestic consumption (APP 1995). However, in recent years dairy and poultry farming are turning into industries making a large contribution to the national gross domestic product (NGDP). Planners have identified three main ecological components of Nepal to implement various development activities (Carson and Sharma 1992). The three ecological zones of Nepal have different distributions of livestock numbers, as illustrated in Table 1, with higher numbers in the mid

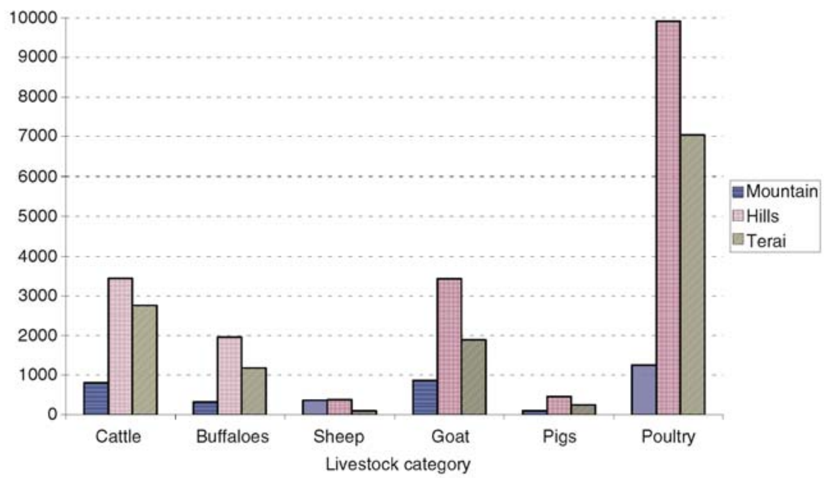
Veterinary Practice in Nepal. Table 1 Status of Livestock Population by Ecological Zone, 1998/99

Unit: ('000 no)

Region	Cattle	Buffaloes	Sheep	Goats	Pigs	Fowl	Ducks
Mountain	809	317	368	870	101	1250	11
Hills	3453	1970	382	3435	468	9830	84
Terai	2769	1184	106	1899	256	6717	326

Veterinary Practice in Nepal. Table 2 Percentage of Households Keeping Livestock and Birds by Region, 1998/99

								Unit: %	
Region	**Cattle**	**Chauri**	**Buffaloes**	**Goats**	**Sheep**	**Pigs**	**Horses**	**Poultry**	**Ducks**
Mountain	82.8	2.9	44.8	55.5	6.5	10.3	1.3	56.4	6.0
Hills	77.3	0.1	60.0	54.2	4.2	12.2	0.4	67.6	9.2
Terai	74.4	0.0	35.8	46.8	1.8	7.1	0.4	32.4	15.7
Nepal	76.6	0.3	48.5	51.3	3.4	9.9	0.5	51.9	11.6



Veterinary Practice in Nepal. Fig. 1 Status of livestock population by ecological region, 1998/99.

hills. Almost every household in the villages has an animal. The percentage of households keeping livestock and birds by region is shown in Table 2. The status of livestock population by ecological region according to the reports of 1989/99 as in Fig. 1 shows poultry population higher in the hills, but commercial poultry farms are located in plains and valleys. Poultry farming is the one most successful story of Nepal's transition of animal husbandry (Kaphle 2000).

Situation of Animal Health Care Systems in Different Ecological Zones

The mountainous regions, ranging in altitude from 4,877 to 8,850 m above sea level, covers 35% of the country. This area is less developed and has only 6.97% of the country's population. The mountainous topography makes it virtually cut off from other parts of the country; transportation is by foot and on the back of yaks and ponies, although there are some airstrips with irregular schedules. This region has the highest number of sheep, yaks, and chengras (hill goats). The population and economy of the mountain region is based on trade with Tibet and tourism, as well as support from animal husbandry. The demographic distribution is mostly people like the Tamang, Rai, Limbu, Gurung, and Sherpas famous for their mountaineering skills. The pastoral communities have been employing unique ethno-veterinary practices since time memorable. This region has 16 districts and each district headquarters has a government veterinary hospital. A veterinarian supported by junior technicians and some other staff mans these hospitals; their prime duty is to give outdoor health care support, monitor disease outbreaks, and implement and monitor government policy in the related sector. Private practitioners are out of question in these situations where farmers consult veterinarians as a last resort. Traditional veterinary practices like herbal medicines and bloodletting are used for simple cases; however parasites, foot rot, plant poisoning, and microorganism related diseases are commonly encountered and they respond poorly to traditional medication. The region, with its rough topography and difficult communication networks, has a slow economic growth with livestock, tourism, and herb collection as the only path to greater income. Tourists in this area provide markets for local livestock products. Lack of proper technical and financing institutions with difficult communication and marketing opportunities can be viewed as the obstacles for livestock development. However if successfully harnessed, high altitude animal husbandry will flourish well and the standard of living of the people in this region can be raised substantially.

The hilly region comprises 42% of the land area and 43.97% of the total population of the country. This region has some major cities. The livestock health diagnosis aspect of this region is also controlled by the government veterinary hospitals with only a few private organizations and practitioners concentrated in the main cities. The government disease diagnosis mechanism is more concentrated in this region with the location of central veterinary laboratory and major regional laboratories. These laboratories are mainly concerned with large animal diseases and only the central veterinary lab at Tripureshwor, Kathmandu has some facilities for poultry disease diagnosis. This region is making progress, as roads linking to district headquarters make the flow of goods and people easy and convenient. There are some milk collecting, chilling and processing centres in this region that are boosting dairy farming. As the genetic makeup of the livestock is being improved by upgrading with pure breeding males distributed by government or use of artificial insemination, so is the demand for commercial feed and health care attention. There was an early setback when pure Holstein and Jersey breeds of dairy cattle were introduced, as they could not receive optimum management and nutrition, they developed gynecological and metabolic disorders. Thus government policy has been to see that the genetic make up remains at 62.5% so that increased productivity and the thriving ability of the animals are enhanced at the same time. The law forbids cross breeding of some indigenous cattle, buffalo and sheep species to preserve genetic composition. Poultry, goat and swine farming are gaining popularity with the effort of private entrepreneurs, government poverty elimination schemes and support of non-government organizations. Co-operatives and villagers' group formations, mainly for women, are encouraged, and facilities for providing loans are adopted to initiate cottage industry and livestock farming. Similarly leasehold forestry projects are implemented in some parts of the region which aim to provide the community a means to use and protect the forest and to help small unit livestock development and at the same time conserve the forest.

The plain region or the terai is the major centre for buffaloes, cattle and poultry. The terai and inner terai accommodate almost 50% of the nation's population. The plains are densely populated, and migration from the hills and abroad are using up the fertile agricultural land for settlement purposes. There are private practitioners along with the government animal health care system; farmers are educated to a certain extent and like to be in touch with veterinarians for consultation. The supply of western drugs is also bountiful, with many veterinary drug stores located in this region. Farmers sometimes seek the support of the Indian Veterinary Research Institute (IVRI) and other institutions in India as they have advanced technology for disease diagnosis. This region is developing fast and the livestock industry is making rapid progress. The extreme summer temperature, marketing facility and occasional disease outbreaks are hampering the established poultry and dairy industry. Lack of proper regulation in line with consumers health and public health concerns compounding with transportation to markets in cities is a major hurdle too (Joshi and Oleson 1999).

History of Animal Disease Diagnosis Pattern in the Country

The government and the private sector both provide animal disease diagnoses. The history of the animal health care system in Nepal is not old; previously traditional health care practices dominated.

The first recorded establishment of a veterinary dispensary at Kathmandu was in the year 1950 B.S (beginning of the nineteenth century in the Julian calendar). In 1940 the present Central Veterinary Hospital was established at Tripureshwor, Kathmandu. The period from 1943 to 1957 saw the establishment of ten veterinary hospitals in different district headquarters of the country. In the year 1964 AD14 zonal and 19 district veterinary hospitals (DVH), 21 veterinary dispensaries and 18 veterinary check posts were established. With the addition of 25 veterinary hospitals in 1981 and 16 in the year 1984, the country had a government veterinary hospital at all headquarters in the 75 districts. There are five regional laboratories set up to speed up disease diagnosis with special programs for epidemiologically important diseases. There are also regional training centres training farmers on recent techniques of management and primary health care, while selected candidates are given preliminary training to work as auxiliary village animal health workers (LSMP 1993).

The private sector involvement in this regard is mostly concentrated with the poultry and dairy industry as they are commercially practiced. The share of the private sector in poultry health care is around 60%, while the government jointly handles the remaining section. The central veterinary hospital and laboratory at Tripureshwor is the most refereed one in the country. It is equipped with modern laboratory facilities and manned by skilled personnel. The district veterinary hospitals and their sub-centres are limited in providing this service. Pet animal veterinarians are based in Kathmandu having their private clinics, while many government vets also have private practices outside their office hours. The military have five veterinarians in their service to take care of stud farms while in the police a single veterinarian looks after the health of the dog squad.

Most commonly encountered communicable diseases of livestock in Nepal are peste des petits ruminants (PPR), rinderpest, foot and mouth disease (FMD), rabies, brucellosis, haemorrhagic septicaemia, black quarter, anthrax, mastitis and swine fever. Infectious bursal disease, Newcastle disease, Marek's disease, infectious bronchitis, chronic respiratory disease and coccidiosis are common poultry diseases. Fasciolosis and infertility are other common diseases of dairy animals (Mathema and Joshi 2000).

Traditional Animal Health Care Practices in Nepal

Ethnoveterinary medicine describes the traditional practices used by livestock raisers all over the world to keep their animals healthy and productive, and to treat and control diseases (Mathias 1996).

Ethnoveterinary medicine is an effective means to safeguard the health of animals and the interests of the poorer communities around the world. Poverty and remoteness prevent access to conventional animal health care. To counter this, traditional animal health care has been reborn and now plays a greater role in the lives of poor farmers. Traditional animal health care is cheap, readily available and safe for poor livestock keepers, but lack of information on its scientific validity, lack of policy support, and the negative attitude from modern veterinary practitioners has until recently limited its promotion. Ethnoveterinary practice in Nepal is a blend of Tibetan and Indian practices. The medicinal plants in the Himalayan range that stretches across the whole length of the country and the diverse ecological conditions have provided suitable grounds for traditional animal health care practices. Adding to that process was the late exposure of the nation to the outside world (~1950s), the fact of having no history of colonization and snail-paced industrialization of animal farming. All these shielded traditional animal health care knowledge from being overwhelmed by Western medicine. However, in recent times, with poultry and dairy farming using advance rearing practices, ancient ways are frowned upon. The consequences of Western medicine misuse in animal production from elsewhere in the world has yet to be learned by the Nepalese industrialists. However, there is a rising awareness to preserve ancient knowledge in the art of traditional animal health care. Encouraging the use of ethnoveterinary medicine, or preventing misuse of Western practices, is part of an important policy for the non-governmental agencies working with their international counterparts in the field of poverty elimination. Restrained if not total ban in use of chemical pollutants in the communities around the vicinity of wildlife reserves is gaining momentum. Nepal is at a crossroads, deciding whether to subsist in the safe ancient way of animal health treatment or to industrialize animal husbandry to meet the growing food challenge and leave the consequences for generations to come.

Animal husbandry is rapidly changing from the traditional system to an industrial form. There are ample opportunities for its growth, as it is deemed the only option for over 80% of the national population. The small farmers relying on age-old traditional agricultural practices will not be in a position to compete with cheap products from India, China and elsewhere. Tourism, a major source of foreign exchange, is also seeing its worst days with international terrorism. Thus with no other clear options available, livestock enterprise is making progress. The animal health care system is also making progress, but the speed is much slower. With around 400 veterinary doctors and slightly more junior technicians, the country is not able to meet its requirements. The Institute of Agriculture and Animal Science (IAAS), the only agriculture college, has started to produce around 25 veterinarians per year which is partially filling the growing demand. The lack of infrastructure and other factors makes the level of education below the global level. With advanced training to faculties and infrastructure development the future of the veterinary school at IAAS is bright. Research activities with the limited resources available have been a trademark of IAAS, and it will only get better. Some works on buffaloes (Dhakal and Salman 1992) and poultry (Kaphle 2000) have to great extent helped the farmers gain confidence and will to invest and upgrade their animal production activity. Commercialization of animal husbandry and increase in farmer's awareness will make animal health care an important factor, as can be evident from the hustling activities around IAAS, Chitwan. Thus, the nation needs to set up strict guidelines and regulations in implementing the policy of animal health care practices. At the same time, making service available to all the community at an affordable price and in a sustainable way should be the priority of the government (Linet al. 2003). There should be a mandatory flow of information regarding epidemiological reporting from the field level to the concerned authorities and a rapid execution of appropriate steps. The reckless import of vaccines from foreign countries and reckless use of medicines like antibiotics and hormones should be controlled and a governing authority should look into the necessary criteria. Emphasis should be given to the preparation of vaccines from the local strain of pathogens within the country. Basic laboratory facilities should be developed for disease diagnosis in all district veterinary hospitals. The school of veterinary medicine and animal science at Institute of Agriculture and Animal science should be strengthened. The manpower development program as well as faculty and student research activities should be initiated. One research area that has the potency to be of great use not only to Nepal but to the whole world is the research of medicinal herbs for various animal healthcare Hence, in spite of the huge resources in form of traditional ethnoveterinary practice and bountiful medicinal plants, Nepal still needs to pull up its socks to learn from success stories of others, Taiwan being an ideal example (Kaphle et al. 2006).

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V

Wang Chong

Fabrizio Pregadio

The Chinese philosopher Wang Chong was born in Shangyu (modern Zhejiang) in AD 27. According to his biographies, he came from a poor family and devoted most of his life to teaching, but also held minor posts in the state administration. Later he retired to compose the work by which we know him today, the *Lunheng* (Balanced Discussions). This extensive treatise in 85 chapters (one of which is lost) was completed in AD 82 or 83, about 15 years before the author's death.

Wang Chong lived about one century after Confucianism had emerged as imperial ideology. In this process, the "rationalist" and socially minded philosophy taught by Confucius had been integrated with cosmological doctrines extraneous to the letter of his teaching. The school of though: to which Wang Chong belonged propounded, on the contrary, a reading of the classic texts devoid of esoteric interpretations.

In his work, Wang Chong analyzes, with a strongly skeptical and even iconoclastic spirit, ideas expounded by earlier thinkers and beliefs shared by the people of his time (e.g., the recourse to divination, the belief in ghosts, the search for physical immortality, and the idea of an individual spirit that persists after death). Wang's typical procedure is to bring out contradictions in the anecdotes and accounts that he first quotes in full. Through an exemplary logical method, he often does not hesitate to take as true one detail that he has previously refuted, if this may serve to invalidate a different detail.

Philosophically, Wang Chong maintained that all phenomena arise spontaneously, and are not expressions of Heaven's will. Related to this was his opposition to the belief in prophecies and portents, through which Heaven was deemed to legitimate or censure rulers, and assent to or dissent from their policies. While Wang Chong rejected the blend of these forms of esoterism with Confucianism, he fully accepted the metaphysical and cosmogonical doctrines traditionally placed under the egis of Daoism. In this way, he anticipated some of the new developments in post-Han Confucianism.

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Wang Xiaotong

Ang Tian Se

There is no record of Wang Xiaotong's early life nor his year of death. We estimate that he flourished from the second half of the sixth century to the first half of the seventh century. The little we know of him is from a memorial he presented to Emperor Gaozu of the early Tang dynasty (AD 618–906) on the occasion of the submission of his mathematical text to the throne. The mathematical text he submitted was known as *Jigu Suanjing* (Continuation of Ancient Mathematics) and was subsequently selected as a prescribed text for imperial examinations in AD 656. In his memorial, which is now attached to his mathematical text, he mentioned that he had studied mathematics from a very young age. He studied the *Jiuzhang Suanshu* (Nine Chapters in Mathematical Art) thoroughly and had great admiration for Liu Hui's in-depth commentary on the text. On account of his mathematical acumen, Wang Xiaotong was appointed as an instructor in the Department of Mathematics, and later as a deputy director in the Astronomical Bureau. In AD 623, together with Zu Xiaosun, an official of the board of Civil Office, he was appointed to re-examine the adequacy of the current calendar.

Composed by Fu Renjun and promulgated for use since AD 619, the calendar had on several occasions been found to be losing accuracy in the predictions of solar and lunar eclipses. Based on the structure of the Kaihuang calendar composed by Zhang Bin of the previous Sui dynasty (AD 581–618), Wang Xiaotong criticized the adoption of the *ding shuo* method and the precession of equinoxes in the current calendar. The critique sparked a 3-year debate between Fu Renjun and Wang Xiaotong, culminating in a submission of a proposal for rectifications consisting of more than 30 errors to the Astronomer-Royal. This does not necessarily reflect Wang Xiaotong's achievement in calendrical science. On the contrary, his view of adhering to the traditional model without taking into consideration the uneven apparent motion of the sun and the precession of equinoxes in calendrical calculations was a retrogressive one. His contribution lies in mathematics.

From the late Han dynasty in the first century onward, Chinese mathematicians were familiar with quadratic equations and their solutions. But it was not until the appearance of the *Jigu Suanjing* that equations of the third degree were presented. They arose because of the special needs of engineers, architects, and surveyors of the Sui dynasty. There are 20 practical problems in the *Jigu Suanjing* consisting of a problem (No. 1) on calendrical calculation, six problems (Nos. 2–6 and 8) on engineering constructions, seven problems (Nos. 7, 9–14) on the volume of granaries, and six problems (Nos. 15–20) on right-angled triangles. The solutions of most of the problems involved equations of the third degree. For example, problem No. 15 says: "There is a right-angled triangle, the product of two sides of which is $706\frac{1}{50}$ and whose hypotenuse is greater than the first side by $36\ \frac{9}{10}$. Find the lengths of the three sides." Wang's solution amounts to the formation of the cubic equation as follows:

$$x^3 + \frac{S}{2}x^2 = \frac{p^2}{2S'}$$

where *P* is the product and *S* the surplus. As a matter of fact, most of the problems in the last three categories involved the use of the equation

$$x^3+Ax^2 + Bx = C,$$

where *A*, *B*, and *C* are positive numbers. Wang Xiaotong provided the rules for the arrangement of the equations in all these problems but did not explain the procedure for arriving at such equations. He also did not discuss the equations of higher degrees. Numerical equations of degrees higher than the third degree occurred first in the work of Qin Jiushao around AD 1245.

See also: ►Liu Hui and the *Jiuzhang Suanshu*, ►Calendars, ►Qin Jiushao

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Wang Xichan

Liu Dun

Wang Xichan (July 23, 1628–October 18, 1682), sometimes known by his literary name, Xiao' an, was from Wujiang, Jiangsu province, China. When he was sixteen, the Ming Dynasty (1368–1644) collapsed and the door to social advancement through the imperial examination system was suddenly closed. After several unsuccessful suicide attempts, Wang abandoned his hopes for an official career and became one of the most distinguished Ming loyalists in his area. He seems to have survived by teaching literature, although his main interest was in astronomy, which he had studied on his own since his youth. Despite both poverty and illness, Wang made unremitting efforts to observe the heavens, calculate planetary positions, and write about astronomy.

Beginning in the late Ming Dynasty, Western astronomy had been disseminated intermittently into China, and subsequently it was adopted by the Qing (1644–1911) rulers. In 1646, a number of astronomical treatises, earlier written or translated by Western missionaries serving the Ming court, were published together by order of the Qing emperor under the general title *Xi Yang Xin Fa Lin Shu* (Astronomical Treatises of the New Methods of the West, 1646). Unfortunately, the "New Methods" introduced by the missionaries did not reflect the advanced achievements of modern astronomy in seventeenth-century Europe. Even worse, there were some defects and internal contradictions, especially in the parts dealing with the cosmological theory of planetary motions.

In his *Xiao An Xin Fa* (New Method of Xiao'an, completed in 1633), Wang argued that all of the Western techniques could be reconciled with classical Chinese schemes and therefore could be used to revive the lost traditional astronomy of ancient China. By means of trigonometry, which was not used in traditional Chinese astronomy and mathematics, Wang created a series of methods to calculate ecliptic positions and predict planetary occultations. Forty years later, in his *Wu Xing Xing Du Jie* (On the Angular Motion of the Five Planets, completed in 1673), Wang criticized the contradictions in the *Xi Yang Xin Fa Li Shu* and proposed instead his own model of the planetary motions which differed from both the Aristotelian–Ptolemaic and the Tychonic geostatic models. In addition, he attributed the planetary motions to an attractive force radiating from the outermost moving sphere (i.e., the *primum mobile*). Wang also suggested that there were planets inside the orbit of Mercury which might account for the appearance of sunspots. All of these thoughts, along with some of his methods, were heuristic and had considerable influence on his successors.

In general, Wang was one of a few pioneers who responded to Western science by conscientiously studying it; he was open to critical acceptance of its major ideas when suitably reinterpreted for use in seventeenth-century China. Nevertheless, some of Wang's arguments were clearly exaggerated. For instance, he assumed that Western astronomy had in fact originated in ancient China, but such claims were due to his radical nationalism and traditional reluctance to recognize any innovations from the Westf.

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Water in India: Spiritual and Technical Aspects

K. N. Sharma

The subject of water has been treated spiritually, philosophically, cosmologically, medically, and poetically in the ancient Indian literature comprising the *Veda(s)*, *Brāhmaṇa(s)*, *Upaniṣad(s)*, *Purāṇa(s)*, and *Smṛti(s)*. Water is regarded as the primordial substance from which the universe came into being. Water occupies the highest place amongst the five basic elements of nature, called *pañcamahābhūta*. These are: *ākāśa* (ether, substratum, space), *vāyu* (air), *teja* or *agni* (radiation, energy, or fire), *āpa* (water), and *pṛthivī* (Earth). These five *bhūta* constitute the physical universe. Air is said to have been generated from space, fire from space, water from fire, and earth from water. Fire and water, which are said to pervade the entire universe, have a close nexus and are believed to possess procreative powers (Narayana, 1995). The tripartite nature of *agni* has been connected with the three forms of water – celestial, atmospheric, and terrestrial, called by different synonyms in Sanskrit so that they have characteristics and attributes responsible for different cosmic, atmospheric, or terrestrial actions.

In the social and religious traditions and culture of India since Vedic times, water has enjoyed a unique status. Water is the single most important tool/mode for performing daily religious rituals or social ceremonies and a primary means for purification of body and soul in Hindu culture.

From birth till death in a Hindu society, water remains an essential ingredient in performing all rituals.

Vedas and Their Chronology

The content of the Vedas is astonishingly scientific although much of it remains to be interpreted correctly. Knowledge of the Vedas is synonymous with knowledge of the science and metaphysics of creation.

The time periods of various Vedas are as follows:

Ṛgveda	6500–3100 BCE
Sāma Veda	3100–2500 BCE
Yajurveda	2500–2000 BCE

An organic chronological development in India from 6500 BCE has been suggested (Frawley 1994), taking into account both Vedic literature and recent archaeological findings:

6500–3100 BCE	Pre-Harappan (early Rigvedic period)
3100–1900 BCE	Mature Harappan (period of four Vedas)

The Myth of Aryan Invasion

For the past hundred years or so, Mortimer Wheeler's hypothesis of "swashbuckling, horse-riding light-skinned Sanskrit-speaking people, called Aryans, coming to Northwest India from Central Asia or Central Europe in about 1500 BCE and razing to the ground the

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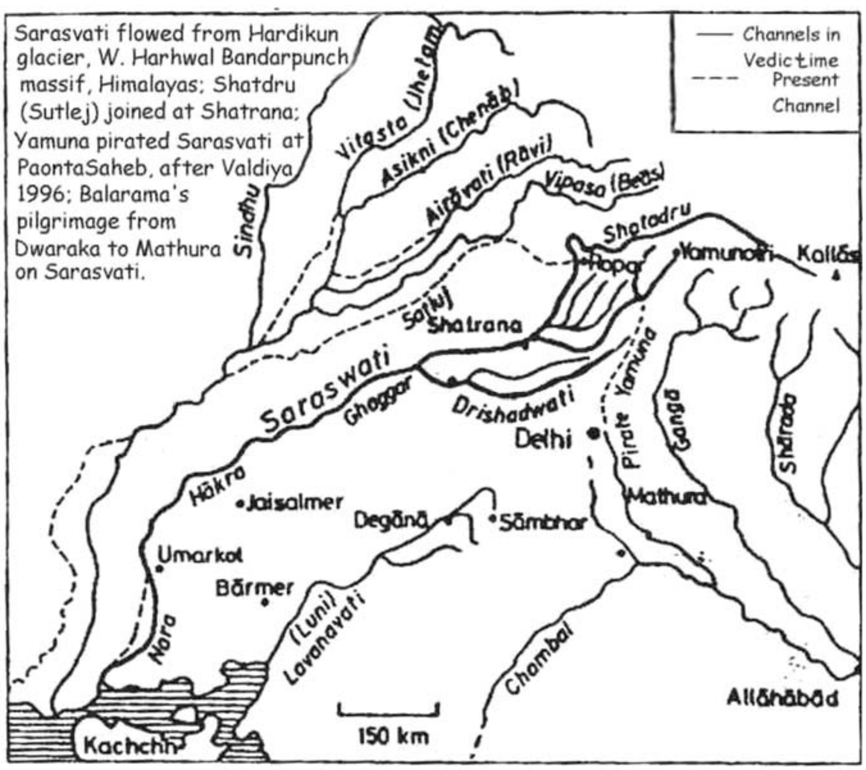
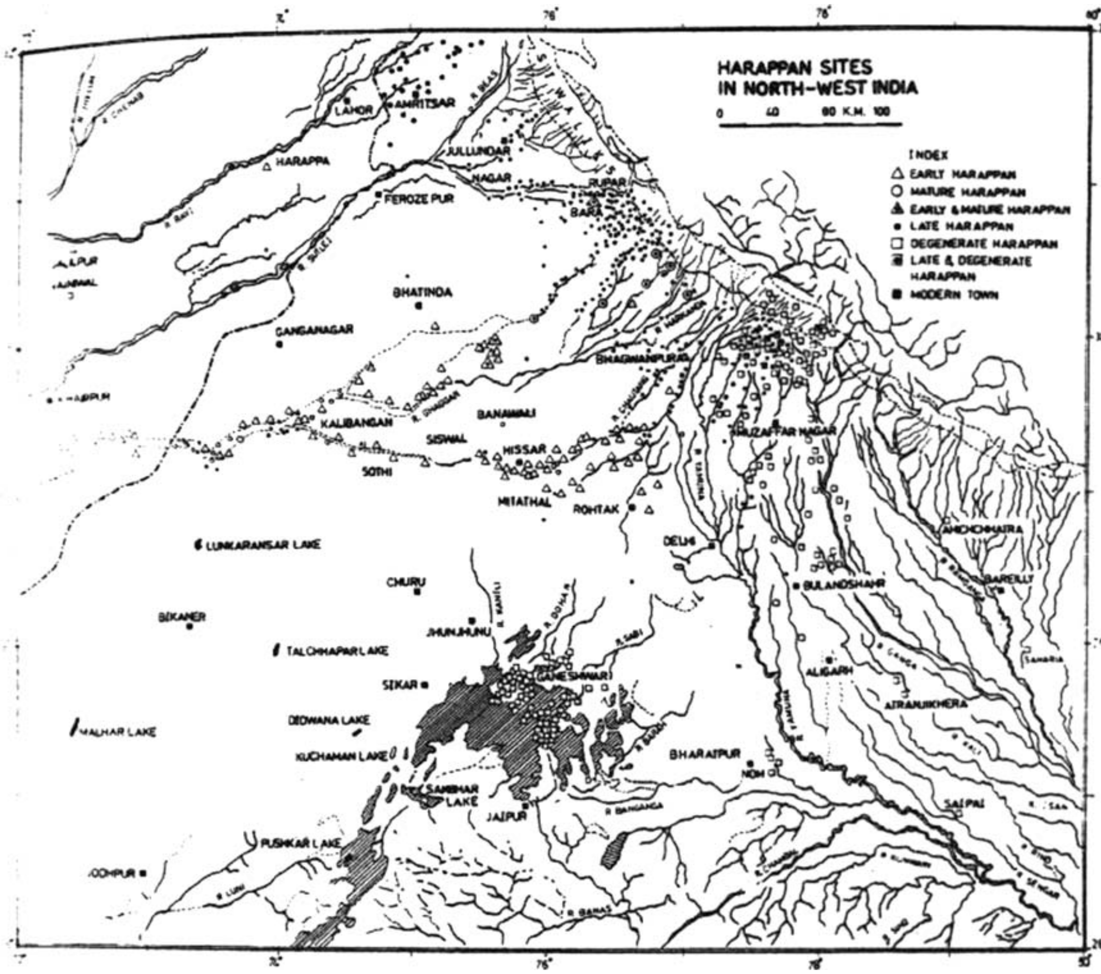
highly urbanised Harappan civilization," was accepted. These so-called Aryans were supposed to have composed the Vedas over the centuries, spread Sanskrit, and built the Ganges civilization. According to this concocted theory, these "invading" Aryans destroyed the Harappan civilization which had been flourishing there for over a millennium and whose habitants were Dravidians.

References in the *Ṛgveda* point to India's being a land of mixed races. The *Ṛgveda* also states, "We pray to Indra to give glory by which the *dasyu* will become *āryan*." This statement confirms that to be an *āryan* was not a matter of birth. While the word *dasyu* meant uncultured and illiterate, *āryan* meant noble, well-cultured people. It is also used in the context of addressing a gentleman or lady (*āryaputra*, *āryakanya*). Nowhere in the Vedic literature is this word used to denote race or language. This was a notion of Max Mueller who, in 1853, introduced the word *ārya* into the English language to refer to a particular race and language. When challenged, he refuted his own theory later in 1888.

Jean-Francois Jarrige, Director of the National Museum of Asiatic Arts of Paris, the excavator of the famous proto-historic site of Mehrgarh (Pakistan) and member of the French Academy, carried out extensive work over the last 30 years in the Indian subcontinent and showed that the excavations revealed artifacts from a much older civilization of the Sarasvatī era (Pushkarna, 1998). The civilization included metropoli like Mohenjodaro, Harappa, Ganveriwala (in Pakistan), and Dholavira and Rakhigarhi; towns like Lothal, Surkotda, Banawali, and Kalibangan, and villages like Kunal, in India. The excavations exposed not just these towns or cities, but also an earlier settlement beneath it, and an even earlier one further down. Figure 1 is a map indicating rivers in the time of Sarasvatī, and Fig. 2 shows the spread of Harappan and Sarasvatī civilization sites. According to archaeologist Bisht, before the mature Harappan stage, many regional cultures like Amri, Kot Dirji, Kalibangan, Dholavira, and Lothal had coalesced into the cultural umbrella of Harappa. They were bound by common economic compulsions and cultural ethos. The site of Dholavira is an excellent example of a Harappan city that tells the history of Early, Transition, Mature, Late, and Final Phases of the Indus-Sarasvatī (Harappan) civilization in India (ca. 3500–1700 BCE). The site spreads over an area of 100 ha. This compares well with the size of Harappa, Rakhigarhi, or Ganveriwala. All these evidences have proved the invasion theory to be unfounded, showing that the Aryans were the native Indians, having an unbroken chronology of civilization.



Water in India: Spiritual and Technical Aspects. Fig. 1 Course of erstwhile Sarasvatī River (Kalyanaraman, 1998).



Water in India: Spiritual and Technical Aspects. Fig. 2 Harappan sites in Northwest India (Kalyanaraman, 1998).

Place of Water in Ancient Indian Literature

Water has enjoyed a high status in the social and religious context of ancient Indian culture. It was an essential medium for performing daily religious rituals and social ceremonies and a primary means for purification of body and soul. Even after thousands of years, the rivers in India, especially Gangā (the Ganges) and Yamunā are considered divine and capable of purifying a sinful body with a few drops of water. *Agni* (fire) is said to be born from the waters. Both water and fire are said to possess procreative powers. Water is considered a mother while fire is seen as a prolific generator (Narayana, 1995).

The place of water as a life-giving and life-sustaining element was very high. It was considered a cleanser of sins and regarded as a divine protector. It was addressed by various names – nectar, honey, ambrosia – in prayers. Stagnant water was considered unhygienic.

> The cosmic energy is the generator of the universe, the embryo of waters the leader of humans, most virile defender of the human race, it remains ever illuminated by its own radiance and it provides sustenance for its beloved progeny (RV 3.1.12).

> Water verily is *arka* (essence). What was there as froth of water hardened and it became earth (the embryonic state of the Universe).

> Earth was formerly water upon the ocean of space (*Atharvaveda* AV 13.6).

Water or the water element had many names in the Vedas and other Vedic literature. It has more than 100 synonyms. These are not synonyms in a strict sense, since they have been used to indicate their different forms/states and contexts. Some names for water are: *Ambu*, *toyam*, *vāri*, *jalam*, *āpaḥ*, *bheṣajam*, *udakam*, *salila*, *madhu*, *ambha*, *ghṛtam*, and *kṣīram*. For example, *salila* is a technical word in the Vedas which is different from *āpaḥ* as mentioned in a mantra from *śatapatha brāhmaṇa* (11.1.6.1) which says that *āpaḥ*

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were indeed *salila* earlier. *Salila* is the primordial state of the universe, when there is nothing manifest.

Nature's Forces as Deities

In Vedic cosmology, *pṛthivī* (earth) symbolizes the material base and *dyāvā* (heaven) symbolizes an unmanifested immortal source. Together and between them, they form the *paryāvaraṇa* (environment).

The seer praises Heaven and Earth (*dyāvā pṛthivī*) by saying, "You are surrounded, Heaven and Earth, by water; you are the asylum for water; imbued with water; the augmenters of water; vast and manifold; you are the first propitiated in the sacrifice; the pious (people) pray to you for happiness, that the sacrifice may be celebrated. May Heaven and Earth, the effusers of water, the milkers of water, dischargers of the functions of water, divinities, the promoters of sacrifice, the bestowers of wealth, of renown, of food, of male posterity, combine together." RV 6.70.4–5.

Water stands for all the elements, because it is really a combination of water, fire, and earth, according to the tripartite creation of the gross elements. Water is all pervading.

Waters Regarded as Having Medicinal Powers

The Vedas also mention the medicinal qualities of water. *Ṛgveda* hails water as the reservoir of all curative medicines and of nectar. It invokes water which the cows drink and offers oblations to deities presiding over the flowing waters:

> O Water, which we have drunk, become refreshing in our body. May you be pleasant to us by driving away diseases and pains – O divine immortal waters (RV 63).

The *Atharvaveda* describes various sources of waters and describes them as dispellers of diseases and as more healing than any other healer. The scriptures believed that waters avert pain that they are restorative and curing. Wherever waters fall on earth, plants grow. The hymns in *Atharvaveda* (6.23, 24, 57) hail water as possessing medicinal qualities. A hymn in *Atharvaveda* prays for waters to cure "incurable" diseases.

The scriptures, *Saṃhitā(s)*, also regard water as capable of alleviating pain. "O water which we have drunk, become refreshing in our body. Be pleasant to us by driving away diseases and pains."

The *Ṛgveda* (1.161.9) states, "There exists no better element other than water which is more beneficent to the living beings. Hence waters are supreme." Varuna is a cosmic ruler as well as the deity that dwells in waters, presides over them and is prayed to for granting strength and virility from waters.

Another hymn from the *Ṛgveda* says,

> Ambrosia is in the waters, in the waters are medicinal herbs; therefore, divine (priest), be prompt in their praise. Soma has declared to me, 'all medicaments, as well as Agni, the benefactor of the universe, are in the waters': the waters contain all healing herbs. Waters, bring to perfection all disease-dispelling medicaments for (the good of) my body, so that I may long behold the Sun. Waters, take away whatever sin has been (found) in me, whether I have (knowingly) done wrong or have pronounced imprecations (against holy men) or (have spoken) untruth. I have this day entered into the waters – we have mingled with essence – Agni, abiding in the waters, approach, and fill me, thus (bathed), with vigour (RV 1.23. 19–23).

According to *Taittareyī Āraṇyaka* (7.3.2), Agni is an antecedent form and sun the later. Water is a compound and lightning is the joining element. *Maitreyī Saṃhitā* further divides water into three places – sky, earth, and mid-region.

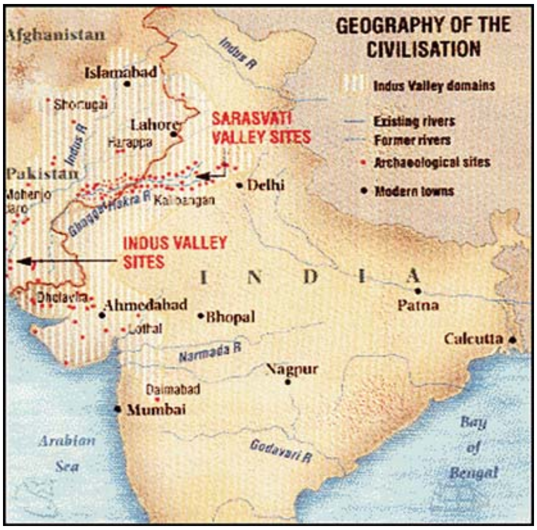
Vājasaneyī Saṃhitā describes the medicinal use of waters. "O water, which we have drunk, become refreshing in our belly. May you be pleasant to us by driving away diseases and pains." The verses are recited while touching one's navel after drinking liquid in a sacrificial procedure. Like Agni and Vāyu, *āpaḥ* (water) also serves as a purifying agent.

Rivers as Goddesses

The rivers and river waters have been treated with great reverence since ancient times. Traditionally, rivers such as Gangā, Yamunā, or Narmadā are worshipped as goddesses. Every morning and evening, on the banks of the Gangā at Haridwār, there is daily "Gangā worship" with lighted lamps in the presence of thousands of devotees, traditional holy music, and chants of mantras. The Sarasvatī River was one of the largest rivers in ancient India before 3000 BCE and drained the Sutlej and the Yamunā. By the end of Harappan culture, the Sarasvatī went dry, bringing about the end of Harappan civilization around 1900 BCE. The Vedic texts are replete with references to the river Sarasvatī and the seas.

River Sarasvatī: Myth or Reality?

Whereas the famous River Gangā is mentioned only once in the *Ṛgveda*, the River Sarasvatī is mentioned at least sixty times. Sarasvatī is now a dry river, but it once flowed all the way from the Himalayas to the ocean across the desert of Rajasthan. Research by Dr Wakankar has verified that the river Sarasvatī changed course at least four times before going completely dry around 1900 BCE. The latest satellite



Water in India: Spiritual and Technical Aspects.
Fig. 3 Archaeological sites along erstwhile Sarasvatī River.

data combined with field archaeological studies have shown that the Ṛgvedic Sarasvatī had stopped being a perennial river long before 3000 BCE (Giri).

Numerous archaeological sites have also been located along the course of this river, thereby confirming Vedic accounts. The Sarasvatī is now dated long before 3000 BCE. This means that the *Ṛgveda* described the geography of North India long before 3000 BCE. This shows that the *Ṛgveda* must have been in existence no later than 3500 BCE.

Tritium (hydrogen isotope) analysis of deep water samples taken by Bhabha Atomic Research Centre (BARC) has provided a broad spectrum dating for the waters of the Sarasvatī river now revealed as groundwater sanctuaries and aquifers. The waters range from 4,000 to 8,000 years BP (Kalyanaraman).

For over 2,000 years (6000–4000 BCE), the Sarasvatī flowed from Bandarpunch massif (Sarasvatī-Rupin glacier confluence at Naitwar in western Garhwal). Figure 3 shows the location of archaeological sites along Sarasvatī river. A remote sensing study of the India desert reveals numerous signatures of palaeochannels. The LANDSAT imagery highlights the course of the River Sarasvatī in Punjab, Haryana, and Rajasthan. The digital enhancement studies of IRS-1C data (1995), combined with radar imagery from European remote sensing satellites ERS I/2, have identified subsurface features and reorganized the palaeochannels beneath the sands of the Thar desert in northwestern India (Paik, 2000).

Ancient Weather Science

In the early Ṛgvedic period, the performance of *Yajnas* (sacrifices) as described in Vedic and Brahmanic literature has some scientific basis. These rituals were performed to ensure timely and adequate rainfall for abundant availability of food, thriving of animal and plant life and for overall human prosperity (Sharma, 2002). The *Yajnas* are very closely related to the evolution of the universe, the solar system, human procreation, occurrence of the seasons, rainfall and life on earth. Several places in the Vedic literature mention that *Yajnas* produce rain which in turn produces food.

The subject of meteorology was dealt with by several ancient sages, including Nārad, Kashyap, Garg, Parāshar, Vasishṭha, Druhin, Brihaspati, Devala, Vajra, Sahadev, and Rishiputra. *Ashṭādhyāyi* (500 BC) by Pāṇini is perhaps one of the earliest post-Vedic works giving information on rainfall measurement and droughts. The *Arthashāstra* (fourth century BC) of *Kauṭilya* gives information on rainfall distribution in the country as well as the methods of its measurement. Several of the old treatises in the form of *Purāṇas*, such as *Matsya Purāṇa*, *Vāyu Purāṇa*, or *Vishṇu Purāṇa*, dealt with the role of the sun in rainfall. Water science, which was initially based on observations, kept being refined and in the post-Vedic period from the third century BC to the sixth century AD, many of the earlier hypotheses came to be perfected. *Kauṭilya* even gave an estimate of the average rainfall in various parts of India.

In Varāhamihira's time, the units of measurement of rainfall were the *pala*, *adhaka*, and *droṇa*. The raingauge was round with a diameter of one *hasta* (18 in., 46 cm) and had marks of *pala*. When it was full, it indicated one *adhak* of rainfall. One *droṇa* means 2–1/2 in. (6.4 cm) of rain. Accordingly to Parashar, the height and diameter of the raingauge should be 8 *angulas* (6 in., 15 cm) and 20 *angulas* (15 in., 38 cm), respectively, and when it is filled to the brim it measures one *adhaka*. Parashar also gives a method of measuring rainfall on the ground. If it measures four cubits on the ground it amounts to one *droṇa*.

Ramanathan (1993) described the significance of rituals and *yagnas* (sacrifices) with their cosmic and scientific interpretations in great details. Observations and measurements of wind, clouds, lightning, thunder, rain, solid precipitation, atmospheric optical phenomena, and agricultural meteorology were presented.

> Just as the water vapours are carried higher in the form of clouds and are condensed in the presence of cold air existing in the sky, similarly one can reach the height of spiritual progress and can get strengthened due to restraining the breath through Yogic exercise (YV 23.26).

> The uniform water passes upwards and downwards in the course of days, clouds give joy to the earth; fires rejoice the heavens (RV 1.164.51).

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Water in India: Spiritual and Technical Aspects. Fig. 4 Major river basins of India.

Water in India: Spiritual and Technical Aspects. Table 1 Basinwise surface water potential of India (cubic km or BCM/year)

Sl. No.	Name of the river basin	Average annual potential in river
1.	Indus (up to Border)	73.31
2.	a) Ganga	525.02
	b) Brahmaputra, Barak & Others	585.60
3.	Godavari	110.54
4.	Krishna	78.12
5.	Cauvery	21.36
6.	Pennar	6.32
7.	East Flowing Rivers Between Mahanadi & Pennar	22.52
8.	East Flowing Rivers Between Pennar and Kanyakumari	16.46
9.	Mahanadi	66.88
10.	Brahmani & Baitarni	28.48
11.	Subernarekha	12.37
12.	Sabarmati	3.81
13.	Mahi	11.02
14.	West Flowing Rivers of Kutch, Sabarmati including Luni	15.10
15.	Narmada	45.64
16.	Tapi	14.88
17.	West Flowing Rivers from Tapi to Tadri	87.41
18.	West Flowing Rivers from Tadri to Kanyakumari	113.53
19.	Area of Inland drainage in Rajasthan desert	NEG.
20.	Minor River Basins Drainage into Bangladesh & Myanmar	31.00
	Total	1869.35

> O all learned people, fully realise your conduct towards different objects of the universe, know ye the electricity that maintains all beautiful objects, the sun, the invisible matter brought into creation, the invigorating vital airs, thus ye become the utilisers of all objects. Homage to him who knows the science of clouds, and to him who knows the science of electricity (*Yajur Veda*).

These hymns give insight into the cloud-seeding phenomenon and occurrence of rains. Various activities occurring in the firmament were well observed and formulated in scientific terms.

Festivals Related to Water

The focal point of Hindu social, cultural, and religious rituals has been water. Indian mythology attaches a lot of importance to the bath (*snāna*) which is mandatory for participation in any important religious occasion. A dip in holy rivers is considered an essential part of Hindu culture, especially on specific occasions such as the solar and lunar eclipses or occasions specified on the basis of specific planetary configurations, which are considered to have a cosmobiological effect on the human body. In a cycle of 12 years, a great Indian festival takes place which is known as Mahā Kumbha or Great Kumbha, where millions assemble and have a dip in the waters of the sacred rivers. Every third year, a smaller water festival called Ardha Kumbha (half Kumbha) is also held, where people congregate at specified places at the banks of the holy rivers (Sharma, 1998). In the mythological scriptures it says that the elixir of life, ambrosia (*amṛt*), that emerged from the churning of the ocean by the gods and demons, splashed out of the pitcher and fell to earth at four places: Haridwār, Prayāg, Ujjain, and Nāsik. These are located on the banks of the River Gangā, at the confluence of the rivers Gangā, Yamunā, and Sarasvatī, on the banks of Shiprā, and on the banks of Godāvarī. A tussle ensued among the gods and the demons for 12 days. During this period the moon did not let the *amṛt* fall from the pitcher, the sun did not let the pitcher crack, Jupiter protected it from demons, and Saturn saved it from being whisked away. Thus, these four planets, which were responsible for saving the pitcher of ambrosia (*amṛt kumbha*), have become an integral part of the Kumbha. Various astronomical conjugations during Kumbha represent various stages of the solar cycle which have a direct influence on human beings and the biosphere. The holding of Kumbha at an interval of 12 years is symbolic of the need for purifying the body by sublimating the inherent vices of the 12 sense organs – five organs of action, five organs of perception, and the mind and the intellect – thereby arousing the six psychic centres or *chakra* separated from each other at distance of 12 *angula* (finger widths) for attaining the *amṛt kumbha* or pitcher of ambrosia (Dixit, 2001).

Water festivals are also celebrated in several other ways in North and South India. It is customary to take a dip in the holy waters of rivers on various auspicious occasions.

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Water Management and Reservoirs in India and Sri Lanka

Andrew M. Bauer, Kathleen D. Morrison

Water storage and distribution technologies have played an important role in the histories of southern India and Sri Lanka. Given the variability in rainfall and the relatively dry conditions over much of the region, it would have been difficult for southern Asian agriculture, diet, and cuisine – particularly the heavy emphasis placed on rice – to have taken the forms they did without the historical development of water management techniques. Moreover, debates about the efficiency, sustainability, and equitability of modern "big dam" projects versus "traditional" methods of providing much-needed domestic and agricultural water continue to dominate Indian politics today. Here, we review historical forms of water management in South India and Sri Lanka, paying particular attention to ancient reservoir systems.

South India and Sri Lanka are dominated by a monsoonal climate, whereby the southwest (or advancing) monsoon generally brings rains between the months of June and October, and the northeast (retreating) monsoon in November and December. In addition to monsoon strength, a variety of topographic factors relate to the distribution and concentration of rainfall across the region. Parts of the southwestern and western coasts of India receive between 3,000 and 3,200 mm of rainfall a year due to the orographic (related to, or caused by, physical geography, such as mountains or sloping terrain) effects of the Western Ghats – South India's most pronounced north–south ranging mountain chain. On the eastern side of the Ghats, however, a rain shadow is created that markedly reduces the amount of precipitation in the central areas of the southern peninsula. For example, Bangalore – the capital city of the modern state of Karnataka – receives an average of around 850 mm of rainfall per year, while Hyderabad – the capital of Andhra Pradesh – receives an average of only 700 mm of rainfall. Indeed, much of the area within the orographic rain shadow of the Western Ghats can be considered a semiarid climate, with average rainfall levels falling as low as 400 mm (India Meteorological Department 1981). Sri Lanka's topography creates a similar pattern in which the southwestern coastal areas receive the bulk of the advancing monsoon and the northern and eastern coasts – largely in the rain shadow of Sri Lanka's central highlands – receive precipitation from the shorter, retreating monsoon. However, it is important to note that actual rainfall in all parts of the Indian peninsula and Sri Lanka can show significant intra- and interannual variability as a result of being dependent on the relative strength of the monsoon.

South Indian and Sri Lankan reservoirs include a range of facilities constructed for the purposes of collecting and storing water, generally for agricultural production. These consist of artificial embankments built across paths of gravity water flow, whether intermittent streams, rivers, or simply slopes that might carry runoff after a monsoon rain. Reservoirs may or may not involve excavation of a basin to contain this water, but they are all storage or storage/distribution devices built on a relatively large-scale and meant to contain water behind an embankment or dam, rather than within its major construction. In this sense, we make a distinction between cisterns (which collect and store water within a rock-cut or other constructed facility), wells (which tap the water table), reservoirs, and tanks. The term "tank" is widespread in the South Asian literature, indiscriminately used to describe almost any water-holding feature, although the term most frequently refers either to reservoirs or to temple tanks – large masonry structures that hold water for ritual ablutions and other functions associated with temple worship. Temple tanks often derive their water from the water table. As such, temple tanks and reservoirs are wholly different in construction, morphology, and operation, similar only in their capacities as water-holding devices and in certain parallels of meaning and symbolism (Morrison in press).

Early Forms of Water Management in South India and Sri Lanka

The earliest culturally significant water catchment features in South India were not constructed reservoirs (in the terminology outlined above), but seasonal pooling basins, or cisterns, which developed naturally from the differential weathering of bedrock. In geomorphological terms, these are known variably as gnammas, rock pools, or weathering pits, and are considered to be characteristic features of residual hills and inselbergs – isolated hills composed of resistant rocks (e.g., granite or gneiss) that express pronounced topographic relief from a surrounding plain – throughout the heavily weathered terrain of the tropics and subtropics (Thomas 1994; see also Porembski and Barthlott 2000). In South Asia, such basins occur on the granitic gneiss hills that characterize much of the central and southern portions of the Indian peninsula, as well as parts of Sri Lanka (e.g., Fernando 1976). Indeed, because granite and gneiss are particularly impermeable rock types, the bare hills of South India generate large volumes of runoff water during the heavy monsoon months that collects in such depressions (Fig. 1).

Water retaining rock pools appear to have taken on cultural significance as early as the Iron Age (1000–500 BCE) in several regions of South India. During this period, mortuary and ritual sites were often marked by the construction of megalith monuments, and a clear cultural association between such ritual constructions and seasonal water basins can be established. Large concentrations of elaborately constructed megaliths – ranging from dolmen cists, stone circles, rock cairns, platform enclosures, stone spirals, and more – appear to have been deliberately placed adjacent to water basins in hilltop locations. Perhaps the most striking example of such an association occurs at the site of Hire Benkal in northern Karnataka, where hundreds of megaliths are found near a broad shallow water basin that likely began as a rock pool and was subsequently

Water Management and Reservoirs in India and Sri Lanka. Fig. 1 A rock pool at VMS 579 – an Iron Age occupational site in the Koppal district of northern Karnataka. Notice the artifact debris in the foreground (photo by Andrew M. Bauer).

Water Management and Reservoirs in India and Sri Lanka. Fig. 2 The site of Hire Benkal, showing dolmen cists on the quarried banks of a basin feature that likely began as a natural rock pool (photo by Andrew M. Bauer).

expanded by quarrying activities for the construction of monuments (Fig. 2).

Additional sites also demonstrate associations between water and culturally significant ritual places. For example, a brick platform structure enclosed by granite boulders at Bandibassapa Camp, also a large megalithic complex in northern Karnataka, appears to have been situated adjacent to a rock pool that was later modified. Moreover, Gordon and Allchin (1955) reported 80 megaliths at a site near Bilebhavi where they identified two "tanks" (cisterns), one of which was "lined with stone slabs." They also recorded a similar construction on a hilltop megalith site near Koppal (Gordon and Allchin 1955: 99). The association between megaliths and water basins has also been noticed in Tamil Nadu and Sri Lanka (cf. Seneviratne 1984; Myrdal-Runebjer 1996), suggesting a ritual importance to water, and possibly a sacred dimension to early water management throughout much of the region.

Although rock pools likely served as the earliest water retention features in the region, it is clear that during the Iron Age humans began deliberately expanding pooling basins and creating them through activities of quarrying, excavation, and the construction of embankments, or bunds. This is evidenced not only at megalithic ritual sites, such as Hire Benkal, but also at settlement sites, where both cobble lined basins and constructed bunds are present. At the Iron Age habitation site of Kadebakele (northern Karnataka), for example, inhabitants modified the drainage pattern on top of a granitic hill to form a water catchment basin. Excavations in this reservoir show that it collected and held water for only part of the year, partially a consequence of the reservoir's relatively small catchment area of .027 km^2. The facility also experienced major drying episodes as well as significant siltation. Nevertheless, it certainly provided much-needed water to local residents at certain times.

It is difficult to say to what extent these early water retention features may have supported cultivation. Most are quite small and lack provisions for water distribution necessary for large-scale agriculture. Moreover, they are often perched atop high hills with little cultivable land. However, some early reservoirs do occur within natural drainage ways, occasionally in association with check dams and at the base of topographic features where seasonal water could potentially be pooled for crop production. In fact, Devaraj et al. (1995: 66) report "interlaced, hydraulically laminated" deposits behind a "rammed" earthen construction near the base of a granite outcrop at Watgal – a Neolithic (3000–1000 BCE) to Iron Age (1000–500 BCE) period settlement site in northern Karnataka.[1] It is difficult to characterize the entire range of variability in form and function of early water management constructions without more systematic work. Indeed, few regions have been systematically studied, and the patterns described above may not hold true across the entire region. Nevertheless, it is clear that water retention techniques began to be practiced in a variety of settings during the Iron Age (see also Allchin 1954). In addition, the development of water management technology during this period generally coincided with the introduction of new cultigens – including rice cultivation – suggesting that water retaining features became increasingly important to

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[1] However, it is important to note that the authors do not identify this feature as a reservoir, or attribute it with any water retaining "function."

agricultural production by the end of the first millennium BCE.

In the first millennium AD there is stronger evidence for the construction of larger reservoirs that were used to meet the hydrological requirements of cultivation. A series of reservoir walls have been reported in the environs surrounding Sanchi – a well-known Buddhist monastic site in west-central Madhya Pradesh spanning the third century BCE to the twelfth century AD. These reservoir features are built of earthen embankments reinforced by stone masonry, with dams reaching nearly 6 m in height and expanding across drainage valleys, in some cases exceeding 1 km in length. Moreover, catchment areas range from 0.74 to 17 km^2 (Shaw and Sutcliffe 2001), potentially damming considerably more water than the Iron Age reservoirs discussed above. Artifact associations, as well as the proximity of the embankments to the site of Sanchi, have allowed scholars to suggest that several of these features were constructed as early as the second century BCE, while others were built throughout the first millennium AD (Marshall 1940: 13; Shaw and Sutcliffe 2001).

Although dating features such as reservoir walls remain problematic without direct geochronological assessment (e.g., radiocarbon, optically stimulated luminescence, etc.) or inscriptional data, textual references from the Early Historic Period suggest that reservoir construction was prevalent in some parts of India, and in South Asia more generally, during this time. For example, Chakravarti's (1998) analysis of the *Arthaśāstra* – an economic and political treatise composed sometime in the late centuries BCE or early centuries AD – suggests that Mauryan rulers (ca. 324–185 BCE) were concerned with establishing irrigation works. Moreover, numerous inscriptions and textual references indicate that the construction of reservoirs and irrigation facilities underwent remarkable development in Sri Lanka during the Early Historic Period, particularly on the island's drier north and east sides. Northeast of Sigiriya, the Minneriya reservoir built during the reign of Mahasena (AD 276–303) is particularly noteworthy. This reservoir – fed by a canal as well as surface runoff – consisted of an embankment nearly 2 km in length and at places exceeded over 13 m in height. Inscriptions dated to the reign of Mahasena's successor speak of "three harvests of [rice] paddy per year," suggesting a marked impact on agricultural production (Gunawardana 1971: 8).

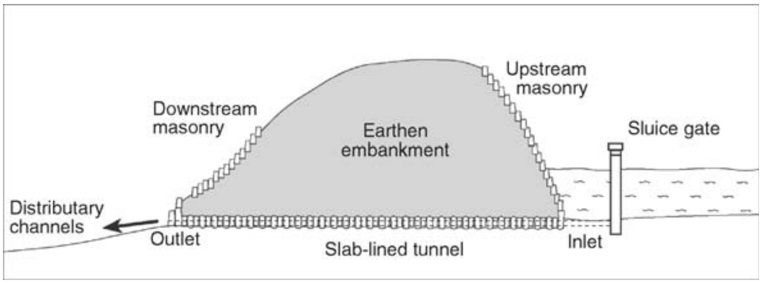
Middle Period Reservoirs: The "Traditional" System

It should be clear from the above discussion that reservoirs and water storage features have a long history in South India, and South Asia more generally. However, the proliferation of large reservoir construction for the purposes of agricultural intensification is most salient in South India after the Early Historic Period, and in Sri Lanka only slightly earlier.

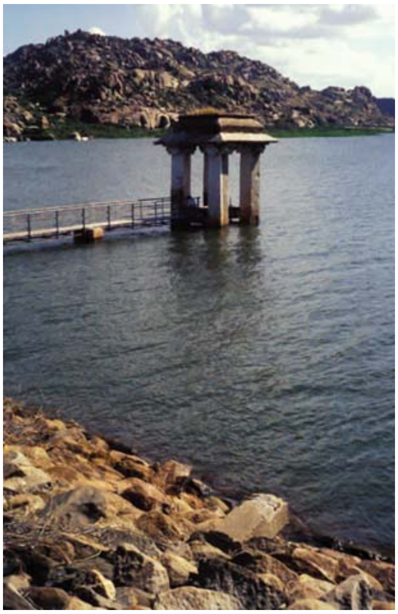
Numerous textual sources clearly indicate that reservoirs played an important role in the Early Middle Period (AD 500–1300). Although small dam-and-basin facilities for water impoundment continued to be built and used, Middle Period reservoirs typically consist of masonry-faced earthen dams thrown up across valleys, at the base of hills, and in other locations where seasonal runoff and small streams could be captured (Fig. 3) (Morrison 1993, in press). Like the Minneriya reservoir in Sri Lanka, some were supplied by canals, which took off via diversion weirs or anicuts, from perennial rivers or intermittent streams. Water was moved downstream from reservoirs to agricultural fields through masonry-lined tunnels under the embankments, which were regulated by sluice gates (Figs. 4 and 5). Some water was also released over specially constructed waste weirs, facilities which range from boulder-filled cuts to elaborately built spillways (Fig. 6). Although the focus was clearly on the storage and downstream distribution of water, reservoir beds were also sometimes used for cultivation and reservoirs served as important sources of fish, silt and clay, and water for livestock. Reservoirs were also used to raise the water table around them, an important function even when the bed failed to fill. In fact, we have documented a consistent (but not universal) pattern of wells down-slope from sluice gates (Morrison in press).

Reservoirs were particularly important in the far south, in present-day Tamil Nadu, where many of them were supplied by river-fed canals (Ludden 1999).

Water Management and Reservoirs in India and Sri Lanka. Fig. 3 A Middle Period reservoir embankment and sluice gate used to dam a valley below the Iron Age site of Hire Benkal (photo by Andrew M. Bauer).



Water Management and Reservoirs in India and Sri Lanka. Fig. 4 Diagrammatic cross-section of a reservoir embankment and sluice gate.



Water Management and Reservoirs in India and Sri Lanka. Fig. 5 The northern sluice of the Daroji reservoir, south of Vijayanagara. This "double sluice" construction became prominent in the sixteenth century, when the Daroji embankment was constructed. This sluice and reservoir have been maintained and continue to operate (photo by Kathleen D. Morrison).

Water Management and Reservoirs in India and Sri Lanka. Fig. 6 Masonry waste weir, or spillway, to regulate high water levels at the edge of a Middle Period reservoir embankment near the village of Kurugodu (photo by Kathleen D. Morrison).

There it is possible to see perhaps the greatest elaboration of the so-called "system reservoirs" – long chains of reservoir facilities that flow one into the other, linking large areas into tightly knit watersheds (Sharma and Sharma 1990; see also Mosse 2003). Unfortunately, none of these systems has been specifically analyzed on the ground to determine precise construction sequences, so although we know of many specific single-reservoir projects dating as early as the seventh century AD, we cannot say exactly how the overall system functioned at this time or even how much of the landscape was under reservoir irrigation. It should be noted, however, that Early Middle Period reservoirs, "traditional" by any reckoning, ranged widely in size from very small ponds to vast "seas," the latter falling well within the contemporary definition of a "large dam."[2]

Similar to the "systems reservoirs" of Tamil Nadu, large Sri Lankan Early Middle Period reservoirs were linked through vast networks of canals. The Minneriya reservoir, for example, was connected to other facilities via the construction of a "great canal" during the reign of Aggabodhi I (ca. AD 571–604), and composite maps of the irrigation facilities around Sigiriya show that it fed at least two large reservoirs – the Kaudulla and Kantalai reservoirs. Moreover, detailed survey has shown that smaller dam-and-basin features were also probably constructed and maintained throughout the period (Myrdal-Runebjer 1996). Again, it is difficult to know how the overall systems functioned simulta-

[2] Crest length $\geq$ 500 m, maximum flood discharge $\geq$ 2,000 $m^3 s^{-1}$, "especially difficult foundation problems" or "unusual design" (ICOLD World Register of Dams 1998).

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neously. However, it is clear that Middle Period rulers and elite made demonstrative efforts to construct new irrigation facilities and repair older ones. In fact, the Minneriya inflow and outflow canals were repaired at least several times in the early centuries of the second millennium AD (Myrdal-Runebjer 1996; see also Brohier 1934; Gunawardana 1971).

This pattern of extensive reservoir use in Sri Lanka and the far south of the Indian peninsula contrasts with that of drier regions in the northern interior of the subcontinent (Karnataka and parts of Andhra Pradesh). In these northern regions, reservoirs were (and are) almost exclusively runoff-fed and, given lower rainfall, they are generally not as closely spaced as those of the southern Tamil country. Still, many regions saw the use of both system and isolated reservoirs. In the area we have studied in northern Karnataka, reservoirs seem to have been only a minor component of Early Middle Period agricultural strategies. However, by the Late Middle Period (1300–1700 AD), and especially with the expansion of the large but loosely knit empire of Vijayanagara (ca. AD 1330–1600) across much of the peninsula, reservoir irrigation expanded considerably, especially in the drier zones where it had previously been limited. In and around the eponymous capital city of this empire, urban foundations in the early fourteenth century and the subsequent expansion of settlement and population explosion in the region propelled reservoirs into increasingly important components of larger agrarian and political strategies (Fig. 7). Important from the start of the Vijayanagara period, reservoirs also constituted a key form of agricultural intensification in the sixteenth century, or Late Vijayanagara period, especially in regions where canal irrigation was not feasible (Morrison 1995, 2001).

Reservoirs played variable roles in the processes of Vijayanagara agricultural intensification and change; this variation was structured as much by political factors and settlement dynamics as by environmental variables such as runoff and soil conditions. What is common to most parts of the urban hinterland, however, is the way in which the vast majority of reservoirs fell out of use after (in some cases, during) the Vijayanagara period. Very few of the reservoirs from the original system still effectively function, though there are a few notable "living" reservoirs with long histories of maintenance and reconstruction (Morrison 1993, 1995). For example, the Daroji reservoir, the terminus of one of the largest systems in our study area, continues to collect runoff from a catchment area of 955 km^2 and provides water for downstream agricultural fields (Fig. 8).

Research on Middle Period reservoirs includes analyses of pollen and charcoal from reservoir sediments (which allow the reconstruction of fire and vegetation histories), sedimentological studies of reservoir fill and changes to erosional regimes and local hydrology, and stylistic analyses of sluice and embankment construction (e.g., Morrison 1994, 1995; Myrdal-Runebjer 1994, 1996). In addition, we have also considered tens of thousands of textual and inscriptional records describing facility construction and

Water Management and Reservoirs in India and Sri Lanka. Fig. 7 Small Middle Period reservoir and sluice gate in the Daroji Valley, south of Vijayanagara (photo by Kathleen D. Morrison).

Water Management and Reservoirs in India and Sri Lanka. Fig. 8 ASTER satellite image of the Daroji reservoir first built in the sixteenth century, south of Vijayanagara. Notice the strong growth of agricultural crops indicated by the reflection of near-infrared wavelengths (shown here in red) downstream from the embankment. Vegetation growth is also occurring on the edges of the reservoir as receding water exposes moisture retaining sediments (data originally obtained from NASA).

maintenance as well as conflicts over water, land, labor, and rule (Kotraiah 1995; Morrison 1995; Morrison and Lycett 1994, 1997). All of these diverse lines of evidence suggest that Middle Period reservoirs, like their contemporary and colonial counterparts (Mosse 2003: 45–46), were highly unreliable sources of irrigation. Runoff-fed reservoirs, in particular, may fail to fill in dry years; in the drier districts, this meant not only that reservoirs could usually not support wet crops such as rice, but also that dry crops such as millets might not be assisted by the facility. The situation was somewhat better in areas of higher rainfall, but everywhere in southern India reservoirs are marked by high evaporation rates, high siltation rates, and ongoing maintenance challenges (Fig. 9).

Reservoirs, Politics, and Contemporary Development

Across much of South Asia, contemporary "big dam" projects have been cast as the legacies of high modernist social and environmental engineering (cf. Gadgil and Guha 2000; Scott 1998). In India, well-organized and highly visible social protests have been made against specific projects such as the Sardar Sarovar project and others along the Narmada River. Often, antidam groups suggest that the answer to sustainable and equable development lies in a return to a "traditional" system of technology and management. It is not our purpose to argue the case for "modern" or "traditional" forms of water distribution. Rather, we wish to suggest that arguments that hinge on the dichotomies of large/small, equitable/inequitable, and political/apolitical that often accompany distinctions between "modern" and "traditional" forms of water management are inappropriate.

The notion that large political dam projects are entirely a product of modernity is decidedly incorrect. This is no clearer than in South India, where some Middle Period reservoirs were created with embankments more than 3.5 km in length and over 15 m in height. As already noted, the Daroji reservoir in northern Karnataka pooled runoff over a total catchment area of nearly 1,000 km^2; however, size alone is not the issue. Both small and large reservoirs were deeply political projects, tied to networks of patronage and power. Middle Period reservoir construction was sponsored by a wide range of political leaders from kings (rarely) to local chiefs (commonly) and was also connected with Hindu temples in a number of ways (Morrison 1995; Morrison and Lycett 1994, 1997). Moreover, even during the Iron Age and Early Historic Periods, shifts from a reliance on rain-fed agriculture to reservoir irrigation would have produced a new material order on the landscape that was necessarily related to sociopolitical fields. Indeed, the questions – How was labor mobilized? Who had access to irrigation water? And how was this decided? – are entirely appropriate in examining the entire history of water management. The answers to these questions undoubtedly had sociopolitical ramifications for ancient inhabitants. This may have especially been the case when irrigation accompanied the introduction of new cultigens and cultural values of cuisine shifted. It is not difficult to imagine the profound social consequences of being a dry-farming millet producer/consumer versus a wet-farming rice producer/consumer when rice was a high status cultigen and the preferred donation to Hindu temple gods during the Middle Period, for example.

Water Management and Reservoirs in India and Sri Lanka. Fig. 9 Photo showing the accumulation of an estimated 2–3 m of silt and clay, to near the top of a sluice gate. This reservoir is adjacent to the village of Avinamodugu, south of Vijayanagara (photo by Kathleen D. Morrison).

The above considerations of the (un)reliability and the political nature of historic reservoirs of South India and Sri Lanka are not to suggest that these impressive systems have no contemporary value with regard to (re) developing water management strategies. Quite the opposite is true: work on the 3,000-year history of irrigation in southern India shows both success and failure in equal measure, portents for a reasonably hopeful future. Thus, although there is no simple solution to the water problems of the dry tropics of South Asia, surely an informed perspective on the actual historical experiences of the region must provide a more secure basis for future planning than either a romantic and unrealistic view of "tradition" or a blind faith in "modern" science and technology.

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Water Management in Peru

C. R. Ortloff

The Chimu Empire of ancient South America in the time period between 900–1480 CE dominated the north Peruvian coast from the Santa to the Lambeyeque Valleys west of the Andean Cordilera Negra mountain range. This region, in terms of present-day geographical locations, extended just north of the Peruvian capital city of Lima to the Ecuadorian border and eastward from the Pacific Ocean coast to the eastern slopes of the Andes. From the central administrative center at Chan Chan in the Moche Valley, successive generations of Chimu rulers exercised political and economic control of adjacent valleys through administrative centers charged with overseeing and maximizing agricultural production and development. Within the territorial domain of the empire, many of the westward-running rivers leading runoff water from highland Andean rainfall collection zones to fertile coastal fluvial valleys were intercepted and redistributed through extensive canal distribution systems to irrigate agricultural fields. Many valleys even today still contain well preserved canal networks from this era as land under cultivation by the Chimu far exceeded present-day cultivation areas by perhaps as much as 50 per cent. While only a few of the ancient valley irrigation systems have been extensively explored, mapped and analyzed to any extent (Eling 1986; Kosok 1965; Ortloff et al. 1982, 1985; Ortloff 1988, 1993), some novel canal hydraulic control features have been recently discovered that warrant analysis as they provide a window into the level of hydraulic science existing within the Chimu empire of ancient South America.

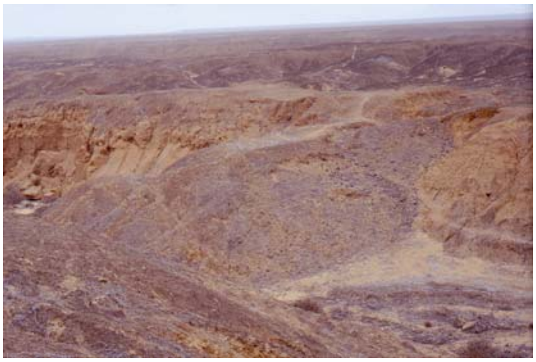
Since most major valleys under Chimu control showed evidence of massive state-sponsored, hydraulic canal infrastructures to support irrigation agriculture, it follows that a hydraulic science was co-developed to provide tailored flow rate canals to supply field systems distant from river inlets. As considerations of soil and crop types, crop water demands, alternate field system watering strategies, valley topography and defense from drought and large rainfall runoff events influence canal design and placement, an accompanying hydraulic science with flexibility to design and modify canals according to these considerations is expected in the archaeological record. Most probably, cumulative observations of water flow phenomena over time served to provide a database for empirical design principles used for canal layout and design. Canal volumetric flow rate relies on inlet geometry, bed slope, canal cross-section, wall roughness and subcritical, critical, and supercritical flow characterization. Allied technical disciplines related to route layout, surveying, water delivery sequencing and water routing through multiple canal branches are additional key technologies vital to understanding Chimu hydraulics practice. While investigation of all aspects of applied Chimu hydraulic science would give a complete picture of their technology base, the present investigation is focused on but one facet of the Chimu engineering repertoire: hydraulic control systems.

This entry details an investigation of a recently discovered canal hydraulic feature of the Chimu Talambo-Farfán Canal located in the Jequetepeque Valley of northern Peru. While the remains of the canal system are of late Chimu origin due to association with the Chimu site of Farfán, some upstream versions of canal segments may be associated with earlier valley occupation by Gallinazo and late period Moche occupants. For the present analysis, however, only the last Chimu phase of canal construction is considered.

Analysis Results

The Talambo-Farfán Canal originates far upstream in the valley neck of the Jequetepeque River and passes late hillside Chimu occupation zones in the Talambo region through a series of aqueducts and deep canal cuts through upvalley low hills before finally emerging onto the agricultural plains east of Farfán. The canal was further extended to provide water to the extensive agricultural field zones directly south of the Chimu mountain redoubt of Farfán Sur. In the canal extension region, deep *quebradas* (canyons) were formed over time from successive El Niño rainfall runoff events sculpting deep erosion channels into the soft soil deposits that formed natural obstacles to canal extension. In order to bridge the multiple quebradas, a series of three large earth-fill aqueduct structures and many small aqueducts were constructed to extend the canal to the vast Pampa de Faclo bordering the site of Pacatnamú. Two of these (largely destroyed) quebrada-crossing aqueducts are shown in Figs. 1 and 2; the Hoya Hondada aqueduct is the largest and final aqueduct in the downstream sequence and is shown in Figs. 3–5.

Water Management in Peru. Fig. 1 View of one of the three destroyed aqueducts breaching a deep, erosionally-incised quebrada upstream from the Hoya Hondada Aqueduct. Photo by C. R. Ortloff.



Water Management in Peru. Fig. 2 Another view of a further destroyed aqueduct in the upstream sequence from the Hoya Hondada Aqueduct. Photo by C. R. Ortloff.

Water Management in Peru. Fig. 3 View of the low Hoya Hondada aqueduct across the wide quebrada. Photo by C. R. Ortloff.

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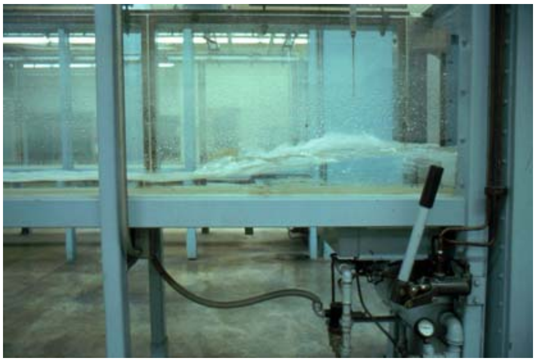
Water Management in Peru. Fig. 4 Alternate view of the Hoya Hondada aqueduct. Photo by C. R. Ortloff.

Water Management in Peru. Fig. 5 View of the cross-section of the Hoya Hondada aqueduct at the destroyed south end; height of the channel approximately 5 m from ground level. Photo by C. R. Ortloff.



Water Management in Peru. Fig. 6 Demonstration of a hydraulic jump in a hydraulic test channel induced by a supercritical flow interacting with a plate obstacle; a similar hydraulic phenomena is induced at the channel intersection point of the steep chute and low slope Hoya Hondada aqueduct channel. Photo by C. R. Ortloff.

Due to the much larger depth and width of the Hoya Hondada quebrada as compared to upstream quebradas, aqueduct design changes from upstream high fill height designs breaching narrow and deep gorges to maintain slope to a long, low height aqueduct deep within the quebrada with a steep 40 degree approach chute from the southernmost upstream bluff. After the canal passes over this low aqueduct, it continues to the downstream northern sidewall of the Hoya Hondada quebrada to field systems located on the southern boundary of Pampa de Faclo approximately 8 km south of the ancient Moche-Chimu religious center at Pacatnamú. The intent of the canal extension through difficult terrain north and west of Farfán Sur was apparently to provide water to settlements and field systems in the south part of the pampa east of Pacatmanú. While further canal extension to the city limits of Pacatnamú may have been the ultimate intent of the canal builders, traces of a continuous connection path to the many canal fragments on the Pampa de Faclo are yet to be discovered.

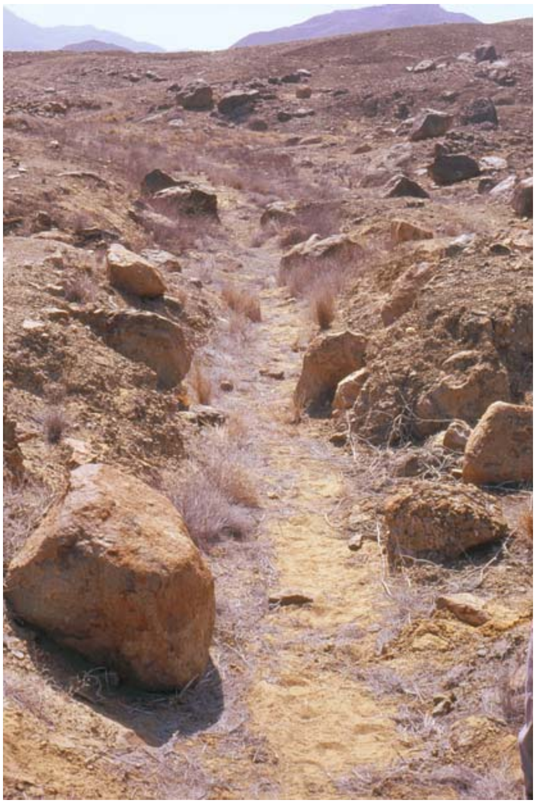
The canal and aqueduct design within the Hoya Hondada quebrada area contains many novel hydraulic features indicative of the state of Chimu hydraulic knowledge. As opposed to using a massive earth-fill aqueduct that would span the 150 m width and 20 m height to connect opposite sides of the quebrada with a constant slope canal, a 5 m high aqueduct is constructed low in the quebrada with a 25 m long steep chute joining the upstream high elevation part of the canal to the downstream low aqueduct. This alternate design eliminates the possibility of a massive high dam structure trapping a large height of quebrada rainfall runoff behind it that would constitute a dam breakage hazard to downstream occupation areas. The low dam design, should breakthrough occur, would be easily repairable due to its low volume of fill material and contain relatively less impounded water than the alternate design. While some Chimu aqueducts spanning quebradas contained culverts or boulder bases to let water pass underneath to alleviate water damming during heavy rainfall events, use of a low aqueduct height design reduced backwater hydrostatic pressure effects that lowered destructive transverse forces that could lead to breakthrough failure.

Continuing, with no upstream hydraulic controls, the effect of a high velocity, high volumetric flow rate down the steep 40-degree downward-sloped chute to the low slope aqueduct would be to create a massive hydraulic jump at the angle-change junction. Fig. 6 shows a typical hydraulic jump created by an obstacle placed in a high velocity, supercritical flow – in this case, the hydraulic jump is typical of that resulting from the effect of the rapid flow down the steep chute – low slope aqueduct junction. The severity and height of a large hydraulic jump is sufficient to destroy the aqueduct by turbulent erosion's acting on the unlined aqueduct structure unless a hydraulic control is in place upstream of the aqueduct to dissipate stream energy, lower stream velocity and/or remove excess water from the canal by a side weir – which is another mode of stream energy reduction. The height of the hydraulic jump also would cause sidewall overflow from the aqueduct leading to precious irrigation water loss for downstream field systems. By lowering the channel water velocity and/or volumetric flow rate, the height of the downstream hydraulic jump can be reduced to a level that does not imperil the integrity of the aqueduct structure or cause sidewall overflow water loss problems. This then constitutes the hydraulic design problem faced by Chimu engineers.

The channel upstream of the Hoya Hondada aqueduct shows that an energy dissipation hydraulic structure had been installed to influence flow leading on to the aqueduct. Figs. 7 and 8 show a ground view of this hydraulic control structure in its unexcavated state. The hydraulic structure consists of two pairs of opposing boulders with a 70 cm separation distance between boulders and with a 13.2 m downstream separation distance between boulder pairs. The channel containing this structure also had variations in width and sidewall angle. A FLOW-3D computer model (FLOW-3D 2004) incorporating field measured channel geometry is shown in Fig. 9. In the distance between the boulder pairs, a side overflow weir that activates when water height exceeds a given height is in place that led to a channel that guided overflow water into the quebrada downstream of the Hoya Hondada aqueduct. The hydraulic function of the control structure is next described by use of numerical solution of the governing equations of fluid flow; results of the solutions indicate the free surface shape and internal velocity within the channel and provide the basis to understand the hydraulic functioning of the control section.

The first upstream choke (defined as the open separation zone between boulder pairs) apparently forms a hydraulic jump at incoming stream velocities past about 7 m/s while the downstream choke apparently forms a hydraulic jump at inlet velocities about 3 to 4 m/s. The second downstream choke is therefore controlling as it actives first at a lower limiting velocity. For all cases, an increase in water velocity occurs in the zone downstream of the first upstream choke due to

Water Management in Peru. Fig. 7 Unexcavated view of the hydraulic control structure upstream of the chute and the Hoya Hondada aqueduct; structure consists of opposing boulder pairs in the main channel separated by a 13.2 m distance. Photo by C. R. Ortloff.



Water Management in Peru. Fig. 8 Ground view of the hydraulic control structure upstream of the chute and Hoya Hondada aqueduct. Photo by C. R. Ortloff.

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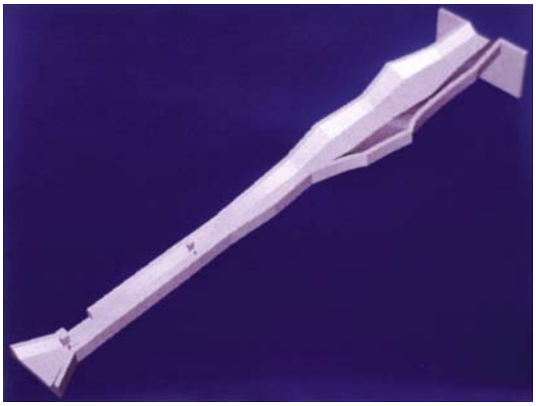
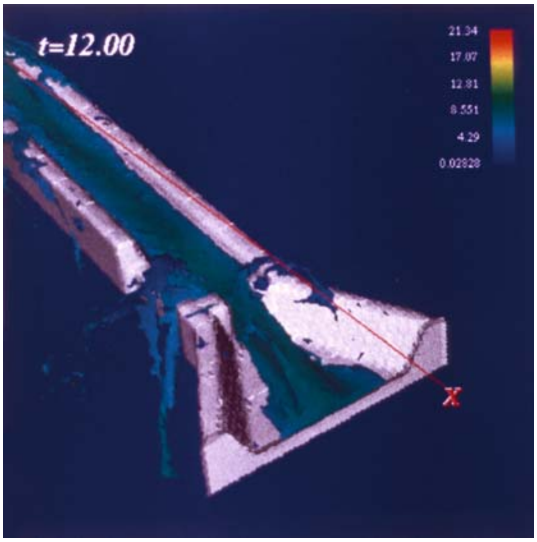
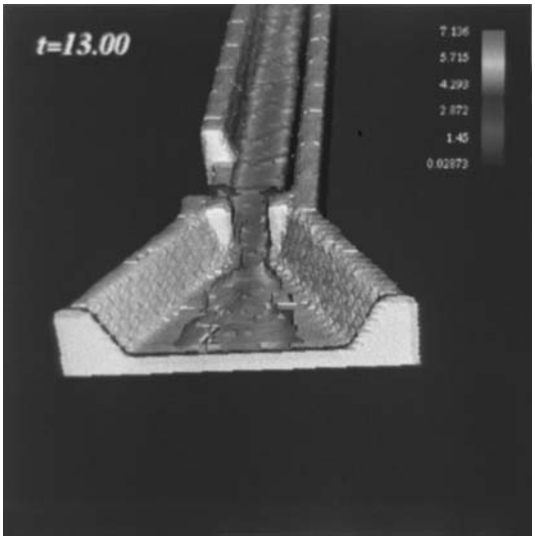


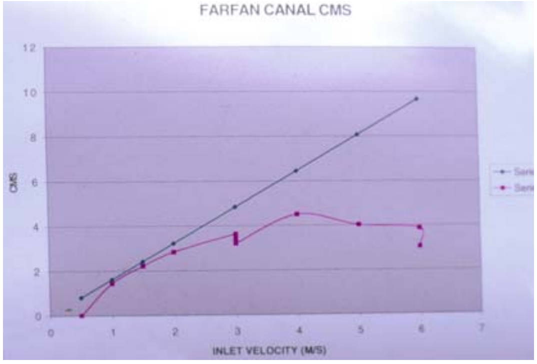
Water Management in Peru. Fig. 9 FLOW-3D computer model of the excavated hydraulic control section upstream of the chute and Hoya Hondada aqueduct from measured field data. Note the presence of the side overflow weir. Photo by C. R. Ortloff.



Water Management in Peru. Fig. 10 Solution results for water free surface geometry for a channel flow rate exceeding 3 m^3/sec; note the spillage over the side weir from the action of the downstream choke limiting the transmitted flow rate on to the Hoya Hondada Aqueduct. Photo by C. R. Ortloff.



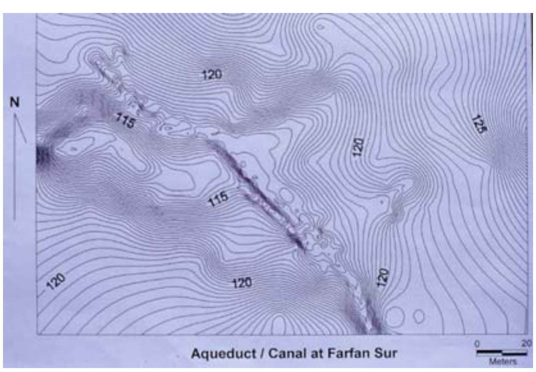
Water Management in Peru. Fig. 11 Solution results for a channel flow rate less than 3 m^3/sec; note that flow is fully contained within the channel and the side overflow weir is not activated. Photo by C. R. Ortloff.



Water Management in Peru. Fig. 12 Plot of flow rate (m^3/sec) into the control structure vs. flow rate exiting: the difference is the flow exiting over the side weir. Note that transmitted flow rate is limited past 3 m^3/sec due to the action of the choke system and overflow weir activation. Photo by C. R. Ortloff.

water gravitational acceleration on a hydraulically steep slope influenced by expansive channel cross-sectional geometry changes. These velocity changes account for the different hydraulic behavior of each choke. Since flow into the second choke is supercritical over the range of subcritical input flow rates, the second choke forms a hydraulic jump and the flow rate is limited by critical conditions at the throat. As the choked flow rate of the downstream choke is less than that of the upstream choke, the flow rate difference results in a water height change between chokes that activates water overflow from the side weir. The overflow flow rate is equal to the volumetric flow rate difference between up- and downstream chokes. Fig. 10 shows side weir over-spillage typical of inlet flows exceeding about 7 m^3/s; Fig. 11 shows conditions obtaining when the inlet volumetric flow rate is less than 3 m^3/s and the side weir is inactive. Fig. 12 shows that the flow rate passed on to the Hoya Hondada aqueduct is automatically altered past 3 m^3/sec inlet flow due to activation of the overflow weir. The upper curve represents a linear condition present when no control section is present and the input flow rate is equal to the output flow rate in the channel. The lower curve indicates that when the control section is in place, the output flow exiting from the control section is reduced by the side weir overflow to a limiting value about equal to 3 m^3/s. The limiting flow rate of 3 m^3/s then ultimately limits the height of the downstream hydraulic jump before the aqueduct to acceptable design values to control turbulence generation and contain the flow in the aqueduct channel without sidewall overflow.

The double choke system described is augmented with yet a further downstream energy dissipation system on the steep sloped chute. The Fig. 13 contour map, which shows the channel depression where the control section exists, contains a leadoff bifurcation channel that subtracts a fraction of the water downstream of the hydraulic control structure and leads it around a small hill into a low slope channel. This flow rejoins the main channel flow at a downstream junction point. The lower subcritical velocity stream from the lower slope channel acting on the main supercritical stream at the channel junction creates a further energy dissipating oblique hydraulic jump in the channel. The hydraulic jump converts velocity kinetic energy into random turbulent and potential, height change energy. This has the effect of subtracting further energy from the stream approaching the chute junction zone. Note that no energy gain exists as subtracted flow from the main channel is added back into the downstream flow to maintain the constant flow rate. The net effect of the two energy reduction controls – the first from subtracting energetic water by means of the overflow weir, the second from hydraulic jump energy dissipation – is to limit the channel flow rate and also reduce entry velocity onto the Hoya Hondada aqueduct to limit hydraulic jump erosive and overflow damage. Although a large part of the steep slope channel is no longer extant, there is indication that stones placed in the chute bed provided yet a further energy dissipation mechanism to reduce stream velocity. The totality of these hydraulic controls then serve to limit erosion damage to the Hoya Hondada aqueduct – particularly under El Niño conditions. For example, as the coastal area is frequently subject to massive El Niño rainfall runoff from the nearby Cerro Faclo mountain range, large canal flow rates arising from water washing into the canal could easily produce excessive canal flow conditions beyond the design flow rate. An excessive flow rate could destroy the Hoya Hondada aqueduct by creating a massive hydraulic jump at the channel-aqueduct junction. By diverting water over the weir into a channel leading to the downstream side of the aqueduct together with use of additional energy dissipation controls, excess water and energy is removed from the canal to provide a protective hydraulic feature for the aqueduct.



Water Management in Peru. Fig. 13 View of a minor hydraulic control system found extensively in the Pampa Faclo field system. The presence of a dual, opposing stone choke downstream of a steep chute creates a hydraulic jump ahead of the choke. This reduces the velocity of water entering a field system to promote gradual water absorption into the soil over time. The inlet from the main canal is tailored only to let a certain amount of water into the chute to make the system work as planned, indicating careful design of this irrigation system control. Photo by C. R. Ortloff.

As the canal can transport up to 3 m^3/s before weir overflow activation, this flow rate represents a sustainable maximum flow value to a location 35 km from the river inlet. This flow rate may be available to the Pampa Faclo fields and settlements, despite evaporation and seepage losses, by blocking all other canal branches from the main canal to temporarily direct all flow to the Pampa Faclo. As the needed water volume delivered through each canal branch to a field sector was a known quantity to sustain crops in that sector according to their importance, yield, and water requirements, the assignment of water volumes therefore was metered for maximum agricultural productivity effect. As settlements on the outlying southern section of Pampa Faclo were somewhat remote from the Farfán center and field systems discovered to date rather limited in size, it may be surmised that water resources reserved for this sector were proportional to its potential expansion and importance. The fact that water could be directed to this secondary location perhaps indicates that further expansion of the area's agricultural potential was anticipated but still in the construction phase. The major effort to construct multiple elaborate aqueduct structures to bring water to this zone through difficult topography perhaps indicated that a valuable agricultural resource in the Pampa Faclo land area overrode labor-to-build considerations – perhaps due to population increase pressures.

The transition to Chimu from Moche eras in the seventh century CE sees a vast expansion of population, cities, administrative centers, agricultural and settlement zones as well as a development of hydraulic technology that permits intra- and intervalley canal network development to exploit available agricultural zones. The success of the agricultural program, supported by a knowledge base of technical achievements, undoubtedly underlies this expansion. The present study adds an example of an application of hydraulic technology that played a role to protect critical aqueduct structures from flood damage to ensure field system survival through time. Other examples of steep-slope channel constrictions formed by opposing stones set with a narrow opening are numerous within the Farfán field system area (Fig. 13) indicate an understanding of creative use of hydraulics knowledge to enhance the efficient use of field systems. Basically channel constrictions of this type create a hydraulic jump ahead of a constriction with a high height, low velocity flow leaving the throat that flows slowly into downstream distributive channels within the field system to regulate water seepage rates into the soil. The channel size, slope and inlet configuration supplying water to maintain a stable hydraulic jump without overflow must therefore be intelligently constructed to allow just a sufficient flow rate for that purpose. This design capability appears to have been well understood by Chimu engineers as demonstrated by many canal design examples.

Examples of hydraulic controls in the form of flow rate limiting and velocity-reducing hydraulic structures point to a yet little explored creative aspect of Chimu irrigation agricultural practice and the Chimu hydraulic science knowledge base. While examples illustrating applications of Chimu hydraulics engineering are somewhat limited by scant exploration and analysis to date, undoubtedly more remains to be discovered as focus is given to exploration and analysis of hydraulic features. By computer analysis of such systems, aspects of Chimu hydraulic science will be revealed and point to a new evaluation of the contribution of indigenous South American cultures to the hydraulic sciences.

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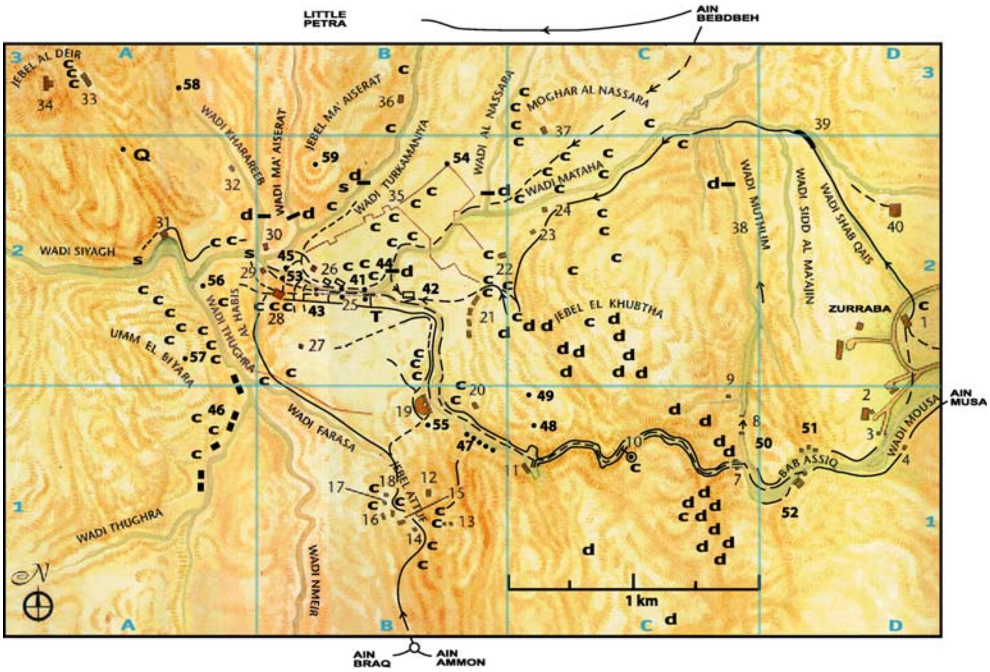
Water Management in Petra

C. R. Ortloff

Many scholars have studied the political history of Petra (Taylor 2001; Guzzo and Schneider 2002; Glueck 1959, 1965; Hammond 1973; Levy 1999; Auge and Denzer 2000; Bowersock 1983; Bourbon 1999; Markoe 2003). Despite the fact that control of water is essential to an understanding of life in the desert, there has been little scholarship on hydraulic engineering at this site. Figure 1 shows details of the supply and distribution system leading water to the urban core of Petra. Numbered locations denote major buildings, temples, and site features listed in the Appendix. Shown are major dams (d-), minor dams (d), cisterns (c), water distribution tanks (T), and springs (S). The grid system (A,B,C;1,2,3) serves to define an area coordinate system composed of 1.0 km^2 grid boxes to locate various features mentioned in the text.

The urban core of Petra lies in a valley surrounded by high mountainous terrain. Seasonal rainfall runoff passes into the valley through many canyon streambeds (wadis) and drains out through Wadi Siyagh (A;2). While water storage is a partial key to the city's survival, a number of springs internal and external to the city (Fig. 1: Ain Mousa, Ain Umm Sar'ab, Ain Braq, Ain Dibdiba, Ain Ammon, al Beidha, Ain Bebdbeh) provided water channeled and/or piped to the urban center.

The main Petra water supply originated from the Ain Mousa spring about 7.0 km east of the town of Wadi Mousa (Fig. 1, D;1) combined with waters of the minor Ain Umm Sar'ab spring; this supply still serves the associated tourist complex (2), (3) located outside of the Siq (C;1) entrance (10). The Siq is a 2 km long, narrow passage through high mountains bordering the eastern part of the city core area. Early phases of water supply utilized Ain Mousa spring water channeled through the Siq (dashed line, 29, B;2) to the urban core of the city as far as Q'asr al Bint (29) with final drainage into the Wadi Siyagh (A;2). Due to dam and flood bypass tunnel construction at the Siq entrance and infilling and paving of the Siq floor both in ancient and modern times to reduce flooding, the channel now lies under the current pavement surface attributed to Nabataean construction under Aretas IV and later



Water Management in Petra. Fig. 1 Petra site features and water distribution systems.

Roman paving efforts. Recent excavations in front of the Treasury (11, C;1) have revealed remnants of this early open channel. While this channel provided water to early, low population phases of the city, the later concentration of urban settlement areas north and south of Wadi Mousa (B;2) represented a transition towards full city status with a cosmopolitan society involved in trade and commerce. With demands to increase water supply to spreading urban settlement areas resulting from population increase and a desire to match the city's prosperity from trade with an appropriate elevation in symbols of success, extensive use of pipelines followed to bring larger amounts of water to areas not reachable by the low elevation, open channel system. Pipeline systems, however, introduced new hydraulic design complexities that involved knowledge of ways to maintain stable piping flow whose maximum transport flow rate matched (or exceeded) spring flow rate input. Flows in poorly designed pipeline systems are capable of a number of transient, self-destructive hydraulic instabilities (e.g., water hammer, pressure surges, transient wave structure, flow intermittency, or internal oscillatory hydraulic jumps). Thus analysis of Petra's piping systems provides insight into the available technical knowledge base applied to problem solution. Pipeline routing involved constant angle contour path surveying through rugged, mountainous terrain as well as choices of hydraulic technical parameters (slope, diameter, internal wall roughness, sinuosity, and supply head) that govern piping carrying capacity. Choices of these parameters, as extracted from the archaeological record, as well as insights into the management strategy of these assets, indicate the level of technical achievement of Nabataean engineers.

Water Management in Petra. Fig. 2 The Zurraba (al Birka) reservoir.

One example of later phase technological advances is a reservoir at Zurraba (1, D;2) (Figs. 1 and 2). It was constructed to store and transmit water along the Wadi Shab Qais (D;2) around the northern flank of the Jebel el Khubtha mountain (C;2) in an elevated channel (D;3, 40) containing piping (Fig. 3) that continued over royal tombs (22–24) to supply a typical large basin at its terminus (Fig. 4). Descending channels from this basin to cisterns at the base of the mountain added water to that collected from rainfall runoff for urban housing needs, celebratory rituals at nearby tomb complexes and for piping elements conducting water

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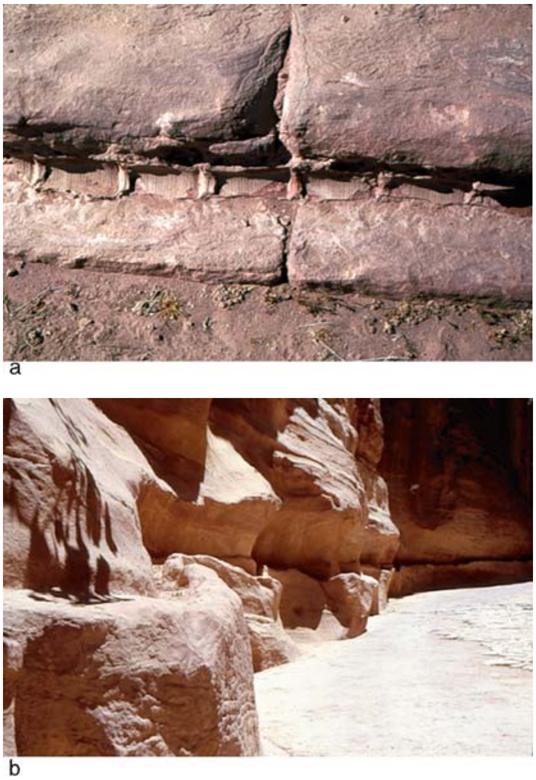
Water Management in Petra. Fig. 3 Elevated water channel/piping system on west face of el Khubtha Mountain.

Water Management in Petra. Fig. 4 Elevated settling basin typical of the el Khubtha channel/piping system.



Water Management in Petra. Fig. 5 (a) Piping channel elements on the north side of the Siq. (b) Channel trough on the north side of the Siq for piping placement.

further on to city center locations. While runoff capture is one probable sourcing of the Zurraba reservoir, connection to local spring sources, including Ain Mousa, remains probable for additional charging. Although reservoir water could be used to supplement the Siq open channel flow, later city phases involved shifting Ain Mousa water supplies to a Siq piping system after the open channel was abandoned. In this case, rainfall runoff and spring charging still enabled the Zurraba reservoir to supplement Ain Mousa Siq pipeline flows when required. The Jebel el Khubtha pipeline appears to be the main outflow path for reservoir water along Wadi Mataha (B;2, C;2) and surplus water, after cistern topping, was most certainly directed to the main city fountain (Nymphaeum 42, B;2) through a pipeline (as some pipeline fragments in the area suggest). From a systems point of view, the reservoir served principally to maintain cistern levels by on-demand water release while the Ain Mousa spring provided the continuous spring supply source to the Nymphaeum through piping supported in a channel through the Siq (Fig. 5a, b; Ortloff 2005). The ability to provide an "on-demand" water supply from this backup source would prove most useful to large caravans entering the city that would place a sudden demand on water supply capability.

Pipeline Carrying Capacity Considerations: The Zurraba–Jebel el Khubtha System

While a spring produces a given volumetric flow rate, a limitation on how much can be transported by pipeline relates to pipeline technical characteristics (diameter, internal roughness, slope and supply head). Piping design considerations require the spring output flow rate to match (or be less than) the theoretical carrying capacity of the pipeline. Technical examination of Nabataean pipeline designs then yields insights into solutions to increase flow rate throughput. If the long Jebel el Khubtha piping system were to function in full-flow mode typical of a very low-flow rate, its flow rate would be somewhat less than that derived from an open channel, near critical flow mode due to internal wall frictional resistance; larger diameter piping would then be required to match the spring flow rate. For a steeper slope design, gravitational acceleration causes flows to become supercritical and tend to an internal free surface normal depth. Rapid supercritical flows, however, may be subject to intermittent zones of subcritical full flow induced by internal piping wall roughness and curvature resistance effects as well as transient hydraulic jumps that create pulsations in delivery flow rate at the piping exit. Such effects can lead to destructive tensile forces that weaken mortared piping joints. The best piping design to produce a stable volumetric flow rate is therefore a partially full flow at near, but below, critical conditions that empties water gently into a terminal reservoir. Selection of this piping design would then be a measure of knowledge of hydraulic principles required to achieve a steady, high flow rate to the terminal elevated basin placed far left in C;2 and would explain the high elevation positioning of this pipeline (to maintain a low slope) around Jebel el Khubtha. The Nabataean design, given its slope and piping diameter, closely matches the near critical flow rate (Morris and Wiggert 1972) and provides for the largest possible flow rate from the Zurraba reservoir to meet on-demand large flow rate requirements. Additional benefit from the Nabataean design resides in the presence of partial, open channel flow in the piping to greatly reduce the leakage rate compared to a pressurized system. Since particles settle in the reservoir, no particle transport occurs to clog piping; this is particularly important as access to the high elevation piping (25 m above the ground) on the near vertical Jebel el Khubtha mountain face would limit the possibility of cleaning procedures. The combination of all these features designed into the Jebel el Khubtha pipeline indicates that much thought went into the best placement and design of this system to achieve the multiple goals that ensured not only system longevity but also rapid, on-demand water delivery capability with minimum leakage.

From an exit pipeline leaving the basin to a ground level cistern, additional piping led to the Nymphaeum fountain to complete the Jebel el Khubtha circuit from the Zurraba reservoir. As the Nymphaeum was a major water supply to the urban core and market areas, much effort and innovation was employed to guarantee its year-round functioning from the Siq piping system (Ortloff 2005) supplemented, on-demand, by the long Jebel el Khubtha pipeline from the Zurraba reservoir.

Supplemental Water Supply Systems Supply Redundancy

A number of cisterns and dams on Jebel el Khubtha (Akasheh 2003) (C;2) captured and stored rainfall runoff. Some of the upper level cisterns appear to have channels leading to ground level cisterns that led to urban housing or field areas to the west of Jebel el Khubtha to supplement the water supply from the Zurraba system. As previously mentioned, the Siq floor open channel was abandoned in late Nabataean phases and replaced by a Siq north wall pipeline system (Fig. 5a, b) that extended to the area across from the theater district (B;1) and ended at the Nymphaeum. Thus at least two separate supply lines (Siq and Jebel el Khubtha) led to the Nymphaeum to ensure supply redundancy. The construction for the Siq pipeline system is generally attributed to Malichus II or his predecessors, Aretas IV or Obodas III, in the first century BCE or early in the first century CE (Guzzo and Schneider 2002). Since water demands south of Wadi Mousa (transecting urban Petra) are high due to the nearby marketplace, theater, temple, and housing districts and significant water resources are available from the north side piping systems, a pipeline transfer connection from the Nymphaeum to this area is logical for development of this area. While a bridge or piping from the north side of the Jebel el Khubtha system in the El Hubtar Necropolis area (20, B;2) across the Wadi Mousa may have existed in the vicinity of the theater (19, B;1) to carry water (at the same level) to the south side, traces are lost due to extensive erosion flood damage. In addition to water delivered by these means, the theater water source was supplemented from large, upper level reservoirs in the Wadi Farasa area, and pipelines originating from Ain Braq and Ain Ammon sources (Fig. 1) again indicating built-in supply redundancy from multiple sources. Some of the larger reservoirs appear to function in connection with a spring supply system and are situated to collect rainwater runoff; reservoir usage, therefore, is mainly to provide water for occasional peak requirements. Surface cisterns appear to be opportunistically placed to collect rainwater runoff; other than seasonal rain recharge, the numerous, widely scattered catchments appear to serve local community needs for supplemental supplies of lower quality water when piped water is not readily accessible.

Traces of a south side piping system (Fig. 6) are found in front of the theater. Two parallel pipelines

Water Management in Petra. Fig. 6 Dual pipelines continuing past the theater to supply tanks (T) above the Cardo.

W

Water Management in Petra. Fig. 7 Great Temple on the south side of Wadi Mousa.

continue past the theater along the ridge (B;2) above the commercial district along the Roman Cardo (25), Hadrian's Gate (43), upper and lower marketplaces and the Paradeisos water garden (Bedal 2004) to locations above the Great Temple (28, Figs. 1 and 7; Joukowsky 2001, 2003) where they form part of the water supply to structures located in (B;2). The two separate pipelines may indicate branch lines to separate destinations or a later elevation change that continues piping to Q'asr al Bint through the Great Temple to supply the Sacrificial Altar area, although no excavations exist to connect the multiplicity of subterranean canals below the altar to a specific water source. Hadrian's Gate (43) separates the secular commercial district from the western sacred temple district containing the Great Temple, Temple of the Winged Lions (26), and Q'asr al Bint. The Paradeisos water garden complex west of the gate consisted of an open house structure situated on a platform island within a large water filled basin; bridge structures connected the island to outer precincts, and greenery added to the city's elegance as indicated by reconstructions reported by Bedal (2004). The basin walls contain overflow channels as well as supply piping that may emanate from both the Nymphaeum piping extension into this area and water from a south side spring supply system. Distributed along this piping system, a number of elevated basins (T, Fig. 1) lined with hydraulic plaster (Fig. 8) served as receiving basins; earth-fill mound structures extended from these tanks to the lower Cardo area and served as pipeline support structures. As the basins are elevated 20 m on a bluff above the Cardo, sufficient head existed to provide pressurized water for fountains in the market area below as well as for the Great Temple (and possibly Q'asr al Bint). Because the south side urban core region contains the marketplace area, water requirements were high; consequently, additional supplies are channeled to this area by means of an underground channel (B;1; B;2) from the combined flows from Ain Braq and Ain Ammon. Some as yet unexcavated branch of this system running through high elevation channels may be part of the system that provided water to piping located in front of the theater.

Water Management in Petra. Fig. 8 Fragment of one of the elevated water collection basins (T) above the Cardo area.

Water from these springs may be supplemented by elevated cistern storage water from the Jebel Attuf area (B;1) in one of the many high places (12, 13, B;1) of the city. Water to the Lion Fountain (14, B;1) and al Hamman pool area in the vicinity of elite tombs (16–18; B;1) came from this supply line that continued on to the Great Temple area and clearly indicated that a continuous spring supply is part of the system due to the presence of the Lion Fountain. A large elevated cistern located on a plateau above the Tomb of the Roman Soldier (16) (Browning 1982) also contributes rainfall runoff water supplies into this system. Details of the Wadi Farasa water system in this area (B;1) have been investigated (Schmid 2000) and indicate the existence of large reservoirs and piping systems that not only serve local usage, but also have sufficient capacity to transfer water further west to the Great Temple area. Numerous channels, pipelines, and multiple cisterns within, and leading from the Great Temple, indicate that water supplies within the temple were abundant (Joukowsky 1999, 2001, 2003). Water export lines to the marketplace area and the Q'asr al Bint region from the Great Temple served as part of the water system.

Water Supply System Management Operations

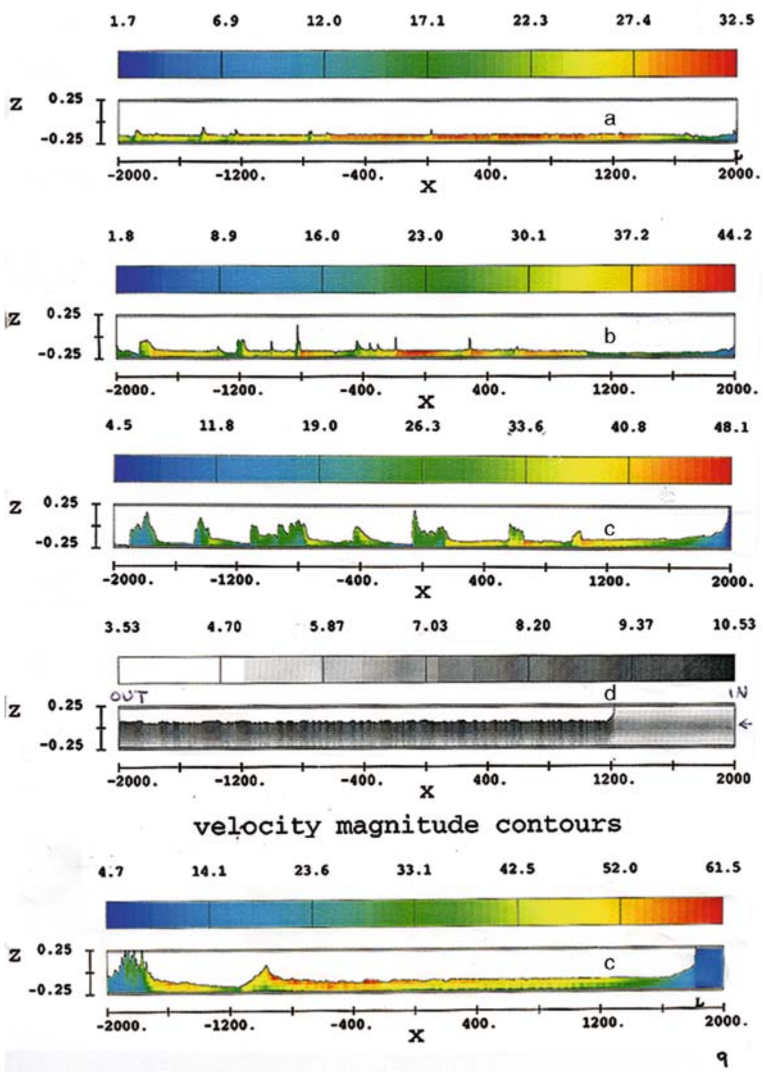
The evolution of the water system to incorporate piping networks transformed the site to meet the demands of a large urban population estimated to reach 30,000 (Guzzo and Schneider 2002). The water system incorporated both intermittent, on-demand supplies piped from large reservoirs or drawn from cisterns and continuous supply piping systems from remote springs to provide daily requirements of city inhabitants. No water could be wasted. As a consequence, transfer piping from north side systems (Jebel el Khubtha and Siq pipelines to the Nymphaeum) provided water that could be transferred to south side downhill locations for further usage or storage before final discharge into the low elevation Wadi Siyagh.

Water storage through use of major, on-site dams presented yet a further aspect of Petra's water system. For example, on the north side of Wadi Mousa, numerous high status structures exist in the B;2 quadrant [Temple of the Winged Lions, Royal Palace (41), North Defense Wall and Fortress (35), Conway Tower (54)] and are logically associated with some water supply system. A dam (d) at Wadi Turkamaniya (B;2) may have trapped and stored sufficient runoff to provide water to the lower reaches of the Temple of the Winged Lions although no excavation data is available. Excavations reveal that lower portions of both the Temple of the Winged Lions and the Great Temple spanned the Wadi Mousa stream by means of bridging. It appears then that supply redundancy derived from pipelines from different spring/reservoir sources crossing from one to another part of the city is an aspect of the design approach. This design philosophy ensures that water supply to any area may be composed from different sources depending upon variations in individual spring flow rates and reservoir/cistern storage amounts and implies that management oversight was in place to monitor and control the system network.

While cisterns are well dispersed through the urban settlement area, a main underground channel starting from Ain Bebdbeh north of (D;3) and running toward the convergence of Wadi Mataha and Wadi al Nassara (B;2), runs into the lower reaches of the north side below the temple areas. To illustrate the Nabataean mindset to utilize all water resources, a further element based upon on-site dams constituted yet further complexity to the water management picture. Local histories mention the existence of large dams – one on the Wadi Mataha (Taylor 2001), the other on the Wadi al Nassara (Fig. 1). Destroyed remains are found to verify that these dams provided water storage from rainfall runoff within urban Petra. Judging from Nabataean placement of the Wadi Mataha dam (d), piping to the nearby Nymphaeum must have been an additional third backup water source to the fountain. Since the Ain Mousa spring could also serve to place water behind the Wadi Mataha dam through the Wadi Shab Quais pipeline branch from Zurraba (in addition to seasonal rainfall runoff storage behind the dam from diversion of the Wadi Mousa stream through the bypass tunnel, 8 in Fig. 1), the water level behind the dam could be maintained to provide backup water to the Nymphaeum throughout the year. The Nymphaeum could then be supplied by contributions from stored runoff water behind the Wadi Mataha dam, a canal or pipeline from Ain Bebdbeh, the pipeline along the western face of Jebel el Khubtha feeding ground level cisterns and pipelines, and the north side Siq pipeline. This degree of redundancy indicates that planning for water supply variations was a consideration addressed by a complex design that could tap into various pipeline-water storage resources depending upon available supplies.

Flood Control, Groundwater Recharge, and the Great Temple Water Subsystem

Floodwater drainage during the rainy season was a major concern. Since heavy rainfall and flooding characterize the Petra area, measures to divert Wadi Mousa floodwater from the Siq by means of a bypass tunnel (Fig. 1, 8 at C;1), a low dam at the Siq entrance and elevation of the Siq floor near the entrance provided flood control. While this strategy had proven effective in deflecting small flood events, continuous deliberate infilling and accumulating flood deposits in the Siq helped protect against floodwater incursion.



Water Management in Petra. Fig. 9 FLOW-3D calculations of a rectilinear model of the Siq piping for entry full flow input flow rates of 1.0 (a), 2.0 (b), 5.0 (c), 10.0 (e) ft/s (0.305, 0.610, 1.52, 3.05 m/s) velocity indicating internal flow development for the observed wall roughness distribution. Fig. 9d shows results for smooth interior piping at 1.52 m/s initial, full flow inlet velocity.

While large flooding events had negative consequences, there were also ways to utilize the sudden water bounty: storage dams across the numerous wadis intersecting the urban core served to reduce floodwater entry into the city while seepage from the impoundments provided water table recharge suitable for well extraction during protracted drought. Thus a fraction of the seepage from dam storage, canals and pipelines ultimately can be recaptured and used as an ultimate groundwater defense against drought on a citywide basis.

The same idea could also be used on a more localized basis for elite structures. Within the Great Temple, an elaborate south boundary wall drainage channel system collected infiltrated rainfall seepage and directed it to a nearby underground cistern with 50 m^3 capacity located within the eastern, upper part of the temple structure. A channel connected to the upper part of this cistern conducted overflow water to lower level structures before exiting to Q'asr al Bint and Wadi Siyagh in order to regulate its maximum capacity. Large channels located in an upper room north of the Theatron (Joukowsky 2003) of the temple most likely indicate the terminus of a subterranean channel from the Ain Braq, Ain Ammon system (B;1, B;2) with water transfer access to the cistern. Some additional water sources may have been available from springs in Wadis Kharareb and Ma'Aisert (Fig. 1) although piping connections await further excavations. Channel water, supplemented by cistern water to meet peak demands, was then distributed to subsidiary open cisterns located in east and west sides of the temple and then through subterranean channels under the lower temenos (a

Water Management in Petra. Fig. 10 Typical rippled wall pattern within the interior of some Nabataean piping elements.

sacred enclosure around a temple or holy site) platform to lower level rooms near the temple entrance stairway. Thus the cistern functioned as a reservoir adding stored runoff and seepage water to the channel-delivered base supply when required – much in the same way that previously described reservoir–pipeline systems worked to meet occasional peak demand requirements. Because such a system is contained within the temple itself, its position of importance as a major canal terminus and water distribution node is clear from the complexity of hidden channels, cisterns, and piping thus far discovered. Perhaps the internal water system of the temple, capable always of providing ample water supplies for rituals, had special significance to demonstrate the premier role of religion in the lives of the Nabataeans; only later under Roman rule are these supplies used for more utilitarian Cardo marketplace purposes indicating Roman predilection to practical concerns.

While the north side piping of the Siq provided the main potable water supply, the south side channel system was probably meant for animal watering and may have been supplied by a channel from Ain Braq and supplemented from a cistern atop the bluffs with a drop hole to this channel (C0, Fig. 1).

Per Capita Water Availability

For estimates of total water volumetric flow rate into the city, conservatively assuming about a third of the north side supply rate for the south side due to the less robust south side springs, and assuming a combined flow rate between the Siq and Wadi Shab Qais reservoir release lines to be about 40 $m^3\ h^{-1}$, then the city could receive at minimum 50 $m^3\ h^{-1}$ from these sources. While additional sources [Ain Braq (0.8 $m^3\ h^{-1}$), Ain Dabdabah (2.5 $m^3\ h^{-1}$), Ain Ammon, and Ain Siyagh (<1.0 $m^3\ h^{-1}$)] add to this estimate, released storage water and additional springs would add yet further capacity to arrive at a yet higher flow rate estimate – perhaps to 100 $m^3\ h^{-1}$ total if less conservative leakage estimates are used. For about 30,000 inhabitants, then at least 0.04 $m^3\ day^{-1}$ (40 l day^{-1}) would be available on a per capita basis, which is minimal to maintain hygienic standards. Considering public use of fountains, watering troughs, baths, water gardens, and workshops, per capita water availability is well within the Rome urban water usage rate of 0.6 $m^3\ day^{-1}$ per person (Butterfield 1964). Considering hot climate survival water intake per person of about 0.003 $m^3\ day^{-1}$, then surplus water beyond human consumption/survival rates is available by these estimates. Estimates for water storage from dams and cisterns on Jebel el Khubtha alone (Akasheh 2003) is 0.36 m^3 per person; for a personal consumption rate of 0.003 $m^3\ day^{-1}$, then theoretically, considering evaporation losses, about a 2 month emergency supply was available through Jebel el Khubtha cisterns if spring flow rates declined precipitously.

A similar calculation shows that Zurraba reservoir contained about 3 weeks emergency supply and additional cisterns and dams on site, particularly those of the Wasi Farasa system (Schmid 2000) add yet further reserves totaling several month's supply. While per capita water supply for Petra is somewhat lower than Rome city standards, still the amounts supplied to the city on a continuous basis are more than sufficient to maintain quality living standards.

As the city underwent major construction in the period 50 BCE–100 CE during the reigns of Obodas II (III) and Aretas IV, Roman/Greek technologies most probably influenced water system design. The availability of advanced Roman surveying techniques used for aqueduct system design (Lewis 2001) would be particularly useful in constructing long distance lines of prescribed slope to and within Petra to maintain stable open channel flows in piping to match spring flow rates. While the design capability to achieve such balances still remains elusive due to fragmentary knowledge of ancient hydraulics practices, some hints of water flow rate measurement capability exist (Cohen and Drabkin 1966; Ortloff and Crouch 1998).

In essence, the Nabataeans utilized all possible above-and-below groundwater supply and storage methodologies simultaneously. While water storage in contemporary Hellenic cities also emphasized cistern water storage for household use, the Petra systems advanced this technology to citywide systems with elaborate dam and cistern systems that served both water storage and flood control purposes. Water storage in groundwater aquifers was also practiced by multiple dam system storage; this allowed for the possibility of constructing wells as backup systems should all other supply systems decline due to long-term drought effects.

Appendix: Site Features

1. Zurraba reservoir (al Birka)	31. Quarry
2. Forum Rest House	32. Lion triclinium
3. Park Entrance	33. El Dier
4. Hospital	34. 468 monument
5. Dijn monuments	35. North City Wall
6. Obelisk Tomb and Bab el Siq Triclimium	36. Turkamaniya tomb
7. Entrance elevated arch	37. Armor tomb
8. Flood bypass tunnel and dam	38. Little Siq
9. Eagle monument	39. Aqueduct
10. Siq	40. Al Wu'aira Crusader Castle
11. Treasury (El Khasneh)	41. Byzantine tower
12. High place	42. Nymphaeum
13. Dual obelisks	43. Paradeisos, Market, Hadrian's Gate
14. Lion monument	44. Wadi Mataha dam
15. Garden tomb	45. Bridge abutment
16. Roman soldier tomb	46. Wadi Thughra tombs
17. Renaissance tomb	47. Royal tombs
18. Broken pediment tomb	48. Jebel el Khubtha high place
19. Theater	49. El Hubtar Necropolis
20. Uneishu tomb	50. Block tombs
21. Royal tombs	51. Royal tombs
22. Sextius florentinus tomb	52. Obelisk tomb, snake monument
23. Carmine façade	53. Columbarium tomb
24. House of dorotheus	54. Conway tower
25. Colonnade Street (Cardo)	55. Tomb complex
26. Temple of the winged lions	56. Convent tombs, crusader fort
27. Pharaoh's column	57. Tomb complex
28. Great Temple	58. Pilgrim's spring
29. Q'asar al Bint	59. Jebel Ma'Aiserat high place
30. Museum	60. Snake monument

A water supply system consisting of dams, cisterns, channels, pipeline networks, and groundwater storage exploited multiple spring supply systems and rainfall runoff collection. Examination of two different pipeline system designs with different slopes and delivery requirements (one on-demand, the other continuous flow) indicates that technology is in place to provide designs that minimize leakage, maximize flow rate, minimize particle transport, and eliminate transient flow instabilities that cause system vibration and prevent steady flow from developing. Further advances, as related to the Siq pipeline, relate to water purification by four easily cleanable settling basins (Bellwald 2004) whose positioning eliminates a complex flow stability problem (Ortloff 2005). The totality of solution options confirms that a hydraulic design methodology is applied with skill to solve complex hydraulic engineering problems.

While it is traditional to look for earlier Greek and Roman technical advances (Ortloff and Crouch 2001; Cohen and Drabkin 1966) that improve the Nabataean system, few are found, indicating that Roman engineers perhaps viewed the Nabataean system as optimum. In this case, it is likely that the water management techniques observed by the Romans served to increase their library of water conservation and management techniques as applied to desert cities and outposts. While details related to technical transfer and hydraulic engineering practices of ancient societies are still a matter of research, it is certain that the longevity of Petra based upon its innovative water system design constitutes a vital chapter in the history of water management (Fig. 9).

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Water Procurement in the Prehistoric Caribbean

Peter Drewett

When Ceramic Age peoples arrived in the Caribbean, water was readily available on some volcanic islands like Dominica but virtually absent on most of the coral islands like Barbados. Initially this would have been a major constraint to settlement and survival. In years of regular rainfall, rainwater could be collected from rock pools, caught in foliage of plants and collected in pottery vessels or even upturned conch shells. When the rains failed, however, drought would have led to serious problems on islands without the ability to maintain surface water supplies in the form of rivers and streams. On at least three islands in the southern Caribbean, Barbados, Mustique and Carriacou, Amerindians developed a specific alternative way of guaranteeing a water supply. It may be assumed that the technique was used on other islands although archaeological evidence has not yet been located.

On coral rock islands (Machel 1999), where the bedrock is highly permeable, salt seawater may infiltrate under all of the island or at least around the coastal fringe. Rainwater falling onto the island will seep down until it reaches denser salt water. It will then flow towards the sea on this denser water. At the head of beaches it will be quite shallow before it mixes with seawater (Schultz 1995). Somehow Amerindians recognised this source of sub-surface fresh water and tapped into it. Although similar to sinking wells elsewhere in the world, the process of tapping into this water required great skill; otherwise salt and fresh water would be mixed and the water source spoiled.

Excavations at the Amerindian settlement at Heywoods (Port St Charles) on the west coast of Barbados revealed two methods used to tap into this shallow supply of fresh water (Drewett 2000). The main Ceramic Age settlement at Heywoods was occupied from about AD 600 to AD 1200 (Late Saladoid – Troumassoid). Several round houses and burial areas have been excavated together with wood- and pot-lined water holes (Drewett 2000).

Two wood-lined water holes were excavated. These consisted of wood planking some 1 m in length sunk into the soft sand and held in place by large coral rocks. Both were roughly square in shape (Fig. 1).

Water Procurement in the Prehistoric Caribbean. Fig. 1 Wood-lined water hole at Heywoods, Barbados. ca. AD 800–1000 (source by author, photo by Abel Drewett).

W

The wood used was false mastic (*Mastichodendron* sp.) and *lignum vitae* (*Guaiacum* sp.). One was dated to ca. AD 780–1020 (B-147314) and the other to ca. AD 790–1030 (B-147313). In both wells calabash (*Crescentia cujete*) remains were recovered suggesting these were used to scoop up the fresh water (Fig. 2).

More common, and possibly more successful, were the pot-lined water holes. A shallow hole was dug into the underlying wet sand and a large cooking/storage pot was sunk into the wet sand. These pots had been pre-prepared with their bases carefully removed (Fig. 3).

The pot was carefully pressed into the wet sand while more sand was scooped out of the interior. Additional pots were then stacked on top, acting as a cofferdam to stop wet sand slumping back in. The pots were held in place with coral rock boulders and/or wooded wedges. After a couple of hours any sediment in the water would settle with the pressure of the underlying water pushing the fresh water up into the pot-lined hole (Figs. 4 and 5).

It is uncertain whether these pot-lined water holes were left open or had a removable cover. None were found covered although several had large sherds of pottery in the water holes, which could have been used as lids. Flat cassava griddles found elsewhere on the site would have also made suitable lids, as would organic materials like large leaves or planks of wood. A major problem was probably local soiling of the water by domestic rubbish or even human burials, which were also within the domestic area. This might explain why holes had to be regularly replaced. Twenty three were systematically excavated during the main phase of salvage excavations at Heywoods during 1998/1999, but many more were noted during building work for the Port St Charles marina constructed on the site.

Some of the pot-lined water holes had a highly decorated pot rest resting on the top of the stack. These are like ceramic collars in which large unstable pots

Water Procurement in the Prehistoric Caribbean. Fig. 2 Calabash water scoops from wood-lined water hole at Heywoods, Barbados. Fragments on left ca. AD 800–1000. Modern example on right (source and photo by author).

Water Procurement in the Prehistoric Caribbean. Fig. 3 Large cooking/storage pot with base removed found in pot-lined water hole at Heywoods, Barbados. ca. AD 1000–1200 (source by author, photo by Abel Drewett).

Water Procurement in the Prehistoric Caribbean. Fig. 4 Pot-lined water hole at Heywoods, Barbados. ca. AD 1000–1200. Plan view. (source by author, photo by Abel Drewett).

Water Procurement in the Prehistoric Caribbean. Fig. 5 Pot-lined water hole at Heywoods, Barbados. ca. AD 1000–1200. Section view (source by author, photo by Abel Drewett).

were set to make them stable on uneven ground. One found was 32 cm in diameter and 17 cm high. It was red-slipped with white on red paint and grooved decoration in a concave-ended rectangle and vertical line pattern. This was among the finest pottery found on the site, so it would suggest great importance of the mouth of the hole. Tapping into this underlying source of water may have involved great perceived risk involving careful ritual, for Amerindians believed that a river of the dead ran under their houses and settlements. Ritual specialists were no doubt involved in the placing and digging of these pot-lined water holes and perhaps hallucinogenic drugs, like cohoba, were taken prior to digging rituals (Drewett 2002).

How widespread the use of pot-lined wells was in the prehistoric Caribbean remains uncertain particularly because of limited archaeological excavation in the southern Caribbean. To date they have certainly been recorded on three sites on Barbados: Heywoods, Spring Garden and Maxwell. They have also been recorded on Mustique and Carriacou. Many further examples may have been lost by coastal erosion or await discovery.

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Water Systems in Bronze and Iron Age Israel

Avraham Faust

The Near East is located on the edge of the desert. Part of the region is arid\semi-arid and, as droughts are a frequent phenomenon, water is a scarce resource even in the Mediterranean climate zone. Water was therefore an important factor determining the situation of settlements in antiquity. Initially, many settlements were located near water sources, mainly springs (rivers are a rare phenomenon in Israel). However, since security was also a major consideration, larger settlements gradually tended to be situated on top of hills. In this conflict of interests, security had, in most cases, the upper hand, and alternative means of obtaining drinking water had to be secured.

Wells

A well is an artificial shaft sunk into the ground all the way to the water table. One of the earliest known wells was uncovered at the submerged Neolithic village of ‘Atlit Yam. Later wells are known from Beersheba, Lachish, Tel Zeror, etc., and it seems as if the practice became widespread from the Iron Age onward (and mainly from the Classical periods). Notably, however, wells are typical of lower regions and plains. It is more difficult to dig wells in mountainous areas because of both the depth of the water table and the hardness of the rocks. Wells were, therefore, only a partial solution, and in most cases people used different methods (but see below).

Cisterns

Cisterns were cut out of rock in order to collect and store rainwater. The first known cisterns were apparently dug into the soft limestone of the Coastal Plain in the late Chalcolithic or early Early Bronze Age at Mesar. The earliest cisterns were not plastered, but due to the softness of the stone could still hold the water. The first plastered cisterns were discovered in several Middle Bronze Age sites (e.g., Hazor and Gezer) (see Extra 1). Their use, however, was still sporadic. Plastered cisterns became widespread only during Iron Age I, and mainly in Iron Age II. The use of cisterns became even more widespread in later periods. While cisterns became common, and at times dozens of cisterns were unearthed in a single site, it appears that they were still dug at the family level. Communities, let alone cities/states, had to develop a better solution to the danger posed by the scarcity of water.

Large-Scale Water-Works

Large settlements, if not located on a large spring or a river, needed a guaranteed water source for the summer, and all the more so for periods of siege. After all, the fate of a conquered city in the ancient Near East was horrific, and any effort was done to secure the city and to enable it to withstand siege.

The earliest large-scale water works, evidently beyond the scope of the household, are dated to the Early Bronze Age – the time period when the first cities emerged in the southern Levant. These early water systems are basically large pools, usually located in the lowest part of the settlements, into which rainwater was collected. Such systems were found at ‘Arad, ‘Ai and probably also at Tel Qashish. ‘Arad, located on the edge of the desert, is a unique example. The city was built not on top of a hill, but rather on a basin, probably in order to ease the collection of water. A slightly different type of water system was located outside the city of Jawwa, in Transjordan. Here, dams were built on a dry wadi, absorbing floods, and securing water for the dry season. Such large-scale works were able to support a large population.

Still, in the climatic conditions of the Land of Israel, in which droughts are frequent, rains cannot be regarded as a secure source of water. In cases of failing rain, people would have to go to the nearest spring (usually just below the city). In times of siege, however, which began to become a major consideration as time progressed, such an enterprise was not feasible. Cities had to rely on a more permanent source of water. They developed more sophisticated methods to guarantee access to permanent sources of water, i.e., to springs (which were usually located in the valleys below the cities).

Waterworks technology seems to have advanced substantially in the first half of the second millennium BCE. The notable water system of this period (Middle Bronze Age) is that of Jerusalem (see Extra 2). Here, an attempt was made not to collect rainwater, but to secure access to the water of the nearest spring – the Gihon – which was located below the city at the Kidron valley. From within the city, a large tunnel was dug in the hard limestone. The tunnel went outside the city wall until it opened into a large pool that was located not far from the spring and was protected by fortifications. Water flew from the spring to the pool by way of two tunnels. Due to level differences, the engineers had to raise the level of the water by more than 2 m, in order to let them enter the first tunnel. This was done by the use of dams.

The real "breakthrough" in water systems, however, was accomplished during the Iron Age, and mainly during Iron Age II. A relatively large number of Iron Age water systems were unearthed over the years, and these can be divided into the following types:

1. Covered stairways (galleries). This is the simplest form of Iron Age water work. A shallow tunnel was dug on the tell's[1] slope, from beneath the city wall, all the way down to the spring. The tunnel was then covered. Thus, in times of siege, city inhabitants could sneak from the city to the spring through the covered stairway, without being seen by the enemy. Such systems were discovered in Megiddo and Tell es-Saiyidyeh. Obviously, these systems had their limitations. The spring was known to the enemy, and the gallery could easily be discovered. Once discovered, it could not have been used anymore.

2a. Tunnels. Many Iron Age water systems were dug under the ground, from within the city to the spring. Initially, a large shaft was dug through the earlier layers of the tell. Since these were pretty loose, the shaft was supported by massive retainer walls that prevented their collapse. After reaching bedrock, a smaller tunnel was dug in the rock, at an angle that lowered it toward the spring. Such systems were discovered for example in Gibeon and Megiddo (early phase of the tunnel).

2b. A modification of this type of water system is also known. In some cases, a tunnel brought the water from the spring toward the bottom of the shaft (i.e., toward the city). Such systems are known, for example, at Megiddo (a later phase); the Warren Shaft system in Jerusalem (see note: Jerusalem water system during the Iron Age) is a variation of this type.

While in many cases the enemy who besieged the city could still enjoy the water supplied by the spring, such systems provided (1) a secure approach to the water by the defenders; (2) a better chance of concealing the system from the enemy. Still, such systems were still susceptible to discovery, and the enemy could harm the water source itself (e.g., poison it). Furthermore, the enemy could even use the tunnels as a mean to approach the city in surprise.

3. "Tunnels" dug to the water table. This type is very similar in its form to the previous one. A wide vertical shaft was dug through the tell's layers to bedrock, and this was followed by a narrow diagonal tunnel that was dug in the rock. This diagonal tunnel, however, did not reach the spring; it descended until it reached the water table. While very similar in form to type b, this is simply a large and complex well. Such systems were not only concealed from the enemy, but were also completely secured. Some were discovered, for example, at Hazor and Gezer.

4. The last type of large scale Iron Age water works is that of large underground reservoirs, dug into bedrock (inside the cities). Rainwater was collected through an extensive system of plastered tunnels (e.g., at Beth Shemesh), or from floodwaters in nearby wadies[2] (Beersheba). Smaller reservoirs are also known in this period, e.g., in the fort at 'Arad. While not as reliable as permanent water sources, it appears as if such large reservoirs could absorb enough water underground, to overcome the limitations discussed above (regarding the dependence on rain water).

[1] A tell is an artificial mound formed by the accumulated remains of ancient settlements.

[2] A wadi is a valley, ravine or channel that is dry except in the rainy season.

The galleries (type 1) were the simplest type, and indeed they were used earlier in the Iron Age. It appears as if type 2 was developed to overcome the limitation of the galleries. Type 3 was seemingly the most advanced system. We do not know if these systems were developed on the basis of the knowledge that there was a water table "down there" (the people of the time had to have had this knowledge, as they were familiar with wells), or whether hewers of a type 2 system accidentally reached the water table, and this discovery gave rise to the development of this type (structurally, type 3 is very similar to type 2). This reconstruction is of course speculative, and we need more detailed chronological information in order to confirm or refute it.

Various water systems are also mentioned briefly in the period's written sources, e.g., the Bible (e.g., II Kings 20: 20; Isaiah 22: 9–11; II Chr. 32: 30), and ancient inscriptions (e.g., the Mesha inscription).

The most sophisticated Iron Age water system is Hezekiah's tunnel, which was dug in Jerusalem during the late eighth century BCE. A 533 m. long underground tunnel brought the water from the Gihon spring to a lower point that was located in the other side of the city, in order to collect the water in a pool in a secure place.

In later periods, and especially from the Hasmonean and Roman period onward, larger water systems, e.g., ten km of aqueducts were built, but this is beyond the scope of this entry.

Extra 1: The Open Cisterns of the Negev in the Tenth Century BCE

During the tenth century BCE, the period of the biblical United Monarchy, dozens of settlements were built in the Negev desert of southern Israel. The exact nature of these sites is debated: some view them as royal forts, others believe that only the initiative was royal, while some consider that the entire phenomenon resulted from the settlement of the desert's nomads. Notably, these sites were located away from the few springs that exist in the Negev, and their main source of water was large open cisterns that were discovered at practically every site. These large cisterns were probably covered with skins in order to minimize evaporation. It is also likely that when the rains failed, the inhabitants of many of the sites could go back to the springs, located several kilometres away, and bring drinking water from them.

Extra 2: Jerusalem's Water Systems During the Iron Age

The Gihon spring of Jerusalem is one of the major springs in the central hill country. It is likely that it was one of the causes for the establishment of the city on the low hill, later known as the City of David. Notably, the spring was used by the inhabitants of the city from earliest times. The most ancient water systems are two tunnels, probably dated to the Early or Middle Bronze Age. During the Middle Bronze Age an impressive water system was dug in Jerusalem (above in the text). It is during the Iron Age, however, that the most famous water-works were constructed. As many issues are still debated, the following is only a brief summary that is intended to give a succinct overview (and it cannot deal with all the debated details). The earlier Iron Age system, known as the Warren Shaft (after Captain C. Warren who rediscovered it in the nineteenth century), enabled free access to water through a system of underground tunnels and a shaft. In the past, many scholars believed that it is through this shaft that David conquered Jerusalem (II Samuel 5: 6–9). It appears, however, that this system was constructed only in the eighth century BCE. At this time, improvements were made in the existing system of tunnels (that were cut in the Middle Bronze Age). The works included lowering the bottom of an existing tunnel that led from within the city wall, outward (henceforth, the upper tunnel), thus, exposing a natural karstic shaft that was not known before. Once the shaft was discovered, its significance was apparently observed, previous works ceased, and it became the central part of a new system. A lower tunnel, connecting the spring and the bottom of the shaft, was dug, enabling the water to flow from the former to the latter. Thus, people could walk in the upper tunnel, from within the city walls to the top of the shaft, and draw water. The level of the water at the bottom of the shaft was increased through the use of dams, making water drawing easier. Notably, this system was not very convenient, and was probably intended to be used only at times of siege. The Warren Shaft system, however, was not in use for long, and it went out of use in the late eighth century BCE, when Hezekiah's tunnel was constructed. Hezekiah's tunnel involved the digging of an underground tunnel that led from the spring to a pool at the other side of the City of David ridge, within the city walls. Hence, all the water from the spring was secured. The last stage of the enterprise involved the meeting of two groups of hewers who worked from both sides of the tunnel simultaneously; this is commemorated in the famous Siloam Inscription[3]. Hezekiah's tunnel is an impressive engineering enterprise. Even today, some of the accomplishments still raise questions as to how they were achieved. Among the intriguing questions are, for example, how the workers had enough air during the work, how were the two groups able to meet, and how were they able to maintain such a shallow sloping angle.

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[3] The inscription was discovered in 1880 by a boy who was bathing in the waters of the Gihon Spring, and was studied by Conrad Schick, one of the first explorers of Jerusalem. Engraved in the rock, the inscription describes the meeting of the two groups of hewers who had begun digging from opposite ends of the tunnel. "The tunneling was completed... While the hewers wielded the ax, each man toward his fellow... there was heard a man's voice calling to his fellow... the hewers hacked each toward the other, ax against ax, and the water flowed from the spring to the pool, a distance of 1,200 cubits..." The inscription is now in the Istanbul Museum.

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Weaving Cotton in Ethiopia and Nubia

Michael Gervers

Archaeological material finds provide invaluable information about the nature and source of textiles and textile fibres in Nubia in the early Christian era. In the half century since Griffith and Crowfoot first identified cotton among the textile fragments excavated at Karanog and Meroe, much more cotton fabric has been retrieved from the rescue excavations of early habitation sites along the Nile subsequently inundated by Lake Nasser; i.e., between Aswan in Upper Egypt and Wadi Halfa in northern Sudan. The oldest fragments identified as cotton have been dated to the Roman period and may be as early as the first century AD. The great majority are attributable to the late Meroitic period, ca. 200–ca. 330 AD, at which time cotton appears to have been the most commonly available fabric. The following period, from ca. 330 to ca. 550 AD, sees a swift and remarkable change in the predominant textile fibre in the region. The use of cotton plummets and is replaced by animal fibre, largely camel's wool.

The quantity of cotton found in excavations of the Roman and late Meroitic periods has led many to conclude that the fibre reached Lower Nubia from the south, where it is thought to have been grown, since this area lies in the rain belt and could have provided the environment necessary for growth. However, no specific sites for cotton cultivation in Nubia and the Sudan at this period have been identified and in view of the chronology of the archaeological evidence, and of what is known of the political and economic situation and agricultural production of the period, there is good reason to suppose that vegetable fibres for textiles were not then grown in Nubia or even in the Sudan. Rather, the Nubians, lacking any such indigenous source of raw material, were obliged to import whatever they required either as cloth or raw fibre. These goods included linen, which, throughout much of the Middle Ages under the provisions of the *baqt* agreement, was one of the principal items received by the Nubians in exchange for slaves. The *baqt* was first formulated in the seventh century, by which time, in the absence of adequate supplies of cotton, the Nubians seem to have sought imported linen as an alternative. The cotton would have been *gossypium arboreum*, and its ultimate source would have been the west coast of India. How it reached Nubia is uncertain. It could have come via the eastern desert trade routes from such ports as Suakin on the Red Sea, or via the kingdom of Axum, which by 300 AD. enjoyed a thriving trade with India. The costs and difficulties of overland transport, however, make it more likely that cotton reached Nubia through the Roman world to the north via the Nile. Since the archaeological cotton remains from Nubia were not made from locally grown fibres, there can be little question of cotton reaching Ethiopia from the Sudan. One early reference which is universally accepted speaks of the direct importation to the Red Sea Axumite port of Adulis of cotton from India in the first century AD. The first indication we have of the production of fine cotton cloth in Abyssinia occurs at the end of the thirteenth century in the commentary of Polo: "Good cotton and buckram cloths are woven here". If his source for the supply is accurate, one can reasonably conclude that by that time cotton cultivation and weaving was well established in the highlands.

Textiles, especially imported, have always been an expensive commodity. Their distribution through the ranks of a society depends directly on the geographical diffusion of the raw material, the quantities produced and the availability of mechanisms to spin and weave it into cloth. An Egyptian source for cotton grown in India would explain why a blue and white cotton tapestry decorated with Egyptian symbols was among the Meroitic finds from Qasr Ibrim. It would also explain why the cotton, if imported raw from India and locally spun, would appear different in texture from contemporaneous cotton cloth of Indian origin discovered at Palmyra. Cotton cloth woven in the humid atmosphere of India could be much finer than that produced in the arid climate of Egypt or Upper Nubia. The latter, if woven on the warp-weighted loom, as is supposed, would have to be much thicker and coarser to prevent it from breaking under the stress of the weights. Consequently, it would have appeared softer than the material from Palmyra and more like wool. When cotton became less available from the fourth century and was replaced by wool, the warp-weighted loom would have been all the more appropriate for weaving it. Weaving in Ethiopia today is carried out almost entirely on a pit-treadle loom, whose treadles are suspended in a hole in the ground. The weaver sits at the edge of the pit with his legs inside so that his feet can operate the treadles. The origin of this loom in Ethiopia is uncertain, although numerous writers have noted how closely it parallels the Hindu loom, and some suggest that the technology is the result of direct importation from the Indian subcontinent. Endrei believes this loom originated in India for the purpose of cotton weaving. The specific characteristics of the Abyssinian loom, according to Boser, are its sturdy frame, the width of the comb and consequently of the cloth produced, and the depth of the pit. Boser goes on to say that regardless of how this loom got to Abyssinia, it did not spread thence to other parts of Africa. It did not spread, until recent times at least, even to southern and western Ethiopia. A close relative is the warp-weighted pit loom which is found frequently in Persia, Syria and Egypt where it was, and is, used particularly for weaving woollen, and in Egypt at any rate for weaving linen thread. It does not seem to be appropriate for weaving with a cotton warp as the strain placed by the weights on the thread would cause it to break. This restriction would explain the absence of the warp-weighted loom in Ethiopia, where cotton is by far the principal fibre used for weaving today. The technical association of the Ethiopian loom with cotton would also argue in favour of a common development, if not introduction, of cotton growing and weaving to the Abyssinian highlands.

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Wei Boyang

Fabrizio Pregadio

Although many Chinese works relate the name of Wei Boyang to the origins of alchemy, nothing is known about him from a historical point of view, and his figure may be entirely legendary. Some sources, which place him in the second century, relate that he came from Shangyu (in modern Zhejiang) and transmitted his teaching to Xu Congshi, who in turn handed it down to Chunyu (alternative spelling: Shunyu) Shutong. The text deemed to embody the gist of this transmission is the *Zhouyi cantong qi* (Agreement of the Three According to the Book of Changes), a scripture in verses that is attributed to Wei Boyang. The commentaries usually interpret the "Three" as Heaven, Earth, and Man, or as Daoism, cosmology, and alchemy. The *Book of Changes* is the *Zhouyi* (or *I Ching*, also spelled *Yijing*), the renowned divination manual, which also includes a classical exposition of cosmology in its section commonly known in the West as "Great Treatise."

The genesis of the *Cantong qi* is as obscure as its putative author. Current research tends to consider that an originally Han text on cosmology may have been elaborated into an exposition of alchemical doctrines, perhaps at different dates until the seventh century. The very few references to a *Cantong qi* before that time seem to refer to the original cosmological treatise, whose circulation may conceivably have been restricted due to its association with an unofficial and proscribed body of writings propounding esoteric interpretations of the Confucian classics.

Since the late Tang, however, the *Cantong qi* began almost abruptly to exert a far greater influence in the history of Chinese alchemy than that of any other text. Hidden in the highly allusive language, and the thick layers of symbols and images that characterize this scripture, is an exposition of the doctrine that inspired a variety of commentaries (about 30 of which are extant) and other texts, written between the eighth and the nineteenth centuries, in both Daoist and Neo-Confucian traditions. One of the most well-known exegeses was written by the Neo-Confucian philosopher Zhu Xi, who commended the high literary quality of the text.

The *Cantong qi* would hardly be intelligible without recourse to the related literature. Although it was occasionally read as a treatise on cosmology, most commentaries agree that it articulates the theories found in the tradition of the *Book of Changes*, applying them to the alchemical work. The *gua* (trigrams and hexagrams) of the *Book of Changes* are used both to construct a cosmological model and, at the same time, to represent phases of the process performed by the alchemist. The various possible levels of reading of the text possibly mean that it was used within both the main traditions of alchemy in China, i.e., *waidan* or “external alchemy” and *neidan* or “internal alchemy.”

See also: ►Alchemy in China, ►Divination

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Weights and Measures in Africa: Akan Gold Weights

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The subject of gold weights is complex and multidimensional. It can be understood only when placed in the context of its original cultural environment, which was linked intimately to gold for its physical substance and to the package (*dja*) in which it came for its sociocultural identity.

The Akan country, on the Gulf of Guinea in West Africa, was and is an area of gold deposits. This metal is both feared and worshipped. Well before the first contacts with Europeans in the fifteenth century, the Akan people used gold dust as a medium of exchange. However, the concept of “gold weights” came from Western traders (Dutch, Portuguese, English, and French).

The first question to ask is: are the figures really weights? In describing these figures, the Baolé use several different terms: *Dja-yôbwê*, *sika-yôbwê*, *shindra-yôbwê*, *nsangan-yôbwê*, *ngwa-yôbwê*. Let us look at the meaning of each of them.

- *Dja-yôbwê* (dja stone). Here the term refers to the contents; it designates what is contained in the package or *dja*. These original elements would be in stone and would be concerned with different realms of human knowledge deemed worthy of interest.
- *Sika-yôbwê* (stone of gold) money. In this second case, the term describes a price or a monetary total. These elements would deal with economics, calculation, and mathematics.
- *Nsangan-yôbwê* (stone of a fine). This term describes the price of a fine, a tax, or a tribute, and is concerned with elements of economics and finance.
- *Ahindr-yôbwê* (proverb stone). This term evokes the notion of speech, thought, and discourse, the fields of literature and philosophy.
- *Ngwa-yôbwê* (game stone). This term refers to the figures comprised of graphic signs. The exercise of reading or deciphering the signs was considered a kind of game, involving elements of imitation and intellectual training.

As we see, the term “weights” appears nowhere in these descriptions.

The *dja* or *sanaa* was originally a package made of animal skin or thick cloth in which the Akan placed their figurines and certain accessories. It seems to have been a kind of encyclopedia written in miniature figures. The package and its contents symbolized the economic power of the living king and the spirits of the dead sovereigns. The act of taking possession of the *dja* signified for a new ruler that he was assuming the power to raise taxes, impose fines, and take measures to increase the state treasury. For his subjects, knowing that the ruler was in possession of the *dja* of the state meant that they judged him capable of administering the financial and economic heritage of the country.

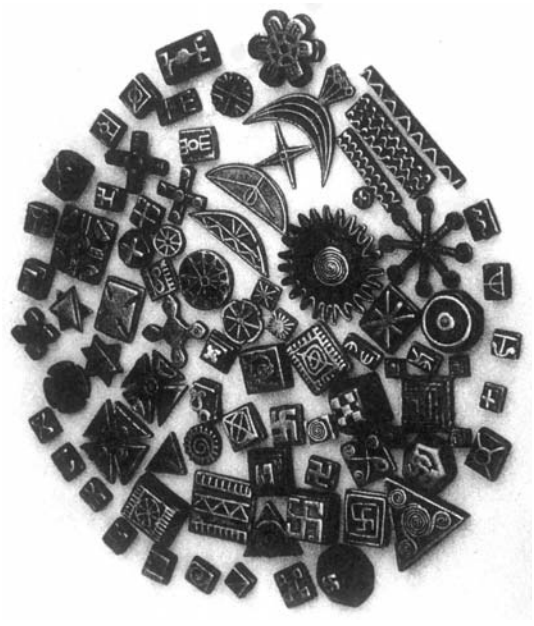
Many different objects can be found in a *dja*, but we will mention here only the essential, original ones.

The equipment is a group of accessories used to manipulate the gold power. They consist of (1) balance scales, used to determine the weight value of different quantities of gold dust used as a medium of exchange; (2) spoons to put the gold dust on the plates of the scales; (3) boxes of many different kinds, their covers often decorated with graphic designs. They are used to hold gold dust already weighed or about to be weighed; (4) winnowing baskets used to separate and rid the gold powder of any impurities; and (5) sieves to separate the different grains of gold dust.

The weights provide knowledge of the weight and monetary value of the quantity of gold powder placed in the plate of the scale. There are three kinds of weights – figurative weights, weights with graphic designs, and geometric weights (Figs. 1, 2 and 3). Gold weights were (usually) made of an original alloy whose composition was similar to that of bronze and brass. However, there are also weights made of silver, copper, and solid gold.

The weights were made by the Tounfouê, an artisans' group, different from blacksmiths and jewelers. These artisans used the lost wax method to produce the weights.

The Akan used a system of computing weight consisting of 11 units. It began at *dama* and ended with *bèna*. It was possible to multiply *bèna* by infinity and the values went from single to double or were



Weights and Measures in Africa: Akan Gold Weights. Fig. 2 Weights with Graphic Designs. Photographs by the author. Used with his permission.

Weights and Measures in Africa: Akan Gold Weights. Fig. 1 Weights with Figurative Elements.

Weights and Measures in Africa: Akan Gold Weights. Fig. 3 Weights with Geometric Elements.

multiplied by two. There were three series of weights – small, medium, and large. They could be added and multiplied.

The small weights series consisted of ten monetary units and was used for all sorts of small transactions:

ba = unit = 0.148 g
ba (*gnon*) = ba × 2
ba (*nsan*) = ba × 3
ba (*nan*) = ba × 4
ba (*nou*) = ba × 5
ba (*nzien*) = ba × 6
ba (*nzo*) = ba × 7
ba (*motchué*) = ba × 8
ba (*brou*) = ba × 10

The medium weights series consisted of 7 units. The computation is done from simple to double, and each unit has multiples and submultiples.

Assan = 4 m.v.
Gbangbandia = 4 m.v.
Tya = 5 m.v.
Anui = 5 m.v.
Gua = 5 m.v.
Anan = 5 m.v.
Tyasue = 5 m.v.
Total = 33 m.v.

These 7 units comprise 33 monetary values. The smallest value is *météba* which equals 12 *ba* or 1.77 g. The largest value is the *ta*, which equals 348 *ba* or 51 g of gold.

In practice, the system worked as follows. For example, the *gua*, the fifth unit, comprised the following five monetary values:

Météba = 12 ba = 1.77 g of gold
Adjratchui = 24 ba = 3.55 g of gold
Tra = 48 ba = 7.54 g of gold
These are all sub-multiples of *gua*.
Gua = 96 ba = 14.20 g of gold (Unit of this series)
Guagnan = 192 ba = 28.40 g of gold (Multiple of *gua*)

The large weight and monetary values series had only 3 units. They were:

Banda = 384 ba = 56.80 g of gold
Banna = 432 ba = 67.44 g of gold
Pereguan = 478 ba = 71.92 g of gold.

In considering the weights and numeric representation, we will consider here only those weights with graphic signs which correspond with calculation and mathematics.

Concerning the signs and marks, the anthropologist François H. Abel has written: "A. Amélékia, a well known man named Diénélou confirmed for me that the Ancients knew how to read from the weights… In the village of Lomo-north, in the region of Toumodi, the village chief knew that the signs on the weights had meaning."

Savary, the Director of the Department of Black Africa in the Museum of Ethnography in Geneva has written: "Each weight is the product of two signs written on it… Reading it is sometimes simple, but often difficult. This is because some Black Africans had a different concept for numeric figuration and for the representation of the product of two numbers. [Also] zero did not exist…". In the system, figures and numbers are represented by vertical and horizontal lines, such as marks and arrows similar to those still seen in charcoal in the houses of African villages.

Commenting in 1605 on the Akan system of accounting and calculating, the Dutch explorer and historian Pieter de Marées made this remark: "The Negroes have weights of copper and tin which they have cast themselves, and, although they do not divide in the same way we do, it comes out the same, and the accounting is always correct."

For the people of the Akan civilization, the gold weights contained in the *dja* constitute a fundamental cultural text, comparable to the Christian *Bible*, the Islamic *Quʾrān*, or the Hindu *Veda*. It is within this sacred package that they had consigned, in idiogrammatic letters and signs, their knowledge and values to be passed on to posterity. In this way, their descendants would not have to reinvent that which had been known by their ancestors and which constituted the foundation of their civilization.

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Weights and Measures: Animal-shaped Weights of Burma

Donald Gear, Joan Gear

The royal animal-shaped weights of the Burmese Empires appear to be unique not only as a weight system, but also as one of the most important artifact series, especially in a country with but few durable artifacts. Their shape motifs are mythically leonine

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(lion-like), elephantine, anserine (goose-like), and gallinaceous (poultry-like). They symbolize Buddhist and pre-Buddhist beliefs, and the Burmese institution of monarchy and its continuity, dynastic, and imperial changes.

For the purpose of this account the Burmese empires comprise those regions of the Southeast Asian peninsula now known as Myanmar (Burma) and northern Thailand (Siam).

Buddhist art in India gave rise to the Burmese choices of animal motifs to use on the weights. The anserine weight, in a tenth century Indian style, apparently was chosen first during a period of Theravāda revival. However, the motifs were ancient even then, originating before the Burmese entered Burma. Shamanistic and animistic influences, both of the post-1000 BCE steppes and China, are also evident. Even more obvious is the use of Chinese models and execution for most of the style groups. Moreover, the decision to use Buddhistic symbolic animals may also have been influenced by the enduring association of Indian and Chinese Mahāyāna Buddhists with commerce.

The mass units and scales reached Burma from India before the twelfth century AD, but India itself obtained them from Achaemenid Persia, which in turn, obtained them from Assyria and Babylonia. However, with the growth of Chinese trade in Southeast Asia from the thirteenth century onward and the adoption in Burma of Chinese mass standards, the Indian mass system was displaced. (A mass unit is defined here as that which was used in multiples to form weights mainly used for heavy trade goods and in fractions mainly for bullion or small amounts of other valuable items, the multiples and fractions together forming the mass scale).

A Burmese term often given to the animal-shaped weights is *shway arlay* (gold weights) which may have been derived from the expression *sri arlay* (king's weights). However, in the East the word gold has customarily been associated with royalty. Also, until the late eighteenth century the weights of Burma were mainly used on behalf of the king, who enjoyed monopolies in trade and was the chief import/export broker.

Of the three main weight shapes, the leonine and anserine were used throughout the empires, while those of elephant shapes were used only in north Siam. The first two shapes were still in use in 1970 along the more remote routes that pass from northeast Burma into Yunnan, north Siam, north Laos, and the Thai cantons of Vietnam.

Most commonly, the diameters and heights of the weights do not exceed about 70 × 120 mm. In shape they occur in three leonine- and seven bird-weight style groups which can be placed in stylistic sequence. A sequence in the elephant-shaped weight styles has not been identified with certainty (Fig. 1).

Weights and Measures: Animal-shaped Weights of Burma. Fig. 1 Weights of different shapes. Photograph by the author.

The leonine shape, called *to* (taw = "royal" in Burmese) is a stylized combination of the parts of four animals. The lion of west and south Asia supplied the model for the open-mouth, bearded head and probably for the crouching torso. The horns were either bull-like or were adapted from the antlered muntjac deer of eastern and southern Asia. The tail of two of the styled groups is usually lion-like, but it is occasionally horse-like. With one exception, all the tails are characterized by the artificially raised tail base of the ancient Yunnanese horse. The legs and feet were modeled upon those of the elephant. All these animal representations are present on the abacus of the Asokan pillar at Sarnath.

The standing bird shapes of six of the bird style groups are in the form of a stylized Chinese mandarin drake (*aix galericulata*) having a knobbed crest and known as a *hintha* (Pali). The model for the squatting/brooding, gallinaceous style group has not been identified.

The elephant shapes are naturalistic. In Siam, the weights of elephant shape, known as *chang* in Thai, are difficult to separate from those figurines of similar shape intended for other purposes. The animal representations stand on usually pyramid-shaped bases which may be rectangular, octagonal, circular, or hexagonal.

Frequently, impressed signs 4–19 mm in size are found, usually on the front or right side of the base. In shape they may be script-like circular, square, bird- or feline-like or in patterns normally of 4, 5, 6, 8, and 9 rays, diverging from a central point. These also can be placed in sequence.

The weights are made of a metal alloy, the essential components being copper (50–80%), lead (3–30%) and tin (0–20%). In some of the nineteenth century weights zinc may amount to as much as 35%. The alloy, formally known as *ganza* (Tamil *kamsa*), was imported either in the form of broken vessels from Canton or as the coins known as *cash* (Sanskrit, *karsha*) from Yunnan.

The *kyat* was the mass unit of the *to* and *hintha* weights and varied with time from about 14 g in the fifteenth century to over 16 g in the eighteenth century.

The 20 *kyat* (320 g) weights constitute about 50% of all weights, while weights with a mass of about 250 *kyats* (3,750 g) amount to about 2%. About one-half of the elephant weights weigh less than 45 g and 2% have a mass greater than 130 g. The average mass unit of the upper part of the gallinaceous mass scale is about 11.2 g and that of the lower part is about 13.9 g. The average mass unit of the elephant-shaped weights is about 12.7 g (Fig. 2).

The essentially decimal mass scale of the *to* and *hintha* weights, based on the mass unit of one *kyat* is 1/8 (or 1/10); 1/4 (or 1/5); 1/2; 1; 2; 5; 10; 20; 50; 100; 250. The elephant-shaped weights occur on the following scale: 1/8; 1/4; 1/2; 1; 2; 5; 10; 20; 40; ?; 60. The gallinaceous scale, at about 37 g, separates into an upper binary scale (1; 2; 4; 8; (?); 32 and what may be a lower trinary scale, 1/9; 1/3; 1. Bengalese and Chinese mass scales of the period are similar in part.

Ninety-nine percent of the *to* and *hintha* weights fall within ± 12% of the mean mass of a particular style group while about 51% of them fall within ± 2%. These variations lie in the making of the weights not in additions, subtractions, oxidation, nor wear. The accuracy of the elephant weights (and figurines) is less.

During the nineteenth century the weights were made at a village near the capital under the supervision of the Chief Minister. These standard weights were stored in the treasury and issued to officials in other towns. It was a criminal offense to use weights other than those made "at the palace". Special sets of weights were kept for the purposes of comparison and the settling of disputes. Though only two nation-wide "standardizations" have been recorded, the earliest in the eleventh century, nevertheless it was the required duty of each new monarch, upon ascending the throne, to verify the weights.

Copies of animal-shaped weights, usually somewhat crude, are still made today in eastern Burma (Shan States) using techniques similar to those of thirteenth century AD and second century BCE Burma and Yunnan. The weights were made by the lost-wax technique, using clay to surround the wax model and metal molds to shape the wax model. The high-melting point wax used was produced in Yunnan by an insect.

Among the goods imported from India which may have required weighing were opium, indigo, and mercury. From Yunnan came gold leaf, silver ignots, copper-alloy, cash, salt, white insect wax, cinnabar, and tea. Burma exported gems, including pearls and coral, costly medicines, musk camphor, gums, resins, waxes, ivory, rhinoceros horn, and rare woods. Considerable trade would have been done with other Southeast Asian states, e.g., tin from Malaya and Laos, arsenic, lead, and silver from the Shan States, zinc from Laos.

Seeds and a Chinese type of equal-arm balance were used for the weighing of small highly valuable articles and the steelyard or datchin for large masses. For moderately valuable articles, e.g., foreign silver coins and ingots, the animal-shaped weights would have been used.

Until after the middle of the eighteenth century ordinary village commerce was conducted by barter, counting, purchase with cowries, and by measurement of volume or length. Weights were rarely necessary. However, from the last quarter of the eighteenth century onward, it was the ordinary Burman, rather than the king's officers, who made use of the weights, mainly to weigh currency ingots. This change was caused by the Burmese wars of the time. These resulted in the cessation of the supplies of copper alloy and cowries, led to the Burmese capture of the large lead and silver mines of the Shan States and so to the copying of the Chinese practice of using chopped lead as a low value currency. As a result of the increased need for weights to weigh the abundance of lead and silver ignots, there was a flood of copies from the formerly Burmese north Siam region, now occupied by south Siam (Ayuthya). This new domination also led to the replacement or adjustment of the animal-shaped weights to agree with those of south Siam.

Weights and Measures: Animal-shaped Weights of Burma. Fig. 2 Weights of different sizes. Photograph by the author.

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Each of the weight shapes together with its base, and each of the parts of the weights, was intended to convey a particular meaning. The meanings had to be understood by illiterate speakers of many different languages. Though they were intended to be understood primarily by animists and Buddhists, they would also have been understood by Confucianists, Daoists, and others. Characteristic of animist/Buddhist Southeast Asia (though originating much further away in space and time) was the belief in the earthly, semidivine king. This is what the *to* weight was intended to symbolize. It combined the physical characteristics of a potential Buddha (*bodhisattva*) and a universal monarch (*cakravartin*). These, in turn conveyed the idea of secular power both to animist and Buddhist, being associated with earth, fertility, and healing, with legitimacy of rule and righteousness of conquest (a prerogative of a universal monarch). New styles of *to* weights were issued only at the times of the "righteous conquests" of a Burmese king, usually at the beginning of a dynasty with the accompanying empire-building.

The *hintha* weight symbolizes, among other things, the heavenly perfection and purity of the Buddhist faith, especially that of the Theravāda belief characteristic of Burma and Siam.

The association of feline and anserine representations for symbolic purposes has an origin more remote than Buddhism. The lion–duck association is present on some Asokan pillars. Lion-shaped weights were in use in Assyria about 1500 BCE and duck-shaped weights in Sumeria and Babylonia.

Concerning the elephant weights the kings of Burma and Siam (Ayuthya) were the incarnations of Indra, the chief of the gods, who was ancient before Hinduism, and who rode on an elephant. Thus, one reason (among several) for the choice of the elephant was to symbolize these kings.

The most generally useful of the techniques for establishing the chronological sequence of the weights were the style and sign sequences; the relation of the *to* weight styles, through their symbolism, to the dates of the dynastic changes and territorial expansions; the sequence of increase in the average unit mass of each style group; the dates of the unit masses obtained from the weighings recorded by many European traders from AD 1515, and their relation to the average unit masses of the style groups.

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Weights and Measures in China

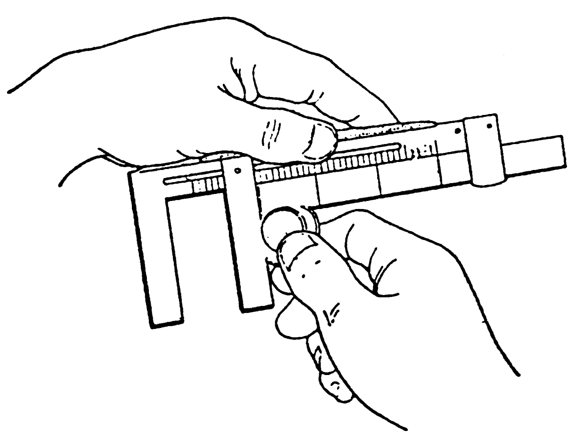
Hans Ulrich Vogel

Metrology means the "science of weights and measures." But when referring to premodern periods the term "knowledge of weights and measures" is more appropriate. In a more concrete sense, metrology is the art of calculation with number, weight, and measure units in the economic and fiscal domains as well as in science. "Metrosophy" may be defined as "number speculation within cosmological philosophemes," but from a more inclusive perspective the relationships between magical, religious, and political thought on the one hand and metrology on the other also have to be taken into account. In both metrology and metrosophy, numbers are of great importance. In metrology, they are used for defining and counting measure and weight units, while in metrosophy they serve as basic stuff for the creation of systems of number symbolisms, magical numbers, and correlative numerologies.

For the study of metrosophy and metrology, two different types of sources are basically available. First, we may mention sources of the tradition type, like the metrosophical and metrological sections in chapters of the dynastic histories. Although these sections also contain information of a metrological nature, it is clear that they are principally metrosophical in character. The second important types of sources are concrete remains, especially the relatively great number of real ancient weights and measures which either have been excavated at archaeological sites or which survived by having been handed down from generation to generation. While the sources of the tradition type are closely related with metrosophical thought and number systems, concrete remains inform us almost exclusively of metrological aspects and realities. The tension between these two clusters of information and data is of particular importance and is rewarding to be investigated.

Chapter 21A in the *Hanshu*, written in the first century AD, contains one of the first surviving texts that gives evidence of a system integrating metrology with such diverse fields as numerology, musical pitch, astronomical phenomena, astronomy, cosmology, historiography, and political, ethical, and moral thought. The textual arrangement of this chapter makes clear that metrology belonged to the traditional Chinese science of mathematical harmonics (*lü* or *lülü*).

Chapter 21A of the *Hanshu* states that harmonics consist of five categories: number, musical pitch, length measures, capacity measures, and weights and balances. All five had their origin in the *huangzhong* pitch-pipe, which had been created and standardized by the legendary Yellow Emperor. Obviously, the antiquity of these conceptual and technical devices was an important criterion for their purported eternal validity. Within the five categories a certain hierarchy is expressed, ranking numbers above, followed, in descending order, by pitch, length, capacity, and weight measures. Numbers are obviously of primary importance, because they provided the basic counting units for the other four categories. Metrology was grounded on a numerological system combining the numbers of the Five Phases (*Wuxing*) and other numerological concepts with the numbers derived from the changes of *yin* and *yang* as they are described in the *Yijing* (I Ching Book of Changes) and its commentaries. Moreover, weights and measures were conceived as an integrated system. With grains of medium-sized black millet, the length and capacity of the *huangzhong* pitch-pipe were measured and thus the basic length and capacity measure units derived. The weight of the grain filling of the pitch-pipe also served as the basis for fixing the weight units (Fig. 1).



Weights and Measures in China. Fig. 1 Handling the Wang Mang proto sliding callipers. From Liu Dong-rui, "The Earliest Slide Ruler in the world – the Bronze Slide ruler of the Xin Dynasty (AD 923). *Bulletin of the Museum of Chinese History* 1 (1979): 96 (in Chinese).

Concrete remains of ancient Chinese weights and measures are of great importance for supplementing the information contained in the largely normative written sources. A spectacular example are the proto sliding callipers of the Wang Mang period (AD 9–23), of which apparently three pairs survived.

The intaglio inscription on the movable part says: "Manufactured at the first day of the first month of the first year of the Shijian guo reign-period." This corresponds to March 15, AD 9, the first day of Wang Mang's interregnum. The front side of the fixed part of the sliding callipers is divided into 5 in. (*cun*), that of the movable part into 5 in. In addition, the 4 in. of the fixed part are further subdivided into ten parts (*fen*) each. With the Wang Mang proto sliding callipers outer diameters of less than 4 in. could be measured. The most conspicuous difference between modern sliding callipers and the Wang Mang piece is that the latter does not have the differential scale of the vernier.

No less spectacular is the great number of other Chinese metrological remains. For instance, more than 240 ancient length measures are known, which can serve as a basis for ascertaining the "true" length of a length measure unit of a given period. This is no easy task as may be shown in the case of the length measure unit *chi* of the Eastern Han period. Modern measuring has shown that the actual lengths of 85 concrete *chi* measures of this period vary from 20.49 cm to 24.73 cm. Obviously, state efforts at unification and standardization of weights and measures were of limited success and collided with diverging interests having their origin in different regional, local, political, economic, fiscal, and social conditions. Small wonder that in the *Suishu*, the dynastic history of the Sui dynasty written in the early seventh century, 15 different *chi* measures are listed.

The development of the types of weighing apparatuses can be divided into three stages. From the fifth century BCE to the second century AD balances with equal arms prevailed. In the period from the third to the ninth centuries the steelyard with unequal arms appeared and was used together with the ancient balances. Finally, the third stage from the tenth to the early twentieth centuries was characterized by the emergence of the highly accurate *deng* steelyard and the introduction of a decimal system of weighing units. An important promoter in the introduction and improvement of the *deng* steelyard was the eunuch Liu Chenggui (950–1013). Liu was in charge of the court treasury and fiscal affairs. The purpose of the introduction of the *deng* steelyard was to reduce disputes in the weighing of precious metals, which arose between different officials involved in fiscal affairs.

See also: ►Acoustics, ►Five Phases, ►*Yinyang*

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Weights and Measures in Egypt

Ruth Hendricks Willard

The gradual change from a nomadic to a settled existence, which began about 8000 BCE, marked humankind's determination to shape the environment to their requirements. Needing units of measure for both building and agriculture, people chose the most readily available and useable references – simple parts of the human body in various positions. The need for uniform measurements was recognized, and as early as 3000 BCE official reference standards of length, volume, and weight were being maintained in temples and royal palaces in Egypt, Mesopotamia, and around the eastern seaboard of the Mediterranean.

The standards developed in these ancient cultures moved westward, mostly as a result of trade, to the Greek and Roman empires, thence to Gaul and Britain via the Roman conquest. Egypt, by virtue of its geography a great trading nation and of its climate a preserver of archaeological treasures, has provided an incomparable record of this metrological heritage.

Measures of Length

Throughout the ancient Middle East, the basic unit of linear measure was the cubit, which was defined as the length of the forearm from the point of the elbow to extended fingertips. In Mesopotamia, the cubit was generally subdivided into 2 ft each of 3 or 4 palms, a palm having 4 digits. In Egypt, however, the most ubiquitous standard was the royal cubit. It was subdivided into 7 palms (28 digits), these divisions having significant mystical relationship to the four 7-day phases of the 28-day lunar month by which time was reckoned. The basic sub-unit was the digit (finger width): 4 digits = a palm; 5 digits = a hand; 12 digits (outstretched forefinger tip to little finger tip) = a small span (1/3 cubit); 14 digits (outstretched thumb tip to little finger tip) = 1 large span (1/2 cubit). Measurements smaller than a cubit were expressed in digits (up to 10), in palms and digits, or rarely, as 1/2 or 1/3 cubit.

Surveys of the Great Pyramid confirm its construction according to the royal cubit of 20.62 in (52.4 cm). The skill of the Egyptian workmen is shown by the fact that the sides of its base vary no more than 0.05% from the mean length of 440 cubits (9069.45 in or 230,364 m). The Egyptians also employed a short cubit of 6 palms (24 digits) = 17.68 in (44.9 cm) for general purposes including calibration of the Nilometers (masonry stairwells leading down to the river at points where the priests recorded the rise of the annual floods).

Egyptian measuring scales are square rods with one face half-beveled to form a reading surface. The fractions of the digit are shown by dividing the first into halves, the second into thirds, and so on down to sixteenths. The oldest extant cubit rods date from the 18th Dynasty, 1550–1307 BCE; none are longer than the double cubit, 41.2 in. Most of those used by the workmen are made of wood with deeply cut notches of division. The stone cubit rods are generally ceremonial, belonging to the temples and crowded with inscriptions referring to the religious aspects of the digits as connected with the gods and with the signs of the nomes. On these, the calibrations are often carelessly marked.

Land was measured by a linear unit called *khet* or *khet u nu* (reel of cord) 100 royal cubits in length.

Measuring cords were made of palm-fibre or flax-fibre and knotted at 5-cubit intervals. For long distances the foot (12 digits) and the pace (double step) were used; 2 paces measured heel to toe = the extended arms (4 cubits), and 100 paces = a stade. This distance later used by the Greeks in the Olympic foot races known as a stadium.

Measures of Area

The basic unit for reckoning areas of fields and nomes [a name given to regional divisions in Egypt] was the *setat*, the square of the khet, containing, therefore, 10,000 square cubits. Such an area was called a cubit of land, but was visualized as 100 parallel strips of land each 1 × 100 cubits. Ten setats were called a thousand of land. In devising ways to re-establish field boundaries after the annual flooding of the Nile, the Egyptians discovered the rudiments of geometry. A new unit formed from the diagonal of a square with sides equal to the royal cubit was found to be divisible by 40 digits of 0.73 in, twice the length of the *remen* (forearm from elbow to clenched knuckles) and consequently named the double remen. Half of the area of 100 × 100 cubits was also called remen in land measure. By having two standards, one the diagonal on the square of the other, it was possible to denote areas in squares equal to one-half or double the area of others.

Measures of Time

Through studies based primarily on the movements of the heavenly bodies in relation to the regular flooding of the Nile the Egyptians established two calendars. The priests followed an exact year of 365 1/4 days, while the civil year was subdivided into 3 seasons of four months each having 30 days – inundation, cultivation, and harvest – plus 5 days-upon-the-year.

Measures of Volume

In establishing standard units of capacity for barter, taxation, and medication convenient reference was made to human factors such as a mouthful (tablespoonful), handful, cupful (two handfuls) and sack- (hide-) ful for easy carriage. The principal Egyptian standards from small to large were the *ro, hin, hekat*, and *khar*.

Medications were prescribed in terms of the ro (mouthful, tablespoonful) = 1/2 fl oz (14.5 cc). By the usual Egyptian method of doubling this standard produces 2 ro = 1 handful (fl oz, jigger); 4 ro = 2 handfuls (jack, jackpot); 8 ro = 4 handfuls (gill); 16 ro = 2 hands cuppedful (cup); 32 ro = jugful (pint, *hin*); 64 ro = pitcherful (quart) and, by extension, the old English measures including the gallon, peck, bushel, barrel, hogshead, and tun.

The hin for liquids was subdivided dimidially down to 1/32 = 1 ro. There was also 1/3 hin known as the *khay*, thirds being a peculiarity of Egyptian metrology occurring also in the subdivision of the cubit and *qedet* standards. There were two principal standards for larger volumes. Multiples of the hin were decimal: 10 hin = 1 *hekat* (4.7 L). The hekat was the official corn measure: hekat = 10 hin; 30 hekats = 1 cu cubit. The khar, orginally a hide or sackful, was a special standard = 20 hekats (94 L). Subdivisions of the hekat in the dimidial series 1/2 to 1/64 (=5 ro), an amount frequently prescribed for internal medications) were always written in symbols now known as the Horus-eye notation. The Rhind Mathematical Papyrus, attributed to the 12th Dynasty (1991–1783 BCE), provides the following conversion table: 9,600 ro = 300 hin = 30 hekat = 3/2 khar = 1 cubic cubit (37 U.S. gallons).

The early use of additional capacity standards is documented by wall paintings in a Mastaba tomb of the 3rd Dynasty, ca. 2630 BCE. Two series of cylindrical capacity measures, one of copper, for measuring wine and oil, and one of hooped wood staves for grain, have been shown to conform to a mixed series in binary progression based on the standards of both the Egyptian hin and the Syro-Phoenician *kotyle* (21.4 cu in or 350 cc). Other standards of volume used in Egypt include the Syro-Babylonian *log* (33.1 cu in or 542 cc), the Attic kotyle (17.2 cu in or 282 cc), and the Persian *kapetis* (74.9 cu in or 1227 cc).

Measures of Weight

A search for the origins of weighing reveals that this intuitive use of the lever evolved independently in at least three ancient civilizations – Mesopotamia, the Indus Valley, and Egypt – and that all three were routinely employing balance and weights by the middle of the third millennium BCE. The weights, made in durable stone, have survived in sufficient numbers to permit study of the ancient weight standards. However, very few balances, which were usually constructed of wood in the earliest periods, exist today.

It is possible, nonetheless, to trace not only the evolution of weighing instruments but also the uses to which they were put in dynastic Egypt during the period 2700–650 BCE. As a means of enhancing the quality of the afterlife of their leaders, Egyptian artisans carved or painted scenes from their earthly life in tombs and temples. Because of a mild, dry climate, many of those monuments survived into modern times. While it is still possible for visitors to experience the excitement of discovering the weighing scenes in situ, not all of the tombs and temples have survived the two centuries of study and tourism to which they have been subjected. Colors have faded; walls and in fact entire structures have disintegrated or been destroyed or closed. We turn, therefore to the remarkable work of the

Egyptologists of the nineteenth and early twentieth centuries, a period of intensive recording and copying of Egyptian inscriptions, reliefs, and paintings. Hence, it becomes necessary to consider not only possible errors in the original, but also the errors resulting from the deterioration of the works being copied.

For information regarding the practice of weighing, we are indebted primarily to Sir W. M. Flinders Petrie. He was the first Egyptologist to identify, collect, and study the ancient weights for the insights they could provide into the cultural and trade relations among the various nations of the Near East. His numerous publications include chapters on the metrological findings of each site excavated. Most large museums have specimens of ancient Egyptian weights.

The practice of weighing began with the discovery of metalworking. The earliest weights are of a small order, suggesting that at first only small quantities needed to be weighed. Egyptians developed two indigenous weight standards and as an international trading center employed at least six more. The Egyptian national standard was based on the qedet, which varied over time from 138 to 152 gr giving a median value of 144 gr (9.33 gm). It was multiplied decimally: 10 *qedet* = 1 *deben*; 10 deben = 1 *sep*, as first recorded in a 3rd Dynasty tomb painting. The unit was sometimes divided into thirds as evidenced by a series of graves from the 1st Dynasty (2920–2770 BCE). The qedet is the basis of nearly all statements of weight from the 18th Dynasty onward. The qedet and deben were also known as the *kite* and *uten* when applied to pieces of copper used as a medium of exchange.

Less well known but more influential in world affairs was the *beqa*, which was associated with the weighing of gold and silver from pre-Dynastic times and used in Egypt for nearly 4,000 years. Although the standard is seldom mentioned in Egyptian inscriptions, numerous beqa weights have survived. These are sometimes marked with the hieroglyph for gold (*nub*) perhaps recalling its origin in the Nubian gold fields. As in most Middle Eastern standards, the basic unit was called a *shekel*; 50 beqa shekels = 1 *mina*. The beqa shekel was multiplied decimally to 7,000 shekels and subdivided dimidially down to 1/16. Over time, the several distinct values merged into a single standard of 192 gr (12.4 g), which was adopted by the Greeks around 700 BCE as the standard of Aegina. From it evolved two of the Roman pounds, the silver denarius and the gold aureous coinage. In the seventh century AD it was adopted by the Arabic Empire for bulk gold and it ultimately became the basis for the English troy weight standard.

Other standards in use in Egypt included the Palestinian *peyem*, 120 gr (7.78 g); Mesopotamian *daric*, 129 gr (8.36 g); Attic *stater*, 135 gr (3.75 g); Persian *khoirine*, 178 gr (11.53 g), and Phoenician *sela*, 218 gr (14.13 g).

The Evolution of the Equal Arm Balance

All of the balances used in Egypt before the Roman occupation in 30 BCE were equilateral, doubtless inspired by the yokes with which men balanced heavy loads on their shoulders. During the Old Kingdom (2686–2181 BCE) most balance beams were flat and rectangular, pierced vertically for support at the fulcrum and for the hangers, which were single cords hooked at the end to hold baskets or bags of gold dust. With but one exception, shown in (Fig. 1), they were made of perishable wood until about 1550 BCE. Hence, the only records of their design and use come from reliefs, paintings, and inscriptions.

Significant innovations during the Old Kingdom include specialized tongs to hold metal vessels, counterweights of a predetermined mass, tongues, and plummets to help in sighting the vertical. Nearly all of the 5th and 6th Dynasties weighing scenes come from the tombs of royal officials, and depict the

Weights and Measures in Egypt. Fig. 1 This is the earliest known Egyptian balance. It was skillfully cut from pinkish brown limestone, a material commonly used for making vessels in prehistoric times, but seldom later. The three suspension holes were drilled with a primitive bow drill and flint point. The beam is 3.35 in long. Its width varies from 1.6 in to 2.0 in and its depth from 1.7 in to 2.0 in. The diameter of the central hole is .03 in and that of both end holes is .07 in. As to sensitivity, a change of 1 in 500 can be seen by the change of level. A plaster model of this balance was tested at the Science Museum in London. Photo at the Petrie Museum, University College, London by O. W. Willard in 1993.

weighing of metal in the course of manufacturing. There is no evidence of buying selling, or exchanging goods by weight in this early period.

The decline of the Old Kingdom was followed by the First Intermediate Period, an epoch of chaos, civil war, hunger, violence, and invasion. No evidence of weighing has been found from this period, which encompassed the 7th to 10th Dynasties and lasted from 2134 to 2040 BCE. Eventually Theban warlords gained supremacy and established the Middle Kingdom with its capital first at Thebes and later at Itjtawy, a newly built city near Memphis.

The Middle Kingdom

Weighing scenes are found at Beni Hasan, the most noteworthy necropolis of the Middle Kingdom, where 39 tombs are cut out of the rock cliffs at Beni Hasan, on the east bank of the Nile. The tomb paintings here depict balances with an improved suspension system. The beam is suspended from a bracket near the top of the upright and can swing more freely because of a ring added to the top of the tongue. As in the fifth and sixth Dynasties, the plummet appears to hang from a point near the bottom of the tongue suggesting that the tongue and beam are rigidly attached and move together. The baskets are now suspended by multiple cords, depicted as two but presumed to be four, since that is also the case in the New Kingdom, from which we have extant pans with four holes. One representation shows workers weighing two sets of objects against one another. Another representation shows the introduction of shallow, concave pans made possible by the multiple suspension cords. Weight boxes are shown below each standing balance.

A totally new aspect of weighing appears in one 12th Dynasty relief. Here we see a jeweler who has left the workplace to show his finished product to the nomarch (local ruler). Reading between the lines, we note that he has suspended the balance from a full-length stand, but by using an extension cord, he has brought the scale and its contents down to a level he can reach while kneeling before his ruler.

During the Second Intermediate Period, from 1640 to 1532 BCE, the political situation was unstable, with several dynasties ruling in various areas simultaneously. While there was undoubtedly turmoil during the takeover, Egyptian life was enriched by the introduction of horses, wheeled chariots, hump backed cattle, and new tools, weapons and musical instruments. Innovations relevant to metrology included the working of bronze and weights cast in the shapes of animals.

The New Kingdom 1550–1070

Both the equipment and the philosophy of weighing underwent major changes during the New Kingdom (1550–1070 BCE). While the equal arm balance of the Old and Middle Kingdoms had been modified in ways that made using it more convenient, there was still the problem of accuracy. The end suspension cords could wander in holes drilled vertically through the beam and those holes, even if exactly equidistant from the fulcrum initially, might not remain so after the wearing away inherent in use. Either early in the New Kingdom (or possibly late in the Second Intermediate) a radically different scale beam made its appearance. Constructed of either wood or bronze, it was round in section. Suspension cords entered at the beam end through longitudinal bores and emerged through intersecting radially drilled holes, being knotted on top of the beam. Any inequality in the distance of the beam ends from the fulcrum could be adjusted by simply filing the longer end, restoring the balance to accuracy. This principle was later improved upon in the large standing balances with flared beam ends that allowed the four strings to diverge from the lowest point on the flange, making for even greater accuracy.

While the great majority of representations from this period depict large, stately standing balances, the extant specimens are all small and portable. The beams, which may be of bronze or wood, are invariably round in section. The Cairo Museum displays several. A hand-held balance at the Science Museum in London was excavated at Amarna and dates from the reign of Akhenaten, 18th Dynasty, c. 1331 BCE. The length of the round, tapering wooden beam is 30 cm and the diameter of the copper pans is 7.4 cm; the sensitivity is plus or minus 2 gr per hundred in each pan. Bronze animal weights characteristic of the 18th Dynasty are shown with this balance. Two previously unpublished specimens were found at the University of California's Phoebe Apperson Hearst Museum of Anthropology. Both were excavated at Naga ed-Deir during the 1899–1904 Hearst Expedition led by G.A. Reisner. While it is impossible to date either one with certainty, both have the general characteristics of New Kingdom balances (see Fig. 2).

Specimen 6-13624, from a cemetery dating from the late Old Kingdom through the Middle Kingdom, was found near the entrance of tomb 434 with the excavator's notation *ghadim* (fill). The wood is acacia,

Weights and Measures in Egypt. Fig. 2 Two New Kingdom-type balance beams. Photo by O. W. Willard by permission of the Phoebe Apperson Hearst Museum of Anthropology, University of California.

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sub-species not identified. The round, tapering beam is 50.3 cm long with a diameter of 2.7 cm at the center, drilled in the New Kingdom manner for central and end suspensions. Unlike the Amarna balance above, the beam has a definite arch in the middle. There is the imprint of a narrow saddle or support of some kind at the fulcrum. The ends are knobbed, with a decorative channel around each. On each side of the suspension holes, there is a decorative double annulet with a channel between. No pans were found.

Specimen 6-2702 is believed to have come from a cemetery dating from early dynastic to Roman times. The wood is acacia, sub-species not identified; the round beam is 31.2 cm long and 2.0 cm in diameter at the center. There is a bulge in the center of the beam and the ends are slightly flared, foretelling the more pronounced flanges of the large ceremonial balance. There is also an unexplained diametric hole about 1.0 cm from the fulcrum hole. No pans were found.

The most magnificent weighing scenes are those representing the brilliant 18th Dynasty, which ruled Egypt from 1550–1307 BCE. The ceremonial balances, sometimes 10 ft tall, are often adorned with the head of a god as a finial. The beam hangs from a bracket that may be in the shape of the feather representing Maat, the goddess of truth. The bronze tongue, which has evolved into a pointer, moves with the beam. In many examples, the operator holds the plummet in his hand as if to inspect it for flaws before beginning the weighing procedure. Shallow concave pans, usually of metal, are suspended by multiple cords thought to be four in number although sometimes depicted as two or three. The conventional stone weights, geometric in form, have been replaced with handsome animal shapes in cast bronze.

Ambiguities in the drawings coupled with the lack of physical specimens have fostered intense interest in the central suspension and indicator system. The explanation most generally accepted was offered by Petrie in 1888:

> The beam was suspended by a loop or ring from a bracket projecting from the stand; this bracket is shown in side view though at right angles to the beam just as the Egyptians drew a full eye in a side face. Then below the beam, a long tongue was attached, not above the beam, as with us. To test the level of the beam, a plummet hung down from the tongue, and it was this plummet which was observed to see if the tongue was vertical and the beam horizontal. The weigher is often shown steadying this plummet with his hand, as it would be set swinging by the motions of the beam. Such is the whole system, which is so simple that it seems strange that any mistake could be made about it to say nothing about the mechanical absurdity of the explanation which has been current for so long.

The "mechanical absurdity" theory to which Petrie referred had been offered by Wilkinson in 1837. Referring specifically to an illustration showing the balance being used by the *Qabbaneh*, or Public Weighers, he wrote,

> The beam passed through a ring suspended from a horizontal rod immediately above and parallel to it, and when equally balanced, the ring, which was large enough to allow the beam to play freely, showed when the scales were equally poised. It had the additional effect of preventing the beam tilting when the goods were taken out of one, and the weights allowed to remain in the other. To the lower part of the ring a small plummet was fixed and this being touched by hand and found to hang freely indicated, without the necessity of looking at the beam, that the weight as just.

Though acclaimed for his understanding of the Egyptian artistic canon and for the accuracy of his copies, Wilkinson overlooked the obvious fact that the vertical plane of the bracket, shown in profile, would have been perpendicular to that of the beam. The single-ring hanging mechanism as shown could not possibly have worked. It would appear that either the original drawing was erroneous, or deterioration in the ancient surface caused Wilkinson to miscopy it.

Recent research has centered in the nature and function of the triangular shape bisected by the plumb line that project below the beam. Spiegler postulates an arrangement of three strings fastened at the beam and equipped at the tip with a plummet. As the beam is tipped, a slack string allows the plummet to swing. Jenemann and Robens note that such a mechanism would work only with large deflections that could be seen more easily by visual observation. Furthermore, in colored drawings the triangle is clearly opaque, indicting a solid object. They then suggest that the flat side of the triangular plane, while shown frontally in the drawings, is actually perpendicular to the beam, while the plummet hangs independently in front of the tongue, an arrangement considered to be more sensitive than one in which the tongue pierces the beam longitudinally.

Skinner states, "For larger wooden or bronze beams a bronze tongue was driven vertically through the center of the beam with a ring on top for suspension from a bracket. The tongue protruding below the beam acted as a swinging index, which was sighted against a freely-suspended plum-bob to denote when the beam was horizontal and in balance." In the absence of New Kingdom specimens, perhaps conclusions can be drawn from a small bronze goldsmith's balance dating to the Greco-Egyptian period, 304–30 BCE. The beam is suspended from a ring in the bracket intersecting a ring in the top of the tongue or pointer, which pierces the beam and extends below it. The plummet hangs from the bracket, behind the tongue. The original is in the Cairo Museum and its replica, a plaster cast, is in the Science Museum, London.

Expanding Roles for the Balance: Trade, Tribute, Offerings

With Egypt's transformation to an international power, new roles evolved for the balance. Along with the customary depictions of jewelers and other metal workers there are scenes of the balance used in weighing tribute to the pharaoh and offerings to the national god Amun and, for the first time, in domestic and foreign trade. Short gold or silver cylinders about five inches in diameter served as a sort of currency. Variable in mass, these must have been weighed in each transaction. Medicine however, continued to be measured rather than weighed.

The earliest known depiction of the balance in commerce is found in a remarkable painting from the tomb of Kenamun, Mayor of Thebes and Superintendent of the Granaries of Amun under Amenophis III, 1391–1353 BCE. Syrian ships were anchored on the Nile off Thebes, while on shore two male shopkeepers engage in private trading with the sailors. Since the commodities – sandals, apparel, and various objects – are too large to weigh on the hand balances shown, the sellers are obviously weighing out the amount of gold needed to make the purchases.

Among the various public officials were the Qabbaneh, or public weighers, who erected their balances in the market place while a notary stood by to record the details. They were required by law to adjust the sale of each commodity with the strictest regard to justice, without favoring either the buyer or the seller. The penalty for falsification of weights or records was the loss of both hands, inflicted upon the seller, the weigher, and the notary alike. The Qabbaneh were still functioning in early twentieth century Thebes.

Hatshepsut, who ruled as Egypt's only female Pharaoh (1473–1458 BCE) built at Deir el Bahari a magnificent temple with extensive terraced gardens facing the Nile. She dispatched an expedition to the fabled land of Punt in search of treasures to be offered to the sun god Amun, to whom the temple was dedicated, and recorded the presentation in a monumental relief on the south face of the second terrace. In the weighing scene, a massive balance is piled high with cylindrical gold ingots being weighed against some loaf-shaped weights of the Middle Kingdom and some bronze animal-shaped weights characteristic of the 18th Dynasty. In the background are trays holding additional loaf shaped weights and quantities of electrum (a naturally-occurring alloy of gold and silver) in bars and rings. The inscriptions read,

> The balances accurate and true of Thoth, which the King of Upper and Lower Egypt (Hatshepsut) made for her father Amun, lord of Thebes, in order to weigh the silver, gold, lapis lazuli, malachite, and every splendid costly stone, for the sake of the life, prosperity, and health of her majesty. Weighing the gold and electrum, the impost of the southern countries, for Amun-Re, lord of Thebes. Recording in writing, reckoning the numbers, summing up in millions, hundred of thousands, tens of thousands, thousands, and hundreds.

Thutmose III, successor to Hathepsut, so extended the Egyptian holdings in Asia and northern Ethiopia that he has been referred to as the Napoleon of Egypt. During this period, the coffers of the state were greatly enriched by both tribute from and trade with the nations they had subdued. A weighing scene in the tomb of his Vizier, Rekhmire, is inscribed in part, "This great heap of electron, which is measured by the heket, making 36,692 deben.

The Papyrus Harris, now in the British Museum, represents the testimony of Rameses III, Pharaoh (1194–1163 BCE) as he nears the end of his life and affords an understanding of both the physical nature and the significant role of the ceremonial balance in the New Kingdom. Describing his stewardship as the god's representative, he states as part of the prayer and recital of the king's benefactions,

> I made for thee splendid balances of electrum, the like which had not been made since the time of the god. Thoth sat upon it as guardian of the balances, being a great and august ape of gold in beaten work. Thou weighest before thee, O my father Re, when thou measurest of gold and silver by the hundred thousands, brought as tribute before thee from their coffers, and given to thy august treasury in the house of Atum. I founded for it (namely the balance; evidently offerings were made to it) daily divine offerings in order to supply its altar at early morning.

In another section, Rameses describes the king's gifts to Re including (in part), "Fine mountain gold and gold for the balances 1,278 deben, 9 2/3 kedet[1]. Crude silver for the balances and silver in vessels 1,891 deben, 1/2 kedet. Black copper for the balances 67 deben, three kedet.

[1] The gold amounts to some 311 3/4 pounds troy, and the silver to nearly 461 pounds troy.

Weights and Measures in Egypt. Fig. 3 The Judgment Scene: Ani's heart being weighed in the balance (the first three of six panels). Left to right, top: The company of the gods, who hear Ani's testimony. Lower register, left to right: Ani and his wife Thuthu entering the Hall of Judgment; Rehenet and Meskhnet, the Goddesses of birth; (small figures. L 2 r) Ani's soul, Ani's Embryo, Ani's luck or destiny; Anubis testing the tongue of the balance; Thoth recording the result of the weighing, The Devourer of the Unjustified; Not shown here: Horus, the falcon-headed god, introducing Ani into the presence of Osiris; Ani kneeling before Osiris, Osiris enthroned within a shrine. Behind him are Isis and Nepthys, and before him upon a lotus stand, the children of Horus (Budge 1969). The original Papyrus of Ani is in (the British Museum, No. 10470 Sheet 3 and 4).

Weighing the Soul

Souls too were weighed. The Egyptian concept of right conduct as a prerequisite for admission to paradise grew out of the cult of the god Osiris, which with its promise of immortality began to flourish during the First Intermediate Period. But it was first represented pictorially in the New Kingdom, when an elaborately illustrated roll of papyrus known as the Book of the Dead (or, more properly, The Book of Coming Out by Day) was placed in the tomb. Along with spells and instructions for entering into the kingdom of the gods, each Book of the Dead included a weighing scene in which the heart of the deceased, often represented by the hieroglyph for heart, was weighed against the feather of truth, symbol of the goddess Maat. The deceased was required to make a "negative confession" denying the commission of 42 specific sins such as giving short measure or falsifying the scales of the balance. The jackal-headed god Anubis tested the plummet of the scales, while the ibis-headed god Thoth prepared to record the results and a beast called the Devourer of Souls stood by to perform his duty, should the applicant's heart be found wanting (see Fig. 3).

This allegorical concept, first presented graphically by the Egyptians, persisted in the Christian world through the Middle Ages as demonstrated by surviving legends, stained glass windows, and paintings in which Anubis is replaced by St. Michael and the feather replaced by a toad. In 1901, Dr. Duncan McDougal of Haverhill, Massachusetts conducted the first of several experiments to determine whether the soul has weight. He found that in addition to the gradual weight loss related to the loss of body fluids as death approached, at the exact moment of death there were sudden weight losses of 3/8 oz, 1/2 oz, and 3/4 oz. He attributed this weight loss to the departure of the soul. In his book, *Weighing the Soul*, Fisher relates other scientific research dating from Leonardo da Vinci in 1515 to American and European physicists in modern times. As recently as 1972, according to Agence France Press, a Swedish doctor set out to determine the mass of the human soul by placing the deathbeds of seriously ill patients on extremely sensitive scales. As each died and the soul left the body, the needle dropped 21 g, he reported.

The reliefs and paintings with which the Egyptians adorned tombs and temples celebrate the enduring values of their culture over a period of more than 3,000 years. The 18th Dynasty weighing scenes with their monumental balances and graceful animal-shaped weights are generally considered the apex of the genre. After this period of artistic and religious ferment Egypt returned to the old familiar ways, recasting their weights in geometric shapes. And as time went on, the illustrations grew more and more fanciful, as if the artists preparing them were not familiar with the actual instruments. While these enigmatic drawings, at once lively and serene, do not reveal all the technicalities of the Egyptian balance, they do provide a window into an ancient culture whose achievements in many fields are still reflected in modern life.

Whether constructed of wood or of bronze, the improved Egyptian balance became the standard weighing instrument of the Near East until Roman times. Glassmaking, another technical innovation of the 18th Dynasty, was applied to metrology with the production of a few weights during the Roman and Byzantine periods. The Arabs, after their conquest of the country in AD 640, continued the tradition, issuing a fine series of reference weights for their coinage.

These are circular discs of transparent glass in various colors molded with a thick rim surrounding a central depression and civil inscriptions in Arabic. The Arabic standard of metrology continued to be dominant through the nineteenth century with standards varying city by city and by commodity. The metric system was made permissible in Egypt in 1873.

See also: ►Calendars in Egypt, ►Pyramids

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Weights and Measures of the Hebrews

Lionel Holland

Weights

The earliest Biblical reference to a unit of weight is in Genesis 23:16: "Abraham came to an agreement with him and weighed out… four hundred shekels (of silver) of the standard recognized by merchants." Abraham was a new immigrant in Canaan. The *shekel* units which he used to weigh out the silver for Ephron the Hittite may have been those of his native Mesopotamia, with which he would have been most familiar.

The Mesopotamian shekel weighed about 8.3–8.5 g. Sixty shekels = 1 *maneh* (Greek: Mna, mana. English translations of the Bible often render *maneh* as "pound") of 497–508 g. Sixty *maneh* = 1 *kikar* (Greek: Talanton; English: talent) of 29.8–30.5 kg. This system, which was originally Sumerian, in the fourth or third millennium BCE, was used with little change for thousands of years by the peoples of Mesopotamia; the terms SH-Q-L, M-N-H, and K-K-R are Semitic in origin and were first used by the Akkadians. Systems similar in structure, though varying in detail and in the absolute mass of the units, were used by most of the peoples of the Eastern Mediterranean, well into Roman Imperial times.

The term shekel is, in short, a generic one, and in this context could apply to any one of a number of units (including the Mesopotamian) in use in Canaan in the Bronze Age. Since the price of 400 shekels for the Cave of Machpelah was quoted by Ephron himself (Genesis 23:14), these may very well have been shekels of the Syrian standard (also called Ugaritic), weighing about 9.4 g. Weights on this standard were used throughout Canaan and northern Syria, and are found at Bronze Age sites in the Aegean sea, as far north as Troy. The standard also reached Egypt, where its unit became the qedet. Three thousand Syrian shekels made one *talent*.

Genesis 24:22 says: "…the man took a gold nose-ring weighing half a shekel, and two bracelets for her wrists weighing ten shekels…" The Hebrew word rendered in English as "half a shekel" is *beka*'. The word means "half," and appears on certain Iron Age weights described below.

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The next mention of units of weight in the Bible is in the Book of Exodus. Several hundred years have passed; the Children of Israel, now a numerous people, have received the Law at Mt. Sinai. This includes instructions for the payment of taxes and the performance of religious ritual, which call for clearly defined units of measurement. The first specifically Hebrew unit of weight is *shekel ha-kodesh*, which the King James version translates as "shekel of the sanctuary" and the New English Bible as "shekel by the sacred standard," "twenty *gerahs* to the shekel" (Exodus 30:13). This unit is referred to repeatedly (Exodus 30:24, 38:24–26, Leviticus 5:15, 27:25, etc.). Reference is now also made to *talents* of silver and gold: the *talent* weighed 3,000 shekels (Exodus 38:25, 26). There are no surviving artifacts of this period from which the absolute mass of these units might be inferred.

It should be stressed that the *shekel ha-kodesh* and its fractions were used by the Hebrews for religious purposes, but not necessarily in commerce. In the ancient world, as in medieval Europe, there were many weight systems in simultaneous use in international trade. Weights representing all the major systems of the ancient Near East are found at all important archeological sites in Israel, and were obviously in use there. These systems are often linked by networks of interrelationships, with multiples of different units having a common mass and being used interchangeably.

The oldest extant weights bearing Hebrew inscriptions date from the period of the Kingdom of Judah (tenth to sixth centuries BCE). They are normally of limestone, dome-shaped with a flat bottom; a few bronze specimens exist. There are several types, all rare. The total number of known specimens of all groups is a few dozen. They are:

- *Necef*. Average mass about 9.8 g. The *necef* is not mentioned in the Bible. The name means "half": it may have originally been half of some more ancient unit. Scholars today identify the *necef* with the Canaanite/Syrian/Aegean unit already described. It is also equivalent to 1 Egyptian *qedet* and to four-fifths of the royal *shekel* of Judah (see below).
- *Beka*'. This word also means "half" (Genesis 24:22, see above). The mean mass of this group is about 6 g. The beka' is one-half of the "shekel of the king" first mentioned in II Samuel 14:26.
- *Pym* (Petrie: *peyem*). Mean mass about 7.8 g. The word appears once in the Bible (I Samuel 13:21): "The charge was two-thirds of a shekel (Hebrew: pym) for (sharpening) ploughshares and mattocks, and one-third (of a shekel) for sharpening the axes and setting the goads." The pym is two-thirds of the royal shekel.
- *Shekel*. Weights of this group are inscribed, not with a word, but a sign γ. Its meaning has been variously interpreted as being an official adjuster's mark, a symbol of the bag (*tsror*) in which lump silver was often carried, and a stylized representation of the royal scarab emblem of the kings of Judah. Sir Flinders Petrie read it as a monogram composed of the Greek letters *chi* λ and *omicron* ο, and on this basis, erroneously attributed these weights to a (supposed) system which he called Khoirine. The mean mass of the shekel, calculated from all known marked specimens, is about 11.4 g.

The shekel sign is accompanied by a mark indicating the denomination: 1, 2, 4, 8, 16, 24. Since numbers of shekels are given in the Bible in multiples of 50, this binary multiplication seems illogical; it is explained by the fact that this shekel is equal in mass to one and a quarter Egyptian qedets. Hence, 4 shekels = 5 qedet, 8 shekels = 10 qedet, etc. The denomination marks on the shekel weights are, in fact (apart from simple strokes to indicate 1 and 2), Egyptian hieratic decimal numerals, the sign for 4 shekels meaning in Egyptian 5, that for 8 meaning 10, and so on. These weights thus could be conveniently used interchangeably to weigh either in shekels or qedets. In fact, it can be seen that all the units here described are closely related. The Canaanite/Syrian/Aegean maneh of about 940 g can be divided into either 80 royal shekels, 100 necef (or qedet), 120 pym, or 160 beka', providing simple arithmetical relationships between the systems prevalent in different regions.

The name "royal shekel" is confirmed by the existence of a two-shekel weight inscribed in Hebrew "L-M-L-KH" (of the king). A series of fractional weights also exists, both for the shekel and for the necef, showing that both were divided into 20 units (*gerah*). The denominations of these are also indicated by Egyptian hieratic numerals.

Scholars attribute most of these weights to some time near the end of the seventh century BCE, leading some of them to suggest that the religious reforms of Josiah (II Kings 22, 23; II Chronicles 34, 35) were accompanied by a reform of weights and measures. There is no direct documentary evidence of this. In fact, biblical references are less than enlightening. Ezekiel, foreseeing the rebuilding of the Temple, orders that the maneh shall consist of "twenty, and twenty-five, and fifteen (i.e., 60) shekels." This is so inconsistent with other data that the translators of the New English Bible assume a misspelling in the Hebrew text, and render *essrim* as "ten" (Ezekiel 45:10), giving 50 shekels to the maneh as before. After the Temple was rebuilt, the people of Israel pledged to pay an annual tax of one-third shekel, not one-half as in Moses' time (Nehemiah 10:32).

Nothing more is heard of the *shekel ha-kodesh*; it is last mentioned in Numbers 18:16. Yet the correct weight of the Temple tax was a subject of deep concern to the Jewish religious authorities; it is discussed at length in the Mishnah, the textbook of Jewish laws. By the first century BCE it had been decided that all religious taxes should be paid in "shekels of the sacred standard, of the maneh of Tyre." The Tyrian shekel at that time weighed a little over 14 g and was famous for its purity of metal and uniformity of weight. No other coin would do. This is the reason why Jesus found so many money-changers in the Temple precinct (Matthew 21:12): Jewish pilgrims arriving from foreign parts and wishing to pay their dues needed Tyrian shekels in order to do so.

From AD 66 to 70, when Jerusalem was besieged by the Romans, and Tyrian coin was no longer obtainable, the shekels struck throughout the siege by the embattled Jews (probably for religious use) were of the Tyrian standard.

The use of Hebrew weights and measures for secular commerce almost certainly ended with the fall of the Kingdom of Judah and the destruction of the Temple by Nebuchadnezzar in 586 BCE. There is no evidence from the successive periods of Persian, Hellenistic, and Roman domination of the Land of Israel (or from times of relative independence, under the Hasmonean and Herodian dynasties) of the use of any specially Jewish units. Rabbinical discussions of weights and measures usually center on attempts to define Biblical units in terms of contemporary non-Jewish systems, in order to ensure the proper performance of the Mitzvoth (commandments).

Measures of Length and Area

The Hebrew unit of linear measure was the *ammah* or cubit – the length of a man's forearm, from the elbow to the tip of the middle finger. Deuteronomy 3:11 actually uses the expression *le-ammat ish* – "by the forearm of an adult male." The measurement of length by units based on parts of the human body is universal among ancient cultures.

The Bible mentions no unit greater than a cubit. *Kaneh ha-midah*, the surveyor's measuring rod (or reed), was six cubits in length (Ezekiel 40:5). The measurements of the inner temple are given by Ezekiel as 500 × 500 *kaneh* (Ezekiel 42:16–20): the Authorized Version translates these as "reeds", the New English Bible as "cubits". Surveyor's measurements of up to 25,000 cubits are on record (Ezekiel 45:1). Long distances are expressed in terms of a day's journey, *derekh yom* (Genesis 30:35; Numbers 11:31; II Kings 3:9).

The Hebrews used two cubits, one a hand's breadth (*tefah* or *tofah*) longer than the other (Ezekiel 40:5, 43:13). The longer cubit was used in the rebuilding of the Second Temple (Ezekiel 40–48), and also, presumably, in building the Temple of Solomon, since the dimensions quoted for the Holy of Holies and the Sanctuary are the same in both cases (20 × 20 cubits and 20 × 40 cubits, respectively: I Kings 6:14–28, Ezekiel 41:1–4).

The use of two cubits suggests an association with Egyptian linear measure. The greater ("Royal") Egyptian cubit was of seven hands, each hand of four fingers (also four spans of seven fingers each). Its length of about 52.5 cm is attested by many surviving measuring rods and by records of the dimensions of surviving monuments. The lesser Egyptian cubit was of six hands.

The Biblical fractional units of length are the span (*zeret* – Exodus 28:16, 39:9; I Samuel 17:4), the hand (*tefah* or *tofah* – Exodus 25:25, 37:12; I Kings 7:26; II Chronicles 4:5), and the finger (*etzba* – Jeremiah 52:21). The only direct clue to the absolute value of the Hebrew cubit is the Siloam inscription (ca. 700 BCE) from which Conder estimates a value of 17.1 in. (43.4 cm); he warns, however, that this estimate may be in error by 10% or more.

The Mishnah (second to third century AD) states that the greater cubit was of six hands, the lesser of five; the hand is of four fingers. Six hands of Egyptian dimensions would measure 45 cm. Most rabbinical estimates, however, are in the range 58–66 cm.

There are no specially named units of area in the Bible. Ezekiel, discussing the layout of rebuilt Jerusalem, speaks of "twenty-five thousand cubits square (*revi'it*)" (Ezekiel 48:20).

Measures of Cubic Capacity

> …your bushel (Heb. *ephah*) and your gallon (Heb. *bath*) shall be honest. There shall be one standard for each, taking each as the tenth of a *homer*, and the *homer* shall have its fixed standard (Ezekiel 45:11).

Solid and liquid measure are thus given a common basis. The volumetric measures mentioned in the Bible are *Ephah* (Leviticus 19:36; Deuteronomy 25:14 ("measure"); Judges 6:19; Ezekiel 45:24); *S'ah*, *seah* (Genesis 18:6; I Samuel 25:18; I Kings 18:32 (always "measure")); *Kab*, *cab* (II Kings 6:25); *Omer* (Exodus 17:36 – "An *omer* is one-tenth of an *ephah*"); these are always associated with solid measure. *Letekh* (Hosea 3:2 – AV: "a half *homer* of barley"; NEB: "a measure of wine") is mentioned only once. *Homer* – (Ezekiel 45:11, see above) and *Kor*, *cor* (I Kings 4:22, 5:11) are associated with both solid and liquid measure. *Bath* (I Kings 7:26, 38; I Chronicles 2:10) and *Log* (Leviticus 14:10, 12, 15, 21, 24) are associated with liquid measure. The relations between any of these measures are only mentioned once or twice. The Mishnah gives a table relating some of them: 1 *ephah* = 3 *se'ah*; 1 *se'ah* = 6 *kab*; 1 *kab* = 4 *log*; 1 *log* = 6 eggs. The water displaced by 1 egg is about 55 ml (there are differing rabbinical views on the precise quantity), which would give the *log* a volume of 330 ml and the *ephah* and *bath* each about 24 l.

Attempts to establish mathematical relationships between ancient units of length, mass, and volume were popular a century ago, but today are not taken seriously. Reliance on post-Biblical authors such as Josephus Flavius is also risky: Josephus lived more than a thousand years after King Solomon, and is more likely to have been concerned with giving his (mainly non-Jewish) reading public a notion of orders of magnitude than with achieving a maximum of mensural precision. Hebrew weights and measures will always remain a subject fraught with uncertainty, which will be dispelled only when archeologists are able to recover the actual instruments of measurement.

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Weights and Measures in the Indus Valley

Shigeo Iwata

The golden era of the Indus civilization in ancient India extended from 2300 to 1750 BCE. This vast civilization had significant uniformity and standardization in its material culture, as reflected in its town planning, building construction, pottery, metallurgy, and system of weights and measures.

The prosperity of the Indus cities depended to a large extent on trade. Many raw materials were brought by land and sea routes from within and outside the Indus valley. Inland trade must have extended beyond the Baluchistan to Afghanistan route and the Iranian highlands on the one hand, and to the Punjab and Aravalli hills on the other. Overseas trade covered the Makran and Persian Gulf ports on the west and the Gujarat and Konkan ports, if not those of the Malabar coast in the south. The writing system has not yet been deciphered, and the names of their measuring units are still unknown.

Length

A unit of length, which corresponds to a fathom, was revealed in the process of analyzing the city plans of Lothal, Surkotada, Kalibangan, Dolavira, Harappa, and Mohenjo-daro. The mean value with standard deviation of the units used in these cities was 168 ± 1.1 cm.

The minimum division of graduation found in the segment of an ivory-made linear measure excavated in Lothal was 1.79 mm (that corresponds to 1/940 of a fathom), while that of the fragment of a shell-made one from Mohenjo-daro was 6.72 mm (1/250 of a fathom), and that of bronze-made one from Harapa was 9.33 mm (1/180 of a fathom).

Area and Volume

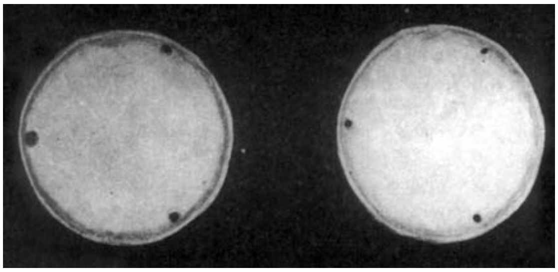
The use of area measures should have been quite common. There is, however, no piece of evidence that could be connected with an area measure. In the excavations carried out at various sites of the Indus civilization a variety of pots made of clay, and sometimes of metal, have been discovered. No systematic determinations of the volumes of pottery seem, however, to have been made.

Mass

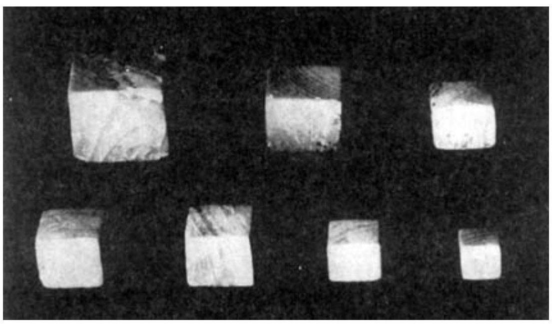
The oldest known weight in the Indus measuring system was excavated from Dashli Tepe, south Turkmenia in Russia. This era dates back to the fifth millennium BCE. The other three weights belong to the fourth millennium BCE and were discovered in northern Iran. These weights belong to pre-Indus civilization. In the third millennium BCE the Indus measuring system was further developed in the ancient regions of Iran and Afghanistan.

A total of 558 weights were excavated from Mohenjo-daro, Harappa, and Chanhu-daro, not including defective weights. They did not find statistically significant differences between weights that were excavated from five different layers, each measuring about 1.5 m in depth. This was evidence that strong control existed for at least a 500-year period. The 13.7-g weight seems to be one of the units used in the Indus valley. The notation was based on the binary and decimal systems. Eighty-three percent of the weights which were excavated from the above three cities were cubic, and 68% were made of chert.

Balance pans were made of copper, bronze, and ceramics. A bronze beam was found with the two pans in Mohenjo-daro. The fulcrum was the cord-pivot type (Fig. 1).



Weights and Measures in the Indus Valley. Fig. 1 Balance pans (photograph by the Maninichi Newspapers, 1961; used with permission).



Weights and Measures in the Indus Valley. Fig. 2 Weights (photograph by the Mainichi Newspapers, 1961; used with permission).

The measuring system used in the Indus valley was different from the Mesopotamian and Egyptian measuring systems, but the sensitivity of precision balances used in these regions is assumed to have been comparable. The weights excavated from Taxila (sixth century BCE to seventh century AD) descend from the system of weights used in the Indus civilization (Fig. 2).

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Weights and Measures in Islam

ULRICH REBSTOCK

In the sphere of Islamic influence the Quranic injunction "to give full measure and to weigh with the right scales" (*Qur'ān* 17:35), led - in the long run - to systems of measuring that were subjected to the authority and control of politics and law. But only a few measuring standards were substituted by new Islamic prescriptions. The most lasting novelty set off through the Quranic revelation affected the measure of time. It assumed a dual character. The natural solar year gave way to the ritual lunar year (29–30 days of the month), except in some fields of public administration and astronomical science. Within the sphere of the metrological systems of measures and weights, however, the *Qur'ān* remains vague. Among the terms most often mentioned, *kayl* or *mikyāl* (Sura 12:12 and *passim*, 'measure of capacity'), *mīzān* and *mithqāl* (Sura 6:152, 21:47 and *passim*, 'weight'), range first. Others, like *qinṭār* (3:75, 'hundredweight'), *darāhim* (3:75, pl. of *dirham*), *dīnār* (3:75) and *ḥabba min ḫardal* (21:47, 'grain of mustard'), are used in a metaphorical sense. A more systematic elaboration of metrical definitions and ratios, mainly for juridical purposes, was effectuated in the 'traditions of the Prophet' (*ḥadīth*, pl. *aḥādīth*). The characteristic aspects of the genesis of Islamic law – a cumulative development until the fourth and tenth century, geographically restricted proliferation of the various law schools (*madhāhib*), lack of normative authority – did, however, not allow for the introduction of uniform and ubiquitously accepted Islamic metric systems. Thus, the weights and measures which were used in Arabia and outside it, in the lands conquered by the Muslims, co-existed side by side, replaced each other, sometimes only by function, or by name, or intermingled. The striking feature of the metric systems that were in use in the early, medieval and pre-modern Islamic countries was their diversity. Neither in time, nor in space, could standard values develop that were accepted beyond their regional borders and their rulers' period. Although some names of units of measure, e.g. *dhirāʿ, dirham* or *raṭl*, were widely diffused throughout the Islamic world, their absolute values and use in practice differed considerably. Notwithstanding this bewildering array of measures, a few basic terms that have survived until modern times stand for the cultural continuity between the Ancient Orient and the Islamic world: *raṭl* (Greek litron, 'litre'), *irdabb* (Greek artabe, Persian 'measure of capacity'), *maṭar* (Greek metretes, 'measure of 40 L'), *ḳisṭ* (Greek xestes, Latin sextarius, 'jug'), *ḳinṭār* (Latin centenarius, 'hundredweight'), *ḳafīz* (Persian 'measuring cup'), *ḳīrāṭ* (Greek

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keratios, 'carat'), *istār* (Greek stater, 'weight of gold coin'), *dirham* (Greek drachme), *dīnār* (Latin denarius), *kayl* (Aramaic measure of capacity), *mann/mannā* (Babylonian unit of weight), *kurr* (Babylonian measure of capacity).

The development of systems of measure was influenced by the interplay between cultural tradition and the order of authorities. Until the tenth century, the spread of Islam brought about an intercontinental economic and cultural sphere which amalgamated measuring standards of Egyptian, Arabic, Greek, Roman-Byzantine, Mesopotamian and Persian origin. This resulted in a multiplicity of regional and functional systems of measurement, which were constantly modified by power politics, institutional reforms or, simply, by the rulers' autocratic order. Quite often, the advent of new dynasties brought about the introduction of new metrological standards, mainly in the field of the basic weight units of currency of gold (*mithqāl*) and silver (*dirham*), and the exchange rate of gold *dīnār* and silver *dirham,* which were fixed at a very early state by the canonical texts of the *Qur'ān* and the prophetic tradition (*ḥadīth*). Contrary to the more or less stable weight rate (10 weight *dirham*s equal 7 weight *mithqāl*), which everyday use polished into the handier ratio of 3:2, the prescribed rate of value (10 silver *dirham*s equal 1 gold *dīnār*) incessantly deteriorated over the course of time. Ratios of 12:1, 16 4/5:1, 20:1,

Alphabetic list of abbreviations used

ar	*aruzza,* pl. *aruzzāt*	grain of rice
ash	*ashl,* pl. *ashwāl, ushūl*	part of a 'rope'
az	*azla/azāla,* pl. *azāla, azālāt*	unit of capacity measure
ʿas	*ʿashīr,* pl. *ʿashīrāt, ʿushrān, aʿshur*	tenth
ba	*baṭṭa*	leather bottle
bā	*bāb,* pl. *abwāb*	portion
bāʿ	*bāʿ,* pl. *abwāʿ*	arms' span
da	*dāniḳ,* pl. *dawāniḳ, dawānīḳ*	1/6 of a dirham/dīnār
dh	*dhirāʿ,* pl. *dhirāʿāt, adhruʿ*	ell
dī	*dīnār,* pl. *danānīr*	Gold dīnār
dir	*dirham,* pl. *darāhim*	silver-dirham
dj	*djarīb,* pl. *djirbān, adjriba*	unit of square measure
djo	*djou*	barleycorn (Persian)
fa	*fals,* pl. *fulūs, aflus*	small coin
fad	*faddān,* pl. *fadādīn*	yoke of oxen
far	*farq*	unit of capacity measure
fā	*fātil*	small unit of weight
ghi	*ghirāra,* pl. *gharā'ir*	sack
ḥa	*ḥabba,* pl. *ḥubūb, ḥabbāt*	seed
ḥab	*ḥabl,* pl. *ḥibāl, ḥubūl*	rope, thread
ḥi	*ḥiml,* pl. *aḥmāl*	camel-load
ir	*irdabb,* pl. *arādibb*	unit of capacity measure
is	*istār,* pl. *asātir*	unit of weight measure (Greek)
iṣ	*iṣbaʿ,* pl. *aṣābiʿ*	width of middle finger
ka	*kaff,* pl. *kaffāt*	hand
kā	*kāra*	load carried on the back
kay	*kayl/kayla,* pl. *akyāl, akāyil*	unit of weight measure
kayl	*kayladja,* pl. *kayladjāt, kayālidj*	unit of capacity measure
ku	*kurr,* pl. *akrār*	unit of capacity measure
ḳa	*ḳafīz,* pl. *aḳfiza, ḳifzān*	unit of capacity weight
ḳab	*ḳab(a)ḍa,* pl. *ḳabaḍāt*	width of fist
ḳad	*ḳadaḥ,* pl. *aḳdāḥ*	unit of capacity measure
ḳal	*ḳalam,* pl. *aḳlām*	'strip'
ḳām	*ḳāma*	build, fathom
ḳaṣ	*ḳaṣaba,* pl. *ḳaṣabāt*	pole, rod
ḳin	*ḳinṭār,* pl. *ḳanāṭīr*	'hundredweight'
ḳis	*ḳisṭ,* pl. *aḳsāṭ*	'portion'
ḳī	*ḳīrāṭ,* pl. *ḳarārīṭ*	carat
ḳu	*ḳulla,* pl. *ḳulal, ḳilāl*	jug
ma	*mann/mannā,* pl. *amnān, amunnā'*	unit of weight measure
mak	*makkūk,* pl. *makākīk*	unit of capacity measure
mar	*marzbān*	unit of capacity measure (Persian)

Alphabetic list of abbreviations used (Continued)

maṭ	*maṭar,* pl. *amṭār*	unit of liquid
mi	*mithḳāl,* pl. *mathāḳīl*	unit of weight measure
mish	*mishḳā‘*	drinking-vessel
mu	*mudd,* pl. *amdād*	unit of capacity measure
mud	*mudy,* pl. *amdā’*	unit of capacity measure
na	*naḳīr*	‘small spot’ (Arabic)
nu	*nügi,* pl. *nügiler*	unit of weight measure (Turkish)
oḳ	*oḳḳa,* pl. *oḳḳalar*	unit of weight measure (Turkish)
pe	*peymāne*	bowl
r	*raṭl,* pl. *arṭāl*	‘litre’
ru	*rub‘,* pl. *arbā‘*	fourth
sha	*sha‘īr,* pl. *sha‘īrāt*	grain of barley
shi	*shibr,* pl. *ashbār*	span of hand
si	*silsila,* pl. *salāsil*	chain
su	*sunbul,* pl. *sanābil*	ear of grain
ṣa	*ṣā‘,* pl. *aṣwu‘, aṣwā‘*	unit of capacity of weight
th	*thumn,* pl. *athmān*	eighth
ti	*tillīs*	unit of capacity measure
ṭa	*ṭassūdj,* pl. *ṭasāsīdj*	unit of weight measure
‘ush	*‘ushr,* pl. *a‘shār*	tenth
ūḳ	*ūḳīya,* pl. *awḳiyā, ūḳīyāt*	unit of weight measure
wa	*waiba*	unit of (dry) capacity measure
was	*wasḳ,* pl. *awsāḳ*	(camel’s) load
za	*zabīl*	basket made of palm-leaves

30:1 and even 50:1 are recorded. Nevertheless, modern Islamic jurists insist on referring to the canonical rates (10:7; 10:1) when, for example, fixing the minimum income (*niṣāb*) for the obligatory alms payment (*zakāt*) by Muslims of a determinate portion of their lawful property. The canonical ratio of the value of gold and silver (10:1) reflected the historical situation in the Mediterranean region and the Middle East after the Roman period (12:1). During the Il-Khānid period (thirteenth to fourteenth century), silver from Central Asia was massively imported to the West, the price of silver sank again, for a short period, to the Roman value. Gold, in contrast, remained remarkably stable over the millennium. Under the Persian king Darius the Great (522–486), mutton cost the same as in Anatolia in 1340: the equivalent of 1.9355 g pure gold.

The overall cultural diversity of the Islamic world corresponds to the diversity of the metric systems, which came into use between the Atlantic and the Indian sub-continent. Three geographical units can be differentiated: The Islamic Arab West, from Andalusia to Iraq, Persia and the adjacent areas under Persian influence, and India. The following comments omit the metric systems of India (see *EI* [2] VI, pp. 121a–122a, s.v. *makāyīl*, and VII, pp. 138a–140b, s.v. *misāḥa*) and concentrate on the development in the Arab West, in consideration of the situation in Persia. Emphasis is laid on the early Islamic and medieval period. The absolute equivalents in modern metric values stem back to archaeological evidence or observations of European travellers.

Measures of Length

Along with the basic unit of length, the *dhirā*ᶜ, several other units were used, some of them only for particular purposes (construction, geometry, etc.). In theory, i.e. without considering their actual common occurrence or precise values, these units could be arranged to the following equation:

1 *ash* = 1 *si* = 10 *bā* = 10 *ḳaṣ* = 15 *bā‘* (or *ḳām*) = 60 *dh* (= Persian *gaz*) = 360 *ḳab* = 1,440 *iṣ* = 3,600 *fa* = 8,640 *sha.*

The ‘black ell’ (*al-dhirā‘ al-sawdā’*), being ca. 54.04 cm, is said to refer to the length of the ell (from the elbow to the tip of the middle finger) of a slave of the Caliph al-Manṣūr (r. 754–775) or the Caliph al-Ma’mūn (r. 813–833). Another etymology links the measure to the unit by which the ‘Nilometer’ of the island of al-Rawḍa was operated. There are almost thirty variants of the ell, some varying 30-fold from the original. By the eleventh century, at least 11 different types of *dhirā’* can be differentiated:

- 1 *dhirā‘ sawdā’* = 1 + 1/7 + 2/3 ·1/7 *dh al-yad* (of the hand)
  = 1 + 1/8 +1/9 *dh al-ḥadīd* (iron ell)
- 1 *dh fiḍḍīya* (silver) = 1 – 1/7 *dh al-sawdā’*
- 1 *dh yūsufīya* (of Abū Yūsuf, d. 798) = 1− 2/3 ·1/7 *dh al-sawdā’*
- 1 *dh hāshimīya* (of the Banū Hāshim) = 1 + 1/8 + 1/10 *dh al-sawdā’*

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- 1 *dh bilālīya* (of Bilāl b. Abī Burda, d. 739) = 1 *dh al-sawdā'* + 2 + 2/3·1/7 *iṣ*
- 1 *dh fiḍḍīya* (al-misāḥa) = 7 or 8 *dh al-yad*
- 1 *dh ʿumarīya* (of ʿUmar b. ʿAbdalʿazīz, d. 720) = 1 + 1/2 *dh al-yad*
- 1 *dh mīzānīya* (surveyor's ell) = 3 *dh al-yad*
- 1 dh *mābahrāmī* = 1 + 1/2 *dh al-ḥadīd*

In addition to these different norms of the *dhirāʿ*, a multitude of ells was used depending on the profession involved: carpenters, cloth-makers, constructors etc. Moreover, the ells used in different cities under the same name differed: the medieval cloth-ell of Damascus (ca. 63.035 cm), for example, was 1/12 longer than the cloth-ell of Cairo (58.187 cm).

Measures of Area

The calculation of the surface of (straight) areas operated with the conventional measures of length. The basic units, however, were the *ḳafīz* and the *djarīb*, two specific measures of surface area. Originally and throughout the Islamic period, both units also served as measures of capacity. One *djarīb* was conceived of as representing the surface area of agricultural land which could be sown with the amount of seed one *djarīb* contained.

Based on the ratio of the length units (1 *ash* = 10 *bā* = 60 *dh* = 360 *ḳab* = 1440 *iṣ*), the following ratio of units of surface area measurement can be generated:

$$1\ ash = 60\ dh \cdot 60\ dh = 3{,}600\ dh^{2} = 1\ dj$$

and:

$$1\ dj = 10\ ḳa = 10 \cdot 360\ dh^{2}$$
$$= \text{[in Persia] } 60\ ka = 600\ ʿas = 600 \cdot 6\ dh^{2}$$
$$= 100\ ʿas = 100 \cdot 36\ dh^{2}$$

This *djarīb* was called the 'small' *djarīb*, being 100 square *ḳabaḍa* (or *ḳaṣaba*; the units being often exchangeable) which renders: 100 · (399 cm · 399 cm)^{2} = 1,592 m^2. The 'big' *djarīb* had 5,837 1/3 m^2, i.e. 3 2/3 'small' *djarīb*, and corresponded roughly to the predominantly Egyptian *faddān* which was calculated as 400 square *ḳaṣaba*, i.e. 6,368 m^2. During the nineteenth century, the *faddān* was reduced to 4,200.833 m^2.

If multiplied with one another these units render the matrix (see above).

There is substantial evidence that the professional surveyors during the Abbasid period used a specific system of calculation. They divided the biggest unit, the *azla*, into 100 *dh mīzānīya* which corresponded to 48 *iṣ ʿumarīya* (see above), hence:

$$1\ az = 100\ dh^2 = 100 \cdot 12^2\ ḳab^2 = 100 \cdot 12^2 \cdot 4^2\ iṣ^2$$

In the Turkish lands of the Ottoman Empire (Minor Asia, Iraq, Syria and Palestine) the *dönüm* (turn), Arabic *dūnam,* was – until recent times – the standard measure of area. Originally measuring 939 m^2, it has been adjusted in colonial times to 1,000 m^2 (in Iraq to 2,500 m^2).

Measures of Capacity

Most of the confusion about the system of the Islamic measures of capacity, both in primary medieval and in modern secondary texts, dates back to the Oriental practice to measure grain, pulse, and some liquids in capacity, but not in weight. The Arabic term *mīzān* does not clearly differentiate between the two. The transition from volume to weight needs the related quantity of the litre of water: the volume of approx. 75–77 kg of wheat and 60–72 kg of barley correspond to the volume of 100 kg/L of water.

From this economic and agricultural use of measures of capacity the proper mathematical and technical calculation of volumes must be set apart. This calculation is built on the calculation of the surface area multiplied by the third dimension. The names used for the cubic units of measure do not change. Related to the *dhirāʿ mīzānīya* and based on the ratio 1 *az* = 100 *dh* ^{3} = 100 *ku*, the following values are produced: (see matrix below)

Most of the units of measures of capacity are regarded as units of weights too. It is therefore impossible to separate the two systems properly. Depending on

	ashl	bāb	dhirāʿ	ḳabaḍa	iṣbaʿ
ashl	1 *dj*	1 *ḳab*	5/3 *ash*	1/6 + 1/9 *ash*	1/24 + 1/36 *ash* = 2 1/2 *dh* ^{2}
bāb		1 *ash*	1 *ash* = 6 *dh* ^{2}	1/36 *ash* = 1 *dh* ^{2}	1/144 *iṣ* = ¼ *dh* ^{2}
dhirāʿ			1/36 *ash* = 1 *dh* ^{2}	1/216 *ash* = 1/6 *dh* ^{2}	1/864 *ash* = 1/24 *dh* ^{2}
ḳabaḍa				1/1,296 *ash* = 1/144 *dh* ^{2}	1/5,841 *ash* = 1/576 *dh* ^{2}

	azla^3	dhirāʿ^3	ḳafīz^3	ḳabaḍa^3	iṣbaʿ^3
azla^3	1	100	6,000	172,800 = 10^2 · (12 *ḳab*)^3	11,059,200 = 10^2 · (48 *iṣ*)^3
dhirāʿ^3				1,728	110,592

the material measured, additionally different types of the same unit, e.g., a ‘honey-*farḳ*’ or a ‘barley-*irdabb*’, were used. The absolute values of these types differed considerably in different regions and periods. In order to allow a comparative overview, units that are related to each other by practical use are grouped together. Minor local variations and temporal changes are ignored.

Few of these units have a canonical background: 1 *was* = 60 *ṣāʿ* = 240 *mu* = ca. 252 L. Far bigger than this *mudd* (ca. 1.05 L) of Medina were the *mudd* of Egypt and Iraq (2.5 L), of Syria (3.67 L), of the Maghreb (4.32 L), and that of Jerusalem (100 L). The prophetic *ṣāʿ* was exactly 4.2125 L. Being the quantitative lower limit (*niṣāb*) for the liability for the *zakāt* (alms) taxes, the measure of 5 *wasḳ* of dates, for example, was equated in value with 5 *ūḳīya* (= 200 *dir* = 529.9 g), 20 *dī* (or *mithḳāl,* = 84.7 g, see later), 5 *dhawd* (camels), the *niṣāb* of cotton (5 *was* = 1,600 *dir ʿirāḳī* à 130 g), or 50 *kay.* Therefore, the values given for one *wasḳ* greatly differ. In the time of Hārūn al-Rashīd (around 800), a short-lived *wasḳ* (1 *was* = 2 1/2 prophetic *was*) was introduced.

Towards the end of the seventh century, the *ḳafīz* (usually corresponding to 1/10 *dj* = 1/60 *kurr*) was used instead of this prophetic *ṣāʿ* in Iraq. Another specific *ḳafīz* of capacity is recorded from Iraq around 990: 1 *ḳa* = 1 *ḳaffa* (basket) = 1/2 *zabīl* (basket made of palm leaves).

In Egypt grain, but in particular wheat, was measured by *irdabb*: 1 *ir* = 6 *wa* = 24 *ru* = 48 *ḳad* = 90 *ma* = 96 *ḳad* (small) = ca. 90 L. Different values extant for the *irdabb* (between 72.3 kg, modern 182 L) may be explained also by the difference of volume between, for example, wheat, barley and lentils (100:80:104).

Egyptian flour was measured in *tillīs*: 1 *ti* = 3/2 *wa* = 3 *ba* = 15 *ma* = 24 *ḳad* = 22.5 L. There, the *waiba* of rice (1 *wa* = 8 *ḳad* = 24 *r kabīr*), as observed around 1665, contained only 12.5 l. Three centuries before in Tunis, it was equal to 12 prophetic *mudd* (ca. 12.6 l).

In Medina and Iraq, honey but also wheat was measured in *farḳ* : 1 *fa* = 3 *ṣa* = 36 *r bagdādī* = 19 L. In Egypt and Syria, the *mudy* – not to be confused with the *mudd* - replaced the *ḳisṭ* when not oil but food was measured. It is sometimes called ‘the Syrian *djarīb*’, sometimes equated with the *ḳafīz*. The practice in Syria, however: 1 *ḳa* = 8 *mak* = 12 *ṣa*, the indication: 1 *mud* = 15 *mak* = 22 1/2 *ṣa* does not confirm this. In Palestine, a square *mudy* was known (1 mud^2 = 1 *ḥab* · 1 *ḥab*).

Olive oil was merchandised in *maṭar* (1 *maṭ* = 2 *ḳu* = ca. 17 kg) in the Maghreb, in *ḳulla* (1 *ḳu* = 12 *th* = 27 *r* = 13.6 kg) in Andalusia. In Egypt, the *thumn* corresponded to 1/8 *ḳad* (today 0.29 L), in Qayrawān to 6 prophetic *mu* = 6.32 L. Oil and other liquids were also measured in *ḳisṭ*: In Iraq, the ‘small’ *ḳisṭ* (1 *ḳi* = 3 *r* = 1.22 L) was half of the ‘great’ *ḳisṭ,* in Egypt it was half of a *ṣāʿ*: 211 L; elsewhere the *ḳisṭ* is given as: 1 *maṭ* = 4 *ḳi* = 21 1/3 *r djarwī* (see below) = 192 *ūḳ* (capacity) = 256 *ūḳ* (weight). In Andalusia, wine and vinegar were sold in *rubʿ* (1 *ru* = 1/4 *ḳad* = 18 *r* = 216 *ūḳ* = 1,728 *mi* = 8.16 L, in Persia the *peymāne* (bowl, 8.3 L) was in use for this purpose. In Iraq, wine, but also oil and honey, were measured by *makkūk* or *mishḳāʿ* (drinking-vessel): 1 *mak* = 48 *th* à 50 *dir* = 64 *mish* à 37 1/2 *dir* = 7.5 L.

Another widespread unit of capacity was the *ghirāra*, mainly used for grain: 1 *ghi* = 3 *ir miṣrī* = 12 *kay* = 14 *mak* = 72 *mu dimashḳī* = 73 1/2 *mu miṣrī* = 265 L. In Egypt, the *kayla* = 8 *ḳad* was 7.5 L (modern 16.5 L).

This *kayla* is not identical with the *kayladja*, presumably an originally Persian unit of capacity measure: 1 *kayl* = ½ *ṣa* = 1/3 *mak* = 3/14 *ghi* = 1/6 *ḳa* wheat = 1/5 *ḳa* barley = ca. 1 7/8 *ma* = 2.5 L (or 2 L in East Iran).

The most basic of all grain measures, especially in the Islamic East, was the old Babylonian *kurr.*

> 1 *ku* = 30 *kā* = 60 *ḳa* = 480 *mak* = 600 ‘*ush*/‘*as* = 1,440 *kayl* = 5,769 *ru* = 7,200 *r* = 11,520 *th* = 2,925 kg (wheat).

Smaller than this ‘big’ *kurr* of Baghdad was the *kurr* of Wāsiṭ and Baṣra (1 *ku* = 60 *ḳa* = 480 *mak* = 1,440 *kayl* à 600 *dir* of wheat = 2,700 kg); a ‘reformed’ *kurr* even amounted only to: 1 *ku* = 60 *ḳa* à 25 *r baghdādī* = 609.375 kg (wheat). Moreover, depending on the kind of grain measured, different *akrār* were used: In fourteenth century Baghdad, the *kurr* of wheat weighed 2,925 kg, that of barley 2,437.5 kg, and that of rice 3.656,25 kg. The common sub-units of the *kurr*, the *ḳafīz*, *makkūk*, *kayladja,* and *thumn* differed respectively, sometimes not only proportionally. Thus, in twelfth century Aleppo, a quite different *makkūk* existed: 1 *mak* = 19 *sun* = 28.5 *r* à 684 *dir* à 3.125 g = 60.92 kg. About the same time, the *ḳafīz* of Ḥamāh was 7/8 *ḳa* of that of Shayzar. In Aleppo, 4 *mak* made one *marzbān* (1 *mar* = 1/4 *mak* = 19/4 *sun* = 57/8 *r* = 4,873 1/2 *dir* = 15.23 kg).

Towards the end of the tenth century, the mathematician al-Būzdjānī compared the new ‘reformed’ (Arabic *muʿaddal*) *djarīb* - this *djarīb* was not measured with 10 but with 2 1/2 *ḳa* only – which was introduced after 978 by his Lord, the Būyid ʿAḍud al-Dawla, with four different common types of the *kurr*. His systematic treatment of the issue will throw some light on the complex variety of the units used and their specific relation when being transformed from one into another (see matrix below).

Besides *simsim* (sesame), *ḥinṭa* (wheat), *djahkandam* (mixture of 1/2 *ḥinṭa* + 1/2 *shaʿīr*), and *shaʿīr* (barley), a fifth category is formed to include all kinds of grain and dry goods that do not belong to one of the aforementioned categories: nuts, like almonds, pistachios and hazelnuts, dried pears, plums etc. From the

1. Ratio of *kurr*-Variants

Types of *kurr*	***mu‘addal***	***kāmil***	***fālidj***	***hāshimī***	***sulaymānī***
mu‘addal	1	2	2 1/2	3	3 1/2 + 1/4
kāmil	1/4	1	1 1/4	1 1/2	1 1/2 + 1/4 +1 1/8
fālidj	2/5	4/5	1	1 1/5	1 1/2
hāshimī	1/3	2/3	5/6	1	1 1/4
sulaymānī	1/6 + 1/10	1/3 + 1/5	2/3	4/5	1
[ratio]	60	30	24	20	16

2. Djarīb per *kurr*

Types of *kurr*	***mu‘addal***	***kāmil***	***fālidj***	***hāshimī***	***sulaymānī***
djarīb/kurr	24	12	9 3/5	8	6 2/5
fraction	1/3 · 1/8	1/2 · 1/6	1/2 · 1/6 + 1/6 · 1/8	1/8	1/8 + 1/4 · 1/8

3. Ratios Between sub-units (as indicated by Al-Būzdjānī)

	makkūk	***‘ushr***	***kayladja***	***rub‘***	***raṭl***	***thumn***
kurr	480	600	1,440	5,760	7,200	11,520
makkūk		1 1/4		12	15	24
‘ushr			1/4 + 1/6			
kayladja					5	8
ḥubūb	4	5			60	
rub‘		1/12 + 1/48			1 1/4	
thumn		1/20 + 1/60			1/2 + 1/8	

4. Ratio of Capacity Between Different Kinds of Grain

	simsim	***ḥinṭa***	***djahkandam***	***sha‘īr***
simsim	1	2	2 2/3	4
ḥinṭa	1/2	1	1 1/3	2
djahkandam	1/4 + 1/8	1/2 + 1/4	1	1 1/2
sha‘*īr*	1/4	1/2	2/3	1
[ratio]	8	4	3	2

matrixes 1–4, exactly 280 possible combinations result by which the transfer of one given quantity (and value) of one commodity into another can be calculated.

Example: If 24 *ku* of oats (*ḥurṭumān* = category of *sha‘īr*) should be transferred into *kurr sulaymānī* of pepper grass (*ḥabb al-rishād* = category of *ḥinṭa*), then the rule of seven is required, in short:

24 ku kāmil sha‘īr – 1/6 · 24 = 22
ku sulaymānī ḥinṭa + 30 *ḳa*.

Measures of Weight

The entire Islamic system of weights is based on the *dirham* and the *raṭl*. The *raṭl* is the most common smallest unit, or reference, of weight. The weight of the *dirham* is used for two different purposes. The two values differ correspondingly:

a) *dirham al-fiḍḍa* (silver *dirham*)

Calibration of the silver (*dirham*) and gold (*dīnār*) coins was done with the help of glass weights. The earliest preserved exemplars date back to the second half of the eighth century. The *dirham* weight defined the weight of the *dirham* coin, the *mithḳāl* weight the weight of the *dīnār*. The most precise glass weights of the *mithḳāl* have an average weight of 4.233 g (max. tolerance 1/3 mg). Archaeological finds affirm both the weight of the *dirham* in accordance to the canonical ratio of *dirham: mithḳāl* (= 10:7): 2.97 g, as to the ‘rounded’ ratio (= 3:2): 2.82 g. An exceptional *mithḳāl* weight was in use in Egypt under the Ayyubid dynasty and in the Maghreb under the Almohad dynasty (4.722 g).

The *mithḳāl* gold and the *dirham* silver were divided into *ḳīrāṭ* and *ḥabba*.

1 *mi* gold = 20 *ḳī* = 60 *ḥa*;
1 *dir silver* = 12 *ḳī* = 48 *ḥa* (Iraq)
1 *mi* gold = 24 *ḳī* = 60 *ḥa*;
1 *dir silver* = 16 *ḳī* = 60 *ḥ* (Arabia, Egypt, Syria)

Hence, the values (see matrix below).

In addition to these general systematic differences a variety of deviating systems from different regions, authors and periods are recorded (tenth to thirteenth century; indicated as I–V), that integrate sub-units like the *dāniḳ, ṭassūdj, ‘ashīr, fals, and aruzza* (which

	gold *ḳīrāṭ*	gold *ḥabba*	silver *ḳīrāṭ*	silver *ḥabba*
Iraq	0.212 g	0.0706 g	0.247 g	0.062 g
Egypt etc.	0.176 g	0.0706 g	0.186 g	0.0495 g

	dāniḳ	*ḳīrāṭ*	*ṭassūdj*	*ḥabba*	*ʿashīr*	*fals*	*aruzza*
I. Dīnār	12 1/2	20	24	60			
Dirham		12	24	48	60		
II. Dīnār	6	20 *baghdādī*		60 *baghdādī*	60		
		24 *baṣrī*		72 *ḫurās./shāmī*			
Dirham	6			48 *baghdādī/baṣrī*	60	96	
				36 *ḫurās./shāmī*			
III. Dīnār	[12]	[20]	24	60			240
IV. Dīnār		24/20	576	[72] 600/7		600	

elsewhere corresponds to 25 *ḥa ḫardal*, grains of mustard, i.e. ca. 0.0186 g); one author defines the ḥa *ḫardal* as 1/70 of a *ḥabba* (which is sometimes replaced by *'ḳamḥa'*, grain of wheat), 60 of which make one silver *dirham*, i.e. 1 *ḥa ḫardal* = 0.0007 g. From the vague comments of sources, it must be assumed that most of these different systems were in use as weight measures too (see matrix below).

According to the actual ratio of value between gold and silver currency, the moneychangers had to take several factors into consideration when transferring amounts of money from one currency into the other. This could result in thirteenth century Egypt, for example, when 16 4/5 *dir* were equivalent to 1 *dī*, in the following calculations:

1 *dī* = 1,440 *ḥa fiḍḍa* [10 · 60/7· 16 4/5 = 1,440]; and
1 *ḥa* gold = 1/5 + 2/25 ḳī = 16 4/5 *ḥa silver*; or
1 *fa* = 2 2/5 *ḥa silver* = 1/7 *ḥa gold* [2 2/5: 1/7 = 16 4/5].

b) *dirham al-kayl* (weight *dirham*)

In contrast to the homogeneous evidence of the weight of the 'silver *dirham*' the extant values of the weight of the 'weight *dirham*' deviate considerably from one another. They range from 3.086 g to 3.148 g. When not indicated otherwise, the following comments will be based on the established average standard value of 1 *dir* = 3,125 g with which the 'canonical' (ratio 10: 7) *mithḳāl* of 4.464 g is corresponding. From textual evidence some of which are included in the matrix above, different regional values of the *dirham/mithḳāl* weight can be deduced:

Egypt 3.125/4.68 g; Syria (Aleppo twelfth century) 3.14/4.427 g, (Aleppo nineteenth century) 1 *dir* = 3.167 g, Damascus 3.086/4.62 g; Anatolia (Ottoman period) 3.086/4.81 g; Iraq 3.125/4.46 g; Iran (fourteenth century) 1 *mī* = 4.3 g, (sixteenth century) [3.26]/4.639 g; Maghreb 3.3/4.722 g; East Africa (sixteenth century) 1 *mī* = 4.41 g.

With the exception of Persia, where the *mann* dominated the system of weight measures, the *raṭl* became the most common and widespread unit of weight measure in the Islamic world, comparable in size and function to the European 'pound' (Pfund, livre, libra, Italian loan word 'rotolo'). The *raṭl* was measured in *dirham*. Depending on what was measured, and where and when, the *raṭl* could take different numbers of *dirham* (values between 96 and 1.040 are recorded) of different *dirham* weights (standard value: 1 *dir* = 3.125 g).
If integrated into the early Meccan system:

1 *r* = 2 *ma* [à 130 *dir*] = 12 *ūḳ* = 480 *dir* = 1/100 *ḳin*,

the *mithḳāl* weights produce the following (fictitious) relation:

1 *mi* = 20 *ḳī* = 60 [or 100] *ḥa* = 10/7 *dir* = 1/336 *r* (for Iraq; 1 *ḳī* = 0.223 g)
1 *mi* = 24 *ḳī* = 96 *ḥa* = 3/2 *dir* = 1/320 *r* (for Mecca, Egypt etc.; 1 *ḳī* = 0.195 g).

From archaeological (glass weights) and textual evidence, several hundred *raṭl* weights are known. The following list enumerates (in order of size, with '[...]' values developed) some of the standard *raṭl* weights repeatedly recorded (see matrix below).

Besides the *raṭl*, the *mann* was an important unit of weight everywhere in the Islamic world, in particular in the Persian East, where it weighed between 260 *dir* (= 816.5 g) and 2,080 *dir* (= 6,656 g). A similar variety of *mann* weights was used In Asia Minor (twelfth century onwards). Until the fifteenth century it was used instead of one half of a *raṭl* à 130 *dirham*. Then a 'big' *mann* (ca. 3 to 3.25 kg), and a 'middle' *mann* of 1.920 g came into use. During the Safawid period (sixteenth century), a 'super' *mann*, later called the 'royal' *mann* (between 5.7 and 6 kg), was introduced. The Ottomans used the *oḳḳa* (1 *oḳ* = 2 *nu* = 400 *dir* à 3.207 g = 1.2828 kg) instead of the *raṭl*. Its stability was proverbial: *Okka her yerde dört yüz dirhem gelir* (… to be no different from anybody else).

Egypt (Abbasid period)	96 dir	300 g
Rūmī (Asia Minor) I	102 6/7 *dir*	321.43 g
Umayyad period	[110 *dir*]	340 g
Rūmī (Asia Minor) II	120 *dir*	375 g
Iraq (medieval)	128 4/7 *dir*	401.79 g
Abbasid period (Egypt, Baghdad)	130 *dir*	406.25 g
Maghreb	130 *dir*	406.25 g
Maghreb	137 1/7 *dir*	428.57 g
Umayyad period (Egypt)	[140 *dir*]	437.5 g
Maghreb (Fāṭimid period)	140 *dir*	437.5 g
Egypt (later Abbasid period)	144 *dir*	450 g
Fulfulī	150 *dir*	468.75 g
Maghreb (Ibn Baṭṭūṭa)	150 *dir*	468.75 g
'big' Egypt (Abbasid period)	160 *dir*	500 g
Maghreb (Ibn Baṭṭūṭa)	180 *dir*	562.5 g
Laithī	200 *dir*	625 g
Djarwī	312 *dir*	975 g
Turkestan (fourteenth century)	330 *dir*	1,031.25 g
Fes/Marrakesh (fourteenth century; = 16 ūḳ)	336 *dir*	1,050 g
Aleppo (twelfth and thirteenth century)	480 *dir*	1,500 g
Syria/Palestine (fourteenth century)	592 1/2 *dir*	1,851.56 g
Ḥimṣ (twelfth century)	684 *dir* [sic]	2,137.5 g
Aleppo (after thirteenth century)	[724 *dir*]	2,273 g
Jerusalem (medieval)	800 *dir*	2,500 g
Ḥimṣ (Syria, medieval)	864 *dir*	2,700 g
Constantinople (eighteenth century)	876 *dir*	2,800 kg
Jerusalem (nineteenth century)	900 *dir*	2,812.5 g
Iran (Shīrāz, Fārs; in *mann*)	1,040 *dir*	3,250 g

The biggest unit - besides the rather colloquial *ḥiml*, camel-load (1 *ḥi* = ca. 250 kg) -, was the *ḳinṭār*, the hundredweight (= 100 *r*). Depending on the type of *raṭl* it was based on, the *ḳinṭār* weights differed. In medieval Egypt, different *ḳinṭār* weights were common: *fulfulī* (pepper) = 100 *r* à 144 *dir* = 45 kg; *laithī* = 100 *r* à 200 *dir* = 62 kg; *djarwī* = 100 *r* à 312 *dir* = 96.7 kg; *mannī* = 100 *r* à 260 *dir* = 81.25 kg; 'big' = 24 *ru* = 240 *r* à 160 *dir* = 38,600 *dir* = 120 kg. In a treatise composed by a customs officer in the thirteenth century, additional *ḳinṭār* names, but no values, for specific goods are mentioned. While the *ḳinṭār* of Syria (Aleppo, Ḥimṣ, Ḥamāh) was always equivalent to 100 local *raṭl*, it was taken for 100 *mann* in late medieval Iraq. In Iran (fifteenth century) and Asia Minor (Ottoman period) 1 *ḳinṭār* weighed ca. 57 kg.

The smaller weight unit of *istār* (1 *is* = 4 1/2 *mi* = 6 3/7 *dir* = 20.07 g), only known from Egypt, was used there to weigh silk: 1 *s-ḳ-ṭ* [?] = 3 *ru* = 90 *man* = 180 *is*.

The Quranic '*ḥabba min ḫardal*' (the 'grain of mustard', see above), being 1/70 ḥa of 1/60 *dir* each (= ca. 0.0007 g), seems to have remained the smallest unit of weight in use in the Islamic world. If calculated properly, the fictitious *naḳīr* (1*djo* = 6 [*ḥa*] *ḫardal* = 72 *fa* = 432 *fāl* = 2,592 *na* = 1/96 *mi* = 0.045 g) would correspond to ca. 5 ng.

al-Ḳurashī

The research of the history of weights and measures and their use in the Islamic world is based on a variety of sources. Unfortunately, no particular literary type of text developed that could claim to be called 'professional'. The information available is scattered over texts on law, social and economic history, administration and geography. They generally lack a systematic character, i.e. ignore comparative and proportionate references. The most recent endeavor to collect all information available in the historical sources was undertaken by Maḥmūá Fākhūrī and Ṣalāḥ al-Dīn knawwām in: *Madjmūᶜat waḥdāt al-qiyās al-ᶜarabīya*

Aleppo: Weights

1 *dir* = 60 *ḥa*
1 *ḳī* = 4 *ḥa* = 2/45 *dī*
1 *ḥa/dī* = (6/7 + 2/21) *ḥa/dī* (Egypt)
1 *ḳī* = (1 + 1/4) *ḳī* (Iraq)
1 *r* = 7,560 *ḳī*
1 *dī* = (22 + 1/2) *ḳī* = 90 *ḥa*
1 *dī* = 3/2 *dī* (Iraq)
1 *ḥa* = [(1 + 3/25) *ḥa* (Syria)]
1 *ḳī* = (1 + 1/8) *ḳī* (Iraq)

Anṭāḳiya: Weights

1 *r* = [16/17 *r sulaymānī*]
1 *r* = [4/5 *r ẓāhirī*]
1 *r* = 384 *dir* = [12 *ūḳ*] = [17 1/7 *mi*] = (268 4/5) *mi*
1 *ūḳ* = 32 *dir* (22 2/5) *mi*
1 *r* = (3/5 + 1/25) *r* (Syria) = (2 + 1/2 + 1/20 + 1/100) *r fulfulī* = 4/5 *r ẓāhirī* = (2/3 + 1/4 + 1/100) *r ḥaythamī*

Ardabīl: Weights

1 *r* = [9/5 *r sulaymānī*]
1 *ūḳ* = 90 *dir*
1 *r* = 1 4/5 *r sulaymānī* = 8 2/5 *r* (Iraq)
1 *r* = 1.080 *r* = [12 *ūḳ*] = 756 *mi*
1 *mi* = 63 *dir*

Asyūṭ (Egypt): Weights

1 *r* = [5/3 *r sulaymānī*] = *r* (Ṭaḥāwī, ‘Akkā)
1 *r* = 1,000 *dir* = 700 *mi* = [12 *ūḳ*]
1 *r* = 1 2/3 *r* (Syria) = 31/3 *r djarwī* = 6 2/3 *r fulfulī* = (7 + 2/3 + 1/9) *r* (Iraq)
1 *r* = 720 *dir* = 1/5 *ḳis*
1 *ūḳ* = 83 1/3 *dir* = 58 1/3 *mi*

Baghdad: Measures of capacity

1 *r* = [3/16 *ṣa* (Ḥidjāz) = [2 *ma*] = [1/4 *mu* (Damascus)] = 3/14 *r* (Syria)

Bardha‘a (Azarbaydjan): Weights

1 *r* = [7/5 r *sulaymānī*]
1 *ūḳ* = 588 *mi*
1 *r* = 1 2/3 *r sulaymānī*
= (6 + 1/3 + 1/5) *r sulaymānī*
1 *r* = 840 *dir* = [14 *ūḳ*]
1 *ūḳ/mi* = 49 *dir*

Damascus: Measures of capacity

1 *mu* = 1 4/7 *mu* (Ḥidjāz) = 4 *r* (Baghdad)

Weights

1*r* = 12 *ūḳ* = 600 *dir* = 1 *r sulaymānī*
1 r = 420 *mi* = 3,600 *da* = 14,400 *ḳī* = 36,000 *ḥa*
1 *ūḳ* = 35 *mi* = 300 *da* 1,200 *ḳī* = 3,000 *ḥa*
1 *ḥa* = (6/7 + 1/28) *ḥa* (Aleppo)
1 *ūḳ* (small, silk) = 10 *dir* = 1/50 *r* = 1/20 *is*
1 *ūḳ* = 50 *dir*
1 *ḳī* = 1 3/8 *da* (Iraq)
1 *ḳī* = [15/16 *ḳī* (Aleppo)]

Diyār Bakr (N-Syria)

1 *dir* = 60 *ḥa*
1 *ḳī* = 4 *ḥa* = 2/45 *dī*
1 *dī* = 22 1/2 *ḳī* = 90 *ḥa*
1 *ḥa* = 1/4 *ḳī* = 1/90 *dī*

Diyār Muḍar (N-Syria)

1 *dir* = 60 *ḥa*
1 *ḳī* = 4 *ḥa* = 2/45 *dī*
1 *dī* = 22 1/2 *ḳī* = 90 *ḥa*
1 *ḥa* = 1/4 *ḳī* = 1/90 *dī*

Djarwī: Weights

1 *r* = [6/7 *ma* (Syria, general)]
1 *r* = [1/2 *r sulaymānī*]
1 *r* = 300 *dir* = 1/2 *r* (Syria) = (1/5 + 1/10) *r* (Ṭaḥāwī)] = 1 1/6 *ma* = 210 *mi*
= 2 1/3 *r* (Iraq) = [3/10 *r* (Asyūṭī)]

Djazīra: Weights

1 *dir* = 60 *ḥa*
1 *ḳī* = 4 *ḥa* = 2/45 *dī*
1 *dī* = 22 1/2 *ḳī* = 2/45 *dī*
1 *ḥa* = 1/4 *ḳī* = 1/90 *dī*

Egypt: Measures of area

1 *fad* = 100 *dh* · 100 *dh* = 20 *ḳab*

Measures of capacity

1 *ku* = 1 *ḳin fulfulī* = 1/4 *ḳin* (Syria)

Weights

1 *dir* = 60 *ḥa*
1 *dir* = (1/2 + 1/5) *dī* = 16 4/5 *ḳī*
1 *dī* = 10/7 *dir* = 24 *ḳī* = 85 5/7 *ḥa/dir*
1 *ḳī* = (1/7 + 1/14) *da* [sic]
1 *dī* = 600/7 *ḥa*
1 *ḥa* = (1/5 + 2/25) *ḳī*
1 *ḥa/dī* = [(1 + 1/21) *ḥa/dī* (Aleppo)]
1 *ḳī* = [21/25 *ḳī* (Iraq)]
1 *r* = 1 *ḳin fulfulī* = 1/4 *ḳin* (Syria)
1 *da* = 6 *ḥa*
1 *ḳī* = 3 4/7 *ḥa*
1 *da/dī* = 8 4/7 *ḥa/dir*
1 *da* = 2 2/5 *ḳī*
1 *ḳī* = 25/7 *ḥa* = (1/24 + 1/42) *dir*
1 *ḥa/dī* = (1/100 + 1/600) *dī*
1 *ḳī* = [15/16 *ḳī* (Aleppo)]
1 *ḳī/dir* = [3/8 *da* (Iraq)]

Filasṭīn (Palestine, incl. Tiberias): Measures of length and area

1 *ḥab* = 40 *dh*
1 *mudy* = 1 *ḥab* · 1 *ḥab*

Weights

1 *ra* = 420 *mi* = 3,600 *da* = 14,400 *ḳī* = 36,000 *ḥa*
1 *ūḳ* = 35 *mi* = 300 *da* = 1,200 *ḳī* = 3,000 *ḥa*

Fulfulī: Measures of capacity

1 *ra* = [7/32 *ṣa* (Ḥidjāz)] = [7/8 prophetic *mu*]

Weights

1 *r* = [7/12 *r* (Syria, general)]
1 *r* = 2 r *djarwī*
1 *r* = [1/4 r *sulaymānī*]
1*ḳin* = 1 *r* (Egypt) =1/4 *ḳin* (Syria)
1 *r*/*ūḳ* = 12 1/2 *dir* = (8 1/2 + 1/4) *mi* = 1/4 *r* (Syria) =(1/3 + 1/4) *ma*
1 *r* = [6/7 *r* (Iraq)] = [3/8 *r ḥaythamī* = [5/16 *r ẓāhirī*] =[3/2 *r* (Asyūṭī)]
= [3/2 *r* (Ṭaḥāwī)] =[25/64 *r* (Anṭākiya]
1 *r* = 150 *dir* = 105 *mi*

Ghaylānī, see Yemen

Ḥaithamī: Weights

1 *r* = 400 *dir* = [12 *ūḳ*] 1 *ūḳ* = 33 1/3 *dir*
1 *r* = 2/3 *r* (Syria) = 2 *r laythī* = 2 2/3 *r fulfulī* = 3 1/9 *r* (Iraq) = 1 5/9 *ma* (Iraq) = 1 5/6 *r ẓāhirī*
= 1 11/150 *ra* (Anṭākiya)

Ḥidjāz: Measures of capacity

1 *was* = 60 *ṣa* = 240 *mu*

1 *ṣa* = 5 1/3 *r* (Baghdad) = 1 1/7 *r* (Syria) = 4 4/7 *r fulfulī* = 2 2/3 *ma* = 8 *r* (Abū Ḥanīfa: Baghdad)

1 *mu* = 1 3/4 *mu* (Damascus)

Weights

1 *dī* = 24 *ḳī*

1 *r* = 3/601 r *sulaymānī*

Iraq: Measures of length and area

1 *dj* = 60 *dh* · 60 *dh* = [3,600 *dh*^{2}] = 10 *ḳa* = 100 *ʿas*

1 *ḳaṣ* = 6 *dh* = 1 *bā* = 1/10 *ash*

1 *ʿas* = 1 *bā* · 1 *bā*

1 *ḳa* = 7 1/2 *dh* = 1/4 (or 1/3) *si*

1 *dj* = 1 *ash* · 1 *ash*

1 *mud* = 30 *ḳal*^{2} = 1687 1/2 *dh*^{2}

Measures of capacity

1 *ku* = 60 *ḳa*

1 *mu* = 3/4 prophetic *mu*

Weights

1 *dī* = 6 *da* = 60 *ḥa* = 20 *ḳī*

1 *dir* = 48 *ṭa* = 48 *ḥa* = 6 *da*

1 *dir* = (1/2 + 1/5) *dī*

1 *ṭa* = 4/5 *ḥa* (Syria)

1 *ḳī* = [4/5 *ḳī* (Aleppo)]

1 *da* = 2 2/3 *ḳī/dir* (Dam., Egypt)

1 *ḳī* = 8/9 *ḳī* (Aleppo, weight)

1 *ūḳ* = [1/1,200 *ḳin* (Syria)]

1 *r* = 128 4/7 *dir* = 90 *mi*

1 *ūḳ* = 10 5/7 *dir* = 7 1/2 *mi*

1 *r* = 1,800 *ḳī* = 6,171 3/7 *ḥa/dī* = 5,400 *ḥa/dir* = 3/14 *r* (Syria) = 6/7 *r fulfulī* = 1/2 *ma* = [9/14 *r laythī*]

1 *r* = [9/28 *r ḥaythamī*] = [9/35 *r* (Asyūṭī)] = [5/42 *r* (Ardabīl)]

1 *ḳī* = 3 *ḥa*

1 *da/dir* = 8 *ḥa/dir*

1 *ḥa/dir* = 1/48 *dir*

1 *dī* = 2/3 *dī* (Aleppo)

1 *ḳī* = 1 1/7 + 1/21 *ḳī* (Damascus, Egypt)

1 *da* = 2 1/3 *ḳī*

1 *r* = [3/14 r *sulaymānī*]

1 *r* = 1/2 *r* (Syria, general)

1 *r* = [12 *ūḳ*]

Laythī: Weights

1 *r* = [1/3 *r sulaymānī*]

1 *r* = 100 *dir* = [6 3/33 *ūḳ*]

1 *ūḳ* = 16 1/2 *dir* = 140 *mi* = 11 2/3 *mi sulaymānī*

1 *r* = 1 1/4 *r fulfulī* = 6/7 *ma* = 1 5/9 *r* (Iraq)

1 *r* = [7/9 *ma* (Syria, general)]

1 *r* = [1/2 *r ḥaythamī*]

Makāyīl al-nabīy (prophetic measures)

1 *mu* = 1 1/3 *r* (Iraq) = 171 3/7 *dir* = 3 3/7 *ūḳ* (Syria) = 1 1/7 *r fulfulī* = 120 *mi*

Sulaymānī: Weights

1 *r* = 1 *r* (Damascus) = 200 1/3 *r* (Ḥidjāz) = 4 *r fulfulī* = 4 1/3 *r* (Iraq) = 3 *r laythī* = 2 *r djarwī* = 2 4/19 *r* (Ghaylānī) = 1 1/2 *r ḥaythamī* = 1 1/4 *r ẓāhirī* = 5/4 *r* (Bardhaʿī) = 5/9 *r* (Ardabīl) = 3/5 *r* (Asyūṭī) = 1 1/16 *r* (Anṭākiya)

1 *r* = [2 2/15 *ma* (Syria, general)] = [7/3 *ma* (Syria, general)] = [5/7 *r* (Bardhaʿī)] = [5/9 *r* (Ardabīl)]

Syria: Measures of capacity

1 *ghi* = 3 *ḳa* (Iraq) = 12 *ru* = 72 *mu*

1 *r* = [7/8 *ṣa* (Ḥidjāz)] = [4 2/3 *r* (Baghdad)]

1 *ūḳ* = [7/24 prophetic *mu*]

Weights

1 *dir* = 60 *ḥa*

1 *da* = 10 *ḥa*

1 *ḳī* = 3 4/7 *ḥa*

1 *da/dī* = 8 4/7 *ḥa/dī*

1 *da* = 1 4/5 *ḳī*

1 *ḥa* = (1/5 + 2/25) *ḳī*

1 *ḥa* = 6 *da*

1 *dir* = (1/2 + 1/5) *dī* = 16 4/5 *ḳī/dī*

1 *dī* = 1 3/7 *dir* = 24 *ḳī* = 85 5/7 *ḥa*

1 *ḳī* = (1/7 + 1/14) *ḥa*

1 *dī* = 600/7 *ḥa*

1 *ḥa* = 4/5 *ṭa* (Iraq)

1 *ḥa/dī* = (1/100 + 1/600) *dī* | 1 *ḥa* = (6/7 + 1/28) *ḥa* (Aleppo)
1 *ḳī* = 25/7 *ḥa* = (1/28 + 1/42) *dir* = 1/24 *dī*

Weights (Syria, specific)

1 *r* = 420 *mi* = 3,600 *da* = 14,400 *ḳī* = 36,000 *ḥa*
1 *ūḳ* = 35 *mi* = 300 *da* = 1,200 *ḳī* = 3,000 *ḥa*
1 *ḳin* = [4 *ḳin fulfulī*] = [4 *r* (Egypt)] = 42,000 *mi* = 60,000 *dir*
1 *r* = [4 *r/ūḳ fulfulī*] = [2 *r djarwī*] = [14/3 *r* (Iraq)]
1 *r* = [3/2 *r ḥaythamī*] = [3/5 *r* (Asyūṭī)] = [16/25 *r* (Anṭākiya)]

Weights (Syria, unspecified)

1 *ḳin* = 100 *r* = 233 1/3 *ma* = 466 2/3 *r* [sic] = 1,200 *ūḳ* (Iraq)
1 *ma* = 260 *dir* ≈ 257 1/7 *dir* = 180 *mi* = 2 *r* (Iraq) = 1 5/7 *r fulfulī* = 13/30 *r sulaymānī*
1 *ma* = 1 2/7 *r laythī* = 6/7 *r djarwī* = 3/7 *r sulaymānī*
1 *r/ūḳ* = 5 1/7 ūḳ = 1/4 *ma* = 3 3/4 *mi*

Ṭaḥāwī: Weights

1 *r* = [3/10 *r djarwī*] | 1 *r* = 1 *r* (Asyūṭī)

Yemen (Ghaylānī): Weights

1 *r* = [19/42 *r sulaymānī*] | 1 *ūḳ* = (15 1/2 + 1/3) *mi sulaymānī*
1 *r* = [271 2/3 + 2/7] *dir sulaymānī* = 190 *mi sulaymānī*

Ẓāhirī (Fāṭimid): Weights

1 *r* = 480 *dir* = [12 *ūḳ*] = 336 *mi* | 1 *ūḳ* = 40 *dir* = 28 *mi*
1 *r* = 4/5 *r* (Syria) = 1 1/5 *r ḥaythamī* = 3 1/5 *r fulfulī* = 1 1/4 *r* (Anṭākiya)
= (3 2/3 + 2/30) *r* (Iraq)

Ells (*adhruʿ*, unspecified):

dhirāʿ al-yad
1 *dh* = 2 *shi* (cloth) = 18 *iṣ* (medium) = 24 *iṣ* (without thumb) = [3/4 *dh* (*ḳāsimī*)]

dhirāʿ ḳāsimī (= hāshimī)
1 *dh* = 1 1/3 *dh* (*yad*) = 24 *iṣ* = 6 *ḳab* | 1 *ḳab* = 1/6 *dh*
1 *Iṣ* = 1/4 *ḳab* = 1/24 *dh*

dhirāʿ hāshimī (mālikī)
1 *dh* = 8 *ḳab* = [3/5 *dh* (*mābahrāmī*)]

dhirāʿ mābahrāmī (sūd)
1 *dh* = 1 2/3 *dh* (*hāshimī*) = 60 *fa* = 1/3 (or 1/6) *ḳab*
1 *dj* = 36 *dh* · 36 *dh*

al-islāmīya, Beirut: Maktabat Lubnān Nāshirūn, 2002. Only occasionally, external sources, records of both European and Oriental travellers, allow the fixation of absolute values. With regard to their geographical and chronological diversity, the reconstruction of entire systems of measurement and of their relation to each other has just begun.

During the tenth century, mathematicians became aware of the complexity of the metric systems in use. Their particular perspective on the issue differed from what their legal and other colleagues had been noting down hitherto. They not only tried to present a systemized enumeration of all units related, but also endeavoured, for pedagogical reasons, to systematize the usage of measuring units in popular treatises. They sometimes even expressed efforts to standardise and facilitate the conversions customs, market and tax officers had to enact. Thus, stimulated by theoretical manuals, mathematically standardised methods of measuring and of converting quantities from one system into another became popularised. To some extent, these devices even had retroactive effects on the practice of Islamic laws.

Among these manuals, the “Book on the Basis of Arithmetic and the Division of Inheritances” (*Kitāb* *al-Tadhkira bi-uṣūl al-ḥisab wa l-farā'iḍ*), written by the Damascene mathematician ʿAlī b. al-Khiḍr al-ʿUthmānī al-urashī (1030–1067 AD) contains the most coherent information on the metric systems that were in use in the Islamic Middle East up to the lifetime of the author. The following list of units of weight, currency, capacity and length, together with the localities they refer to arranged in alphabetical order, is extracted and, if indicated by '[...]', concluded from different chapters of this *Kitāb al-Tadhkira*.

See also: ►Nilometer

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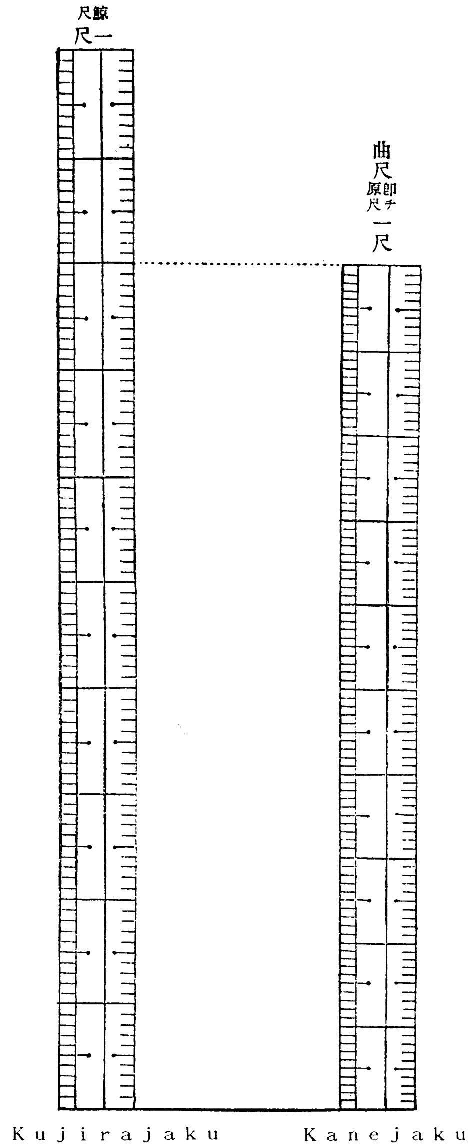
Weights and Measures in Japan

Shigeo Iwata

Japan used the 17.3 cm-long linear measure unit that was common to all the regions in East Asia for a period of 25,000 years. Under the influence of China, the Japanese measuring unit gradually lengthened during the period from the end of the eleventh century BCE to the middle of the third century BCE. Then, the length of the Japanese measure *shaku* was stabilized at 23 cm and remained unchanged until the end of the second century AD. Various civil disturbances in China had the effect of lengthening the linear measure substantially to 29 cm until the middle of the seventh century, and no more significant variation has since been observed (Fig. 1).

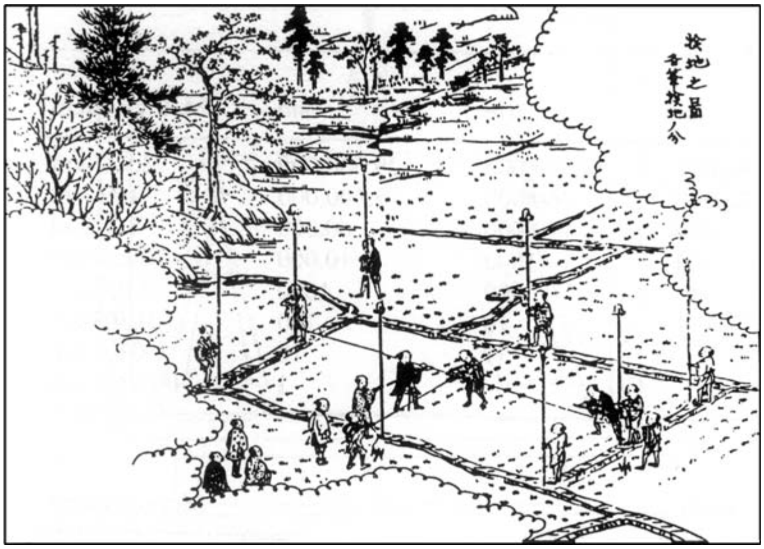


Weights and Measures in Japan. Fig. 1 Linear Measure. Drawing by The Ministry of Finance. *Doryoko Shurui Hyo* (The Classification Table of Weights and Measures) Genbei Kinokuniya, 1875. Chos 1, 4–6, 9–11.

Length

Under the Chinese Tang dynasty, a law was enacted mandating the use of two methods based on large and small linear measures. The large scale was 1.2 times as long as the small scale, which we refer to as the ancient linear measure. The small scale was used for music, astronomy, and ceremonial items.

Japan introduced this Chinese measuring system in 701. The large scale later became known as *kanejaku*, which refers to an L-shaped ruler used by architects. The small scale gradually dropped out of use. Linear measurement tools were mainly made of wood, though



Weights and Measures in Japan. Fig. 2 Land Surveying. From *Tokugawa Bakufu Kenchi Yoryaku* (Essential Summary of the Government of Prefectures, Tokugawa Shogunate). Tokyo: Kashiwa Shobo, 1915.

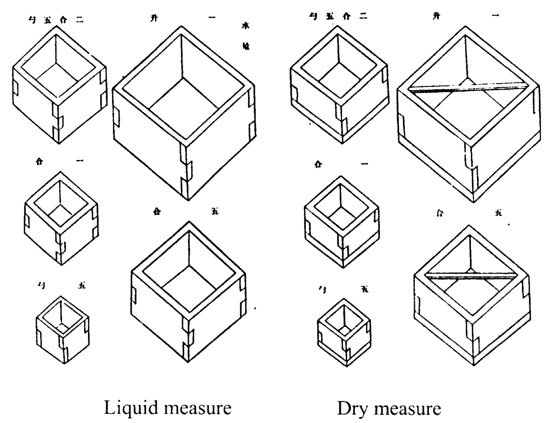
ivory was also used in ancient times. The largest unit of length in ancient times was the *ri*, which was 5–70 *cho* (a *cho* was 109.1 m). The *ri* was set to 36 *cho* in the seventeenth century. One *shaku* was one-tenth of a *jo*. Metal linear measurement tools began appearing in the medieval era.

The average value of one *shaku* was 29.6 cm in the seventh century, 29.7 cm in the eighth century, 29.8 cm in the ninth century, 29.9 cm in the tenth century, 30.1 cm in the twelfth century, 30.2 cm in the fourteenth century, and 30.3 cm in the eighteenth century. The rate of elongation was slower than in China.

Several linear measures for sewing appeared in the medieval era. The length of one *shaku* ranged from 1.15 to 1.27 times that of a *kanejaku*. These linear measures for sewing were neatly arranged into two kinds of scales. One scale, 1.20 times as long as a *kanejaku*, was called *gofukujaku*, while the other was 1.25 times as long as the *kanejaku* and called a *kujirajaku*. The *gofukujaku* gradually dropped out of use in the first half of the eighteenth century and was finally abolished in 1875.

Area

The earliest area unit we know of was the *shiro*, which was in use before the sixth century. One *shiro* was 30 *shaku* square. In 646, new units were defined: the *bu*, which was six *shaku* square; the *tan*, equal to 360 *bu*; and the *cho*, equal to ten *tan*. One *tan* has been equal to 300 *bu* since the end of the sixteenth century. For land surveying purposes, one *bu* was defined as six *shaku* five *sun* square, rather than six *shaku* square. At the end of the sixteenth century, a *bu* was defined as six *shaku* three *sun* square. Despite this, the *bu* was commonly considered to be six *shaku* square, and was finally defined as such in 1891. A *se* was ten times as large as a

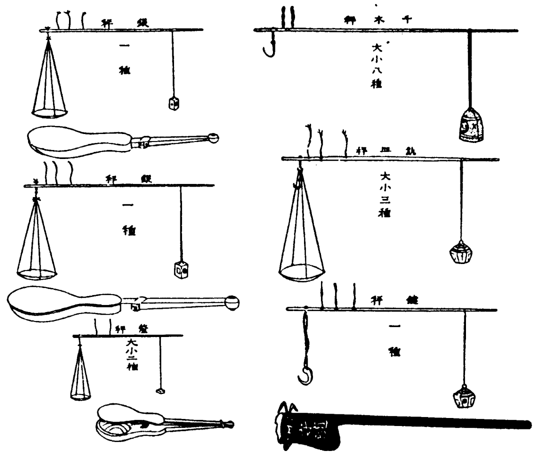


Weights and Measures in Japan. Fig. 3 Measures. Drawing by The Ministry of Finance. *Doryoko Shurui Hyo* (The Classification Table of Weights and Measures) Genbei Kinokuniya, 1875. Chos 1, 4–6, 9–11.

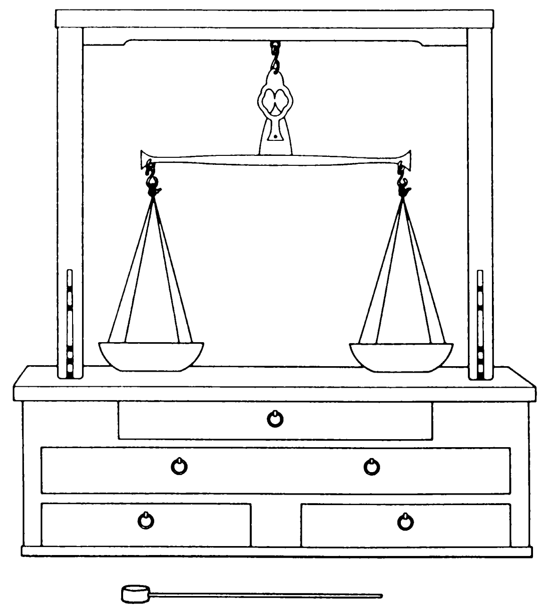
bu, which was also referred to as a *tsubo*. These names appeared in the medieval era. Land surveyors made their measurements using flax string measures and wood measuring poles (Fig. 2, 3).

Volume

The names for most units of volume also came from China. The basic unit was the *sho*. One *sho* averaged 750 cm^3 in the eighth century, 800 cm^3 in the ninth century, 970 cm^3 in the eleventh century, 1,400 cm^3 in the fifteenth century, and 1,650 cm^3 in the sixteenth century. Since the seventeenth century, the average value has remained constant at 1,804 cm^3. During the medieval era, different measures of volume were used for goods, taxes, and financial transactions (Fig. 4).



Weights and Measures in Japan. Fig. 4 Steelyard. Drawing by The Ministry of Finance. *Doryoko Shurui Hyo* (The Classification Table of Weights and Measures) Genbei Kinokuniya, 1875. Chos 1, 4–6, 9–11.



Weights and Measures in Japan. Fig. 5 Balance. Drawing by Shigeo Iwata (1981).

The Tokugawa-Shogunate (1603–1867) established the East and West Measure Guilds in 1655, and exerted strong control over the new standard. Use of *sho* continued until 1958, when the *shaku-kan* system was abolished.

Rectangular measures were made of wood. The brims of many dry measures were protected by bamboo or iron laminae. Most of the large dry measures also featured a narrow iron bar positioned diagonally across the top. Round wooden sticks were used to level off the tops of measures. Liquid measures had lacquered surfaces to prevent the contents from leaking.

Standard sizes for measures have been one *to*, seven *sho*, five *sho*, one *sho*, five *go*, two *go* five *shaku*, and one *go* since 1655, and one *to*, five *sho*, one *sho*, five *go*, two *go* five *shaku*, one *go*, and five *shaku* since 1875.

Mass

Between the eighth century BCE and the fifth century AD, the Chinese expressed mass in terms of the *liang*, which was equal to 14 g. In this measuring system, one *jin* was equal to 16 *liang*, and one *liang* to 24 *zhu*. The civil disturbances of the third and seventh centuries also had their effect on the *liang*, which tripled in mass. Under the Chinese Tang dynasty, a law stipulating two measuring scales was enacted, which fixed the mass of the new large *liang* at three times that of the mass of the older *liang*, which became used only for medicine.

Japan adopted this Chinese measuring system as well, changing the names of *jin*, *liang*, and *zhu* to the *kin*, *ryo*, and *shu*, but retaining the same characters. The absolute mass of the *ryo* in the large scale decreased year by year, while that in the small scale became rather unclear. The average mass of one *ryo* was 42 g in the eighth century, 40 g in the tenth century, 39 g in the twelfth century, and 37.47 g at the end of the sixteenth century. Under the strong control of the Tokugawa-Shogunate, the average mass of the *ryo* remained almost unchanged until the end of the nineteenth century. The *kan* and *monme* appeared in the medieval era. One *kan* was equal to 100 *ryo*, and one *monme* equal to one-tenth of a *ryo*. These units gradually became standard.

Chinese use of the steelyard dates back to at least several centuries BCE. The steelyard was also used in Japan, where the Tokugawa-Shogunate established the East and West Steelyard Guilds in 1653. Steelyard beams were made of white oak, persimmon wood, ivory, horn, and bone. The beam had from one fulcrum to eight fulcra, which were made using string, cord, or rope. A copper pan or bronze hook was installed on the end of the beam, and the bob-weight was made of bronze or iron. Steelyards were used for most commercial transactions (Fig. 5).

Balance makers did not belong to a guild, so standards for making balances were never formulated. The most famous balance makers were members of the Nakabori family, who lived mainly in the western counties of Japan. The balance beam was suspended by its pointer from the center of a box-mounted rectangular wooden stand. A central pin was used for the main fulcrum, and during the final stages of weighing, bearing friction was overcome by tapping on the pin with a small wooden hammer. Balances were mainly used in the manufacture of gold, silver, and copper coins, and in money-changing transactions.

Beginning in the seventeenth century, users of the balance had to be supplied with weights made by the Goto family. Two sets of weights were available: one consisted of weights of 20, 10, 5, 4, 3, 2, 1 *ryo*, 5, 4, 3, 2, 1 *monme*, and 5, 4, 3, 2, 1 *fun*, and the other was identical to the first but for the addition of 50 and 30 *ryo* weights. Weights were made of bronze, and engraved on the surface with the inspector's mark and maker's crest, leaves and flowers of the Japanese paulownia. The Goto family belonged to the Guild of Goldsmiths, and were inspectors authorized by the feudal government. They examined user's weights periodically by comparing them with standard weights.

Transition to the Metric System

In 1886, Japan signed the Treaty of the Meter, and promulgated the Law of Weights and Measures. As a result, the *shaku-kan* system and metric system began to be used jointly in 1891. The conversion coefficients between these two measuring systems were also fixed at the same time (Table 1). The law went into formal effect in 1893. In 1903, the Central Inspection Institute of Weights and Measures was established in Tokyo. Japan also adopted the units of the foot-pound system as legal in 1909.

A Measurement Law was passed by the Diet in 1951, and went into effect on March 1, 1952. It mandated that measuring units be based on the metric system. The *shaku-kan* system and foot-pound system were abolished in 1958.

A new Measurement Law was promulgated on May 20, 1993, and went into effect on November 1, 1993. The law made a sweeping revision of the regulations by adopting the Système Internationale d'Unités. The units of the other measuring systems on commercial transactions and certifications were abolished by the end of the twentieth century.

Weights and Measures in Japan. Table 1 Conversion tables of Japanese weights and measures (1891–1958)

Length

ri	*cho*	*ken*	*shaku*	*sun*	*bu*	*rin*	*mo*	Metric system
1	36	2,160	12,960	129,600	1,296,000	12,960,000	129,600,000	3.927 km
	1	60	360	3,600	36,000	360,000	3,600,000	109.1 m
		1	6	60	600	6,000	60,000	1.818 m
			1	10	100	1,000	10,000	30.30 cm
				1	10	100	1,000	3.030 cm
					1	10	100	0.303 cm
						1	10	0.0303 cm
							1	0.00303 cm

Area

cho	*tan*	*se*	*bu (tsubo)*	*go*	*shaku*	Metric system
1	10	100	3,000	30,000	300,000	9917 m^2
	1	10	300	3,000	30,000	991.7 m^2
		1	30	300	3,000	99.17 m^2
			1	10	100	3.306 m^2
				1	10	0.331 m^2
					1	0.0331 m^2

Volume

koku	*to*	*sho*	*go*	*shaku*	Metric system
1	10	100	1,000	10,000	180,400 cm^3
	1	10	100	1,000	18,040 cm^3
		1	10	100	1804 cm^3
			1	10	180.4 cm^3
				1	18.04 cm^3

Mass

kan	*ryo*	*monme*	*fun*	*rin*	*mo*	Metric system
1	100	1,000	10,000	100,000	1,000,000	3.750 kg
	1	10	100	1,000	10,000	37.50 g
		1	10	100	1,000	3.750 g
			1	10	100	0.375 g
				1	10	0.0375 g
					1	0.00375 g

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Weights and Measures in Mesoamerica

JEAN-CLAUDE HOCQUET

Mexico is said to have used an incredible variety of weights and measures changing according to the region and the period. Different uses of the weights and measures increased the complexity of the situation. The task of the historian consists of restoring the ancient systems and understanding their use by posing the questions: who was using the weights and measures and for what purpose? The more powerful of the two parties in the exchange would impose upon the other modes of measuring and counting to his own advantage.

Indian Measures

In 1520, Hernan Cortes had the opportunity to see the market of Tlalecolco and the transactions which went on there. He wrote, "Everything is sold by count and measure, and up till now I haven't seen anything sold by weight." Antonio de Herrera y Tordessilas reported that the Indians "have measures for everything" and that the judges controlled the weights and measures and punished the cheaters. But his information has not been confirmed. However, the level of development attained by the Mesoamerican people before the Conquest makes it very probable that they had an ensemble of measures and standards used in the apportionment of land, commercial transactions, levying of taxes, construction, pharmacy, etc., and that these measures constituted a unified and coherent system.

After the Conquest, the Spanish imposed Andalusian and Castilian measures such as *brazas*, *codos*, and *pal-mos*, that the Indians adopted easily, as, like their own, they were anthropometric. The result of this adoption was that Mesoamerican symbols of measure were transcribed in European terms on the pictograms of indigenous manuscripts written in the Nahuatl language. Bars represented digits, little black circles were for 20s, and other signs represented hands or feet. Thus, for example, the Indians gave the name *tlamamalli* to the load (*carga*) that a man (porter, *tameme*) could carry on his shoulders during a day's work. In the *novohispano* system, this load had the name *tameme*, by a simple movement of language and meaning. It was equivalent to a Spanish half-*fanega* or to two *arrobas*. This indigenous load varied in weight, in the function of the weighed merchandise, and with the strength of the carrier; for cocoa it was equivalent to three *xiquipilli* of 8,000 grains each.

Among the measures of capacity, of great diversity, the smallest was the *centlachipinilli*, which literally means "a small something" (*una gota de algo*) and which was itself a multiple of *centlachipiniltontli* (*una gotilla de algo*). There were also small measures used in pharmacy, such as spoonsful (*cemixcolli*, *cenxumatli*, etc.). *Testal* designated the quantity of cornmeal necessary to make a tortilla for one person.

To measure dry materials, in particular for grains, they were often able to use measures equivalent to those imported from Spain: the *acalli*, for example, of which we do not know the weight, was part of an arithmetic system with the *cencaauhacalli* equal to a half-*fanega* and with the *cuauha-caltontili* equal to a *celemin*. Such equivalent approaches make it possible to conclude that the conquerors tried to impose their own system while at the same time adopting the native terms.

Measures of length were used for the preparation of clothing, especially for ponchos, made of bands of different widths. Most measures of length were land measures, based on proportions of the human body: *cemiztetl*, *cemmapilli*, and *cemmatl*, literally a finger, a palm, and a span. This "span" designated the height of a man, from foot to raised hand, but it also measured the diagonal, from the left foot to the raised right hand, and it stood for three Spanish *varas* (yards or cubits). Such a dimension proves that the span was a geometric measure and not an anthropometric one; it was obtained by attaching an anthropometric measure such as a digit, measured by its length, to a coefficient. European measures of length did not have the same way of varying, in which a "foot" could vary between 28 and 60 cm. However, for land measures, certain spans were smaller, and the *vara* was therefore equal to two spans. In Tula, there was a division of land in order to reform the tax law, and "each Indian was given one hundred *varas* in length and twenty in width. Each one of these *varas* made two spans; this is the measure which the

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Indians use" (Castillo Farreras 1972). It is possible that this text makes reference to an Indian *vara* and a Spanish *braza*. Standards of measure and length existed, and, to measure land, poles or cords were used, just as European surveyors did.

Road measures also existed, which were used by travelers, soldiers, and merchants. These were the *cennecehuilli* and the *cennetlalolli*, which Spanish authors tended to translate as "leagues."

Weights and Measures of New Spain

In the sources of the eighteenth century the range of different names involved – *carga*, *fanega*, and *arroba* – hides the numerical relations which link multiples and submultiples. The *carga* is made up of two *fanegas*, composed in turn of six to eight *arrobas*. In general the historian goes from the largest to the smallest, whereas in practice, the peasant, the muleteer, or the trader proceeds in the reverse order. In the same way that the metric *quintal* is made up of grams and kilograms between which the factor 10 governs all relations, in the eighteenth century, 2 and 6 (equals two multiplied by three) governed the relations of the *carga* with its submultiples. The decimal metric system is a scientific system, mathematic in character, invariant, exterior to humans. In contrast, previous systems were based on people or on observations concerning them, or on their work and capacity to complete certain tasks with the aid of animals. That is, if a mule must climb steep paths with its load, the muleteer compensates for this by lowering the weight of the load by one or two *arrobas*. At times, the sources mention *cargas pequeñas* in contrast to *cargas regulares de mula*.

> As long as freighting relied chiefly on pack trains and carts, the weight of the loads was determined by distances to the customer, the availability of pasture *en route*, as well as by the nature of roads and tracks. In the case of steep mountain paths, broken country or long distances, the *carga*, the traditional load of a mule, could be lowered in weight. So a mule load could comprise one and a half or two *fanegas*. In 1832 the Governor of Oaxaca stated that because of the poor roads the *carga* could never consist of more than eight *arroads* (Ewald 1985).

Generally the custom of mentioning the number of *arrobas* making up a *fanega* or a *carga* does not eliminate the uncertainties which surround all quantitative data. In 1751, the *carga* of salt in Tehuantepec consisted of 14 *arrobas*. Another eighteenth-century source stated that moist Tehuantepec salt was 16 *arrobas*, while drier salt was computed at 12–14 *arrobas*.

The dampness or dryness of goods being transported markedly affects their weight. The presence of water increases the weight of light goods such as grains, but it lessens the weight of heavier ones, in particular salt. In Tehuantepec, the variation in weight often reached a quarter. Other variations were also noticeable between the different regions: "In eighteenth century Yucatan, one *fanega* of old salt weighed approximately 9 *arrobas*, one *fanega* of new salt 10–11 *arrobas*" (Ewald 1985). The measure known as *carga* in the valley of Mexico was often mistakenly referred to as *fanega* in Yucatan.

But there is another trap: Ralph Roys, for example, noted that a *fanega* "is variously defined as 1.6 bushels, and a load of 100 pounds of grain," which is an example of recent efforts to align traditional measurements with those of the national market governed by the decimal metric system, whilst at the same time conserving the ancient names. But "this statement has led a number of scholars to assume that a *fanega* weighs 100 pounds, which is not necessarily the case. The *fanega*, like the bushel, is a measure of capacity, not weight. Hence, the weight of a *fanega* will vary enormously depending on the goods being measured by this standard. A *fanega* of corn may weigh close to 100 pounds, but salt is much heavier. An extensive survey of the literature on weights and measures used in the Maya area – from Yucatan to El Salvador suggests that a *fanega* of salt commonly weighed about 115 kg" (Andrews 1983). It is important not to confuse measures of capacity, which are volumes, and units of weight which measure mass; weighing the contents of a volumetric measure can only lead to considerable distortions, since each body has a specific weight by which it distinguishes itself from all others.

The foreigners who traveled or worked in nineteenth-century Mexico reported that a *fanega* of salt weighed approximately 70 kg and a *carga* 140 kg. J. Buschmann stated that the *carga* consisted of 138 kg. In 1912–1913, however, the business records of Salinas, Mexico calculated the *carga* of Colima salt at 161 kg. In 1916–1917, the *carga* was again lowered to the more customary 140 kg. The nineteenth-century sources gave 300 pounds as the equivalent of a *carga*. In summary, here are some of the results found in the historical literature on the subject.

In Mexico, on the central plateau (Tehuantepec salt):

carga	1		
fanega	2	1	
arroba, dry salt	14	7	1
arroba, moist salt	16	8	1
pounds, dry salt	300	150	21.4
kg	138	69	

In Yucatan, the substitution of the *fanega* for the *carga* does not modify the system.

β	1		
arroba, old salt	9	1	
arroba, new salt	11		
pounds	300	33.33	1
kg	138		0.460

The historian will recognize the mule load of 300 pounds and the 16 ounce pound, such familiar territory that he would think he was in Castile in the time of the Catholic Kings.

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Weights and Measures in Peru

Shigeo Iwata

Ancient Peru covered most of the Andes, where the Peruvian culture lasted for more than 10,000 years. Because most of the region was in the highlands, more than 3,000 m high, their metrology was slightly different from other civilizations. Also, they had no form of writing until 1532. For calculation and for recording metrological units decimally, they used *quipus*, spatial arrays of multicolored knotted cords. The names of the units and the values differed significantly depending on the period, the people, and the region.

Length

Peruvians used linear measurements that were related to human measurement patterns. Examples are listed in Table 1.

Peruvians chewed lime and *lipta* with coca leaves as a stimulant. They invented a measure called *cocada*, which measures how far one can walk while under the drug's influence. This distance is 3 km on level ground or 2 km on an uphill slope when carrying a 45 kg load for 35–40 min in Pataz county.

A twelfth-century pre-Inca site in Puruchuco, located about 6 km from Lima, was recently restored. The linear measurements of each part of the structure showed that the average stature of men from head to toe was 1.701 m, while the height from the middle fingertip to one's toe was 2.106 m. They used a geometrical design of proportions based on the golden section (1:1.618) between the sides of the rectangles.

Area

The Aymara called the area where they could raise one or two heads of cattle the *callapa*. *Tupu* was the Incan name for an area of cultivated land or pasture where a married couple could live. The Inca called the area, which was equal to 625 m^2 *huiri*. This was the area a man could cultivate in 1 day. The Cuzco called the area equal to 282 m^2 of sweet potatoes or corn *papacancha*.

Volume

The Peruvians used a single hand-cupped gowpen to measure small portions of grain. They also used gourds, dried pumpkins, pots, and jars to measure things. The names of the units and the values are shown in Table 2.

The Quechua called a broad crate filled with coca or red pepper a *runcu*. One-half of a *runcu* was called *checta runcu*, one-fourth was called *cutmu*, and one-eighth was called *sillcu*.

Mass

Because fewer weights have been discovered in the Peruvian region than in other civilizations, it has been difficult to estimate the mass standard accurately. We assume that the average mass of unit was 23.1 g. The notation was based on the decimal system. The maximum unit was assumed to be 23.1 kg, which is about 80% of the maximum units from other civilizations, 27–30 kg in Egypt, Mesopotamia, Indus, and China. This is probably because of the low concentration of oxygen in the atmosphere in the Andean highlands.

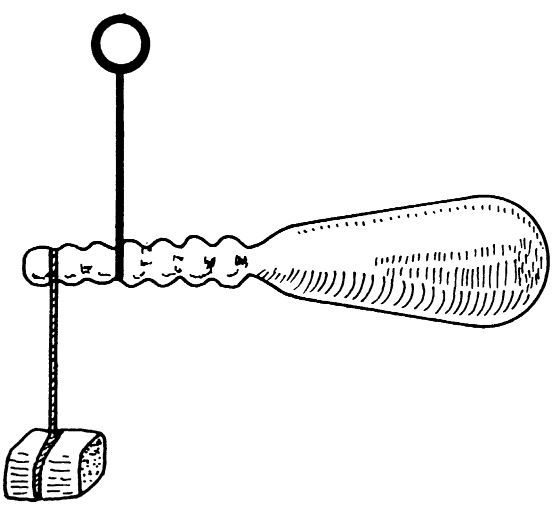
Thirty-nine percent of the weights were made of stone, 32% of iron, 24% of lead, and 5% were made of other nonferrous metals. One-third of the weights were globe-shaped; the others were conical, cylindrical, or in spindle and other irregular forms.

Weights and Measures in Peru. Table 1 Examples of Peruvian linear measurements

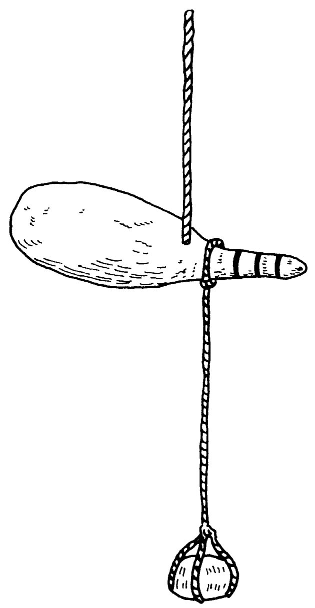
	Quechua	Aymara	Inca	Ratio	Metric system
Handbreadth		*ttkhlli*		0.051	8.5 cm
Link	*yaku*	*vicu*		0.107	18 cm
Span	*capa*	*chia*		0.125	21 cm
Cubit	*cuchuch tupu*			0.25	42 cm
Yard	*sikya*			0.50	84 cm
Pace		*chillque*		0.89	150 cm
Fathom	*rikra*			1.00	168 cm
		loca		10^2	168 m
		ecca		10^3	1.68 km
	cocoda			$1.19–1.79 \times 10^3$	2–3 km
League	*tupu*		*tupu*	3.33×10^3	5.6 km
		yapu		5.00×10^3	8.4 km
		chuta (sayhua)		10^4	16.8 km
			guamanin	10^5	168 km

Weights and Measures in Peru. Table 2 Hand-cupped "gowpen" measure of the Peruvians

	Quechua	Aymara	Ratio	Metric system (cm^3)
Gowpen (double hand-cupped)	*poktoy*	*iuu*	0.043	300
		laqui	1.00	7,000
	pokcha	*hullu*	2.00	14,000



Weights and Measures in Peru. Fig. 1 Bismar (adapted by the author from M. Uhle. La Balance Romaine au Pérou. *Journal de la Société des Américanistes de Paris* 17 (1925): 335).



Weights and Measures in Peru. Fig. 2 Movable load scale (adapted by the author from P. Rivet. La Balance Romaine au Pérou. *L'Anthropologie* 33 (1923): 535).

All types of scales, namely balance, steelyard, bismar, and movable load, were discovered in the northwest region of South America. The fulcrum was the cord-pivot type. Balance beams were made of wood, horn, and bone with humans, monkeys, birds, and geometrical patterns engraved on them. The two items supporting the load and weights were mostly nets, and partly pans of metals. The balance might have been invented by the ninth century (Figs. 1 and 2).

Weights and Measures in Peru. Fig. 3 Balance (from the Museo Amano).

Miquel de Estete, who attended Francisco Pizarro, found a steelyard on the coast of Ecuador in 1531. The steelyard was graduated from the middle of the beam to the end, and had a bob-weight suspended from the arm. The steelyard was used to weigh gold and silver. The bismar was discovered at the market in Tarma, 170 km northeast of Lima. The total length was 27.8 cm, and the capacity was assumed to be 924 g. The movable load scale, called *wipe* in the actual place, was discovered in Huarochiri, 90 km to the east of Lima. The scale was made of wood, and was used to weigh coca leaves (Fig. 3).

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Western Dominance

Michael Adas

Scientific curiosity was a major motive behind Western overseas expansion from the fifteenth century onward and technological innovations, particularly in shipbuilding, navigational instruments, and firearms, made that expansion possible. But early European explorers and conquistadors did not rely heavily on evidence of scientific or technological achievements as gauges of the worth of the peoples they encountered or as explanations for their growing dominance in the Americas and maritime Africa and Asia. In encounters with the great centers of civilization in Africa and Asia, European superiority in these endeavors was highly selective, marginal, or in many areas nonexistent. In fact, travelers to China and the Indian subcontinent in the early centuries of expansion were as likely to dwell on the technological deficiencies of the West, when compared to these great civilizations, as to boast of European advantages. As in India, China, and Japan, the Europeans were able to make little headway into the heartlands of the Islamic world in this era. That standoff and the fact that they had borrowed so heavily from the scientific learning and technology of Muslim cultures in the centuries of Europe's emergence as a global force, rendered it unlikely that material standards would supplant the long contested religious differences that the Europeans had employed to set themselves off from and above the followers of Islam.

In Africa, disease and geographical barriers and the power of coastal kingdoms prevented the Europeans from translating their technological edge into significant conquests. Failure to move into the African interior also meant that the Europeans had only the vaguest notions about African epistemologies or understandings of the natural world, which were usually dismissed as superstition or fetishism. In sharp contrast to their experience in Africa, European invaders encountered few disease barriers in the Americas. In fact, diseases from smallpox to the measles became powerful allies of the Spanish conquistadors in their assaults on the heavily populated and highly advanced civilizations of Mesoamerica and the Andean highlands. The long isolation of the Amerindian peoples from the Afroeurasian people and cultures left them highly vulnerable to both the microbes borne and the Iron-Age technology wielded by the European invaders. Nonetheless, the Spanish tended to attribute their startling successes in battle against seemingly overwhelming numbers of Aztec or Inca adversaries and the rapid conquests that followed to supernatural forces and to the superiority of their militant brand of Christianity over the “heathen” faiths of the indigenous inhabitants of the “New” World.

Lacking in-depth knowledge of the epistemologies and scientific learning of most of the peoples they encountered in the early centuries of overseas expansion and often enjoying only very selective (but at times critical) technological advantages over them, European explorers, missionaries, and Crown or Company officials were unlikely to rely on material standards to judge the level of development attained by other cultures or to compare overseas civilizations to Europe itself. Until at least the end of the seventeenth century, religious beliefs, or the Europeans’ certitude that they possessed vastly superior understandings of the transcendent world, predominated as the gauge by which other cultures and peoples were assessed and ranked. Additional cultural variables, such as the position and treatment of women, were frequently cited as evidence of advancement or savagery; and physical features, especially skin color, were sometimes emphasized in attempts to distinguish and rank the peoples encountered overseas.

Scientific and technological gauges of past attainments and present abilities remained peripheral to most evaluations of the peoples and cultures that the Europeans encountered as they expanded across the globe. None the less, signs of material advancement – the existence of large cities, sophisticated techniques of fortress construction, or evidence of complex scientific instruments – were often noted and even cited to support arguments regarding the level of development achieved by different peoples. In two areas in particular, in the perception and measurement of time and in perspectives on space associated with artistic and mathematical advances of the Italian Renaissance, European overseas observers began to see a clear divide between the West and all other civilizations and cultures. In addition, as early as the sixteenth century, European commentators began to rank African cultures beneath those of Asia and the Americas, not so much because of skin color or other physical features, as has often been argued, but due to what was perceived as a markedly lower level of material culture in Africa than that found by European travelers and traders in India, China, or central Mexico.

Although ideologies justifying overseas expansion and the domination of non-European peoples from the fourteenth to the early eighteenth century were rooted in religious belief and were generally culture – rather than racially – oriented, material accomplishment, including the assumed capacity for invention and scientific thinking, was increasingly associated with racist defenses of the enslavement of Africans. Defenders of the slave trade sought to counter the abolitionists’ objections with often lurid descriptions of the alleged savagery of African life and the debased level of African material culture. Along with skin color and other physical differences, racist writers, such as Samuel Estwick and Dominique Lamiral, emphasized material backwardness and ignorance of the workings of the natural world as proof of the subhuman nature of Africans that justified their subjugation as slaves.

By the last decades of the eighteenth century, this rather broad association between racial ideology, material culture, and the defense of slavery was refined and enhanced by the rise of racist theories allegedly grounded in scientific experimentation and reasoning. Physicians and ethnologists devised a variety of measurements – from skull size and shape to genital configurations – in efforts to prove that there were innate physical, mental, and moral differences between human racial groups. The fact that the measurements reflected a priori assumptions and were based on small and suspect samples, and that even the racial categories themselves were hotly contested, did not prevent “scientific” racism from winning widespread support from European scientists, social commentators, and politicians throughout the nineteenth century. The tenets of scientific racism were popularized among the middle and working classes by practitioners of phrenology, whose booths could be found at county fairs and on the promenades of seaside resort towns, and by the pulp press, where allegedly scientific proofs of European racial superiority were linked to social evolutionist arguments for imperialist expansion.

By the first decades of the nineteenth century, scientific and technological gauges of human achievement and worth were clearly in the ascendant. Earlier measures of the level of development achieved by different cultures continued to be cited. Religious belief, for example, remained of paramount importance to missionaries active in overseas lands. But even missionaries increasingly linked Europe’s advances in the sciences and invention to the rhetoric of Christian proselytization. Ignoring past and contemporary tensions between science and religion in Europe itself, prominent missionaries, such as the Abbé Boilat and David Livingstone, argued that Christian culture had been particularly receptive to scientific investigation and technological innovation, and that conversion to Christianity would promote the scientific and material development of colonized peoples. The growing numbers of ethnologists and professionally trained anthropologists, who found in the colonies relatively safe and fertile environments for their research, also privileged nonscientific or non-technological standards, such as modes of political organization or gender relations, in assessing the level of development attained by African, Asian, Amerindian, and Pacific Island peoples. But evidence of material culture was increasingly linked to societal advance, and indigenous “superstitions,” or at best magical beliefs, contrasted with the scientific mindset that was seen as typical of the educated West.

A number of factors account for the dominance of material standards, particularly those linked to science and technological innovation, in nineteenth-century ideologies of European global hegemony. Most critically, the transformations wrought by industrialization from the middle of the eighteenth century in England and somewhat later in Belgium, Germany, France, and Italy made the gap in scientific and technological capacity and material development between western Europe and non-Western societies increasingly apparent to European and non-European observers alike. Maxim guns, steamboats, and railway lines carried elements of Europe's industrialization to colonized areas, and champions of imperialist expansion reasoned that these wonders could not help but impress subjugated peoples with the unprecedented degree to which European societies had advanced over their own. Not only did European superiority in science and technology seem obvious, but also it could be empirically tested in ways that claims of higher religious understanding or moral probity could not. Europeans had vastly more firepower, could produce incomparably greater quantities of goods much more rapidly, and could move both these products and themselves about the globe with much greater speed and comfort than any other people, including the once highly touted Chinese. In an age when what were held to be scientific proofs were authoritative, attainments that could be measured statistically were viewed as the most reliable gauges of human ability and social development. Mechanical principles and mathematical propositions could be tested; cast iron or steel bridge spans could be compared for size and strength with the stone or wooden structures of non-Western societies; and human skulls could be quantified in seemingly infinite ways to assess the highly variable mental capacity of the "races of man."

The preeminence gained in the nineteenth century by scientific and technological standards of human worth and ability not only bolstered proponents of theories of European racial supremacy, but it also proved vital to various formulations of the civilizing mission ideology that both inspired and rationalized European imperialist expansion from the early 1800s to 1914. Chauvinistic politicians in the metropoles and imperial proconsuls in the colonies increasingly stressed the importance of the diffusion of Western science and technology to what they viewed as the benighted peoples and backward lands that had come under European control. Proponents of the civilizing mission confidently predicted that the world would be remade in the image of industrializing Europe. Given Europe's material advancement, it was seen as appropriate that Europe and North America serve as the sources of capital, both machine and financial; of entrepreneurial, scientific, and managerial expertise; and of manufactured goods for the rest of the globe. In this view, the non-Western world, including both areas that had been formally colonized and those that had come under the informal sway of the Great Powers, were best suited to provide abundant and cheap land, labor, and raw materials that were required to fuel the industrial economies of Europe and North America.

According to the "improvers" or nonracist advocates of the civilizing mission, the spread of Western education among colonized peoples – emphasizing the inculcation of at least rudimentary Western scientific learning and technological skills – would provide the critical means by which the material level of non-Western societies would gradually be raised. Though they approved of the diffusion of essential Western technology to overseas areas under the paternalist supervision of European colonizers, racist apologists for imperialism had little faith in the ability of subjugated peoples to master the sciences or engineering of the West. Thus, they envisioned the period of European "tutelage" extending for centuries, if not indefinitely, into the future.

The non-Western peoples who were the targets of the European colonial enterprise were very often awed and overwhelmed by their initial encounters with the science and technology of the industrializing West. Whether they were indigenous leaders resisting the growing encroachments of European forces or scribes and merchants who allied themselves with the invaders, the colonized could not help but be impressed with the clear and increasing advantages in power that the Europeans gained through their superior capacity to tap the resources of the natural world, to produce material goods, and to devise more deadly weapons. As surveys taken as late as the post-World War II era, such as those which form the basis for G. Jahoda's *White Man*, the science and technology of the colonizers gave them an aura of magical power among the colonized masses in many areas. Though Western-educated Africans, Asians, or Polynesians were likely to scoff at such expressions of popular admiration, most came to accept that Western science and technology were not only on the whole superior to their own but essential for the future "development" of societies they hoped someday to rule. Therefore, nationalist critiques of imperial domination often deplored the fact that colonialism had severely constricted the flow of science and technology from the West to dominated areas, and demanded that technical education and scientific facilities for indigenous peoples be expanded and improved.

By the last decades of the nineteenth century, however, a number of influential African, Asian, and Caribbean thinkers were mounting cogent challenges both to notions of European racial superiority based on evidence of scientific and technological achievement and to the advisability of the wholesale transformation of non-Western cultures and societies along Western, industrial lines. Much of this resistance to the hegemonic ideologies of the Western colonizers focused on efforts to reassert and revitalize indigenous epistemologies, modes of social organization, and approaches to the natural world. Thinkers such as Vivekananda and Aurobindo Ghosh contrasted an Indian spiritualism with the deadening abstractions of Western materialism. African writers, such as the Caribbean-born Edward Blyden, deplored the devastating impact of the Atlantic slave trade on African cultures and celebrated the Africans' strong sense of community, reverence for and care of the elderly, and sophisticated artistic creations.

Ironically, these defenses of colonized cultures were buttressed by contemporary European anthropological studies, usually carried out under the auspices of colonial administrations; by the intense interest in "Oriental" religions fashionable among European intellectuals in the decades before World War I; and by the "discovery" of the abstract power of African masks and other forms of "primitive" artistic expression by Picasso, Derain, Matisse, and other avant-garde artists in the early 1900s. Inadvertently, however, the works of these first generations of Indian and African critics of European hegemonic ideologies often validated the very materialistic standards they sought to contest. For example, Indian thinkers, particularly Vivekananda, repeatedly stressed the scientific accomplishments of India's ancient civilizations, while African and West Indian writers, most notably Anetor Firmin, claimed Egypt, with its impressive engineering and architectural feats, as a civilization that black Africans had done much to build.

With the coming of the First World War, non-Western critics of what had been characterized as the excessively rationalistic, impersonal, and materialistic West found numerous, and highly vocal, European intellectual allies. The horrific trench slaughter on the Western Front and the multitude of ways that Western scientific knowledge and experimentation were harnessed to the war effort as a whole raised profound doubts for noted thinkers, such as Paul Valery, Sigmund Freud, and Georges Duhamel, about the long-assumed progressive nature of Western science and technology.

After such a savage and suicidal war, the tenets of the civilizing mission rang hollow, and "scientific" racist thought came under increasing assault in both western Europe and the United States. Collaboration with indigenous elites was increasingly stressed in the governance of the colonies, and a rhetoric of science and technology as agents of development through cooperation with indigenous peoples permeated colonial policy making.

European doubts about the directions taken by the industrial West and its global hegemony gave new impetus to African, Asian, and Caribbean critiques of European global hegemony. René Maran's *Prix Goncourt*-winning novel, *Batouala*, mocked the pretensions of racial superiority held by European colonizers, and idealized village life in French West Africa. The poets of the *négritude* movement, most powerfully L. S. Senghor and Aimé Césaire, mourned the suffering and destruction wrought by European science and technology in Africa and the lands of the slave diaspora, and inverted racist epithets by exulting blackness, intuition, affinity for the natural world, and indifference to inventiveness. Aurobindo Ghosh and Rabindranath Tagore viewed the war as the fulfillment of earlier Indian prophecies of a coming cataclysm in the aggressive and materialist West, and proof of importance of India's spiritual mission in the modern age. Mohandas Gandhi also cited the senseless violence and colossal destructiveness of the war in support of his sweeping assaults on industrial society. In the decades after the war, he sought to formulate for India (and implicitly for other colonized areas) a community-centered, low tech, and conservationist alternative to industrialized society as it had developed in the West. In this same period, Gandhi also worked out a strategy for confrontational but nonviolent protest that repeatedly proved an effective antidote to the advanced technologies of repression employed by Western overlords in the decades of decolonization from the 1920s onward.

Though battered and under assault, the scientific and technological underpinnings of ideologies of Western dominance survived the crisis of two global wars and the powerful critiques of Gandhi and the *négritude* writers largely due to the emergence of the United States as *the* global power from the 1920s onward. Entering the First World War late and just when new technologies had restored a war of motion and decision, Americans continued their long-standing infatuation with science and technology after the conflict. Faith in the essentially progressive nature and beneficence of science and technology informed the development (later called *modernization*) theory that came to dominate both American thinking on colonial issues and that of the European and Japanese imperialist rivals of the United States. After World War II, America's chief rival, the Soviet Union, also championed a rhetoric of development that privileged science and large-scale industrialization. With modernization theory (in a number of capitalist and socialist versions) in the ascendant, non-Western alternatives to social development and economic well-being, such as that formulated by Mohandas Gandhi, were marginalized or openly spurned by the Western-educated elites that governed the new states that emerged from the collapsing colonial empires. Though alternative approaches have gained significant support in some of these new nations, most notably India and Tanzania, international agencies and Western and non-Western planners continue to rely upon modernization schemes, based overwhelmingly on Western precedents, to solve the problems of poverty and growing wealth differentials and the demographic and environmental dilemmas that have been building on a global basis for centuries.

See also: ►Magic and Science, ►Colonialism and Science, ►Science as a Western Phenomenon, ►East and West, ►Technology and Culture

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Windpower

Richard L. Hills

There is little doubt that the first practical use of the wind as an energy source other than as the motive power for sailing ships occurred in the East. Those of Persia were probably the first but precisely when is uncertain. According to a story of al-Ṭabarī, writing around AD 850, and later writers, the second orthodox Caliph, Umar ibn al-Khaṭṭāb, was murdered in AD 644 by a captured Persian technician, Abū Lu'lu'a, who claimed to be able to construct mills driven by the power of the wind and was bitter about the taxes he had to pay. This early date cannot be confirmed but Arabic geographers of the tenth century all confirm the existence of windmills in the region of Seistan in north eastern Iran. For example, al-Masᶜūdī around AD 950 wrote of the wind driving mills and raising water from streams.

Nothing has survived to show how such mills pumped water but later drawings of one type of windmill suggest that it could have been derived from horizontal corn-grinding watermills. In the lower part of such watermills, the water fell down a chute and struck blades placed radially around a vertical shaft. The top of the shaft passed into a higher room and carried the upper millstone and so rotated it above the bedstone which was set on a floor in the middle of the mill. When developed into a windmill, the wind rotor was situated in the bottom of the mill. The building was constructed with four "loop holes" to direct the wind on to the blades from whichever quarter the wind might be coming. There might be eight or ten blades, and the wind was directed by the loop holes onto one side of the rotor. In this way the sails were pushed round on that side away from the direction of the wind while those advancing into the wind on the other side were shielded by the walls around the loop holes. The grinding stones were placed in an upper room with the upper stone turned by an extension of the rotor shaft in the "underdrift" manner. None of these mills has survived.

The type which may still be in use today had the grinding stones situated in a room below the rotor with the sails above. This necessitated a change to the "overdrift" method of driving the stones where the spindle passed down through the bedstone to a bearing underneath, which had to support the weight of both the upper stone and the sails. It was possible to disconnect the driving shaft at the place where it was connected to the upper stone at the "rynd" to allow for the stones being separated for dressing. The layout for grinding was similar to other corn mills with a hopper mounted on the wall from which the grain was fed into the central hole of the upper stone through a chute or shoe while the flour was passed out around the circumference of the stones.

The advantage of this second layout was that the rotors with the sails could be greatly enlarged. Mills near Seistan and on the borders of Iran and Afghanistan might have rotors approximately 5 m (16.4 ft) high by 3 m (9.8 ft) in diameter. There could be six or eight sails which had wooden framing that was interlaced with straw or covered with wooden boards. The upper parts of these mills were built with one wall that directed the wind on to one side of the rotor while another wall shielded the other half. Sometimes matting screens were erected to help channel the winds to the sails. There were no brakes, but more screens might be placed across the slots between the walls to regulate the wind reaching the sails; to secure the mill when out of use, the rotor and upper millstone were lowered to rest on the bedstone. A wind speed of 22.40 m s^{-1} (50 mph) was needed to drive these mills at only 30 rpm. Such a mill, working with intermittent wind for about four months of the year, would grind enough flour for about 15 families. Seistan was known as the land of the winds and between mid-June to mid-October the wind regularly blew from the north for a period of 120 days.

The mills were built in line to face these winds and the famous example at Neh had a long row of 75 mills.

Because these horizontal mills needed such strong and regular winds to power them, they did not spread in this form much beyond the borders of Iran and Afghanistan. They were invented earlier than the Western vertical type but it is doubtful whether there is any connection between the two. Those in the West, which have been described as the “full admission, axial flow type,” first appeared around AD 1150 possibly either in the southeast of England, the northwest of France, or Flanders. However these Persian mills were probably the source of the later Chinese mills and possibly the Tibetan wind-powered prayer wheels.

The wind-powered Tibetan prayer wheels were not surrounded by elaborate buildings to guide the wind onto the rotors. The most common form had a vertical axle with horizontal spokes at its top, on the ends of which were fixed sails shaped like cups so that they caught the wind on one side of the rotor, but were smoothed or curved to present less resistance on the other. The wind would be caught in the concave part of the cup, or a curved sheet, during half the circle to turn the rotor, while in the other half, the convex or streamlined side would be advancing into the wind and so present less resistance. Power output was minimal but was sufficient to turn the prayer wheels which was the only use to which they were applied.

Prayer cylinders designed for automatic repetition of the Buddhist mantra are unlikely to have been produced before the reign of K’ri-srong-Ide-brtsan in AD 755 to 797 when Buddhism conquered Tibet. It is unlikely that such cylinders were turned by the wind at this period, although no doubt there were prayer flags fluttering in the wind from around this time. Early in the twelfth century, a new fashion for mechanical piety swept China, but again it seems doubtful whether this included wind-powered prayer wheels, which must therefore be placed later, and certainly therefore after the Persian mills.

More is known about the adoption of the windmill in China. Once again early dates for this have been suggested, but these are doubtful. In about AD 1230, Yelu Chu Zai was captured by Jinghi Khan and became his minister. He was an extremely good scholar, administrator and mathematician. An accurate description of the Persian windmill has been discovered in his memoirs, with a comment on how good it would be if the Chinese used it. A Chinese book of the seventeenth century, the *Zhu Qi Tu Shu*, describes the windmill as if it were a European invention, which could be a mistake for Persia. In China, these mills were used for raising water and evolved into an entirely different form from the ones in Persia or Tibet.

Chinese horizontal windmills are still used today along the eastern sea coast north of the Yangtze and in the region of Thangku and Taku near Tientsin to operate chain pumps through gearing for raising salt water for salt pans or fresh water for irrigation. Once again they have no elaborate structures for directing the wind onto the rotors but are closely linked to the way the sails of junks operate. Canvas-covered sails are mounted at the ends of radial arms, each with its own mast, in such a way that they can be spread to catch the wind on the side of the rotor turning away from the wind and be feathered to present the least resistance on the side turning against the wind. The sails can pivot on these masts, and, as on a junk, the sail extends to the front of the mast. The longer, or driving, side of the sail is tied to the rotor framework by a piece of rope of such a length that, when the sail is turning with the wind, it is held into the wind, but can rotate out of the wind when advancing against the wind. The angle of the sail can be set by the length of rope to a position in which the wind can do useful work on it for more than 180°.

These mills must have been the most efficient of the horizontal types developed before the twentieth century, but all horizontal windmills suffer from the same problem, that only a small part of the wind rotor can be used to its maximum efficiency at any time. The theoretical maximum power coefficient for a simple horizontal windmill is only one third, but in practice it will be much less. These are the reasons why the horizontal windmill has not been developed further and few examples remain at work today.

In the eastern Mediterranean, at some period during the Middle Ages, vertical windmills appeared with a different type of sails from those normally used in the West. The horizontal wind shaft was extended in front of the mill like a ship’s bowsprit so that ropes from it could help to stay six or eight radiating spars. The sails were triangular pieces of canvas like the sails of a modern yacht and worked in the same way. The leading edge of each sail was attached to the spar, round which it could be wrapped to reef it in strong winds. The free corner was secured by a rope in much the same way as a ship’s boom. These sails were much lighter than those of a conventional western windmill and have found a new application in water pumping mills in some developing countries today.

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Wine in Anatolia

Alexia Smith

The quest for the earliest evidence of viniculture has led many scholars to Transcaucasia and Anatolia, the latter of which spans the Asian portion of modern-day Turkey and derives its name from the Greek for "Land of the Rising Sun". It is not known precisely when viniculture (the cultivation of grapes for wine) or viticulture (cultivation of the vine) as were first practiced, but both were well established in Southwest Asia by the beginning of the third millennium BCE. Several lines of evidence have provided insight into early wine production, including textual accounts, archaeological data such as drinking vessels, chemical analyses of residues within vessels, and ancient plant (archaeobotanical) data, as well as modern biogeographical observations.

The modern distribution of wild grapes is useful for demarcating the area within which grape domestication could have occurred in the past. Today, wild grape (*Vitis vinifera* L. subsp. *sylvestris* [C.C. Gmelin] Berger), is found as a forest climber along the coastal regions of central and southern Europe, areas surrounding the Black Sea, and the southern reaches of the Caspian Sea, with isolated patches growing in Turkmenistan and Tadzhikistan. Anatolia clearly falls within this natural range.

Archaeobotanical remains provide more detailed information. (See Agriculture: Ancient Methods of Agriculture by Alexia Smith in this volume for a more detailed description of archaeobotanical remains and their recovery.) In general, wild berries are smaller and more acidic than their domesticated counterparts. While entire grape berries can be found, archaeobotanists most typically encounter charred pips which tend to become shorter and rounder following domestication. In practice, however, distinguishing between wild and domesticated grape pips is challenging, since considerable overlap in their shape and size exists. Consequently, determining the precise point in time when grapes became domesticated is difficult. What is clear from the archaeobotanical record is that wild grapes have been collected for millennia to be eaten fresh or dried. Fermentation of grapes into wine requires fruit with a minimum sugar content of 10% and the presence of the principal wine yeast, *Saccharomyces cerevisiae,* which naturally occurs on grape skins. Experiments with wine making may have taken place as early as the Neolithic period (ca. 10,500–5500 BCE), well before viticulture developed as a specialized venture. Some of the earliest grape finds come from Öküzini Cave in southwest Anatolia, and date to the Late Palaeolithic (16,000–10,500 BCE). Grapes also appear consistently during the Neolithic and Chalcolithic (5500–3000 BCE) periods at sites such as Can Hasan III, Çayönü, and Korucutepe. From the Chalcolithic to the Early Bronze Age (ca. 3000–2000 BCE), a rapid increase in the presence of grapes at sites such as Kurban Höyük in southern Anatolia reflects the growth of viniculture.

Changes in the range of Early Bronze Age pottery vessels are also linked with an intensification or expansion of viniculture. At this time chalices and other forms associated with drinking such as the *depas amphikypellon* (a tall, narrow, two-handled tankard) began to increase in number. Other drinking vessels associated with wine include *rhyta* (sing. *rhyton*), which were fashioned out of metal or ceramics in the form of an animal's head. Storage vessels include amphorae[1] and large pithoi[2]. At sites such as Boğazköy and Alişar Höyük, containers fashioned after a cluster of grapes have been found. The association of vessels with wine can be affirmed using infrared spectroscopy through the detection of tartaric acid, a compound that occurs naturally in grapes and forms the primary acid within wine. Tartaric acid was detected in a large ceramic tub found in Early Bronze Age levels at Titriş Höyük in southeastern Anatolia, linking it with activities such as grape pressing.

Early texts written in Assyrian dating to the Old Assyrian Colony Age (ca. 2000–1750 BCE, corresponding with the Middle Bronze Age) and the Hittite period (ca. 1600–1200 BCE, Late Bronze Age) have been synthesized by Ronald Gorny and provide additional insights into early wine production. Texts from Cappadocian trading colonies refer to the months of September and October as *qitip karānim,* the "harvesting of grapes" season. Grape harvesting festivals are also mentioned in Hittite texts (EZEN ^{GIŠ}GEŠTIN *túh-šu-u-wa-aš*). In Hittite, grapes or grapevines were called *wiyana* (which features in the etymology of the word "wine") and are represented in texts with the Sumerogram ^{GIŠ}GEŠTIN. The official position of "GAL.GEŠTIN" is mentioned in the *Palace Chronicle,* an Old Hittite text that documents the court during the reigns of Hattušili I and Muršili I. The early responsibilities of GAL.GEšTIN included supervision of vineyards and their products, which underscores the importance of vineyards as an elite enterprise. Since the majority of the texts document political, economic, and

[1] An amphora is a jar, usually made of clay, with a narrow neck and two handles, used by ancient Greeks and Romans for holding oil or wine.

[2] Pithoi were large ceramic storage jars, mainly used for storing agricultural produce such as olive oil, wine, olives, raisins or grain. Such large jars must have been made in several sections and joined together before firing.

religious matters, bias in the records exists, and little is known about grape production or wine consumption among the general populace. It seems fair to link early viniculture with the elite, however. Since grape vines require a number of years to become established and yield fruits, only people of means could make such a commitment outside of a garden setting. Alexander Joffe even argues that production of alcoholic beverages may be linked to the rise of the state by allowing emerging elites to increase their level of power through surplus production and control over craft production.

A number of Hittite laws pertaining to viniculture bear testimony to well established practices and likely reflect concerns of earlier time periods. The laws clearly outline relative worth of various commodities and assign appropriate penalties for theft or damages to property. Damage to a vineyard is covered by Law 113, whereby the guilty party must take the damaged grapes and provide grapes from their own vines. Penalties for theft are discussed in Law 101 and combine monetary compensation with corporal punishment involving a spear. Over time corporal punishment was stricken from the law and the fine increased from one shekel per vine to six shekels for a free individual and three shekels for a slave. One Hittite shekel is roughly equivalent to 12.5g of silver and could purchase 2 *parīsu* of wine, 3 *parīsu* of emmer wheat, 6 *parīsu* of barley, or 160 shekels of copper. Each *parīsu* is believed to correspond with 30 liters.

While wine was undoubtedly valued as a pleasing beverage, its earliest uses were restricted to Hittite rituals, festivals, and religious ceremonies, which in general were conducted to gain favor of the gods with respect to the particular issue or problem at hand. Offerings of wine to the gods are mentioned in several Hittite prayers, including the *Prayer to Tešub of Kummani,* the *Prayer to the Sungoddess of the Underworld,* and the *Prayer of Muwatalli to the Stormgod Piḫašašši*. A number of myths, such as the *Ašertu Myth* and the Myth of the Serpent Illuyanka, discuss the inebriating power of wine and the potential dangers of becoming intoxicated. The cleansing nature of wine is stressed in several medical rituals, and similarly in rituals intended to purify land and prepare ground for the founding of a new palace. Soldiers also used wine as a metaphor for blood during an oath pledging ritual intended to secure their loyalty.

The association of wine with ritual and religious beliefs perpetuated for some time. During the Lydian period (687–546 BCE) in western Anatolia, Bacchus was celebrated as the god of wine. During Byzantine times in the early part of the first millennium A.D., wine was believed to be blessed by the sky-god; vineyards and stored wine afforded protection from evil spirits. Wine production decreased significantly following the conversion of Anatolia to Islam, although wine has continually been drunk. Today wine production is increasing again and grapes are widely cultivated in many parts of Turkey, including the Mediterranean coast and Central Anatolia.

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Winemaking and Viticulture in the Ancient Near East and Egypt

Virginia Badler

In the ancient Near East and Egypt the development of winemaking and viticulture has a discontinuous record due to the nature of both historical and archaeological evidence. Historical records include texts and pictorial evidence illustrating grapes, grape vines, wine production, and wine consumption. Tracing winemaking and viticulture to its more distant origins in prehistory is now possible through careful archaeological investigations and scientific and chemical analyses. A significant step toward understanding how scant prehistoric evidence could contribute to reconstructing the presence and manufacture of such a specific, delicate and liquid substance as wine emerged with the observation of stains on the interiors of certain pottery jars and the subsequent chemical analysis and identification of key components of these residues. Badler et al. (1990) pioneered chemical residue analysis (the identification of tartaric acid as a marker for grapes and wine) coupled with archaeological evidence to establish new data points in ancient winemaking history. Guasch-Jané et al. (2004) have further differentiated red from white wine by the presence of malvindin-glucoside and its unique by-product, syringic acid.

Prehistoric Wine and Ancient Viticulture

Because of extensive cultivation, crossbreeding, seed dispersion, and deliberate transplantation, it is difficult to determine by grape genetics alone the geographic origins of winemaking and viticulture. Probably they are located in the general area of the wild Eurasian grapevine (*Vitis vinifera sylvestris*) that presently grows from Spain to Lebanon, inland along the Danube and Rhine Rivers, around the Black Sea and southern Caspian Sea, at the headwaters of the Tigris and Euphrates Rivers, and farther east in Central Asia (McGovern 2003: 7). Winemaking preceded viticulture, as grape cultivation is not necessary to make wine – it can be made from the wild grapes that were plentiful in certain areas of the Near East. The development of winemaking could have followed a similar path as that of breadmaking and the cultivation of grains. The motivation for both grape and grain cultivation would have been to provide convenient local sources and a stable supply of raw materials for the end products. Viticulture, the purposeful cultivation of grape vines, would have also provided the opportunity to exercise more control over both grape quality and quantity. If there were no wild grapes in the area, a taste for wine imported from other regions would motivate the transplantation of grape vines to secure a local supply of the beverage.

If burnt or carbonized, grape pips (seeds) can be preserved for many centuries. However, it is difficult to determine whether these ancient grape pips are from wild or cultivated grapes, due to variations in the pips themselves and the shape changes that occur when they are carbonized. Carbonized grape pips have been found in many areas of the Near East and Egypt, dating to 3000 BCE or earlier: Susa and Hajji Firuz Tepe in Iran; Hama, Mureybit, Abu Hureyra, Aswad, Jawa, Tell esh-Shuna, Ohalo, Jericho, "En Besor and Bab edh-Dhra" in the Syro-Palestinian area; and Buto, Minshat Abu Omar, Tell Ibrahim Awad and Abydos in Egypt (McGovern 2003: 2, Map 2). Many of these areas (Egypt, most of the Syro-Palestinian region, and southern Iran) are now too arid to support the wild grape.

Neolithic Wine ca. 5400–5000 BCE: Hajji Firuz Tepe, Iran (►http://www.museum.upenn.edu/new/exhibits/online_exhibits/wine/wineneolithic.html)

Viticulture was likely first established in the Neolithic period (from about 8000 to 4000 BCE), when for the first time in human prehistory there were numerous sedentary villages established in the Near East and Egypt supported by domesticated plants (such as grains) and animals (such as sheep and goats). Fired ceramic vessels first made their appearance ca. 6000 BCE, and it is within these vessels that we can find chemical evidence for the earliest wine.

Hajji Firuz Tepe is located southwest of Lake Urmia in northern Iran, in the Zagros Mountains at an elevation of over 1,200 m above sea level, along the eastern periphery of the wild grapevine's modern distribution. Jars with yellowish and reddish interior residues have been analyzed, and both residues are that of resinated wine. The resin was from the terebinth tree (*Pistacia atlantica*) that grows throughout the Middle East and would have been added as a preservative (McGovern et al. 1996).

Late Chalcolithic Wine ca. 3500–2900 BCE: Godin Tepe, Iran

The chemical analysis of residues in jars from Godin Tepe established that the technique could be used to determine the existence of wine in prehistoric contexts (Badler et al. 1990; Badler 1995). Wine was found in a distinctive jar type (piriform, with rope decoration in an inverted U shape on opposite sides of the vessel) from two different contexts dating from 3500–3100 BCE and 3100–2900 BCE. The complete vessel from

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the later period has a bung hole a short distance from the base drilled after firing, presumably to decant the beverage.

The homeland of viticulture may be Transcaucasia (the region of modern Georgia, Armenia, and Azerbaiijan located between the Black Sea and the Caspian Sea). An early sixth-millennium BCE Shulaveris-Gora jar was shown to have contained resinated wine, making it the earliest known wine jar (McGovern 2003: 75). At Godin Tepe there is an intriguing link between winemaking and the appearance of the first Transcaucasian type pottery. The earliest sherd with wine residue dates from 3500–3100 BCE, when there are significant numbers of Late Uruk type artifacts suggesting contact with sites in southern Iraq (such as Nippur and Warka/Uruk) and Iran (Susa). However, the earliest evidence for wine production (a funnel, heavy lid and empty wine jars, as well as a bin perhaps used for treading grapes) date from 3100–2900 BCE, when there is a marked increase in the number of Transcaucasian type sherds. In fact, the funnel itself is similar to the Transcaucasian sherds in its method of manufacture (handmade and fired in a reduction atmosphere), and the heavy lid is a Transcaucasian pottery type.

Late Uruk Wine ca. 3500–3100 BCE – Susa, Iran and Warka/Uruk and Tello/Girsu, Iraq

The residues of ancient resinated wine have been detected in Late Uruk type jars (a droop spouted jar, a piriform jar, and a stone vessel with vertical rope decoration) from Susa in southern Iran (McGovern et al. 1997), a droop spouted jar from Warka/Uruk (Badler et al. 1996), and a droop spouted jar from Tello/Girsu in southern Iraq (McGovern et al. 1997). Since grapes will not grow in the hot dry climate of southern Iraq (there are no grape remains from this area), the wine was most likely an import from further north, and perhaps an important commodity in the Late Uruk trade network (Algaze 1995).

The Early History of Wine in Syro-Palestine and Egypt

Whereas the Near East looked north to Transcaucasia for the introduction of wine and winemaking, archaeological and clay pottery jar composition evidence clearly suggests that the origins of Egyptian wine and winemaking were to its east from the Levant: modern Israel, Palestine, and Jordan (McGovern 2003: 85–103). Hundreds of jars containing chemically attested wine and wine yeasts were found in tomb U-j of the first Scorpion king (Dynasty 0) dated by radiocarbon determination to ca. 3150 BCE. The closest stylistic parallels to these jars are from Early Bronze I sites in the Levant, later confirmed by additional scientific analyses. Although the wild grapevine does not grow there today, it flourished in the region in ancient times, beginning in the Epi-Paleolithic period nearly 20,000 years ago (McGovern 2003: 212). By at least 3500 BCE, the domesticated grapevine (*Vitis vinifera vinifera*) had taken hold in the region. Very little archaeological or chemical evidence for winemaking has been found so far, although small spouted Iron Age vats could have been used to tread the grapes.

Although there was a royal winemaking industry in the Nile Delta region from as early as Dynasty 3 (ca. 2700 BCE), the wild grape never grew in ancient Egypt. It seems most likely that both the grape vines and the technology for making wine were imported from the Levant. The earliest "wine labels" in the world belong to Dynasties 1 and 2 of the Early Dynastic period (ca. 3100 – 2700 BCE), and show an already well developed viticulture tradition (McGovern 2003: 85ff.).

Once local viticulture and winemaking were established in the Nile Delta, it became a source for royal wine. When there were disruptions, however, such as the Hyksos invasion (ca. 1670–1550 BCE), wine was again imported in large quantities from the Levant and, in particular, Southern Palestine. Exceptionally large quantities of wine were imported into the Hyksos capital of Tell el-Dab'a/Avaris located in the east Delta region of Egypt. The Egyptian winemaking industry rebounded (as evidenced by increasing quantities of native Egyptian wine jars) beginning in the earliest Middle Bronze IIA phases (ca. 1950 BCE) at Avaris. There is evidence that the Egyptian Delta supplied the New Kingdom towns and cities at that time. Avaris also has the only excavated winemaking installation in Egypt, predating Hellenistic times (McGovern 2003: 119). Detailed tomb paintings provide additional evidence for the Egyptian wine industry, from picking and crushing the grapes to filling the jars (the tomb of Nakht at Thebes [1550–1295 BCE]), the addition of additives and stoppering (the tomb of Khaemweset, son of Ramesses II [1279–1213 BCE], at Thebes), and a sequence of grape picking, crushing, pressing, and wine storage (tomb of Intef, Royal Herald under Thutmosis III [1479–1425 BCE], also at Thebes). Chemical analysis of the residues in the wine jars from the tomb of Tutankhamun (d.1327 BCE) established that this wine was made from red grapes (Guasch-Jané et al. 2004).

Wine in the Ancient Near East

There are chemically identified ancient resinated wine residues in a small jar from Warka/Uruk dating to the late Jemdet Nasr/early Early Dynastic period (beginning of the third millennium BCE; McGovern et al.

1997). In the early third millennium BCE, there are grape pips and even grapevine wood identified from the site of Tepe Malyan (ancient Anshan) in the Shiraz region of the southern Zagros mountains (McGovern 2003: 165). Elamite seals depict drinking scenes (most likely of wine) under grape arbors (McGovern 2003: 165–166). Texts from the city of Ur mention a jar full of *geštin* (the Sumerian word for wine). At Tello/Girsu, *geštin* was stored in rooms, and *geštin* was imported from the eastern (presumably the southern Zagros) mountains. Texts mention grapevines growing within walled gardens in and around the region of the city of Tello/Girsu by the end of the third millennium BCE (McGovern 2003: 150). The law code of the Babylonian king Hammurapi, dating to ca. 1790 BCE, mentions wine shops. There are detailed accounts of the wine trade (with cities further north) in the archives of the Syrian city of Mari, located along the Middle Euphrates, and dated to ca. 1750 BCE when the city was destroyed by King Hammurapi, and in the archives of the eighteenth century BCE site of Tell al-Rimah/Karana'a in upper Mesopotamia (McGovern 2003: 169–173).

In the first millennium BCE, the Assyrian rulers not only consumed large quantities of wine, but also undertook an ambitious program of planting new vineyards in their territories. The "Assyrian Doomsday Book" recorded tens of thousands of vines planted in the upper Balikh River to the east of Carchemish, in the eastern part of their territory at Yaluna, probably northeast of Nineveh, and in the land of Zamua in the district of Sulaymanyah. The Assyrians produced wine described as sweet, good, aged, or strong, and in both red and white varieties. Additionally, some wines were spiked with other ingredients (McGovern 2003: 190–191). The Nimrud wine lists contain detailed accounts of the distribution of wine rations. In a wall relief of the palace at Nineveh, Assurbanipal and his wife are shown beneath a grapevine bower drinking what is probably wine, similar to the Elamite scene mentioned above. Chemical analysis of residues from a bronze drinking cup from Nineveh, a bronze goblet and pottery "beer jug" with built-in strainer spout, from Uruk (all from seventh to sixth century BCE tombs) tested positive for resinated wine (McGovern 2003: 201).

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Woodcarving in Malay Architecture

Ismail Said

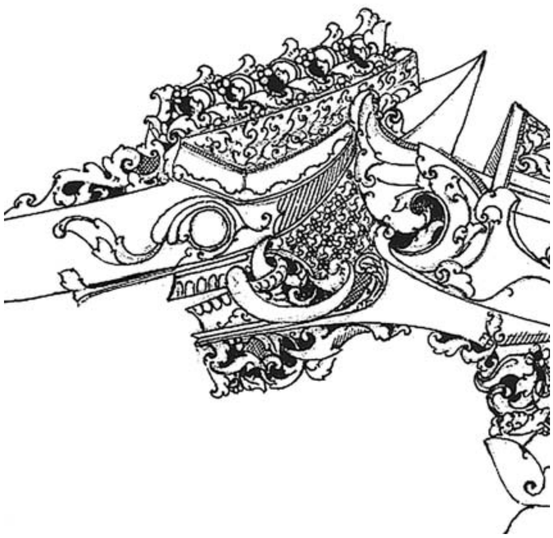
Meaning and Significance

Malay vernacular architecture is characterized by timber as the main building material, pitched roofs and woodcarving on some of the building components. As early as the fourteenth century, woodcarving was a significant craft in the vernacular architecture practiced by Malay craftsmen in Peninsular Malaysia and Southern Thailand (Ismail and Ahmad 2001). Palaces, houses, mosques, gateways, tombs, and *wakafs* (pavilions) are adorned with more than 20 types of carved components (Ismail 2002). The craft is an abstract manifestation of craftsmen's ideas into architectural timber components, symbolizing artistic expression into three architectural components: structural, elemental, and decorative (Ismail 2002). The craftsmen or woodcarvers depict five types of motifs, in order of importance: floral, geometric, calligraphy, fauna, and cosmic. These motifs are laid in six geometrical or floral shapes including oblong, square, circle, octagonal flora, semicircle and triangle. In definition, woodcarving is an art of partially removing wood from a board, a block or a plank following specific motifs, patterns, and orders. The art originated from two fronts: the kingdom of Langkasuka from the north, and the Srivijaya empire from the south of the peninsula (Nik Rashidin 1999; Nik Hassan and Nik Abdul Rahman 1998). In historical and geographical contexts, Malay timber architecture and carving in peninsular Malaysia stretches from the north in the province of Pattani in Southern Thailand to the south in the state of Johor.

Similar floral, geometric, fauna, and calligraphic motifs appear on nonarchitectural components such as boats, weapons, furniture, grave-markers (Fig. 1), house utensils, and musical instruments. The most elaborate carving on a boat is the *makara* carved in relief and perforated styles depicting mostly flora and sometimes figurine motifs. The hilts of kris (Fig. 2), *badek* (small dagger), and spears are some of the weapons that are intricately carved on timber such as *kemuning* (*Murraya paniculatum*), *leban* (*Vitex pubescens*), *sena* (*Pterocarpus indicus*), or *nibong* (*Oncosperma tigillarium*). The craftsmen also showed their ideas and skills on more than 15 types of furniture and house utensils.

In carving Malay craftsmen demonstrated high skills of art changing abstract ideas into physical beauty. This developed through a long apprenticeship whereby the skills and knowledge of woodcarving were passed on. By imitating a carved masterpiece, a woodcarver gradually modified the motifs and produced his own design onto the timber piece. For example, a motif of leaves and buds of *ketumbit* or *getamguri* (two shrubs) are gradually modified by the carvers to demonstrate their own stylish identity called *air-tangan*, but they keep the fundamental motif form (Nik Rashiddin 1999). This pattern becomes the trademark, both for the craver and

Woodcarving in Malay Architecture. Fig. 1 A grave marker (Nik Rashiddin 2003).



Woodcarving in Malay Architecture. Fig. 2 A kris hilt (Nik Rashiddin 2003).

for his architecture or craft. Differences in motifs, layouts and perforations occur from one region to another. For example, craftsmen in the northeastern states of Kelantan and Terengganu depicted different floral motifs from the central states of Negeri Sembilan and Melaka. The motifs of woodcarving signify the identity of the carvers in a region. In spite of the differences, Malay craftsmen observed three common aspects: (a) applying four principal design forms, (b) deducing motifs from home landscape elements, particularly flora and fauna, and (c) manifesting natural beauty as a devotional act to the Creator and as a gift to his fellow men (Mohd Taib 1997).

The degree of complexity in carving varies from one component to another; intricate, or complex ones include door leaves and wall panels, and simple carvings include gable board and fascia board. From the carving characteristics including motifs and types of perforation and incision, one could differentiate the architecture of one state from another. For example, a large gable board distinguishes a Terengganu house, whereas a large-latticed gable portrays a Perak house. As one gets closer to the carved components, the distinction is further distinguished by the composition of the motifs. The elevation of the Terengganu house is adorned with perforated wall and ventilation panels of varying sizes carved in floral motifs: leaves, tendrils, and flowers of local plants such as *ketumbit, getamguri, keraknasi, jari buaya,* and *bakawali* (Ismail 2000; Ismail and Ahmad 2001). The panels of Perak houses are carved in different floral motifs including sunflowers and *ketola*, sometimes mixed with cosmic motifs. These are regionally specific motifs found in Malay woodcarvings in Peninsular Malaysia. However, similarities occur in depicting geometrical motifs on veranda railings or tall window and fascia boards. Likewise, similar Arabic calligraphy motifs are depicted on door and window ventilation panels.

Architectural Components

Carved building components can be categorized into three types: structural, elemental and ornamental. The structural components include *pemeleh* (bargeboard), *tunjuk langit* (king post), cross beams, stringers of stairs and braces. The *pemeleh* is the most prominent component in palaces, aristocratic houses and mosques in the state of Terengganu and in Kelantan. These differentiate the vernacular architecture of this region from other states in peninsular Malaysia. For example, a palace known as tele house, built by Sultan Zainal Abidin in 1868 in the city of Kuala Terengganu, Terengganu, has two pairs of pemelehs, one at the *rumah ibu* (main building) and the other at the *rumah tengah* (subsidiary building). Likewise, Langgar Mosque in the city of Kota Bharu, Kelantan, also has two pairs of elegant pemelehs with a simple motif of barking deer on its three-tiered roof (Marsiti 1976). This exterior component handsomely extends the profile of the building toward the sky, making the mosque a landmark in the settlement.

The next important structural carved component in a house or a mosque is the *tunjuk langit* (kingpost). It supports the roof by holding the ridge beam and rafters. The Kampong Laut mosque in Kota Bharu has eight carved tunjuk langits (Zahar 1989). This timber mosque is perhaps the oldest timber mosque, perhaps 170 years old, in Peninsular Malaysia (Ismail 2001). The tunjuk langit distributes the roof load to the tie beams. The lower end usually is attached with a carved component called *buah buton*. This is an ornamental piece which covers the tenon and mortise joint of the *tunjuk langit* to the tie beam. In contrast, the Telok Manok mosque in Southern Thailand has three tunjuk langits, joining the three-tiered roof to the tie beam one above another (Ahmad 1998) (see Fig. 3). They are beautifully carved with lotus blossom motifs and their ends are equipped with *buah butons* using similar motifs. The tunjuk langits and buah butons greatly enhance the beauty of the interior. Apart from the tunjuk langit as a structural member distributing the roof load to the tie beams, braces, or brackets are also structural components supporting the tie beam load to the post. In the Kampong Laut mosque, braces are elaborately carved in shallow relief with lotus blossoms as centerpieces framed by leaves of a different plant in an intricate arabesque.

There are at least five carved elemental components in Malay houses and mosques. These are essential components that make up the entrances and fenestrations. They are the ventilation panels of doors or windows, door or window leaves, walls, railings and

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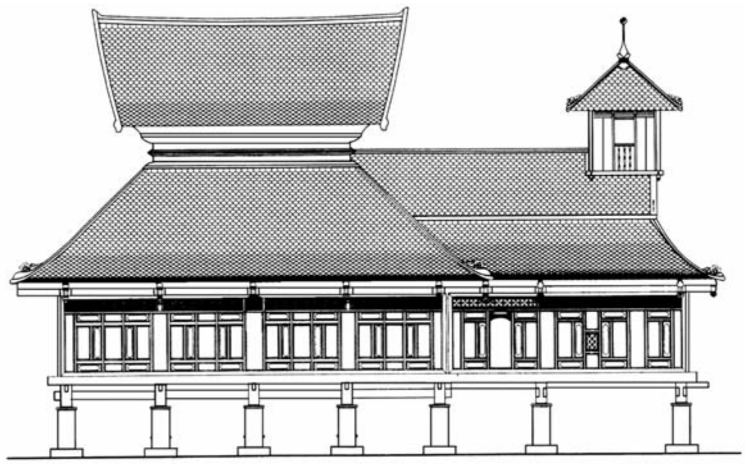


Woodcarving in Malay Architecture. Fig. 3 Elevation of the Telok Manok mosque in Southern Thailand illustrating the carved components (KALAM, Universiti Teknologi Malaysia 1998).

gates. Ventilation panels characterize the architecture of a region. For example, the Tengku Long palace in Kuala Terengganu has 15 tall windows at its *rumah ibu*, the main house, with perforated ventilation panels (Fig. 4a,b). Each panel was designed with different floral motifs in symmetrical and asymmetrical layouts. They are part of the fenestration of the building, allowing air and light in. These perforated boards are placed on top of doors, windows, or walls allowing circulation of air and light into the building. More elaborate motifs, a combination of Quranic calligraphy bordered by floral motifs, are carved for interior door ventilation panels as can be seen in Fig. 5a.

Some ventilation panels are carved in simpler forms, as in the Telok Manok mosque (Fig. 6). A floral motif of a weed called *ketumbit* is abundantly carved on the ventilation panels which are located around the building and are placed above the walls, windows and doors. The carvings transformed tender leaves of *ketumbit* into an arabesque form both in relief and perforated styles. The perforations not only allow air to flow into the building but also permit light to illuminate the interior. This is often dark because the interior is covered by the pyramidal roof and also because of the dark hue of the timber walls and the underside of the roof. The late afternoon sun casts intricate shadows on the praying space when light passes through the carved panels. This phenomenon adds beauty to the interior setting of the mosque. At night, the scene would be reversed when light from lamps passes through the perforations casting a silhouette of the carved panels. The silhouettes of arabesque and geometric forms can be clearly seen from outside especially in the absence of light from other surrounding buildings. Therefore the perforated panels add to the characterization of the mosque architecture.

Inside a timber mosque, the *mimbar* (pulpit) demands the most appreciation from the congregation. It is a piece of liturgical furniture from which the *iman* delivers his sermon (Yacub Zaki 1978). The *mimbar* of Kampong Laut mosque is profusely decorated with perforated

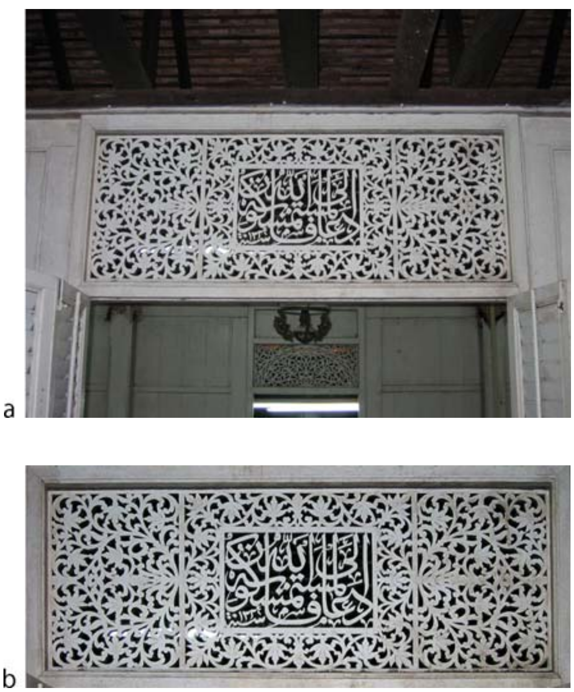
a

b

Woodcarving in Malay Architecture. Fig. 4 (a) A tall window at Tengku Long palace, an example of Terengganu. (b) A ventilation panel with arabesque floral motif on top of a window.

carvings of floral motifs. The most prominent panel is the front carved board attached to the canopy carved in *gunungan*, one of four principal forms. It resembles the form of the headdress worn by Malay women in the marriage ceremony. The side and back walls of the *mimbar* are fully furnished with perforated carved panels as part of the structural component of the four posts.

The gate is also an elemental component for vernacular Malay architecture; it demarcates the access to a palace or an aristocratic house. It is installed as part of the wall or fence in single or double-leaf doors. The leaf is generally carved in simple floral motifs with straight railings, as in the gate of Kota Lama Duyong, an aristocratic house built in 1920 in Kuala Terengganu (Mohd Hanif 1997). This house has five types of gate incorporated with a concrete wall surrounding the building. Big and double-leaf gates are meant for honored guests located at the front yard of the building compound (Fig. 7a). Smaller single or double-leaf gates are located near to the kitchen and deck leading to the rear of the house and are used by the residents and neighbors (Fig. 7b).



Woodcarving in Malay Architecture. Fig. 5 (a) A ventilation panel on top of an interior door of Tengku Long palace. (b) A panel with Quranic calligraphy and arabesque floral motifs.

The third type of carved components found in Malay vernacular houses and mosques are ornaments. *Som* and *buah buton* are ornaments that are carved and attached to the structural members of the building. *Som* is the decorative component located at the ridge end of the pyramidal roof (Fig. 8). Each roof tier has four *soms.* Langgar mosque has the largest and most elaborate *soms* on its first and second roof tiers. A pair of pemelehs accentuates the third tier roof. From a considerable distance the *soms* and *pemeleh* accentuate the profile of the mosque, giving it a distinctive vernacular style. Telok Manok mosque has the most *soms*; each ridge end and minaret roof is decorated with floral motif soms. Another ornament that gives character to the timber mosque is the *buah buton* – a decorative component attached to end of *tunjuk langit* jointing the tie beam or rafter to the tie beam. The attachment hides the tenon and mortise joint and is not a structural part of the building. Telok Manok Mosque has the most buah butons – 18 at the tie beams and three at the end of the *tunjuk langits*. All the carvings are in lotus blossom motif, but each differs in form, resembling the natural form of the flower that shrinks in the morning and gradually opens during the day (Fig. 9). The differences in form resulted from the interpretations of several craftsmen.

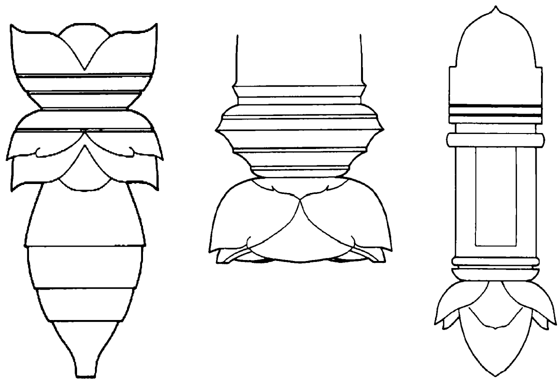
Types of Motif

Malay craftsmen applied five types of motif: floral, geometric, calligraphic, faunal, and cosmic onto the carved components. Flowers dominated Malay woodcarving; the carvers used the fruit, stems, tendrils, leaves, and of course the flower. Fruit of pomegranates, lotus flowers, sunflowers, *ketumbit*, *ketola* and *bakawali*, leaves of *getamguri*, and stems and tendrils of *ipomea* are depicted in a variety of abstract forms. The pomegranate is chosen as a motif because of its interesting shapes and bright orange flowers. The lotus is selected because of its auspicious status and sacredness. Furthermore, weeds such as ketumbit with bright yellow flowers and getamguri with wavy foliage are recognized by Malay craftsmen in Terengganu and

Woodcarving in Malay Architecture. Fig. 6 Floral motif on ventilation panels at the door and wall of Telok Manok mosque (KALAM, Universiti Teknologi Malaysia 1997).

Woodcarving in Malay Architecture. Fig. 7 (a) A gate at Kota Lama Duyong for residents and neighbors. (b) A larger gate at Kota Lama Duyong for honored guests.

Woodcarving in Malay Architecture. Fig. 8 Image of soms at Masjid Telok Manok (KALAM, Universiti Teknologi Malaysia 1997).



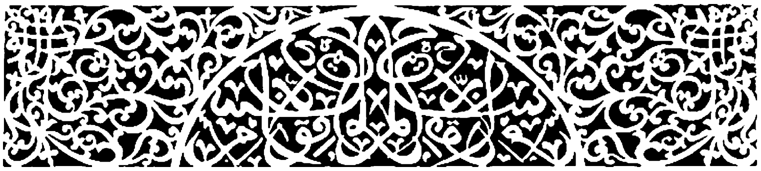
Woodcarving in Malay Architecture. Fig. 9 Lotus blossom motif on *buah butons* at Masjid Telok Manok (KALAM, Universiti Teknologi Malaysia 1998).

Woodcarving in Malay Architecture. Fig. 10 A ventilation panel of Kota Lama Duyong in Kuala Terengganu carved in floral motifs, getamguri and sulur kacang (KALAM, Universiti Teknologi Malaysia 1997).

Kelantan; they translated their beauty into the tangible art (Fig. 10). Craftsmen in Perak and Negeri Sembilan favored bright yellow flowers and the intertwining character of *ketola* and large, bright sunflowers on their door leaves and ventilation panels. Malay craftsmen observed the beauty of their surroundings and transferred their intangible value into a physical product that could be appreciated by others.

Fauna are rare in Malay woodcarving because Islam prohibits depicting figurine motifs. However, a few craftsmen still carved fauna motifs such as: (a) a pair of fighting cockerels on a window ventilation panel of a Negeri Sembilan house, (b) a group of ducks waddling in a row on a stringer of a Malacca house, and (c) a lizard head on a corner of a fascia board of a Perak house (Abdul Halim 1986). These motifs are generally carved in abstract forms, hiding the real figure of the fauna.

Calligraphy is also applied as a motif at wall and ventilation panels on Kelantan, Terengganu and Negeri Sembilan houses. It is either carved in relief, perforated or a combination of both. The Malay craftsmen put Quranic verses into wood panels written in several Arabic styles. An excellent example is a wall panel at a house in Kampung Pulau Panjang, Kelantan where a Quranic verse is carved in perforated form and laid symmetrically on an axis (Fig. 11).



Woodcarving in Malay Architecture. Fig. 11 A wall panel carved in traditional calligraphy motif at a house in Kampung Pulau Panjang, Kelantan.

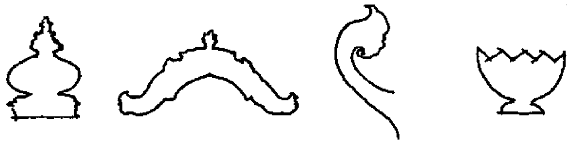
This carving demonstrated the craftsman's devotion to Islam and adoration of the *Quran*. The legacy of calligraphy in Malay letter writing has contributed woodcarving, which has selected it as one of its motifs (Syed Ahmad 1992).

In addition to arabesque motifs, Malay craftsmen also apply geometric motifs on door leaves, ventilation panels, wall panels, railings, and partitions. The configuration can be a series of diagonals repeatedly copied throughout the component. Swastikas and stars are more complex motifs that dominate the carving configurations, for example, on a ventilation panel of a wall. Repetition of similar motifs creates a sense of beauty and contrast against adjacent foliate or calligraphic motifs. The motif of the swastika, which originated from Chinese woodcarving, can be seen in ventilation panels of Kota Lama Duyong (Mohd Hanif 1997). Geometrical motifs are easier to carve than the other four types and thus repetitive components such as railings are done by apprentices or sometimes wives of the master craftsmen (Nik Rashiddin 1999).

The motif of the cosmos is seen the least in Malay woodcarving. The depiction of this motif in Malay carving illustrates the influence of Chinese craftsmanship and the pluralism of cultural values in vernacular architecture. A ventilation panel at Mohd Ali Kulup Mat Yassin's house in Perak is an example where leaf and flower are combined with a cloud.

Principal Forms and Shapes of Carved Components

In terms of iconography, Malay woodcarving depicts four principal forms including *stupa*, *makara*, lotus and *gunungan* (Fig. 12).



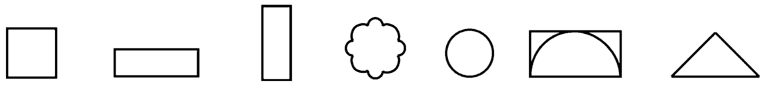
Woodcarving in Malay Architecture. Fig. 12 Principal forms of Malay woodcarving.

The stupa form can be found in house components such as buah buton or on the newel posts of stairs or gates. These are decorative components that enliven the interior of the building. Buah buton is attached to the end of the kingpost hiding the tenon and mortise joint to a tie beam of the roof structure. It is the only volumetric component that becomes the jewel of carving, beautifying the interior of the house. The *gunungan* is a silhouette of a mountain or tree of life, a symbol of status. The gateway of a house compound is carved in gunungan, but other components including the ventilation panel of the door or window and door leaf also used this form. The *makara* reflects the center of the cosmological imagination for a mythological sea monster in Pattani and Kelantan. Gable-end boards on Terengganu or Kelantan houses depicted the form of makara that enhanced the façade of the building. This component differentiates the form of the house in Terengganu and Kelantan over houses in Perak and Negeri Sembilan. The lotus is a symbol of purity, and its form is applied to a variety of house components, including door leaves, fascia boards, ventilation panels and buah butons. Apart from house components, the form is carved at the foot of tombstones and bases of kris hilts (see Farish and Khoo 2003).

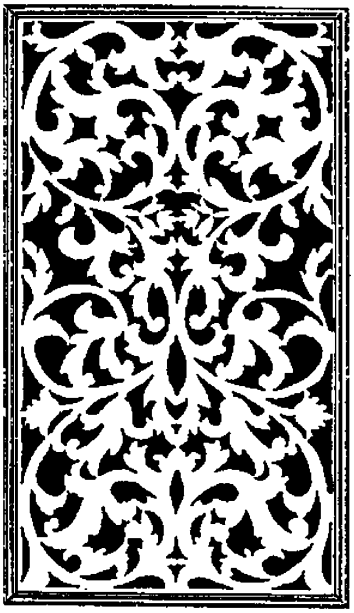
The carved components are designed in six geometrical or floral shapes including oblongs, squares, circles, octagonal flora, semicircles, and triangles (Fig. 13).

Squares and oblongs are common layouts for many components, particularly door leaves and ventilation and wall panels. They are easier to carve than flowers or circles since their outlines are straight. Ventilation panels on doors, windows, and walls of Terengganu and Kelantan houses are dominated by these perforated components in floral motifs. The layout and size of the components are proportionate with the elevation of the building and volume of its interior space. The house builder and craftsmen carved sufficient amounts of fenestration to allow cross ventilation to give thermal comfort to residents without depending on mechanical means (Ismail and Ahmad 2001).

Occasionally, a floral octagonal or circle layout is carved for special components such as the base of a ceiling lamp. Such carving can be found in aristocratic houses such as Kota Lama Duyong. The intricacy of the shape and carving denotes the skillfulness of the Malay craftsman and wealth of the house owner.



Woodcarving in Malay Architecture. Fig. 13 Shapes of carved components in the Malay houses.



Woodcarving in Malay Architecture. Fig. 14 A perforated, arabesque wall panel carved in a symmetrical layout with a vertical axis.

Apart from the shapes, the carvings are generally symmetrical on at least one axis. The axis orientates the carving pattern, repeating the pattern from left to right or from the top to the bottom of a component. Fig. 14 illustrates a perforated carving of a wall panel of Wan Embong house in Kuala Terengganu. Most ventilation panels, wall panels, door and window leaves, and flat railings are done in symmetrical formats with floral motifs.

Factors Influencing Timber Selection

Generally, Malay craftsmen would apply three factors in selecting appropriate timber for their carvings. The factors include availability of timber, its physical characteristics and durability, and the craftsmen's spiritual beliefs toward the timber species. The hierarchy of selection depends on the type of carved components. For example, the making of house components such as door leaves or ventilation panels is clearly determined by the availability of timber which could easily be obtained in large volume. On the other hand, the Malay craftsmen chose only kemuning or kenaung for making kris hilts and sheaths because of their fine interlocked grains and deep yellow sapwoods overlapping with dark brown heartwood. In addition, these timbers are regarded as possessing good spirit that must be respected and that will accompany the weapon (Faris and Khoo 2003; Ismail and Ahmad 2001).

Availability of Timber

Tropical rain forests of Peninsular Malaysia produce a variety of quality, durable timber grown in the low-lying undulating land and hills of the Main Range (Appanah 1993). Heavy hardwood species such as *chengal* (*Balanocrpus heimii*), *balau* (*Shorea spp.*), and *merbau* (*Intsia palembanica*) are the favorites. They are durable species that resist attacks from termites, powder-post beetles and fungi, which would harm their structural properties including flexibility, stiffness, and hardness. These are suitable for making large building components such as door leaves, barge-boards, kingposts, wall, and ventilation panels as well as small ones including railings and buah butons. The same timber species are used to make structural building components such as posts, beams, and floor-boards as well as the carved components. It is common to find an entire house made from chengal, balau, or merbau in the states of Terengganu, Kelantan, Perak, and Pahang in the peninsula. For example, a house at Kampong Bolok in Pahang built in the 1920s, was constructed wholly from merbau.

The timbers are air-dried under a shed or under the houses, allowing prevailing winds and the sun to dry them while protecting them from the rain. No preservative treatment is applied to the timber since the resins of most dipterocarps are able to resist the powder-post beetles, termites, and fungi attack (Farmers 1987). The drying (seasoning) process may take months or even years for some timber species particularly kemuning, kenaung, and sena.

Medium hardwoods from the forests such as *medang* (*Litsea grandis*), *kundang hutan* (*Bouea macrophylla*), and *keladan* (*Drybalanops oblongifolia*) are sometimes used for carving door leaves, furniture such as beds and cabinets, and musical instruments such as the *kenong* and *kompang*. These timbers are more prone to attacks from powder-post beetles and fungi and thus they are placed where they will not come into contact with moisture.

Craftsmen would optimize timber choice by harvesting readily available fruit trees grown in house compounds and orchards. They would cut large branches or sometimes the trunk of mature trees including *ciku* (*Achras zapota*), jackfruit (*Artocarpus heterophyllus*), *rambai* (*Baccaurea bracteata*), *belimbing* (*Averhorra belimbii*), *bacang* (*Mangifera foetida*), and *kundang* (*Bouea macrophylla*). Since these timber pieces are relatively small, the craftsmen would carve them into household tools and utensils and musical instruments in floral and geometrical relief motifs. The tools and utensils include coconut graters, ladles, food containers, biscuit moulds, and *rehal* (a cradle in which to place the *Quran* during readings). The practice of consuming timber from cultivated trees suggests that the Malay craftsmen were attentive to their environment.

Timbers for carving were also extracted from the secondary and coastal forests where mixtures of heavy, medium, and light hardwood species grow. *Leban* (*Vitex spp*.), a heavy hardwood, and *sena* (*Pterocarpus indicus*), a light hardwood, are the common species obtained from the secondary forest for making sheaths of badek or kris and for carving some utensils. The craftsmen living in coastal villages would harvest timber from *penaga laut* (*Calophyllum inophyllum*) and *kelat jambu laut* (*Syzygium grande*) from the beach forest. They were carved for boat paddles and grave markers. Malay craftsmen optimized the timber found within or adjacent to their environments.

Physical Characteristics and Durability

In woodcarving, the physical characteristics that govern the suitability of timber are durability, color, grain and texture, and luster. Before working on the timber, the craftsmen select a timber piece that is free from all defects, namely, knots, pith flecks, resin streaks, brittlehearts, checks and splits, decay, bowing and cupping (Nik Rashiddin 1999). Durability of hardwood is directly related to density; high density generally suggests strong resistance against fungi decay and boring insect attacks. Therefore, chengal, balau, resak, and merbau are the preferable species for most house components including structural, elemental, and decorative types (Watson 1928). Buildings made from these species are known to last for more than 150 years. Their resistance is possibly due to the silica deposits in their storage tissue (Desch 1981).

In some heavy hardwoods there is no color distinction between sapwood and heartwood, but usually the heartwood is more deeply colored (Desch 1981). On exposure to the air, chengal and balau are light brown to dark red-brown and become darker as they age. On the contrary, the merbau's sapwood is pale yellow sharply defined from the dark red-brown heartwood. Generally, the final finish of the carved timber components made from these heavy hardwoods is finished with sandpaper. In carving house components, the craftsmen is less critical about the timber color but very selective when carving weapon hilts and sheaths, furniture and musical instruments. Only kemuning and kenaung, with bright yellow sapwoods and dark brown heartwoods, are chosen for the hilts of kris, badek and *kerambit* (a small knife). These weapons are considered auspicious tools and used only for ceremonial events or special occasions.

Grain and texture are two distinct characteristics of timber. The grain refers to the direction of the fibers, and texture applies to the relative size and the amount of variation in the size of the cells (Desch 1981; Smith 1999). The chengal timber is easy to cut and incise because it has straight fibers and it does not give rise to ornamental figuring. It has a fine and even texture and is thus suitable for almost all carvings, from large features such as a boat's figurehead, to a building's wall panels, to small objects such as rehal. The merbau has a more interesting appearance than the chengal or balau since it has interlocked and sometimes wavy grain and a coarse texture with large vessels and coarse rays (Farmers 1987). But it is more difficult to incise since it is denser and has a higher hardness, thus it is used for large building components such as posts and seldom used for small crafts such as house utensils.

Lustrous woods such as merbau, kemuning, tempinis (*Sloetia sideroxylon*), and kenaung have cell walls that reflect light, particularly on quarter-sawn surfaces (Desch 1981). The luster is a natural asset that craftsmen exhibit in carved furniture and small crafts such as kris hilts, knife sheaths, walking sticks, and picture frames. The luster, however, does not last long without a finishing coat over the timber surface. Craftsmen apply several layers of shellac or varnish to a kris hilt to retain the lustrous surface of the kemuning.

Spirit of Wood

In addition to the tangible characteristics of the timber, Malay craftsmen also select timber based on its possessing either a beneficial or malignant value (Farish and Khoo 2003). Kemuning and kenaung are regarded as the most auspicious species because the craftsmen believe that they possess strong spirits that will accompany a weapon such as a kris, badek, kerambit, or spear. A few craftsmen in Kelantan believe that this spirit is compatible with the iron blade. These timbers are reserved for creating hilts and sheaths of weapons. As work begins, a craftsman cannot be definite on what style of kris hilt that a piece of kemuning or kenaung will finally become. Gradually, during the incision process, the timber reveals its grain, texture, and luster and only then will the craftsmen know the hilt style the timber will become. The motifs on this hilt would be similar to large architectural components such as leaves of getamguri and jaribuaya, flowers of ketumbit and keraknasi; these are shrubs or weeds commonly found in Malay house gardens (Syed Ahmad 1992; Ismail and Ahmad 2001).

Woodcarving is a significant craft in Malay vernacular architectural and nonarchitectural elements. It is a manifestation of craftsmen's imagination using floral, geometrical, calligraphic, faunal, and cosmic. It signifies the identity of a regional architecture as well as a pattern of the craftsmen from a region. In intangible perspective, it illustrates the belief of the Malay craftsmen toward architecture, devotion to god and their contribution to society. To understand the significance of the craft, one needs to investigate its physical forms in term of motifs, principal forms and layouts. In addition, it is important to know the characteristics of the timber species from which the carvings are made.

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Woodworking in Egypt

Geoffrey P. Killen

More is known about woodworking in Egypt than anywhere else in the ancient world. By the New Kingdom, Egyptian woodworking had reached its zenith with examples of woodworking such as furniture being highly prized and often sent as tribute to the rulers of neighbouring countries.

Many Pre-dynastic burials in the Nile valley have the body placed on wooden poles and covered with matting made of plant fibre, while some burials are found in primitive wooden boxes. By the unification of Upper and Lower Egypt we find bed frames, Plate 1, in common use with many examples being found in 1st dynasty (3100–2890 BCE) tombs. The quality of these bed frames ranged from conveniently shaped branches

Woodworking in Egypt. Plate 1 Bed frame, 1st Dynasty, Metropolitan Museum of Art, MMA 12.187.52.

that were lashed together to sophisticated examples made from rounded poles that were jointed together and supported on finely carved bovine shaped legs (Petrie 1913, Pl. VIII–IX).

At the beginning of the Old Kingdom, which opens with the 3rd Dynasty (2686–2613 BCE), we see major advances in building and the associated trade of carpentry. The quality of royal furniture made during this period can be seen in those examples discovered by the American Egyptologist George Reisner, in the 4th Dynasty tomb of Queen Hetepheres (ca. 2600 BCE) at Giza (Reisner 1955). When he opened the tomb, he found that the wooden elements from which the furniture had been made had rotted away to powder. However, it proved possible to reconstruct much of the Queen's furniture by studying the positions of the gold sheaths, which had encased the furniture, and the inlays that had fallen free and lay on the tomb's floor. Hetepheres' furniture consisted of two armchairs, bed frame, bed canopy, carrying chair and two boxes. What Reisner and his team achieved, from a pile of unrelated fragments of gold and faience is remarkable for it has given us a small but superb collection of early furniture, which rivals Tutankhamun's, manufactured over a thousand years later.

We see the introduction of the wooden box at the end of the Old Kingdom. They were manufactured with flat, gable, barrel and shrine shaped lids. Some were very large and were designed with a pair of poles that enabled the box to be carried by a team of porters. In one tomb scene 14 men are carrying a box. During the Middle Kingdom we find boxes were customised to hold cosmetics. Many were designed like crates to hold small alabaster jars, which held perfumed oils. Other boxes have been found to contain mirrors, kohl containers, combs and even a pair of slippers! A box made for Sithathoriunet (ca. 1800 BCE) (Winlock 1934) was decorated with gold fittings and bezels in which were set with polished carnelian stones. Other elaborate boxes held cosmetics or; these were usually inlaid or veneered with sheets of ivory or exotic timbers bought from lands south of Egypt (Plate 2). Scribes even had boxes in which they stored their writing implements and palettes. Their boxes were usually painted to imitate the stringing and veneered panels found on more ornate boxes.

Important directional changes in Middle Kingdom furniture can be seen by studying the large collection of stelae, which are preserved in the Egyptian Museum, Cairo. These Middle Kingdom stelae show that tables were widely used for the display of vases or holding water pots. Many are low with straight legs and have a single stretcher strung below the tabletop. We also see that Egyptian carpenters were constructing splay-legged tables, which had cavetto cornice mouldings below the edge of the tabletop (Plate 3). Slender vase stands were made from thin strips of timber braced with cross and angled struts. They were fitted with a shaped collar, which held the round base of a single vase. They were covered with a gesso foundation before being painted to imitate carnelian and faience inlay. Those chairs made during the Middle Kingdom had either short backs over which was draped a cover or cushion or they had backs of full height. Such chair backs were curved and made from angled slats of timber. They stood on slender gazelle-shaped legs. Often chairs were painted to simulate animal skin, which were painted with a technique, which resembles cow skin and was used on an arrow quiver case, which is preserved in the Egyptian Museum, Cairo.

By the New Kingdom, the homes of officials and nobles would have been furnished with a wide range of wooden furniture, the most common of which would have been the stools. Egyptians used a large number of different types of stool. The most commonly used were lattice stools that were made from thin struts of timber

Woodworking in Egypt. Plate 2 Cosmetic Box, 18th Dynasty, Metropolitan Museum of Art, MMA 26.7.1438.

Woodworking in Egypt. Plate 3 Table with cavetto cornice edge, 18th Dynasty, Metropolitan Museum of Art, MMA 14.10.5.

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Wound Healing in Ancient Egypt[1]. Plate 4 Lattice Stool, 18th Dynasty, British Museum, BM EA 2476.

with angled braces supporting a double cove seat (Plate 4). Round-legged stools appear in some of the more important Theban tombs. The majority of legs from these stools were hand rounded although there is a small corpus of material, which have legs that appear to be turned. During the New Kingdom we see carpenters sitting on three legged stools, which allowed the stool to rest evenly on the workshop floor. The folding stool originated in the Middle Kingdom and was made from two interlocking frames with a leather seat. New Kingdom examples are more elaborate having the floor rails and crossing spindles finished with carved goose head terminals, which are inlaid with ivory to imitate the eyes and neck feathers. We also see that lion legged stools and chairs were used in the homes of high-ranking officials.

The wooden furniture manufactured in the royal workshops was not very different in design to that used by the middle classes. However, they were exquisitely embellished with gold sheet, inlaid with coloured stones and faience or veneered with ebony and ivory. They were also adorned with the uraeus [the sacred serpent found on the headdresses of Egyptian rulers and divinities, representing sovereignty] and the symbols of kingship. Other pieces are inlaid with thousands of slivers of coloured wood in either marquetry or parquetry patterns. In the tomb of Yuya and Tuyu (ca. 1400 BCE), the parents of Queen Tiy and the wife of Amenhotep III (1390–1352 BCE), a small armchair made for Princess Sitamun was discovered. The illustrious examples of furniture discovered in the Tomb of Tutankhamun (1336–1327 BCE) show the outstanding quality of design and construction achieved by 18th Dynasty carpenters.

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Wound Healing in Ancient Egypt[1]

Hedvig Győry

Representations of injuries are relatively infrequent in ancient Egypt. However, the accuracy in the depiction of accidents in the joiner's shop drawn on the wall of the tomb of Ipui in Deir el-Medineh, and the representations of the battle of Qades in Abu Simbel, Luxor and Ramesseum temple, reveal exceptional medical details and the consequences of specific injuries. The exact identification of injuries on the battle scenes is possible in two-thirds to three-fourths of the injured (only Hittite) soldiers. Most of them were inflicted on the chest and abdomen, or neck and head, respectively, these being the largest targets in bow-and-arrow warfare or in hand-to-hand fighting. For instance, a 'decelebrate rigidity' is shown in a Hittite soldier struck by an arrow on the top of his head, or a haematoma (accumulation of blood) is shown deep in the abdominal wall caused by an arrow entering another Hittite soldier's right lower-chest or abdomen below the rib cage. An examination of skeletons show that arrowheads severed most of the spinal cord, resulting in instant paralysis of the body below the neck.

[1] In the text, the following abbreviations are used for two medical papyri: Eb is Ebers papyrus and SM is Edwin Smith papyrus.

Types of Wounds

We can differentiate several types of wounds depending on their characteristic look, origin or severity. The same is true for ancient Egyptians. Moreover, medical papyri, especially the Edwin Smith papyrus, are very accurate and detailed in the description of various types of injuries and their treatments. They tell us that the healer was able to characterise the most important types of injuries, impressive even by today's standards. They differentiated various types of swellings, wounds, fractures and joint injuries.

The general word for an injury, where the protective function of the skin was disturbed or hurt, i.e., a wound, is *wbn.w*. Without any explanation it means the commonest form of injury, the rupture of the soft tissue overlying the bone and leaving a constricted orifice. Beside this simple form, they spoke also about a *wbn.w n kft*, (a gaping wound) describing an open wound with a well-defined gash as, for instance, in Sm 28, where the most important clinical sign for an open oesophagus, drinking water regurgitating through the wound, is mentioned. The axillary could also be open (Sm 47). Another type of *wbn.w* could be *wbn.w sd* (*sg*), (a wound smashing (sg) or contusion), or *wbn.w jsp (r3-r)*, [a wound cutting (through)]. Another description of wound, known only from the Smith papyrus, is *wbn.w jsdb (r)*, [a wound piercing (to)], which seems to be nearly synonymous with *wbn.w ͑r* (*n*), [a wound penetrating (to). According to the examples we have, the penetration reached a solid body part as bone, while the piercing came through into a void. For a simple perforation the common word was *thm*. Finally, in pEbers 877c we find the *wbn.w sḥm*, (a crushing wound), laceration and rupture, and in pEbers *494 wbn.w n wbd.t* (burn wound), although for designating this last type it was enough to write *wbd.t* – (burn) alone, or to give the word for the actual phase of its development. Ancient Egyptians differentiated various types of fractures. Beside the *ḥsb*—simple, open fracture—there was the closed *sd* fracture, where the bone was broken in two inside the body, or the commuted compound or impacted *pšn* fracture, where the bone was broken in several places. The above-mentioned *thm* and *sḥm* could also occur below the skin. As a diagnostic clinical sign of fracture, *nẖbẖb*, meaning, in all probability, 'crepitation' [the noise made by rubbing together the ends of a fractured bone], is mentioned.

Treatment

During the repair of any type of wound, the practitioner has to face three basic factors: pain, bleeding and infection. The ancient Egyptians realised only two of them, since they regarded infection as part of the recovery process. The most common complaints, swelling and fever indicate that wounds were often infected.

Interestingly, they never mention anaesthesia for use in surgical interventions although painkilling must have been an important part of the repair procedure. The possibility of anaesthesia was there because we know that they collected rush, which can be used as a narcotic, that they knew very well the effects of alcohol, that they cultivated mandrake and poppy from the New Kingdom on, and that the medical papyri reveal a knowledge of hyoscyamus [henbane, a genus of poisonous herbs] and scopolamine as well. Their use of analgesia was thus theoretically possible, either in the form of a type of food or concoction, and their use as hypnotic agents might also be hypothetically suggested. The only words, however, which might hint at anaesthesia accompanying the Old Kingdom circumcision scene where the use of local anaesthesia can be deduced from a promise to make it *nḏm* – 'sweet, agreeable', when the region is rubbed with a piece of stone. Some consider that water was mixed with vinegar over Memphite limestone, resulting in the formation of carbon dioxide, which may have had an analgesic effect; the process would then resemble today's cryo-analgesia.

Ancient practitioners were more deeply concerned with arresting haemorrhages, since the *mtw* (Eb. 871), tumours (Eb. 875) and wounds were susceptible to bleeding.

Medical Protocol

In preparation for medical treatment in ancient Egypt a medical protocol was first issued by describing the symptoms, making a diagnosis and giving the form of treatment. This process was usually followed by the medicine man, who was usually a physician or probably a priest of Sachmet.

Diagnosis could be divided into three categories: (1) "an ailment, which I will treat"; (2) "an ailment which I will contend with"; (3) "an ailment not to be treated". The main wound repairing methods were bandaging with an ointment or poultice, scorching (Eb. 876, Eb. 872) and surgery. In doubtful cases, enforced bedrest and normal diet were often recommended to the patient until he reached the decisive moment when the healer could give either a positive or negative prognosis. At the end of the treatment sometimes the verdict was also given as (a) "until he recovers"; (b) "until the period of his injury passes" by; (c) "until you know that he has reached decisive point".

Relatively fewer examples are given for incurable ailments. Only 5 out of 48 cases in the Smith papyrus, and a few in the tumour section of the Ebers papyrus, as Eb. 874, may be leprosy, or Eb. 873, a possible cavernous haemangioma, or a twisted vascular swelling forming knot (in this case, however, the *mtw* should be straightened). The first two steps in Eb. 877 are still unidentified, although cancer, cutaneous leprosy, bubonic plague or neurofibromatosis has already been suggested. In the last step in Eb. 876, the ball-shaped extensions have tentatively been identified by Regöly-Mérei as varicosities.

The cause of wounds can be varied. They are most often trauma by accident or battle, blows or knocks, scratching or scraping, bites, burns or a symptom or stage of an illness. The preferred treatment was drug therapy accompanied by bandages, which was supplemented in severe cases by small surgical interventions. Some mechanical treatments are also known.

Surgery also took place sometimes for religious (circumcision) or aesthetical reasons (ear or nose restitution) and prosthetic surgery was also known, although not all that often.

Types of bites, such as those from crocodiles (Eb. 436, H 239–40, 243), lions (H 244) and humans (Eb 432–435, H 21), were treated like any other wound, preferably by applying fresh meat on the first day and, subsequently, honey, wax and oil or grease as in Eb. 435 or by using other herbal remedies, occasionally with the addition of some animal ingredients. Snake-bites, however, were treated differently, and by different medicine men, mainly by the snake-charmer priest of Selket, because of the venom inflicted by the bite into the body. Tumours were well differentiated. Several sorts of tumours, abscesses, cysts, swellings, and boils (*ḥnḥn.t, ꜥꜣ.t, sfṯ, ꜥnw.t, šfw.t, ḫsd, twꜣ.w, bsj, ḥmꜣ, sḫ, bnw.t, wnm-snf*) are mentioned mostly in the Ebers, Hearst and Berlin papyri, with very brief medical instructions. These were treated by the same methods as wounds caused by mechanical injuries.

In the Ebers papyrus there is a complete book on wounds originating in burns: 482–509. No. 482 lists a sequence of remedies which, it says, should be applied consecutively. In other cases, remedies applying an ointment or bandage are always the same.

Methods

Drug Therapy

Egyptian drug therapy can be regarded as having evolved from a system rooted in magic that developed from empirical observations. Sometimes a sequential approach was used (Eb 522). In the 182 cases given in the Smith, Ebers, Berlin, Hearst and Ramesseum III papyri regarding wound repair, almost 130 types of materia medica were used. All were applied externally. More than 60% of them were herbal remedies; the remaining types were mineral or substances originating from animals (both in about the same degree), with a few undetermined components. The only human remedy was urine.

Very often (in every 6th case), fresh meat was applied to a wound on the first day as an efficient haemostatic and mechanical agent. It was bound on the wound on the first day only, and was usually followed by the application of a lint saturated with ointment composed of grease and honey, also bound on. In specific cases, many other ointments and poultices were also applied (e.g., Eb 510–42). In other cases the treatment started with these materials. Almost 80% of the prescriptions contained oil or grease in either the form of *mrḥ.t* or *ꜥd*, both prepared from various plants or animals, closing off the wound from air and introducing some minerals or vitamins into the injured tissues. In almost half of the prescriptions honey was used, which can be beneficial as a wound dressing because it inhibits the growth of micro-organisms and is hygroscopic, thus attracting an abundant secretion of leukocytes and antibodies. Taking into account that the wax, which was also frequently mentioned in these cases, must have also contained some honey, its use was as popular among Egyptian drugs in wound healing as oil or grease.

ḏꜣr.t was often used (ca. 25%), probably because of a disinfectant effect; this has been determined from the analysis of its use in various ancient Egyptian prescriptions. Unfortunately, the identification is not fully resolved: colocynth[2] and carob are suggested, although the last one seems to be more probable. Besides these basic medicaments, some others are also characteristic. Typical poultice materials were beans, peas, leeks, a sort of fibre (*dbj.t*), faïence powder, *bsn*-clay, *wšꜥ*-mineral, *jmrw* – eventually gypsum or plaster, and linen (both the usual colour and *jrtj.w* -a red one).

Several other materials were used for their antibiotic, antiseptic, astringent, rubefacient (for internal pain), antiphlogistic (counteracting inflammation), analgesic, fever reducing, hygroscopic or wound sealing effects, or because they could contribute to the formation or development of the epithelium. Most of them are listed, but infrequently. Only a few are common: incense, salt, acacia, sycamore, barley, millet, faeces of various animals, Christ thorn, celery, cumin and a few unidentified ones. Some of the materials used only rarely might also be very effective. This can be stated for instance for the willow (*ṯrt*) having salicyl as its analgesic, fever reducer, anti-inflammatory effects, and being also anti-rheumatoid. It is, however, only mentioned in three prescriptions. Another such component is onion, listed only once, but being a good anti-inflammatory and very effective against staphylococci,

[2] The colocynth is the light spongy pulp of the fruit of the bitter cucumber (Citrullus, or Cucumis, colocynthis), an Asiatic plant allied to the watermelon. It comes in white balls, is intensely bitter and a powerful cathartic. Also called bitter apple, bitter cucumber, bitter gourd.

streptococci and some sorts of dermatomycosis [fungal infections of the skin].

The question can be raised, however, how often a certain prescription was used, as we can surely attest that the medical knowledge of ancient Egyptians was slowly but continually developing, incorporating new methods and materials in their papyri, although they continued to practice medicine as they had earlier times. One of these new materials was also the willow.

Mechanical Treatment

Treatment for Joints

Dislocations (*wnḫ*) and sprains (*nrw.t*) were treated. In the tomb of Ipuj in Deir el-Medineh, there is a picture of industrial accidents. Among them the use of Kochers method for dislocated shoulders[3] can be clearly discerned. Other methods are described in the Smith papyrus, for instance, treatment for the dislocation of a jaw (Sm 25). For neurological complications resulting from the dislocation of a cervical vertebra, the inability to move the limbs, priapism, urinary incontinence, and intestinal dilatation with gas (paralytic ileus) are mentioned (Sm 31). In another case, a positive Lasague sign is described, i.e. pain due to a sprain of the vertebral column when the legs are extended (Sm 48), which indicates a prolapsed lumbar intervertebral disc with nerve involvement.

Bandages

For drawing together a gaping wound they applied strips of adhesive plaster, putting them on both sides of the wound (Sm 10, 27). Splints could be used for administering medicament into the mouth, as it could be held open with them. The same supporting use is attested at nose and ear operations. The common application of splints was for fractures. Wounds were usually bandaged after ointment was put on them, or the bandage was saturated with it. The linen for bandaging (Sm 2, 9, 10, 27, 47) varied in texture from the finest silk-like gauze to a canvas-like coarseness. Ancient Egyptians had special knowledge in this field, which was explained in a specific book, as a note in the Smith papyrus says. The skill was first taught for the bandaging of mummies.

Treatment for Fractures

Based on many relatively good healing settings, we can assume that ancient Egyptian bone setting was advanced. Among the skeletal remains from ancient Egypt, there are innumerable completely healed limbs with good realignment of the bone, but most other bone settings often show gross shortening and misalignment. Since fractures of the femoral bones often healed without complication, it may indicate, on the one hand, that the virulence and incidence of pyogenic [producing pus] pathogens was lower than they are today, although their existence is proved by the frequency of osteomyelitis. On the other hand, based on the skeletal remains of pyramid workers and other Egyptians, it is obvious that fractured limbs were splinted using an advanced technique. Cleverly, if only one of the bones of the lower leg or forearm was broken, the remaining intact bone served as a splint for the broken one, and healing was satisfactory. In instances where the damage was so severe, amputation was an alternative course of action.

The standard procedure for the reduction of fracture was traction (Sm 12, 35, 36). And, indeed, many humeri set in splint remained. The first procedure was, after realigning the broken limb, to set it either with a splint wrapped in bandages, or encased in a healing poultice-cast that could be made of various (often unidentified) materials, as, for instance, (to mention some known substances) cow's milk mixed with barley (H 219) or acacia leaves bound together using gum and water (H 223). For reducing a fracture of the clavicle (Sm 35), the ancient Egyptians also used a modern method, first described among Greek physicians by Hippocrates, by stretching the patient 'on his back with a folded cloth between the shoulder blades' and pulling 'on his two shoulders until the fracture falls into position'. Among the neurological complications, as in the case of an impacted fracture of the cervical vertebrae (Sm 33), aphasia, unconsciousness and tetraplegia, are mentioned.

Surgical Processes

- Wounds were often surgically treated by suturing with *jdr* stitching (Sm. 3, 10, 14, 23, 26, 28, 47). The Smith papyrus has the first mention in history of 'stitching' a wound. Other wounds were not sutured, but kept open.
- The *ṯḥn*—piercing with the *ḥmm* instrument—was prescribed for opening the ascites [fluid in the abdomen] in Eb 865. Regarding the only surgical procedures for burns, Eb 504 speaks about opening a blister, this time with a sharp thorn.
- Sandwiched between two pharmaceutical prescriptions, also for a blister in Eb. 501, an incision is suggested, but, as usual, without any details.
- The *ḏw-ᶜ*-'knife-treatment', meaning, probably, excision, was fairly popular, as the many prescriptions show: Eb. 866 for a vascular tumour (haemangioma?), Eb. 867 for a presumably subcutaneous lipoma, Eb. 868 for a possible sebaceous swelling with metathesis (*ᶜꜣt nt sꜣ*), Eb. 869 for an abscess,

[3] Kochers method of reduction involves bending the elbow to 90°. The arm is slowly rotated 75° laterally, then the point of the elbow is lifted forwards, and finally the arm is rotated medially.

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Eb. 870 for a swelling. The identification of the latter has several possibilities, such as a dermoid cyst lined with skin appendages, pilonidal sinus located in the midline or sebaceous cyst of the scalp, as, for instance, atheroma, Eb. 871 for an abscess in the axillary lymph glands.

- Sometimes, the *ḏw-ˁ*-‘knife-treatment’ was applied with a heated (*sšmm*) knife as in Eb. 872 for a probable haemangioma.
- In some cases ‘fire’ is mentioned, treated ‘with the *s3-ḥmm* (firebolt?–man)’s treatment. This scorching was used in the case of the skin-like flesh protrusion in Eb 863 or that of the (umbilical or epigastric?) hernia in Eb 864.
- The method was applied according to the state of the cause, as in the first two cases of Eb. 876, where the tumour was eliminated either by excision or by scorching fitted to its state.

In all the above cases, procedures are not described and thus nothing definite is known. The only complex and detailed surgical process is given in the Ebers papyrus (Eb. 875)—with various knife and forceps devices—and is, in all probability, the month-long treatment for dracunculiasis (which may be the origin of the medical emblem with snakes), and thus a very atypical surgical invention.

Skull Repair

According to the Edwin Smith papyrus, the ancient Egyptians recognised brain disorders and performed skull repair. They were also the first in the history of medicine to identify the inner parts of the cranium. They also provided vivid descriptions of the brain and cerebrospinal fluid. Parallel to the development of weapons, the number of head injuries increased, thus making the discussion of the many cranial injuries in the Smith surgical treatise fully understandable. The dominant factor in healing, however, seems to be the *vis mediatrix naturae*, the expectant healing power of nature. It is also manifest by the signs of treatment on heads with cranial injuries found by Elliot Smith, Wood Jones, Courville, and recently, Nerlich.

The ability to recognise the classic sign of a base fracture in the skull, i.e. bleeding from the nostrils and ears (Sm 4–5, 7–8, 17, 21–22), or the basic sign of meningeal irritation, i.e. the inability to flex the neck to the breast (Sm 3–5, 7), indicates a sound basic medical understanding. And, indeed, pathological descriptions give clues to the identification of cases, like classic meningitis in Sm 3 or cerebral prolapse and nucleal rigidity in Sm 6. In Sm 7, a complex case scenario is given dealing with a fracture at the base of the skull. First, trismus and meningeal irritation (cured by palliating treatment with an unknown hot material, allowing the patient to be able to open his mouth), then infection of the wound causing tetanus is diagnosed, again treated by palliative treatment with *mḏ3.t* – ‘wooden chisel’ and tigernut drink (*wˁḥ*), since recovery was hopeless. The Smith papyrus also discusses a *contracoup* case with a pulsating swelling protruding through the cranial fracture (Sm 8), where, besides the symptoms of the eyes looking in the direction of the affected side, the ears and nose are bleeding and nuclear rigidity with a hemiplegia on the injured side is documented.

Snakebite

According to the Brooklyn Herpetological Papyrus, snakes and the effect of their bites were accurately identified, and their bites treated with rational medical care. The treatments comprised the application of bandages with salt and natron, both being anti-agglutinant and anti-hemolytic, thus hindering the absorption of the venom; drinking of emetic remedies with various drugs to get rid of venom by vomiting; fumigation as adjuvant; magical spells for general and specific divine help and/or the *ḏw-ˁ*-knife-treatment and the *tštš* incision in the swelling. For drug therapy many earlier, not medically attested, substances were used, which may be explained by the 30th Dynasty date of the papyrus or by our missing knowledge of empirical snakebite treatment, but eventually by both of them.

The simple cut (*ḏw-ˁ*) was applied there twice, in the case of a ‘male viper’ (Br. 31) and of a uraeus/cobra (Br. 32); the wound is attributed to Seth and the prognosis is positive in both cases. The action is not specified, and, for the first case, there is nothing else to do. In the second case, however, the knife treatment is preceded by a remedy (‘every thing for …) with a missing part, which is thought to be by Sauneron ‘emetics’). These two procedures resulted in vomiting, thus saving the patient’s life. The word *tštš* originally meant ‘crush’; in these cases, however, the knife determinative finishes the hieroglyphs. Thus, here the ‘*tštš* with many cuts’ means, in all probability, the cutting of the area of the bite into pieces by a knife, applied to the bite swelling of any type of serpent (Br. 72a) or, specifically, to that of an unidentified cobra(?) ‘male snake’ (Br. 81). The next step was, however, the bandaging of the wound with salt or natron, or, in the second case, a medicament with the addition of incense, an unidentified liquid, and cobra blood. The latter one, in addition to the venom, also contains the antitoxins.

Surgical Devices

We do not know very much about medical implements. The earliest tools come from the tomb of Qar of the 6th Dynasty, including forty scalpels and tweezers as well as other medical tools whose purposes are still unknown.

For cutting the flesh they used knives of particular shapes and sizes. Various ancient Egyptian names are also known, such as *ds, ẖpt, šꜣs, ḥmm(?)* or *swt*. There was also a peculiar fish-tailed knife, called *psš-kf*, used for cutting the umbilical cord after delivery. In the beginning the knife was a ‘disposable’ stone, most likely made of flint or obsidian, which was still used for cutting up dead bodies for mummification in the first century AD (Diod. I. 91) or blades fashioned from reed stems. However, cuttings on the body were made from the New Kingdom on, also with a metal knife. This innovation led to a new procedure: the blade was heated until it was red hot before an incision was made so that the knife both cut and sealed at the same time.

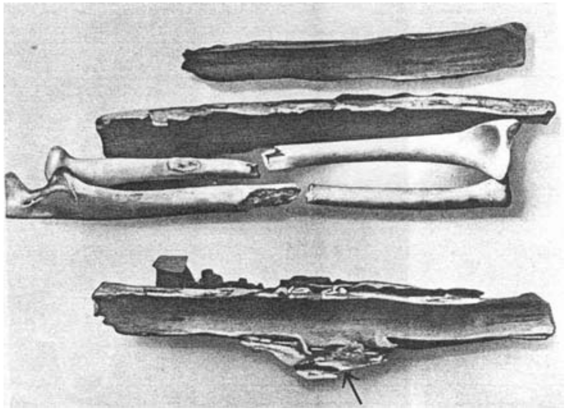
If a bone broke, bark or cartonnage cases padded with vegetable fibre or linen for securing the injured member by splints might be used, but Eliot Smith also mentions splints made of reeds connected by a linen band.

For taking out pieces of bones or any other foreign bodies, tools such as hooks and forceps were used. There was also a pair of small leather forceps, called *hnw(ḥ)*. For discarding pus or other amorphous formations, tweezers or spoons and spatulas or vegetable ‘knives’ (*sw* = bulrush) were used. Other plants were used in other ways; for instance, the thorn of an acacia was used for cutting up blisters (Eb. 504 = L 52 = L56).

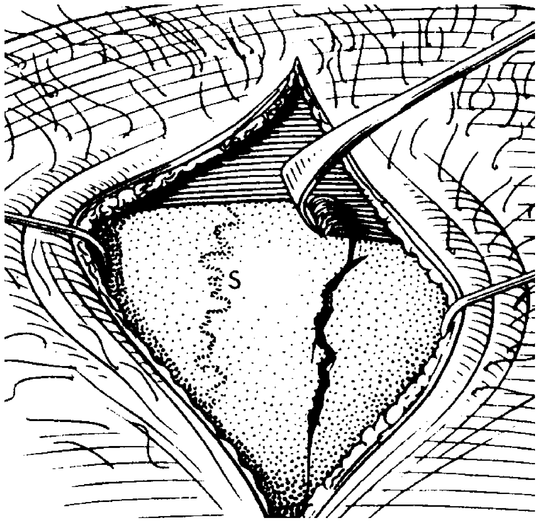
For cauterising there was the *ḏꜣ* – ‘fire drill’ and sometimes heated metal cauteries. For closing open wounds, various types of bandages (*hꜣyt, sšd*) or needles for suturing by *jdr* stitching were employed. Linen strips coated on one side with a gummy substance were used, for instance, as strips of adhesive plaster (*ꜣwy*). They had a sort of cotton wool made of fibres of the plant *dbj.t*, which was soaked in drugs (Sm 28) and enclosed by linen bandages (*sšd*). To prevent the dislocation or slipping of the bandage, they applied a gummy substance or varnish taken from embalmers. A wedge covered with layers of cloth is described in Smith 7 for use in prying open the jaw.

Medical devices seem to be varied and fairly specialised, each used according to its function or to the requirements of a particular stage of the operation. Their refinement was, however, primitive, although the technical skill existed to make complex instruments, as we know that some cosmetic devices are astonishingly complex and of high quality. The repertoire, naturally, continually changed and developed. The state of our current source material, however, does not allow us to deduce details. At the temple of Kom Ombo, a box of instruments for a general practitioner, carved into the outer corridor wall and originating from the Roman Period, contains 37 instruments, identified as metal shears, knives, saws, suction cups, probes, a saw, tweezers, pincers, small bags, retractors, a small scale, lances, specula, chisel, dental or cleaning tools,

Wound Healing in Ancient Egypt. Fig. 1 Detail from the Smith Surgical papyrus. Source: Breasted, J. H. The Edwin Smith Surgical Papyrus in Facsimile and Hieroglyphic Transliteration with Translation and Commentary, Chicago 1930.



Wound Healing in Ancient Egypt. Fig. 2 Broken bones with splints. Source: Majno, G., The Healing hand: Man and Wounds in the Ancient World. Cambridge 1975.



Wound Healing in Ancient Egypt. Fig. 3 Drawing with surgical hook used during operation.

spatulas and spoons, together with some objects having connections with magic. The ensemble presents a good example of the last period of Egyptian medical praxis, when Pharaonic Egyptian and Graeco-Roman medicine were completely fused.

Mythological Background

The medical papyri point to the fact that pernicious beings could enter and leave the organism through the openings of the body and thus harm people. From the Egyptian medical perspective, the wound was also an opening. Thus wound management had to be twofold. The first task was to repair the harm already occurred, by closing the opening and repelling the demons who had entered. Prevention was essential too, to assure the defence of this gate by magical rites and material feared by these illness-causing intruders. Seth often personified their negative power. The association of Seth with wounds was close, whether the wound was received in battle or as a consequence of the mythical fight between Horus and Seth for the succession to the throne of Osiris. According to this concept, any illness could only be healed with religious rites.

Material in connection with a plant or an animal might dispose some magical power and be a device through which people could get in contact with the gods. And the same is true for minerals. Thus any medical material could also express the protective role of a deity itself. This view is the most manifested in 'magical' components of the prescriptions. But even their choice was based with all probability on long empirical observations. Many of the materials are still (may be forever) unknown for us, but most of the identified ones have proved to be reasonably explained, and are appropriate in terms of their effect. The explanation of their effectiveness could only be given at that time, however, by mythological–theological reasoning.

Various material combinations could be used for seemingly the same type or state of illness or health, having the same or similar effect. There were several routes of drug administration, with a wide range of formation for use. They were usually determined by the choice of ingredients applied both for their physical–chemical properties and magical assumptions. The sycamore was, for instance, the tree of Hathor, Nut or Isis, the Christ thorn that of Thot of Pnubis, malachite was the mineral of Hathor, the donkey belonged to the god Seth, excrement was disgusting even for illness-demons, the *s3-wr* resin bore in its name ('great of magic') its magical connotation. For patients who were wounded, bandages were also used as magical devices. They were traps, so that invisible beings could be kept off or removed.

Another way of making a treatment more effective was religious–magical rite. Similar to cases in the London papyrus (15–21, 46–48, 53–61) and also among the Ebers papyrus prescriptions (482–500), magic spells had to be cast, referring to Horus having been burnt in the desert. According to the incantation of Eb. 499, which had to be recited with mother's milk, Isis used 'water in her mouth' and 'Nile springing between her thighs'. Then mother's milk, gum and ram fur (having a high cholesterol content) were put on the burnt wound.

The mythological background worked as a psychological support as well, which recent studies have shown can reduce pain perioperatively and increase patient's satisfaction.

See also: ►Surgery in Ancient Egypt

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Writing

Martha J. Macri

Writing ranks among the most important of human inventions. Yet it is only one of many forms of visual communication. Others include sign language, dance, and bodily adornment, notched tally marks, stones signposts, as well as the more complex painting and carving of complex narrative scenes. Some of these are, like writing, ways of recording information, that is, of creating a more or less permanent record available to persons outside the immediate time or space. All visual communication depends upon at least minimal familiarity with the cultural conventions of those producing it. Specifically, writing is a technique for recording human speech. Today speech, both the aural and the visual aspects of it, can be recorded and reproduced electronically. However, prior to the invention of the wax cylinder phonograph, human language could only be recorded, however imperfectly, in written texts.

Writing is an entirely arbitrary system in which each symbol in a script has an agreed upon value. The symbols may or may not have any association with a real world object. Thus, all scripts must be learned within the context of a specific culture, and within the context of a specific speech community. Although the Chinese script can be read by speakers of a number of different languages, the conventions of the script and the way it relates to a speaker's own language must be painstakingly memorized.

Writing seems to have been invented at least three times in human history: in Mesopotamia, in China, and in Mesoamerica. It may be that there were other independent inventions, or it may be that all the other writing systems have been the result of stimulus diffusion – the spread of a good idea. An evolutionary theory of writing sees a development from pictures to complex symbol systems to scripts with word signs to phonetic (sound based) writing systems.

Logographic scripts (ones in which a picture or symbol represents a specific word) make use of rebuses, that is, of using a picture of an object to represent a word that sounds like the object pictured. Such a script is always language specific. For example, using the picture of a honey bee for the verb *to be* works only in English. Logographic scripts nearly always include additional elements to clarify meaning (semantic determinatives) or to indicate the sound of a word (phonetic complements). Ancient Egyptians had sets of consonant signs indicating one or two or three consonants, as well as hundreds of logographic signs and semantic determinatives. Other examples of logographic scripts are Sumerian, Chinese, Naxi (southern China), and Mi'kmaq (Canadian maritime provinces).

The next step in an evolutionary theory of writing is the addition of a significant phonetic component. In phonetic scripts most signs refer not to words, but simply to sounds. Of phonetic systems there are two types: syllabaries and alphabets. A syllable is composed of a vowel and any consonants that immediately precede or follow it. In practice, in most syllabic scripts, each sign represents a simple consonant–vowel combination. There are, for example, individual signs for *pa, pe, pi, po,* and *pu* instead of a single symbol for the sound *p* and symbols for each vowel. Syllabic systems often include a set of logographic signs (such as the *kanji* component of Korean and Japanese), and may have one or two symbols for a single consonant (in Japanese there is a symbol for *n*, in Cherokee a symbol for *s*). Although early students of writing considered syllabaries to be merely a step toward the culmination of the alphabet, syllabic systems have had a long history of success. Japanese, Linear B, Akkadian, West African scripts, and Cherokee are only a few examples.

In contrast to multiple inventions of syllabic scripts, the alphabet seems to have been invented only once. Certainly there are hundreds of distinctive alphabetic scripts, but the history of each one can be traced from a single origin in the Mediterranean region some 3,500 years ago. In alphabetic systems, each sign represents a single sound – a single consonant or vowel (the earliest alphabets were largely consonantal systems). The Proto-Sinaitic, Ugaritic, and Phoenician scripts are the immediate ancestors of the Greek and Roman alphabets. Alphabets have an advantage for languages with consonant clusters such as English. The word *split*, for example, in a syllabary would have to be written with four syllabic signs: *si-pi-li-ti*, suggesting the presence of more vowels than the word has. The sequence of syllabic signs could also spell *spilt*, or any of a variety of nonsense words. Alphabetic systems generally include at least a few logographic symbols, such as the symbols for numbers.

Any script with a history – one in use longer than a single generation, or used for more than one language or one dialect – suffers from the effects of standardization and carries a baggage of archaic spellings. *Aunt* and *ant* may or may not be pronounced the same. *Beau* and *bow*, *bough* and *bow* reflect language history, and show clearly that English writing is not a purely phonetic system. Standardized spellings are much easier to read than technical transcriptions, in which linguists using a system such as the IPA, the International Phonetic Alphabet, try to capture the precise details of a specific utterance.

Although no script is ever a pure example of the above categories, each category differs in the usual number of total signs. Counting the number of individual signs can sometimes suggest the nature of an unknown script. Logographic systems contain the most signs, sometimes numbering in the thousands. Syllabic systems require only as many signs as there are consonant + vowel syllables in a language, usually in the range of 40–150 signs. Mixed logographic-phonetic scripts can range from hundreds into the thousands. Alphabets have the fewest – only enough to represent the sounds of a particular language. Only 13 letters are needed to write the Hawaiian language, compared with 24 symbols in the Germanic runic script and 44 for Cyrillic. The total number of signs in an alphabet does not necessarily match the number of distinctive sounds in a language. The alphabet used for English has only seven vowel letters (*a, e, i, o, u, w,* and *w*) that are used alone or in various combinations to represent at least 12 distinct vowel sounds.

Another way that script types differ is in their longevity. Two of the best known logographic scripts, Chinese and Egyptian have had far longer life spans than the alphabet. An identifiable Chinese script was functional at least by 1200 BCE, and continues in use by millions of people today. Egyptian hieroglyphic writing ceased by the tenth century CE, but has a history of nearly 4,000 years. Akkadian in Mesopotamia was used for over 2,000 years. Syllabaries seem to have briefer lives. Linear B in Mycenaean Greece was used for about 200 years. The two syllabic components of the Japanese script, *hiragana* and *katagana*, are slightly over a 1,000 years old, developed by the eighth and ninth centuries CE, respectively. The Cherokee syllabary dates only from 1820. What of the alphabet? Probably dating no earlier than the first or second millennium BCE, its future seems promising. As a tool of the electronic age, the alphabet is a system adaptable to any language and is maximally efficient for keyboard use (this may be, however, because keyboards were invented for the alphabet).

One of the errors in an evolutionary theory of scripts is the notion that they become increasingly abstract, i.e., that over time scripts become more efficient, using fewer signs and simpler sign forms. Scripts with a heavy logographic component tend, however, to develop in the opposite direction, collecting baggage over time. Egyptian grew from 700 signs in Middle Egyptian (ca. 2000 BCE) to more than 5,000 signs by the fourth century CE. The ancient Maya script added hundreds of logographic signs over the 700 years of the Classic period (200–900 CE), while the core of syllabic signs grew at a much slower rate. Chinese characters have increased from 9,000 in the first century CE to about 60,000 by the end of the twentieth century, though today only about 2,400 are in common use.

These dramatic increases happened for several reasons. First, cultural and historical events bring additions to a script over time. This can be seen in the archaic spellings of many English words that reflect pronunciations no longer used or used only in certain dialects. Second, although a purely alphabetic script is easier to learn and easier to write, logographic scripts, once mastered, can be read more rapidly. The debate of whether to teach English-speaking students to learn to read through phonics or through word recognition reflects the fact that even readers of alphabetic scripts make use of both its phonetic and logographic aspects. Third, universal literacy has not always been an ideal, and a difficult logographic script has sometimes been seen as a tool for limiting access to knowledge and prestige. Finally, and probably most significantly, languages rarely add a new sound to their sound inventory and rarely add new syllables. Words, however, are constantly being added. Since vocabulary is an open-ended component of language, any logographic script, one in which symbols represent words, is going to have to grow as new words come into use.

Some scripts owe their invention and development directly to contact between neighbors. One example is the Japanese writing system. Initially Chinese characters were used to approximate the Japanese language, then syllabic features were added to provide more specific phonetic information. Today the combination of *kanji* (Chinese logographs) with the *hiragana* and *katakana* syllabaries, make Japanese a script with one of the world's most arduous learning curves. Sumerian, a largely logographic system, was adopted by the Akkadians who like the Japanese added syllabic features, resulting in a mixed logographic–syllabic system that had a large syllabic component.

Some students of writing see the adoption of a logographic script by speakers of a foreign language as an explanation for the development of phonetic scripts. Foreign users reinterpret logographs that carry semantic and phonetic information as phonetic symbols representing sounds without the specific meaning, or as representing the same meaning but with the sounds it has in the new language, or they may invent phonetic signs to add phonetic information or grammatical detail. Such progressions can be seen in the development of Akkadian from Sumerian writing, or of Japanese syllabaries, and the Korean script – both influenced by Chinese.

The vocabulary used to characterize a script varies from one to another. C*haracters*, *hieroglyphs, glyphs, letters, symbols, icons, signs,* and *graphemes* all describe units of written language. The forms of the signs may be described as *pictographic*, *representational*, *linear*, *cuneiform*, *abstract*, and *geometric*. The organization of the units may be *columnar*, *clustered*, *horizontal* (*left to right or right to left*), *boustrophedon* (back and forth, literally, *as the ox plows*). Within the texts themselves divisions between words, phrases, sentences, and larger units may be ignored or may be indicated by spaces, larger symbols (e.g., upper case letters), or a variety of punctuation conventions.

Language that is recorded in writing represents only a small subset of language that is spoken. Nearly every culture places specific limits on the kinds of information presented and on the manner of presentation. Commercial records, calendrical notations, prayers, magical spells, laws, census records, land deeds, court records, sacred and political histories, diaries, personal letters – these are among the earliest written materials. Novels, commercial advertising, and to-do lists are relatively more recent developments. The surviving examples of some ancient scripts are limited only to one or two genres.

Spoken language reflects an awareness of the speaker's audience, while written language may ultimately reach audiences never dreamed of. Written language tends to be more deliberate, generated at a much slower pace than speech. Nor does it have the meta-linguistic features that add dramatic force and subtle nuances to a speech act. Efforts to indicate variation in tempo, volume, and pitch (such as with underlining, boldface, accent marks, exclamation, or question marks) fall far short of the tools available to a speaker. Missing, too, are facial expressions, body posture, and hand gestures.

In contrast to recording language, there have developed a number of systems that approach writing, but do not fit the strictest definition of writing. Several of these hieroglyphic scripts are or were, in fact, readable within the culture that produced them, but with no or with only minimal phonetic components they can have only uncertain meaning to the uninitiated. One example is the Mixtec writing known from eight pre-Columbian screenfold books. In these a complex iconography is tied to narrative images recording sequences of historical events and genealogies. Although the meaning is often clear, it is impossible to know exactly how the texts would have sounded when they were read – impossible to know precisely what words were associated with the images. Another example is the Naxi Dongba writing of southern China dating from the thirteenth century. This hieroglyphic script is still used and studied today. The meanings of the signs are complex, with minimal phonetic information indicated. Mixtec and Naxi represent yet another challenge to the evolutionary model. Rather than pictographic scripts always preceding true writing, some of them were created by cultures imitating neighboring scripts.

Also implied in the evolutionary theory of writing is a gradual development from picture signs to syllabic signs. Many books on the history of writing show charts of simple pictures for objects next to related but more abstract forms that exist in a particular script – the most common scripts pictured are Chinese, Akkadian, and sometimes even the Greek alphabet. However, direct evidence of this gradual development from pictures to a phonetic script is seldom available. An alternate scenario is that at some point in time one person, or a small group of persons, took an existing symbol system, and from it chose a set of signs to produce a phonetic system, usually a syllabary. We know that this happened with Sequoyah, the man who invented the Cherokee syllabary. History also tells us that this is what happened in the fifteenth century when King Sejong, or a committee created by him, developed the Korean *Han'gul* script. Because a phonetic script is a complex interdependent system it can only function when a complete set of phonetic signs are in place. For most scripts, this crucial moment of creation remains a conjecture.

Some have asserted that writing, specifically the alphabet, gave humans the ability to order and to classify information. Linguistic and cognitive anthropologists, however, have demonstrated repeatedly that complex categorization also exists in societies without writing. What then does writing contribute? Certainly it contributes a memory beyond the life span of a single person, knowledge that is independent of oral transmission. This enables an accumulation of knowledge across time and across cultures. Writing has given us detailed insight into earlier societies. Several languages, such as Sumerian, Hittite, Etruscan, and Tocharian, have no direct descendants, and are known only through their written texts.

This essay speaks about script types and script developments. For those who are interested in the variety of the world's scripts there are a number of excellent introductory texts, some generously illustrated. For example, see Coulmas (1989, 1999), DeFrancis (1989), Pope (1999), Robinson (1999, 2002), Rogers (2005), and Sampson (1990). One volume stands out for its quality and comprehensive coverage: *The World's Writing Systems,* Daniels and Bright (1996). Also excellent are the individual volumes of the *Reading the Past* series: Bonfante (1990) Chadwick (1987), Cook (1987), Davies (1987), Healey (1990), Houston (1989), Page (1987), and Walker (1987). Two dramatic stories of decipherment are Chadwick (1967) for Linear B and Coe (1999) for the Maya script. Boone (2000) and Boone and Mignolo (1994) offer enlightened discussions of nonphonetic systems. The potential of the as yet undeciphered Inca knotted *khipu* as a record of detailed information, perhaps including speech can be found in Urton (2003) and Quilter and Urton (2002).

Recent years have seen a growing number of websites, both about scripts in general, as well as sites devoted to a single script. Below are listed two general websites for writing systems, both with links to many other resources, and several sites relating to specific scripts or regions. Searching on the web for *writing systems*, or for any country, language, or script name will yield a large number of sites. Some of these are sponsored by academic institutions, a few are commercial, and a few are sponsored by individuals. Their quality varies, though even sites with incomplete or nonstandard information often provide useful images.

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Websites General

Omniglot: A Guide to Writing Systems ►http://www.omniglot.com/index.htm.

Writing Systems of the World ►http://logos.uoregon.edu/explore/orthography/.

Africa African Writing Systems

►http://www.library.cornell.edu/africana/Writing_Systems/Welcome.html.

The Demotic Dictionary Project ►http://oi.uchicago.edu/OI/PROJ/DEM/Demotic.html.

Easter Island

The Rongorongo of Easter Island ►http://www.rongorongo.org/index.html.

Mediterranean/Mesopotamia

Cuneiform Digital Library Initiative ►http://cdli.ucla.edu/index.html.

Hittite ►http://www.asor.org/HITTITE/HittiteHP.html.

The Origins and Emergence of West Semitic Alphabetic Scripts ►http://as3.lib.byu.edu/~imaging/negev/.

India

Languages and Scripts of India ►http://www.cs.colostate.edu/~malaiya/scripts.html.

Mexico and Central America

Foundation for the Advancement of Mesoamerican Studies ►http://www.famsi.org/.

Mesoweb ►http://www.mesoweb.com/.

Glyph Dwellers ►http://nas.ucdavis.edu/NALC/glyphdwellers.html.

Asia

Library of Congress: Asian Reading Room ►http://www.loc.gov/rr/asian/.

Selections from the Naxi Manuscript Collection ►http://memory.loc.gov/intldl/naxihtml/naxihome.html.

Japanese Phonic Characters ►http://www.uweb.ucsb.edu/~christi/main.html.

Writing in China

Uta Lauer

The origin of a comprehensive writing system in China is a matter of debate. According to an ancient Chinese legend, writing was invented by the three mythical emperors between the twenty-ninth and the twenty-sixth centuries BCE. The earliest evidence for some kind of script is marks on pottery excavated from the Banpo site near Xi'an in Shanxi-province, dating from the Neolithic Age. Proof for a highly developed writing system comes from oracle bones (*jiagu wen*). Datable to around 1300 BCE, inscriptions on bovine, pig, deer shoulder blades or on turtle shell were used for divination. The elite of the Shang dynasty (sixteenth to eleventh century BCE) employed a question and answer model, through which those in power would ask a question, incise it into the bone, and the shaman or priest would drill holes into it, insert a piece of burning coal, interpret the cracks produced by the hot coal, and then write down the answer. About 2,000 different characters have been found on Shang oracle bones, but only half of these have so far been deciphered. Another form of surviving document is short texts cast on the inside of bronze vessels. There are numerous examples of late Shang inscriptions, typically rather short, whereas in the succeeding Zhou period (eleventh century BCE to ca. 771 BCE) inscriptions on bronze ritual vessels were considerably longer. The type of script employed during the late Zhou period was called great seal script (*dazhuan*).

One of the most important steps towards the development of a comprehensive writing system was the unification of the empire under the rule of emperor Qin Shihuang (r. 221–206 BCE) in 221 BCE. Under the jurisdiction of his Prime Minister Li Si, writing was standardised into the small seal script (*xiao zhuan*). This script comprised about 12,000 characters (*zi*). Today, small seal script is still in use on seals and in advertisements. Seals had been made since at least the late Zhou period. They were used instead of a signature and served official, commercial, personal and literary purposes.

With the advent of the Western Han dynasty (206 BCE–9 CE) a new type of script came into use, clerical script (*lishu*). It was easier to write than the angular small seal script and thus more suitable for the ever-increasing amount of official, government related texts. Based on clerical script a kind of shorthand developed for less formal occasions like writing letters or jotting down notes. Literally translated into English it is called grass script (*caoshu*), but is also frequently referred to as draft script, running script or fully cursive script. To avoid confusion of technical terms, it is best to use the unambiguous Chinese terminology. During the Han dynasty, the potential of writing as a medium for artistic expression was fully recognised. It was then, that the art of calligraphy (*shufa*) was born. Another less abbreviated form which emerged from clerical script is semi-cursive script (*xingshu*).

During the fifth century, the last type of script was codified, regular script or standard script (*kaishu*), which is still in use today. After that, the evolution of the Chinese writing system was complete. This had a culturally unifying effect this had to a high degree. Chinese characters serve as a binding element, as an identification factor and as bearers of an uninterrupted tradition.

With the end of imperial rule and the founding of the Republic of China in 1912, a debate about the simplification of characters began. Some argued to abolish Chinese characters entirely and to replace them with a romanization system in order to promote literacy. Several reforms followed until finally in 1964 a list of simplified characters (*jianti zi*) was approved. Today simplified characters are used in the People's Republic of China whereas other countries which employ Chinese characters have maintained the complex characters (*fanti zi*).

In 1979 the government of the People's Republic of China adopted the Hanyu Pinyin system, a phonemic notation and transcription to Roman script. Pinyin is very useful as a cataloguing method and for writing Chinese on computers.

Essential for the development of the art of calligraphy was the material used for writing, namely the pliable brush, absorbent paper and ink. The earliest surviving documents written with a brush and ink on strips of bamboo date to the third and second centuries BCE. Already by the fifth century BCE silk was also in use as a writing ground. Silk existed in China since Neolithic times. Archaeological evidence shows that paper was being made from the first or second century BCE. Paper was much cheaper than silk, relatively easy to make and less cumbersome than bamboo strips. The availability of paper made possible the steady increase in writing throughout the empire. The earliest examples of ink are found in traces of writing dating to the fourteenth century BCE. Chinese ink is made from carbon, lampblack and glue which is then dried and moulded into the form of sticks or cakes. To obtain liquid ink, the ink stick has to be ground by hand on an inkstone with the addition of water. During the tenth century CE, writing equipment (brush, paper, ink and inkstone) came to be known as the "four treasures of the scholar's studio" (*wenfang si bao*).

Since ancient times, calligraphy belonged to the six liberal arts (*liu yi*) practised by the social elite of the country. When looking at a work of calligraphy, the viewer can relive the process of its creation. The writing speed, pressure, energy, any moment of hesitation remains visible on the paper. The flexible brush allows for an endless variation of stroke shapes. Soon, the styles of individual masters of calligraphy were canonized. For transmitting calligraphic styles, various copying methods and the formation of collections were important. Before the invention of printing in the Tang dynasty (618–906 CE), several techniques for copying were employed. Exact copying (*mu*) is basically a tracing technique. To make a free copy (*lin*) the original is placed next to the sheet of paper on which the calligrapher reproduces the work at his own speed. Essential for a wider circulation of calligraphy styles were ink rubbings. For this reproduction method, a copy of the original written in ink is pasted to a stone or wood surface and then meticulously engraved into the surface through the copying paper. Then, a moistened paper is placed over the engraved calligraphy and pushed into the incised areas with a brush. Finally, a pad soaked in ink is dabbed over the surface. The background of such a rubbing appears black and the characters white.

All types of script are employed in calligraphy but semi-cursive script and grass script are the two most suitable for artistic expression. Among the most notable calligraphers are Wang Xizhi (307–365) and his son Wang Xianzhi (344–388), Yan Zhenqing (709–782), Huaisu (725–785), Su Shi (1036–1101), Huang Tingjian (1045–1105), Mi Fu (1051–1107), Zhao Mengfu (1254–1322), Wen Zhengming (1470–1559) and Dong Qichang (1555–1636). Since the fourth century CE records and art historical treatises on calligraphy exist. Calligraphy as the embodiment and a highlight of Chinese culture forms an important part of the imperial art collection.

In 1949, when the People's Republic of China was founded and the Guomindang defeated, the Guomindang took a substantial part of the former imperial art collection to Taiwan, where it was housed at the National Palace Museum Taipei. The remainder of the collection stayed at the Palace Museum Beijing. From the beginning of the twentieth century onwards, collectors outside Asia developed a keen interest in calligraphy. Private collections and museums in the USA and in Europe now own a number of representative works of Chinese calligraphy. Research at universities on the history and the aesthetics of the art of writing is particularly prominent at some major US universities and in Germany.

In China, both the practise and theory of calligraphy are taught at art academies. Exhibitions and competitions are held regularly. Some contemporary Chinese calligraphers have gained recognition outside Asia and their works are on display in museums. Calligraphy is an art that is very much alive. Not only is the tradition passed on but there is also experimental writing. Young artists explore and challenge the basic principles of writing in their works. The brush might be replaced by a neon light, ink by water, thus highlighting the act of writing and pointing towards the perishable material.

Writing in Egypt in its Literary Context

William S. Arnett

The evolution of Egyptian writing (hieroglyphs) is traditionally dated to Dynasty 1 of ancient Egypt's Proto-Dynastic Period ca. 3100–3000 BCE. Until recently,

Writing in Egypt in its Literary Context. Fig. 1 Funerary Papyrus of Hunefer. The Sun god is shown in the form of a great cat killing the serpent of darkness. British Museum (EA9901.8). Photo by Jon Bodsworth. Used with his kind permission.

priority of first place in the history of writing seemed to belong to the Sumerians of ancient Mesopotamia (now southern Iraq). However, the recent discovery of labels in tomb U-j at Abydos, Egypt, tomb of the Scorpion King, have provided evidence of writing in Egypt as early as 3250–3200 BCE. The earliest Egyptian attempts at writing consisted of potmarks, designs painted on jars, and of motifs carved on the surfaces of cosmetic slate palettes and other artifacts found in the graves of Predynastic Egyptians at a number of sites (ca. 4500–3000 BCE) and in temple deposits at Hierakonpolis. These examples were clearly precursors to the classical Egyptian hieroglyphs (Arnett 1982; Elkins 1999; Casson 1965: 141–148; Gardiner 1978).

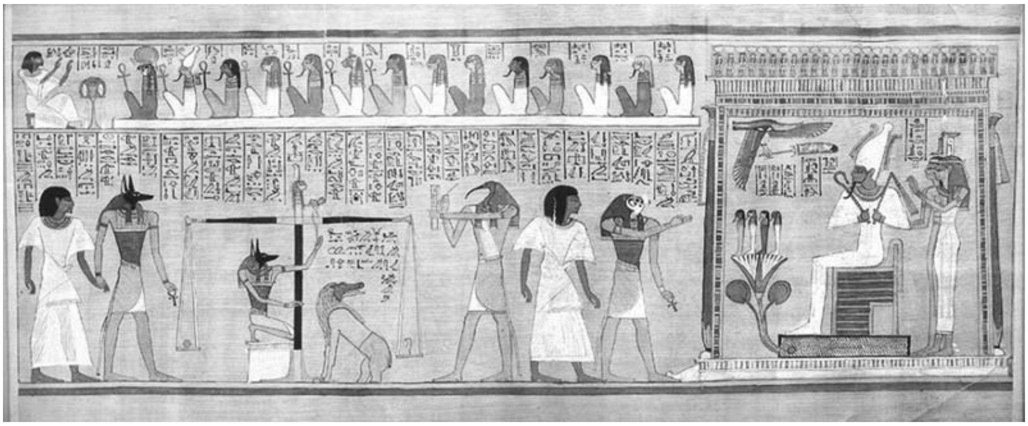
The hieroglyphs worked best on stone, although they were also written on papyrus and other materials. Papyrus was a parchment-like paper made from the reed plant of that name which once grew in abundance along the banks of the Nile River. It was the most common material used for official record keeping, correspondence, literary works, administrative documents, etc. For these purposes the Egyptians developed a more cursive style of writing. This occurred early in the development of hieroglyphs. Scholars call the earliest type of this writing hieratic (literally "priestly" writing), although it was not used exclusively by the priests. The scribes used lampblack and wrote with reed pens when writing on papyrus and brushes when using wood and other materials such as ostraca.[1] Later, in the seventh century BCE, the Egyptians developed another even more cursive system that is known as demotic, or popular. Generally, both of these more rapid writing systems were written on papyrus (Figs. 1–3).

The quantity of such examples of Egyptian proto-writing suggests that Egyptian writing may have evolved as early as (if not earlier than) the Sumerian cuneiform system so prominent in Mesopotamia and much of the ancient Near East from ca. 3000–1000 BCE. It certainly proves that the Egyptians developed their own, unique writing system and that, if they borrowed anything from the Mesopotamians, it was the idea of writing (Arnett 2004; Stiebing 2003: 110–112) (Fig. 4).

The earliest extant Proto-dynastic writings consist of numerous brief texts: funerary stelae, ivory labels and plaques, and a few official monuments and royal inscriptions found in situ at locations both in Egypt proper and in the Sinai Peninsula. These early texts reveal a hieroglyphic writing system that was already fully developed, which led earlier scholars to believe that the Egyptians had borrowed their writing system from the outside world, presumably Mesopotamia. The earlier use by the Sumerians of "symbolic tokens and ideographic inscriptions" as means of the accounting and recording of quantities of products and livestock was assumed to have led to the development of the earliest phonetic writing system in ancient Sumer. But the labels of Tomb U-j at Abydos can be read phonetically and may be earlier than the earliest known Sumerian writing (Stiebing 2003: 112–113). We have evidence of early trade and cultural exchange between late Predynastic Egypt and southern Mesopotamia, and it is highly likely that ideas as well as goods and materials were being exchanged. However, the fact remains that the two earliest systems of writing (Sumerian cuneiform and Egyptian hieroglyphs) use entirely different signs and methods of inscription. While some Mesopotamian writing has survived on stone artifacts, the majority was inscribed upon clay tablets. In Egypt, stone stelae and walls of tombs or temples, stone chips (or ostraca), pieces of wood, and papyrus paper (the use of which dates back to late Predynastic times) were the primary media upon which the Egyptians did their writing. It is more likely that writing evolved in both areas at about the same time (Mark 1997; Wilkinson 2001: 150–182) (Fig. 5).

These early texts provide only minimal details of official political and historical events as well as the accomplishments of the owners of the tombs in which they were found (Lichtheim 1975: (vol. 1) 3; Pritchard 1955; Breasted 1906; Lewis 2003). It is the general consensus that Egyptian writing was initially created for the sole purpose of satisfying the needs of the state

[1] An ostracon is a piece of pottery usually broken off from a vase or other earthenware vessel. In archaeology, ostraca may contain scratched in words or other forms of writing which may give clues as to the time when the piece was used. The word is derived from Greek *ostrakon* meaning a shell or a shard of pottery used as a voting tablet. The plural of ostracon is ostraca.



Writing in Egypt in its Literary Context. Fig. 2 Papyrus of Hunefer. The Judgment, from the papyrus of the scribe Hunefer. 19th Dynasty. Jackal-headed Anubis conducts Hunefer to the balance. The monster Ammut crouches beneath the balance so as to swallow the heart should a life of wickedness be indicated. British Museum (EA9901). Photo by Jon Bodsworth. Used with his kind permission.

Writing in Egypt in its Literary Context. Fig. 3 Padiamenet Papyrus. Hieratic Book of the Dead of Padiamenet, chief baker of the domain of Amun. Dynasty 22. British Museum (EA10063). Photo by Jon Bodsworth. Used with his kind permission.

to record all of its administrative, political, economic, diplomatic, and military activities and transactions (Aldred 1998).

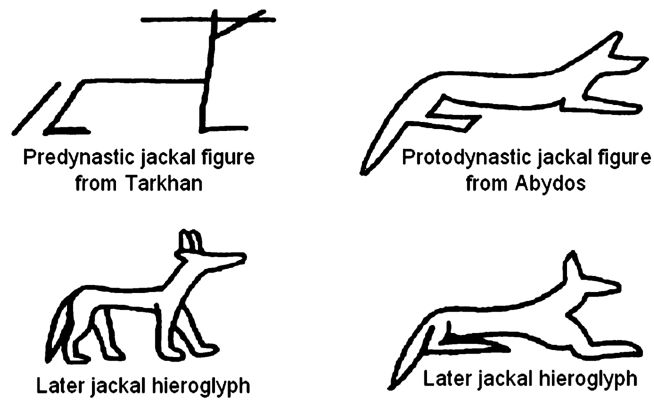
King Lists constitute a genre of Egyptian writing reflecting the above – stated purposes. The earliest, the Palermo Stone, provides the names of kings of the Late Predynastic period through early Dynasty 5. Primarily a list of yearly events and statistics, the main value of this monument is in the ordering of kings by the length of reign and the listing of their achievements as well as recording annual Nile flood heights, a periodic census of men and livestock, and occasional references to public works projects and foreign trade. For instance, there is a reference to forty shiploads of cedar wood imported to Egypt in 1 year during the reign of Snefru of Dynasty 4 (Gardiner 1978; St John 2003; Wilkinson 2000). Other important king lists include the Turin Canon, the lists of royal ancestors of Sety I and Ramses II at Abydos, the Royal List of Karnak, and the Royal List of Sakkarah (Clayton 1994; Shaw 2000) (Figs. 6 and 7).

But, according to Lichtheim, the "first major application" of Egyptian writing was in the omnipresent Offering Lists found in the tombs of the well-to-do Egyptians of the Old Kingdom (Figs. 8–10).

These offering lists consisted of the names of the tomb owners, their family members, a record of the offices and titles held by them, and an accounting of the funerary offerings they required. By Dynasty 5, the Offering List was shortened into a Prayer for Offerings (Lichtheim 1975: 3; Breasted 1906: Vol. 1, 75–175) (Figs. 11–13).

As a result, wall space was freed for the development of a descriptive narrative containing historical and autobiographical material which the Egyptian nobles (administrators, prophets, judges, "overseers of the King's land," viziers, architects, soldiers, scribes, priests, etc.) had written/sculpted/painted on the walls of their tombs and/or tomb chapels. These texts and accompanying illustrations provide us with portrayals of the tomb owner, his family, and his servants (Figs. 14–17).

These texts, also called "Biographies of the Nobles," often contain gross exaggeration and considerable boastfulness, and were meant only for their family, priests, and the gods they were meant to impress. Their discovery in modern times has given historians access to important primary source material for the reconstruction of ancient Egyptian history. They provide us with glimpses of the public careers and achievements of the administrative, bureaucratic, and military



Writing in Egypt in its Literary Context. Fig. 4 Jackal Images: examples which illustrate the evolution of Egyptian writing from the earlier prototypes (proto-writing) to the historical hieroglyphs. Artwork and image by William S. Arnett. Used with his permission.

Writing in Egypt in its Literary Context. Fig. 5 Ugaritic Alphabet using cuneiform characters. From Ugarit (Ras Shamrah), Syria. Aleppo Museum. Photo by William S. Arnett. Used with his permission.

Writing in Egypt in its Literary Context. Fig. 6 Royal Ancestors of Sety I and Ramses II (Dynasty 19). Royal cartouches on the walls of Sety's Temple dedicated to Osiris at Abydos. This scene shows part of the list of previous Egyptian Pharaohs. Photo by Jon Bodsworth. Used with his kind permission.

Writing in Egypt in its Literary Context. Fig. 7 Sety I and Ramses II. Seti I and his son Ramesses II offering praise to a list of royal ancestors. Temple of Sety I at Abydos. Photo by Jon Bodsworth. Used with his kind permission.

personnel who served the kings throughout the history of Dynastic Egypt. Tomb biographies also exist for nobles and some commoners throughout the rest of ancient Egyptian history. Lichtheim notes that, from the First Intermediate Period on, for many individuals, a shortened biography would be relegated to the tomb stela which also contained an offering prayer and an offering scene, making the stela a "self-contained memorial" (Breasted 1906; Lichtheim 1975: 8; 15–28).

A second literary genre, Instructions Literature, is among the Old Kingdom's greatest contributions to

Writing in Egypt in its Literary Context. Fig. 8 Mastaba (tomb) of Mereruka. The tomb of Mereruka is the largest extant noble's tomb at Saqqarah. Mereruka was the vizier of Pharaoh Teti, first king of Dynasty 5 (2345–2333 BCE). Photo by William S. Arnett. Used with his permission.

Egyptian writing. This category is also known as Wisdom Literature, which Miriam Lichtheim calls the "second major literary genre created in the Old Kingdom" (Lichtheim 1975: 5). They are written in the guise of the advice of a King, Prince or Vizier to his son. The earliest known example is the *Instructions of Hardjedef*. The sage Hardjedef (Hordjedef) was the son of Kheops (Khufu) in Dynasty 4. He also figures as a participant in the *Three Tales of Wonder* (from the Papyrus Westcar in the Egyptian Museum of Berlin). Prince Hardjedef claims to have written the instructions for his son, Au-ib-re. Not too much of his Instruction has survived, but his name is always listed among those of the great sages of Egypt (Simpson 1973: 340–341). Lichtheim (1975: 5–7 and 58–59) considers all three of the earliest Instructions (Hadjedef, Dynasty 5, and Kagemni and Ptahhotep, late Dynasty 6) to be pseudepigraphical[2] works.

Another well-known example of this genre is the *Instructions of Ptahhotep*. The sage Ptahhotep, who, supposedly, was the vizier of the Fifth Dynasty pharaoh Izezi (2388–2356 BCE), provides maxims of good and polite conduct and of good speech.

These works constitute a form of political propaganda in a literary format. They posit that order and *ma'at* (justice and balance) are only possible when there is a

Writing in Egypt in its Literary Context. Fig. 9 Ka statue of Mereruka in the Offering Chapel of his mastaba. The family and/or funerary priests left food offerings before Mereruka's statue in order to provide continual sustenance for him in the afterlife. Photo by William S. Arnett. Used with his permission.

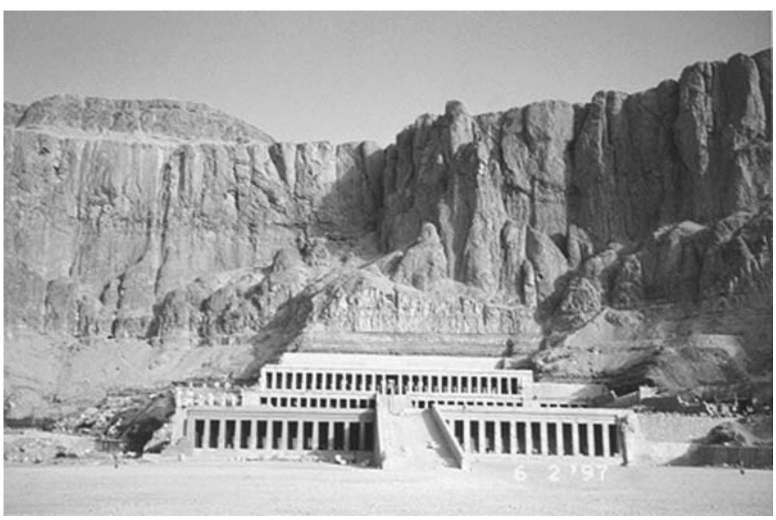
Writing in Egypt in its Literary Context. Fig. 10 Mereruka Wall Scene. The diminutive figure of Meri-Teti, son of Mereruka, is seen at the feet of the Vizier Mereruka. Mastaba of Mereruka (Dynasty 5) at Saqqarah. Photo by Brian Anderson. Used with his kind permission.

strong and benevolent monarch on the throne of a united Egypt. In addition, they offer advice on proper behavior that reflects the mores of nobles of Dynasty 5 and Dynasty 6.

[2] Pseudepigrapha (from the Greek words pseudos = false and epigrapho = write) describes texts whose claimed authorship is unfounded in actuality. The authenticity or value of the work itself, which is a separate question for experienced readers, often becomes sentimentally entangled in association. Yet few Hebrew scholars would insist that the Song of Solomon was written by the King of Israel, or ascribe the Book of Enoch to the prophet Enoch.

Writing in Egypt in its Literary Context. Fig. 11 Deir el-Bahri Offerings. In the private tombs of the nobles of the Old Kingdom, the List of Offerings consisted of prayers and items meant to provide sustenance to the decedent in the afterlife. In a similar manner, the royal temples of the New Kingdom, Kings portrayed themselves making offerings to the gods (see Fig. 6). Here we see a wall relief from Hatshepsut's funerary temple that depicts her offerings to the god Amun. Photo by William S. Arnett. Used with his permission.

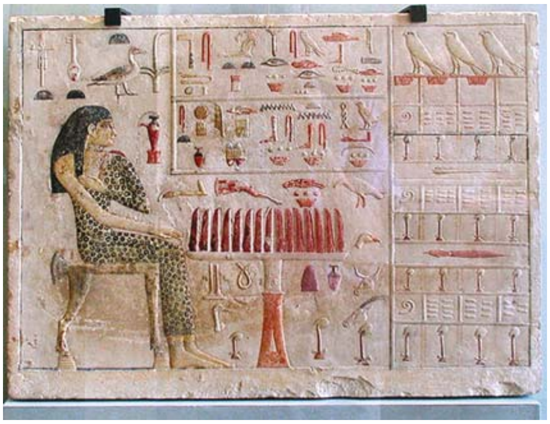
Writing in Egypt in its Literary Context. Fig. 12 The female Pharaoh Hatshepsut presents offerings to the God Amun. Funerary Temple of Hatshepsut at Deir el-Bahri. Photo by William S. Arnett. Used with his permission.



Writing in Egypt in its Literary Context. Fig. 13 The Funerary Temple of Hatshepsut at Deir el-Bahri (Dynasty 18). Photo by William S. Arnett. Used with his permission.

A third example, *The Instruction to Kagemni*, most likely written during Dynasty 6, alleges to be the advice given to Kagemni, the vizier of Huni, the last king of Dynasty 3 and of Snefru, the founder of Dynasty 4. The beginning of Kagemni's Instruction is lost, and its true date and authorship are unknown.

The Instruction of Merikare was supposedly written by King Khety II (ca. 2100 BCE), the father of



Writing in Egypt in its Literary Context. Fig. 14 Stele of Nefertiabet. Princess Nefertiabet, a daughter of the Pharaoh Khufu (Dynasty 4), is seen here seated at her offering table in her tomb at Giza. This wall section is in the Louvre Museum (E22745) in Paris. Photo by Jon Bodsworth. Used with his kind permission.

Writing in Egypt in its Literary Context. Fig. 15 Stele of Rahotep (Dynasty 4) from Meidum. British Museum (EA1242). Photo by Jon Bodsworth. Used with his kind permission.

Writing in Egypt in its Literary Context. Fig. 16 The Necropolis of Gizeh. In the shadows of the Great Pyramids, the tombs of the princes and high-ranking nobles of Dynasty 4 were buried in tombs arranged in orderly rows so that they would be with their king in the afterlife. Photo by William S. Arnett. Used with his permission.

Writing in Egypt in its Literary Context. Fig. 17 The Great Pyramids of Gizeh. Viewed from the desert to the west, the pyramids of Khufu, Khafre, and Menkaure are ancient Egypt's most famous monuments. Photo by William S. Arnett. Used with his permission.

Merikare of Dynasty 10. His (Merikare's) capital was at Herakleopolis. However, most scholars believe that it was actually written by scribes at the court of Merikare. Its uniqueness lies in its new dimension as a royal inscription in which a dying king bequeaths the throne to his son and successor and offers him advice on how to be a good king (Lichtheim 1975: 9–10).

The Instruction of Amenemhet I (*or* Amenemes I), supposedly written by Amenemhet I to his son Sesostris I (Senwosret I), of the Middle Kingdom (Dynasty 12), is a more famous example of this genre. The serenity and balance in Egyptian society as it appeared during the Old Kingdom had been replaced by the political and economic turmoil and social upheaval of the First Intermediate Period. Even though order had been restored by the Kings of the Middle Kingdom, our literary evidence suggests that the crown represented a heavier burden for the monarchs of the Middle Kingdom, and that the dangers of civil strife and revolution were lurking just below the surface. The apparent assassination of Amenemhet I (alluded to in both the *Instruction of Amenemhet I* and *The Story of Sinuhe*) suggests that things had gone awry and that men were doing evil things. In the *Instruction of Amenemhet*, the dead King (Amenemhet I) appears as a ghost to his son Sesostris I (or Senwosret I), tells of his assassination in the palace at the hands of his own palace guard, and suggests that it was instigated by someone in the harem. He advises his son to rule with a strong hand and to trust no one in the "day of evil" (Erman 1927: 72–74; Pritchard 1955: 418–419; Simpson 1973: 193–197; Parkinson 1997: 203–211; Lichtheim 1975:135–139).

The Teaching of Duaf's Son Khety, elsewhere known as the "Satire of the Trades," also dates to the Middle Kingdom and proclaims that the most exulted profession is that of the scribe. The writer belittles all other occupations by listing all the hardships experienced by those employed in them (Parkinson 1991: 72–76).

The Prophecies of Neferti (James 1979:102; Lichtheim 1975: 8–9 and 139–145; Erman 1927: 110–115; Pritchard 1955: 444–446; Simpson 1973: 234–240), the *Admonitions of Ipuwer,* and the *Prophecy of Nefer-rohu* represent a new departure in Egyptian literature. Neferti was a lector priest (literally, "he who carries the ritual") at Bubastis during the reign of Amenemhet I. This composition purports to be the prophetic vision of someone at the court of Snefru of Dynasty 4 who predicted the coming of the troubles of the First Intermediate Period and of Egypt's savior, Amenemhet I, the first king of Dynasty 12. In other words, this piece was probably written to justify the seizure of the throne of Egypt by Amenemhet I. Neferti and Ipuwer address the problem of evil and proclaim that a strong monarchy is the only way to protect Egypt from its dangers. The pronouncements of the sage Ipuwer are reminiscent of those of the Biblical Prophets who chastised the Kings of Israel for not doing their religious and political duties.

The Admonitions of Ipuwer was probably written in the early years of Dynasty 12 and is generally interpreted as being either a warning to a king about the disastrous consequences of misrule or else as a means of contrasting the faithfulness of a good king (presumably one of the Dynasty 12 rulers) with the inadequacies of a bad king whose failure to tend to the religious and political duties of the throne resulted in the chaos and anarchy of the First Intermediate Period.

Nefer-rohu foresees the coming of Amenemhet I and speaks of him in such familiar terms that scholars are convinced that his prophecy was actually written during the reign of Amenemhet (Erman 1927: 110–115; Pritchard 1955: 444–446).

The Song of the Harper dates to the First Intermediate Period, the era of disunity and civil and social unrest following the collapse of the Old Kingdom. It reiterates the above-mentioned concern for the loss of order and expresses the sense of futility in providing and protecting the "houses of eternity" (tombs) of the kings and nobility. In addition, the song offers an unprecedented philosophy of pessimism and skepticism concerning the shortness of life and the uncertainties of life after death (Lichtheim 1975: 193–197, 222–235; James 1979: 98; Pritchard 1955: 18–22; Parkinson 1991: 36–37; Simpson 1973: 57–74; Erman 1927: 14–29). Was this pessimism truly reflective of a new Dawn of Conscience, as Breasted suggested (1976), or was it simply an irreverent farce from some popular poem or drinking song?

The Middle Kingdom (considered by later generations of Egyptians to have been the golden age of Egyptian culture and history for its art, calligraphy and literature) also produced a popular piece of prose, known as the *Story of Sinuhe*, a work of historical fiction. It depicts the adventures of an Egyptian nobleman who fled into exile in Palestine, perhaps because he feared he would be implicated in the murder of King Amenemhet I, and only returns near the end of his life to be buried in his homeland. The story also presents Senwosret I (Sesostris) as a benevolent king who restores *ma'at* (truth, the world order, justice, etc.) and welcomes Sinuhe back to Egypt with open arms. It provides the earliest literary description of Palestine and portrays it in Bible-like fashion as a land of milk and honey: "Abundant was its honey, many sweets were made for me, and milk dishes of all kinds."

Scholars are fairly certain that they know the identity of the author of this famous story. His name was Achthoes. *The Papyrus Chester Beatty IV*, in the British Museum (#10684) avers that, "It was he who made a book as the Instruction of King Sehetepibre." The latter is the name taken by Amenemhet I when he assumed the throne. Achthoes is also known to have written the previously mentioned Instruction book entitled the *Satire of the Trades (*James 1979: 98; Parkinson 1997: 21–53; Erman 1927: 14–29; Pritchard 1955:18–22; Simpson 1973: 57–74; Lichtheim 1975: 222–235).

The Tale of the Eloquent Peasant, like so many of our surviving Egyptian literary texts, is also a product of the Middle Kingdom. In fact all of the manuscripts containing this story come from that era. It may be the mere chance of discovery, but it could also mean that, unlike other tales from the 12th Dynasty, this particular example did not enjoy continued popularity during the later New Kingdom. Social equity and the right of commoners to expect fair treatment at the hands of the nobility and the government are the central themes along with the unexpected eloquence of a peasant (Pritchard 1955: 407–410; Parkinson 1991: 64–65; Erman 1927: 116–131; Lichtheim 1975: 169–184; Simpson 1973: 31–49).

The Tale of the Two Brothers, a work composed in Dynasty 19 (ca. 1210 BCE), has elements similar to the story of Joseph and the wife of Potiphar in Genesis 39. But, as the noted Coptic scholar Plumley pointed out in 1958, the two stories have some common aspects, "but it would require much greater similarity of detail between the Egyptian and the Hebrew stories to justify the oft-made suggestion that the Egyptian story is the origin of the incident described in Genesis."

Writing in Egypt in its Literary Context. Fig. 18 Golden Bowl of Djehuty. A solid gold bowl from the tomb of the General Djehuty. He served the Pharaoh Tuthmosis III. His tomb was found at Saqqara in 1824 but the contents were distributed and the site of the tomb is now lost. Louvre Museum. Photo by Jon Bodsworth. Used with his kind permission.

The Capture of Joppa, found with the *Story of the Doomed Prince* on the same papyrus (Harris, # 10060, Br. Museum), is an historical romance dealing with General Djehuty, who served Thutmosis III in his campaigns in Syria–Palestine (ca. 1504–1450 BCE) and depicts an event otherwise unknown in the official Egyptian annals. Djehuty outwits the city's defenders by having him and several Egyptian soldiers smuggled into Joppa in baskets (James 1979: 112; Erman 1927: 167–169; Pritchard 1955: 22–23; Simpson 1973: 81–84) (Fig. 18).

Space permits only the briefest listing of several other categories of Egyptian writing that have survived in great quantities on papyri and ostraca, as well as in the form of inscriptions and paintings on the walls of tombs and temples. The reader interested in further study will find more scholarly information and examples of texts in the linked sites. These additional genres of Egyptian literature include both secular and religious songs. In addition to the above-mentioned Harper's Songs, Egyptian love songs, dating to the New Kingdom, have also survived. These have a timeless quality and can be very romantic and erotic (Foster 1974; Simpson 1973: 296–326).

Egyptian Poetry is found in several forms, including: hymns to the gods and king; love poetry that is both beautiful and passionate, and the above-mentioned Songs of the Harper, filled with uncharacteristic pessimism and practical questioning of time-honored beliefs. Some of this poetry has been compared to the Biblical Song of Songs. It has also been noted that

Writing in Egypt in its Literary Context. Fig. 19 Egyptian Harp. One of several Egyptian musical instruments found in Egyptian tombs. New Kingdom period (British Museum). Photo by Jon Bodswoth. Used with his kind permission.

Writing in Egypt in its Literary Context. Fig. 20 Musicians from the tomb of Nebamon. A relief from the tomb of Nebamon from Thebes. Musicians and dancers accompany a feast. New Kingdom period. British Museum (EA37984). Photo by Jon Bodsworth. Used with his kind permission.

Egyptian love lyrics "are part of the same ancient tradition of erotic verse which we find in the cultures of the Fertile Crescent" (Kaster 1968: 220–233; Erman 1966: xxxi–xxxviii; Erman 1927: lviii–lxii; Lichtheim 1975: 11–12; Simpson 1972: 169–326) (Figs. 19 and 20).

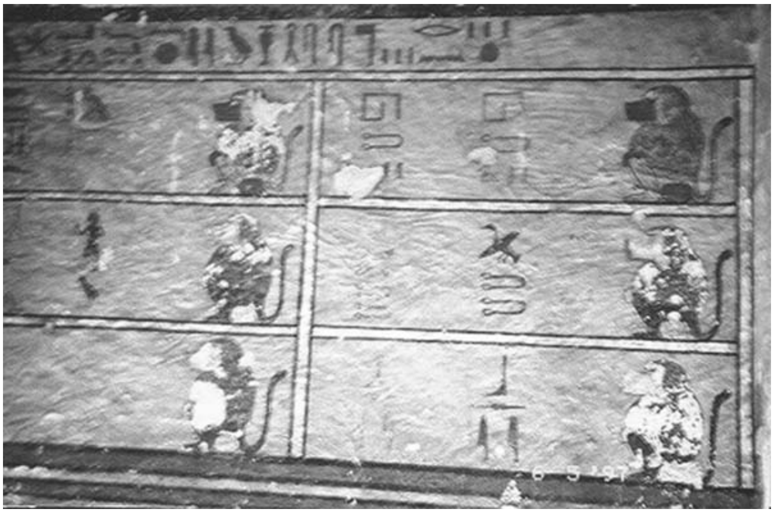
Egyptian hymns are not only dedicated to the gods of Egypt, but also to the kings. The most famous Egyptian hymn is the Hymn to the Aton (Aten), which, allegedly, inspired the wording in Psalm 104 in the Hebrew Bible. It is the earliest known monotheistic text in history (Pritchard 1955: 370–371; Simpson 1972: 289–295).

Egyptian letters have survived on papyrus dating as early as the Sixth Dynasty (ca. 2250 BCE). Many of the surviving letters were used as models in the education of scribes who were trained to master the style necessary for official, business, and interpersonal communication.

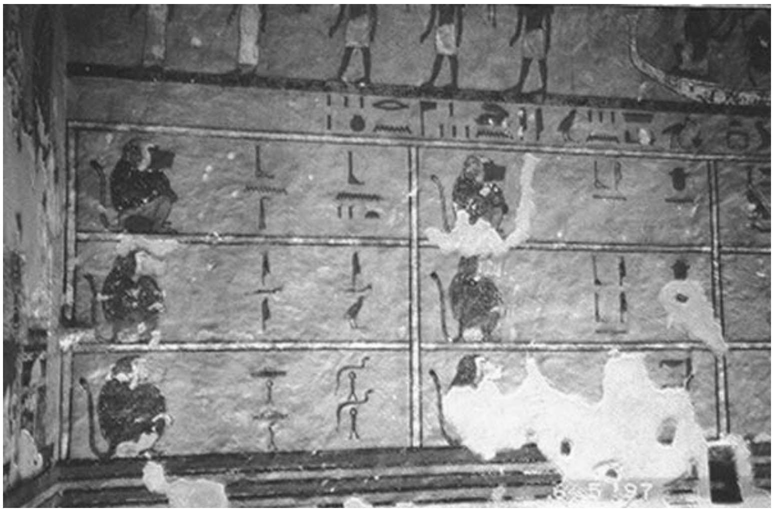
Egyptian Religious Texts constitute by far the greatest number of written Egyptian texts that have survived. The most common examples of this genre include the famous Pyramid Texts, the Coffin Texts, The Book of the Dead, Myths and Creation stories, Oracles and Prophecies, Hymns and Prayers, etc.

The most famous of the Egyptian Mathematical Papyri and texts is the *Rhind Mathematical Papyrus* (ca.1580 BCE). It is believed to have been composed by a scribe named Ahmose during the reign of King Ahmose Auserre in the Hyksos era. It is in the British Museum.

Egyptian Medical papyri and texts are fairly plentiful. The British Museum alone has eight examples. Three of the more important ones include *The London Medical Papyrus* (#10059) which dates to the 18th Dynasty, *The Chester Beatty Medical Papyrus VI* (#10686) and *Chester Beatty X* (a 19th Dynasty text dealing with aphrodisiacs). Perhaps the most famous medical text is the *Edwin Smith Surgical Papyrus*, which is housed in the New York Academy of Medicine. Breasted published a folio-sized edition on this papyrus in 1932. It is a remarkable, scientific



Writing in Egypt in its Literary Context. Fig. 21 *Amduat* scene from the Tomb of Pharaoh Ay. West Valley of the Kings (WV 23). The 12 baboons represent the 12 hours of the night. Photo by Brian Anderson. Used with his kind permission.



Writing in Egypt in its Literary Context. Fig. 22 *Amduat* scene from another wall of the tomb of Pharaoh Ay. WestValley of the Kings (WV23). Photo by Brian Anderson. Used with his kind permission.

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approach to the practice of medicine that deals with 48 different kinds of injury cases and covers surgical treatments for the head and thorax. Ancient Egyptians even knew that a mother's urine is the secret to the determination of the sex of an unborn baby. One of the remedies that it recommended for the treatment of facial wrinkles was described as a lotion that had "proved effective myriads of times." Another very important medical text, the *Ebers Medical Papyrus* (in Leipzig) offers some insights into Egyptian surgical techniques. There is a section on the heart and its vessels, and one of its remedies calls for the use of castor oil as a laxative.

The Egyptian concern with the stars and planets led to serious study of astronomy. From the alignment of the pyramids with the stars to the many myths associated with the day and nighttime journeys of the sun, they have left us both physical and textual

Writing in Egypt in its Literary Context. Fig. 23 The Goddess Nut and the Book of Gates. This painted scene (from the ceiling of the tomb of Ramses VI (KV 9) in the Valley of the Kings, ca. 1141–1133 BCE) shows the upper half of the goddess Nut as she prepares to swallow her "son," the sun god Ra, at the end of his daily journey across the sky. The ceiling paintings portray astronomical themes as well as the various stages of the night journey of the sun god through the underworld. Photo by Brian Anderson. Used with his kind permission.

Writing in Egypt in its Literary Context. Fig. 24 The Goddess Nut and the Book of Gates (b). This scene is a continuation of the previous figure and shows the lower half of Nut's body where she gives birth to Ra at the beginning of each new day. The Book of Gates illustrates the Egyptian interest in astronomy and the universe as well as a new departure in their obsession with the afterlife and the underworld. Photo by Brian Anderson. Used with his kind permission.

evidence documenting their obsession with the universe in which they lived. The earliest evidence of Egyptian astronomical observation takes the form of a series of texts in the lids of coffins dating to the Ninth Dynasty (ca. 2150 BCE) (James 1979: 124–126).

In the New Kingdom, many of the royal tombs in the Valley of the Kings were decorated with scenes from the Amduat ("that which is in the netherworld") (Figs. 21 and 22).

These are found in the form of the *Book of the Day* and the *Book of the Night* in a burial chamber in the tomb of Ramses VI (1144–1136 BCE). These books deal with the day and night journeys of the sun god Ra – in the night, as he travels through the body of his mother, Nut, the goddess of the heavens, and in the day, as he travels across her body, after she gives birth to him once again in the endless cycle of birth, death and regeneration (Silliotti 1997: 64–6); Allen 1988: 38–49; Hornung 1992: 95–113; Shaw and Nicholson 1995: 29, 62, 79, 106, 273, 290, and 299) (Figs. 23 and 24).

Examples of Egyptian writing have survived in fairly great quantities but there are considerable lacunae in our textual knowledge. These lacunae are the result of damage to portions of extant texts as well as to the destruction of tremendous quantities of texts recorded on perishable materials which did not survive the ravages of nature and time. We are indebted to the Egyptians for their strong desire to record their history, religious and philosophical beliefs, as well as the fruits of their imagination and scientific, astronomical, medical, mathematical, and biological inquiries. When considering the great intellectual and cultural debt that the modern world owes to this Egyptian legacy, we can only regret that we have thus far been unable to attain the even greater quantities of writings that remain outside of our reach and understanding.

See also: ►Cuneiform, ►Nilometer, ►Astronomy in Egypt, ►Pyramids in Egypt

Acknowledgments

Thanks to Brian Anderson, a former student at West Virginia University. Photographs featured in Figs 10, 21–24 were used with his kind permission. Thanks also to Jon Bodsworth at The Egypt Archive ►http://www.egyptarchive.co.uk/html/index.html. Photographs featured in Figs. 1–3, 7, 14, 15, 18–20 were used with his kind permission.

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Writing in India

This article deals first with the evolution of writing in India in chronological order, then with the uses of writing.

Indus Civilization (c.2600–1900 BCE): A Forgotten Logosyllabic Script

The Indus or Harappan Civilization flourished in and around the Indus River in present-day Pakistan and western India c. 2600–1900 BCE. The most extensive urban culture of its time, it had its own script, which perished without descendants when the Indus cities and their urban life-style collapsed. Thousands of short inscriptions have been preserved, mostly seal stamps and their impressions (Fig. 1). Because the Indus script has no obvious affinity with any other script (a debated issue) and because there are no multilingual texts, it is exceedingly difficult to decipher.

Writing in India. Fig. 1 A seal stamp (size 20 × 20 mm) from Mohenjo-daro, engraved with the figure of a bison feeding from a trough and above it, a row of Indus script signs. The impression (in mirror image) was read from right to left. Photo Erja Lahdenperä for the University of Helsinki, courtesy Archaeological Survey of India.

Indus merchants sailed to the Gulf and Mesopotamia, where about 40 seal stamps with Indus script have been found. Like the Mesopotamian seal cylinders, they were used to seal containers of goods to prevent unauthorized opening. The Mesopotamian seal inscriptions contain names and titles of the seal owners, and so do probably the Indus seal inscriptions. It is also likely that the Indus script functioned like the Mesopotamian cuneiform script.

Cuneiform writing started as the world's oldest script, Archaic Sumerian (c. 3300–2900 BCE). Initially pictographic, its signs depicted human beings and animals and their body parts, plants and other things. Written on clay with wedge-shaped lines, however, the original shapes became unrecognizable, but the cuneiform script remained a logosyllabic writing system. Each sign either denoted the depicted word (*logos* in Greek)—an arrow-shaped sign Sumerian *ti* 'arrow'—or 'syllabically' its sound irrespective of its meaning —the arrow-shaped sign could also stand for Sumerian *ti* 'life' or *ti* 'rib'.

When the Indus script was created c. 2600 BCE, all the existing scripts were of the logosyllabic type. The Egyptian hieroglyphs and the proto-Elamite script (used widely in the Iranian plateau) were both inspired by the Archaic Sumerian script in the late fourth millennium BCE. The Indus people probably got the idea of writing from the proto-Elamites, but used their own traditional symbols and invented new ones while devising their own script.

In 2004 it was asserted that the Indus script is no real writing system reproducing speech, but only a collection of non-linguistic symbols. However, it radically differs from such symbols widely used in and around the Indus Valley for centuries right until the Indus script came into being. These earlier symbols, called 'potter's marks' because they are mainly found on ceramic vessels, usually occur one by one, whereas the signs of the Indus script occur in long and regular rows, with repeated sign sequences. The script emerged when the weights and measures were standardized and the society became more stratified and completed large and complex building projects.

The Indus script has been "deciphered" more than a hundred times. Most attempts assume the underlying language to be Indo-Aryan, which however was hardly spoken in South Asia before 2000 BCE. The horse is a very important animal in the Rigveda, the oldest surviving Indo-Aryan text composed by 1000 BCE, but the horse is not found among the many animals represented in the Indus art. On the other hand, the Rigveda contains some Dravidian loanwords. Dravidian languages such as Tamil are now mainly spoken in South India, but one (Brahui) survives in Baluchistan and the Indus Valley. Systematic and cross-checked interpretations for more than twenty signs (out of c. 400) based on the Dravidian hypothesis have been presented and won some recognition, but generally speaking the Indus script is still considered undeciphered.

Vedic Times (c. 1300–500 BCE): Accurately Memorized Oral Literature

After the collapse of the Indus Civilization c.1900 BCE its script was forgotten. The Indo-Aryan speakers, who came to South Asia from the northwest during the second millennium BCE, were illiterate, but created sophisticated oral poetry. Over thousand hymns were assembled into a collection called Rigveda c. 1000 BCE. Elaborate repetition techniques developed to assist its accurate memorization have safeguarded the Rigveda from the hazards of oral transmission. Learning the Rigveda by heart takes five years of hard work in early youth, and keeping it in mind requires daily repetition. This way of memorizing Vedic texts still goes on, and their human repositories often are more reliable than manuscripts. The rules created for the preservation of oral literature have been scrupulously observed, and their further development led to astonishing achievements in the study of phonetics and grammar without the aid of writing in the first millennium BCE.

As their standard beginning ("Thus have I heard…") indicates, the earliest Buddhist texts of the fourth and third centuries BCE were likewise orally transmitted.

Old Persian Rule (c. 500–326 BCE): Writing Re-introduced — Aramaic and Kharoṣṭhī

Around 518 BCE, Darius the Great conquered the northern and southern parts of the Indus Valley: they were attached to the Persian Empire as the provinces of Gandhāra and Hinduš for the next two centuries — until Alexander the Great took them over and soon thereafter died in 323 BCE. The Persian bureaucracy used the *Aramaic script* all over the Empire, from Egypt to India.

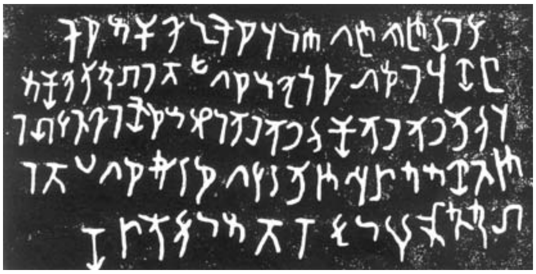
Aramaic is a variant of the Semitic consonantal alphabet which had been created in ancient Syria much earlier (c. 1600 BCE) on the basis of the uniconsonantal signs of the Egyptian script (where signs could express words that contained 1, 2 or 3 consonants). Semitic and Hamitic (i.e., Egyptian) languages can be understood even if the vowels are left unwritten, as they usually are, but the consonantal alphabet is not so suitable for writing other languages.

The Aramaic script was adjusted for writing Indo-Aryan languages by adding markings that express vowels to the consonantal signs; if such an additional sign was missing, the respective consonant was understood to be followed by the most frequently occurring short vowel *a;* consonant groups were expressed by combining consonant signs together. Signs for consonants not represented in the Aramaic script were also created. Why this new syllabic alphabet is called *Kharoṣṭhī* is a much debated question. Kharoṣṭhī greatly resembles the Aramaic script, also in being written from right to left. It was used in the northwest of the Indian subcontinent until c. 200 CE, and in Central Asia until c. 600 CE. (Fig. 2).

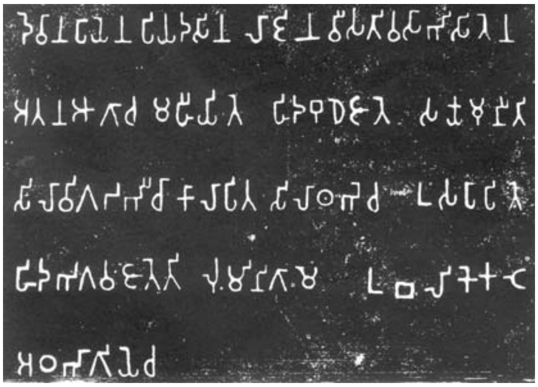
From the Mauryas to the Guptas (c. 320 BCE—550 CE): The Brāhmī script

After Alexander's death, the Persian provinces Gandhāra and Hinduš were quickly incorporated in his emergent empire by Candragupta, the founder of the Maurya dynasty (c. 325–183 BCE). Candragupta's grandson Aśoka (in power c. 268–232 BCE) is one of the most famous rulers of India. Aśoka's rock and pillar edicts, distributed all over his large empire, are the earliest directly preserved historical records of ancient India. Written in local dialects they also provide precious information about the prevailing linguistic situation. Aśoka's inscriptions were written in the Kharoṣṭhī script, in the *Greek script* (introduced by Alexander and used by the succeeding Indo-Greeks in the Indo-Iranian borderlands) and in the *brāhmī script,* which is the basis of most writing systems used in South Asia in later times. The Indian tradition considers brāhmī as an invention of the creator god Brahmā, who is depicted as holding a palm leaf book in the hand.

The brāhmī script is a syllabic alphabet functioning like the Kharoṣṭhī, but with its distinction of short and long vowels and different initial vowels still more perfectly adjusted to Indo-Aryan languages, and written from left to right. It may have been commissioned by Aśoka for his rock edicts around 260 BCE; some improvements in the script appear in the pillar edicts about two decades later (Fig. 3). In that case the brāhmī script is based on the Kharoṣṭhī and Greek

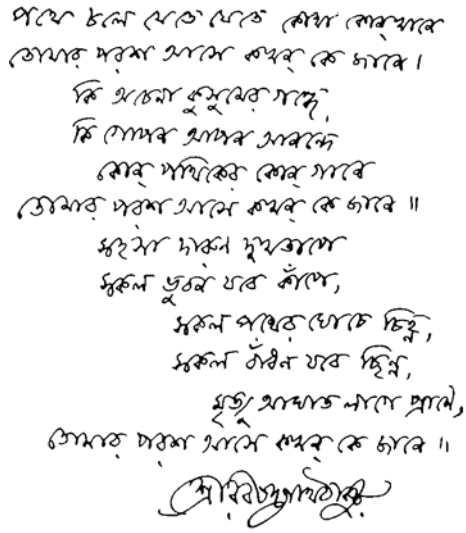


Writing in India. Fig. 2 Kharoṣṭhī script in the Shahbazgarhi rock edict of Emperor Aśoka (c. 260 BCE). Read from right to left.



Writing in India. Fig. 3 Brahmi script in the Rummindei pillar edict of Emperor Aśoka (c. 240 BCE). Read from left to right.

Writing in India. Fig. 4 Siddham script in the "autographed signature of me, Śrī-Harṣa, the overlord of great kings", preserved in a Sanskrit inscription engraved on a copper tablet from Banskhera, dated 628 CE.



Writing in India. Fig. 5 Bengali script in an autographed poem by the Nobel laureate Rabindranath Tagore (1861–1941).

अभ्यावहति कल्याणं विविधं वाक्सुभाषिता ।
सैव दुर्भाषिता राजन्ननर्थायोपपद्यते ॥ ३५५३ ॥

Writing in India. Fig. 6 Devanāgarī script in a quotation from the Sanskrit epic Mahābhārata (Otto Böhtlingk, Indische Sprüche III, St. Petersburg 1895): "O King, a kindly spoken word brings along many kinds of blessings, a harshly spoken word causes misfortune."

முகத்தா னமர்ந்தினிது நோக்கி யகத்தானும்
இன்சொலி னஃதே யறம்.

Writing in India. Fig. 7 Tamil script in an edition of the Old Tamil classic Tirukkura (aphorism 93): "Virtue consists in speaking sweet but truthful words with a smiling face and a friendly look".

scripts. This recent conception about the origin of the brāhmī is however contradicted by the likewise recent discovery of potsherds inscribed with brāhmī characters in stratum J (c. 450–350 BCE) at Anurādhapura in Sri Lanka. If the dating is correct, these finds support the traditional derivation of the brāhmī script from the Phoenician consonantal alphabet long before Aśoka. Alexander's admiral Nearchus speaks of Indians sending each other letters written on cotton cloth, but this statement limited to the northwest may refer to Persian administration in Aramaic. According to other Greek authorities quoted by Strabon, the Indians did not use writing. The Greek ambassador Megasthenes stationed in the Mauryan capital c. 300 BCE specifies that the Indians had only unwritten laws.

Post-Classical Period (550 CE Onwards): Diversified Scripts

Almost all the writing systems that are nowadays being used to write South Asian languages go back to the brāhmī script, which remained in use until the collapse of the Gupta Empire c. 550 CE. The late variety of brāhmī used in North India was c. 600 CE transformed into two principal types of script.

The *siddham* or *siddhamātṛkā script* (Fig. 4) was in general use in North India until c. 1000 CE, and the *Bengali* (Fig. 5) and *Tibetan scripts* and the *śāradā script* of Kashmir are derived from it. The siddham script spread also to Central and East Asia, being still used to write Sanskrit magical formulae in Japan.

The *nāgarī* (later called *devanāgarī*) script has been used to write especially Sanskrit (Fig. 6), Hindi, Marathi and more recently Nepalese. The *gurumukhī script* of the Punjabi language and the *Gujarati script* also go back to early variants of the nāgarī script. The southern Vijayanagara empire (1336–1565) used the *nandināgarī script* imported from Maharashtra.

Tamil was written in the brāhmī script from the second century BCE. This South Indian variant of brāhmī is the basis of the relatively simple *Tamil script* used today (Fig. 7), as well as of the much more complex *grantha script* used in Tamil Nadu for writing Sanskrit, which in turn is the basis of the *Malayāam script* used in Kerala. *Kannada* and *Telugu,* the two further literary members of the Dravidian language family in South India, are written in closely related script derived from the Cālukya kingdom. The Sinhala language of Sri Lanka is written in the *Sinhala script* that has evolved from the Sri Lankan variant of brāhmī.

The *Arabic script* imported to South Asia from Persia by the Muslims since the 8th century CE has been used to write especially Persian — the court language of the Moghuls — and (with important modifications) Urdu — the Muslim variant of Hindi — and Kashmiri, and various minor Indo-Aryan and Iranian languages spoken in Pakistan. The *Roman alphabet* was brought to South Asia by the European colonialists who came to stay with the Portuguese in 1498, and which is used for writing not only European languages but also Konkani spoken around Goa.

Uses of Writing

Inscriptions and Coins

Because they usually can be exactly located and also dated, inscriptions engraved in stone are very important sources of political and cultural history in India. There is a continuous inscriptional tradition ever since Aśoka's edicts (from c. 258 BCE), but their number increases substantially only c. 700 CE. From c. 300 CE, royal grants of villages and the like were engraved on sealed copper tablets. Altogether c. 100.000 inscriptions in stone or metal are known today. Thousands of inscriptions in Indian languages and scripts have been discovered also outside South Asia, in Egypt, Afghanistan, Central Asia, China and most parts of South East Asia.

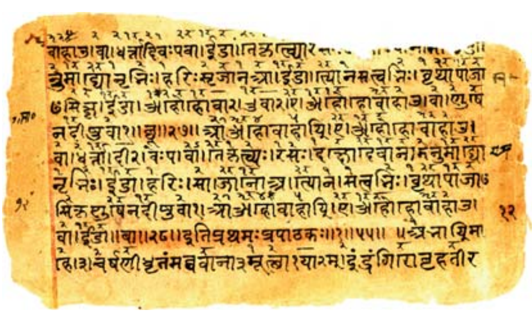
Numismatic material plays a crucial role also in the history of the dynasties of Iranian origin in the centuries around the beginning of the Christian era. The Indo-Greek kings are known almost exclusively from their coins. Being bilingual, these coins moreover opened up the ancient history of India. The text written in the Greek script and language on the obverse side is rendered in the Prakrit language written in the Kharoṣṭhī script on the reverse side. James Prinsep in the 1830s worked out how to read Kharoṣṭhī and applied the results to the Kharoṣṭhī inscriptions of Aśoka. These readings in turn opened up the secrets of the forgotten brāhmī script.

Manuscripts

The book in ancient India was usually written on long leaves of the wine palm *(Borassus flabelliformis),* which had first been cut into regular rectangular form. Wooden covers of the same size were usually put on both sides of the bundle to protect the leaves from breaking. The ready bunch of leaves and covers was then pierced in one or two or three places in the middle, so that a rope could be inserted through the leaves to bind them together into a bundle. The long binding rope had some stopper at both ends which prevented it from coming out when the book was opened and the rope loosened: the reader places the bundle on the ground, and then turns the leaves over from one pile to another. When the book is closed, the leaves are collected together, the rope is tightened, and its long loose end is wound many times around the bundle. "Binding" the leaves thus together has given the ancient Indian book one its Sanskrit names, *grantha.*

While writing on the empty leaves the scribe would leave some margin around the edges and the cord-holes. This was a precaution to secure that no text would be lost if the leaf was broken at its edges. The leaves would also be numbered, by putting a running number in the right or left margin of the obverse or reverse side. The margins could also be used for inserting in them corrections (for letters marked in the text with symbols of cancellation or painted over), supplementary texts (parts of text accidentally omitted in copying but noted afterwards), glosses (explanations of difficult words or expressions) or subtitles (indicating the contents of the text at that place) (Fig. 8).

The colophon at the end of the manuscript often contains not only the name of the work and its author but also the name of the scribe and possibly his genealogy and domicile and the date of completing the manuscript. Just as the author of a literary work, the scribe also starts with an auspicious word and a prayer, most frequently an obeisance to Gaṇeśa, the elephant-headed god of success, who is expected to see the task to its conclusion and to remove any obstacles. Gaṇeśa is thought to have written down the great epic Mahābhārata at the dictation of its compiler Sage Vyāsa: as the



Writing in India. Fig. 8 Verso side of leaf 12 of a paper manuscript written in the devanāgarī script, dating from the 17th century. The manuscript contains the Āraṇyaka Gāna of Sāmaveda. Sāmavedic songs composed c. 1000 BCE are the world's oldest known music. The small numeral signs over the lines of text are musical notation. Textual divisions are highlighted with red colour. Photo Asko Parpola.

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divine scribe he broke one of his tusks and used it as a stylus. This agrees with the South Indian practice of scratching signs on the surface of the leaf by means of a sharp iron stylus. The incised lines were afterwards made more visible by means of the juice of plants rubbed over the leaves. In North India, the scribe would use ink (made of soot) and either a brush or a pen made of reed (Fig. 8). The same methods were used if the manuscript was illustrated with miniature pictures — painted in several colours in North India, incised in South India (from Orissa to Tamil Nadu and Kerala).

In northwest India, parchment may have been used for writing during the Iranian rule, since Sanskrit *pustaka* 'manuscript' or 'book' is an Iranian loanword denoting 'book' and 'hide, parchment, bark' in the donor language. Birch bark was used as writing material in Kashmir. Paper started being used in North India around 1000 years ago, but in South India much later. Paper used to be cut in long rectangular leaves which imitate the shape of the traditional writing material, the palm leaves (Fig. 8). The same applies to thin wooden plates that have likewise been used as writing material, especially in Sri Lanka and in communities of Indian origin in South-East Asia.

Normally manuscripts did not survive long on account of the climate and insects, even if they were treated with vegetable oils or kept in smoky places avoided by insects. Palm leaves usually last maximally some three or four hundred years. In exceptional circumstances palm leaves have survived much longer, however: the oldest manuscripts are from the first centuries CE and come from the dry climate of Central Asia. There they have been kept in pottery vessels — exciting discoveries of Buddhist birch bark and palm leaf manuscripts have been made in recent years in Afghanistan and northern Pakistan. Reed baskets *(piṭaka)* have provided another and more usual implement for storing manuscripts: at one time the entire Buddhist canon could be put into three baskets. In ancient India, temples, monasteries, royal palaces and even private persons had manuscript libraries, which could contain even tens of thousands of volumes. Today millions of Indian palm leaf or paper manuscripts survive in public and private libraries in and outside South Asia.

On account of their poor durability, texts to be preserved in writing had to be copied over and over again, which led to accumulating mistakes. Such copying mistakes have distorted literary texts, but if a number of manuscripts are available, their comparison may enable reconstructing a genealogy of copying and reconstituting the original text.

Palm leaves have been used in South India until the early twentieth century not only for writing literature, but also for book keeping and for legal documents, with seal impressions attached. On the other hand, literature — especially voluminous Vedic texts — has been handed down also in a millennial oral tradition until the present day.

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Writing in Japan

Christopher Seeley

The modern Japanese writing system employs predominantly a combination of Chinese characters (1945 are taught in school education) and syllabic signs called *kana* (close to 100 in total, in two sets, viz. the angular *katakana* and the more rounded *hiragana*) (Henshall 2003). These are used together with an admixture of other signs such as Arabic numerals and Roman letters. The following sentence is an example of how the different elements function together:

□□□□□□□□□□□、□□□□□□□□□ □□□□□□□□□□□□。*Otōto wa sugoi esu-eru mania de, jūnigatsu ni mata Suisu e iku koto ni natte imasu.* 'My younger brother is a huge fan of steam locomotives, and it has been arranged for him to go to Switzerland again in December.' Chinese characters are used for the noun *otōto* 'younger brother', the suffix *-gatsu* 'month (of the year)' and the first part of the stem of the verb *iku* 'to go'. *Hiragana* are employed for elements which include particles such as *wa* (topic indicator), *e* 'to, towards', for the adjective *sugoi* 'great; awful' and the second syllable of *iku* and also for the post-verbal construction *koto ni natte imasu* 'it has been arranged to ---'. *Katakana* represent two European loanword items (*mania* 'fan, enthusiast' and *Suisu* 'Switzerland'), while an acronym-type European loan (*esu-eru*) is represented by upper case Roman letters. Arabic numerals are used here to represent *jūni* 'twelve' in *jūnigatsu* 'December', which can otherwise be written all in characters, viz. □□□ (id.).

Although still very complicated, the system in use today represents a substantial simplification of that which was employed in the early part of the twentieth century. It reflects a heritage of cultural and linguistic history in Japan that extends back to early in the first millennium AD.

Around 400 AD the Japanese, who at that time had no writing of their own, actively adopted Chinese writing. At this very early period, it was the Chinese language, not Japanese, which was represented directly in written form. Due to the difficulties associated with using what for the Japanese was a foreign language, together with a very large and complicated character set, initially there was heavy reliance on Chinese and Korean scribes (Seeley 2000: 3–15).

As time went by, the Chinese script was adapted to represent the Japanese language, sometimes directly, but often in a convoluted manner. The *Kojiki* (*Record of Ancient Matters*) of 712, notable as the earliest large-scale compilation to have survived to the present, constitutes a useful example of such adaptation. The *Kojiki* preface is in Chinese, which was appropriate as the most formal style in a document addressed to the sovereign; the main part of the text is in a hybrid form which reflects Japanese influenced by Chinese (selected by the compiler with the stated aim of ease of reading [!]). The Japanese songs interspersed in the text are represented by Chinese characters employed for their sound value so as to minimise the ambiguity of reading in material of an oral nature (Seeley 2000: 40–46). At an early period, the Japanese had the means to represent their own language directly in writing, but the overwhelming prestige of Chinese culture meant that more often than not they chose a Chinese-orientated style.

Despite the high standing of written Chinese in Japan (and Japanese attempts at Chinese composition), direct representation of Japanese also had its place, and this more straightforward form of writing enjoyed a substantial rise in popularity from around 900 AD. This was due to a development early in the ninth century in the context of Buddhist works in Chinese. Abbreviated Chinese characters employed for their sound value as phonograms – the forerunners of modern *katakana* (used today for such purposes as representing loan-words of mainly European origin) and *hiragana* came to be used quite extensively as a convenient means of annotating the text, albeit sometimes only minimally and sporadically, to help read or 'decode' it as Japanese. Abbreviation was achieved through a process of (1) writing rapidly (cursively) and thereby omitting strokes (e.g., □›□ *me*,□□›□ *ha*) or (2) isolating one part of a character phonogram and taking it to represent the whole (e.g. □□□ *ho,* □›□ *ka*). After a time, *katakana*-type signs tended to be favoured for utilitarian purposes such as annotation, while *hiragana*-type signs came to be used extensively for Japanese poetry and prose. Women were seldom given the opportunity to acquire grounding in Chinese characters, and the convention arose whereby writing in phonograms of the cursivised variety tended to be associated with women. This is reflected in the early term for *hiragana*-type signs, *onna-de*, and 'women's hand/script'. This is best understood as meaning the script typically used by women rather than exclusively by them, for men certainly sometimes employed kana of this type (Seeley 2000: 59–89).

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While some Japanese texts were written entirely in kana, much more commonly there was at least a small admixture of Chinese characters. In the early period, characters were sometimes employed as a convenient means of representing Chinese loan morphemes which involved sound segments difficult to represent in a still emergent system of kana signs. Orthography of this general type, which involved a combination of characters and kana, gradually assumed a position of increasing importance; the role played by Chinese characters as a guide to disambiguating what would otherwise be a Japanese text consisting of a long string of kana signs spaced equidistantly should not be underestimated.

In spite of the above developments, broadly speaking, the cultural and linguistic importance of China continued to be very strong. Written Chinese, or rather an approximation of it, continued to be widely perceived as highly prestigious until modern times, is being used even at the beginning of the Meiji period (1868–1912) in some Japanese newspapers. Increasingly, though, the leaders of Japanese society were being influenced by the West. As a result of extensive debate on language and script, a movement evolved around the end of the nineteenth century with the aim of bringing written language more in line with spoken language (the *Genbun itchi* [Unification of Speech and Writing] movement) (Twine 1991), and there was also support in some quarters for reducing the number of different Chinese characters in general use. In the year 1900 the Education Ministry (Monbushō) published a list of about 1,200 characters for use in primary school texts, together with a standardised set of kana signs and a partially simplified form of kana usage. However, there was still strong opposition from conservative elements to reform the writing system.

A radical turning point in the Japanese writing system occurred in the 1940s, following Japan's defeat in the Pacific War. In that very different environment, simplification of the written language and script was espoused as part of the movement to promote democracy. Changes effected included the adoption and promulgation in 1946 of a list of 1850 Chinese characters approved for active general use called the *Tōyō kanjihyō* (List of Interim Use Chinese Characters), followed by several supplementary lists aimed at restricting the number of readings associated with individual characters and increasing the number of officially approved simplified character shapes (e.g., □□□, □□□). A more rigorous restriction took place in the area of given names which parents chose for newborn children: whereas previously it was permitted to use any Chinese characters out of a potential corpus of tens of thousands, from late 1947 parents found themselves restricted by law in choosing from just the 1850 in the Interim Use List, or alternatively to use kana. This change was seen by many as excessive, and in 1951 this restriction was eased through a supplementary list of additional characters for use in names. 1970 onwards a significant relaxing of guidelines and regulations regarding the range of Chinese characters were used. The year 1981 saw the Interim Use List replaced by a modestly expanded new list (1945 characters) called the *Jōyō kanjihyō* (List of General Use Chinese Characters), which was given the status of a guide (*meyasu*) for usage, and the name character list has been repeatedly expanded, consisting now of close to 300 characters (Seeley 2000: 152–87).

In the Interim Use List era and before, advocates of script reform argued that kana or Romanisation should be adopted for Japanese because of the difficulties associated with mechanical production of text. A manual typewriter for Japanese was devised early in the twentieth century, but it required a specialist operator, and only about ten pages a day at most could be produced. The strength of the argument for script simplification was, however, compromised in the late 1970s with the development of a word-processor which featured Japanese language input in Romanisation or kana and output in conventional (character and kana) Japanese text. The mid 1980s then saw the appearance of portable and affordable machines which gave consumers the ability to handle Japanese text with output which encompassed the Chinese characters contained in a standard corpus of about 6,300 Chinese characters determined for universal data exchange by the Japan Industrial Standards Institute (Gottlieb 2000; Seeley 1994).

The popularisation of word processors and computers from the 1980s for Japanese has led to a significant rift between the number of characters taught in the school system and the corpus by more than three times the size accessible via computer-generated text. This discrepancy needs to be addressed and somehow accommodated. Despite associated problems such as this, what seems certain is that the position of Chinese characters as a central feature of the Japanese writing system is assured for the foreseeable future.

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Writing: Maya Writing

Tom Jones

Some dozen or so writing systems have been identified as having been in use at one time or another in ancient Mesoamerica, all sharing a number of general traits that include (1) pictographic signs, clearly derived from things seen, used in combination with wholly abstract signs, the derivations of which remain obscure; (2) a reading order that generally proceeds from top to bottom and from left to right; (3) a vigesimal number system (base 20) with a dot representing the unit, generally in conjunction with individualized signs for numbers of higher orders of magnitude, though in certain areas, in conjunction with bars for "5" and other signs for "0" to express higher numbers; and (4) a shared, compound, cyclical calendar of 260 × 365 (18,980) days' duration, expressed with readily identifiable calendrical elements such as numbers, day names, year signs, and periods of various magnitude.

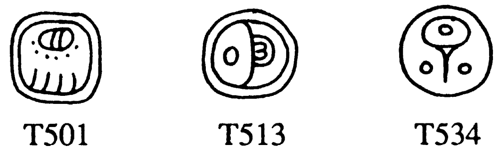
The most sophisticated writing system – and certainly the most intriguing – of Mesoamerica, and that which will serve as the basis for this discussion, is the "hieroglyphic" writing of the Maya region. Examples of Maya hieroglyphic writing are known from many sources: from carved monumental inscriptions in stone and wood, painted stucco-coated, screen-fold, paper books, or "codices", painted and carved ceramic pots, cups, bowls, and dishes, and from other portable artifacts of stone, shell, ceramic, and bone. The visual style, syntax, and content of the writing was shaped by both the nature of the medium upon which it appeared and the message to be conveyed.

Though open to doubt for many years, there is no question today of the Maya writing system not being true writing. It follows linguistically logical rules of syntax, phonetic construction, and semantic expression, although with the same willful departure from those rules as that of creative writers of our own culture – even, at times, to the point of whimsical defiance. The Maya hieroglyphs were capable of accommodating the full range of both the sounds and the syntactical structures of spoken Mayan. Indeed, the relatively narrow range of subject matter of extant Maya writing is surely more of a reflection of its differential survival on imperishable artifacts than of any limitations in the writing system itself.

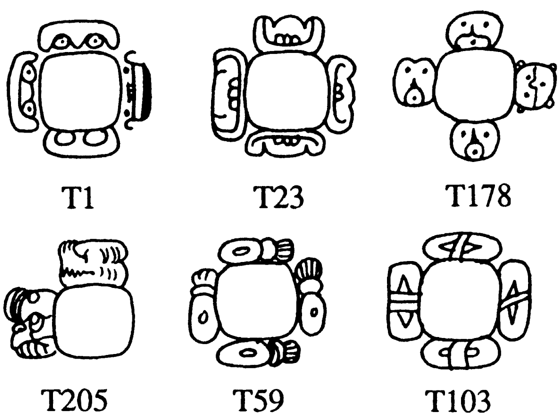
The typical Maya monument inscription is composed of a number of tightly formed glyph-blocks arranged in vertical columns and horizontal rows, with the glyph-blocks formed of glyphic elements of two general sorts: relatively large ones – known as "main signs" – generally positioned at the center of glyph-blocks and occupying most of the area (Fig. 1), and smaller ones – known as "affixes" – often positioned before, atop, after, or beneath the main signs, and sometimes (in the absence of a main sign) forming clusters of their own (Fig. 2). In his 1962 *Catalog of Maya Hieroglyphs*, Eric Thompson attempted a classification of all the known glyphs of his time, assigning to "affixes" the numbers 1–370, and to "main signs" the numbers 501–856, with what he called "portraits" receiving the numbers 1000a–1087. The study and discussion of Maya writing have benefited enormously by the preferred use of these *T*-numbers (as they are called) over the arbitrary nicknames and labored descriptions of individual glyphs that once necessarily dominated their study.

Nevertheless, epigraphic study since the publication of Thompson's *Catalog* has shown that this main sign/affix distinction is an artificial one. For while it is true that certain glyph designs seem only to have been employed as main signs and that certain others were used exclusively as affixes, a considerable number of glyphs are known to function in both categories with no apparent change in their semantic or phonetic value. This is easily seen in the variety of ways in which the well-known *bakab* title is recorded in the inscriptions (Fig. 3). Size, then, is not necessarily correlated with significance.

While not entirely true, it is generally the case that both the reading order of the glyph-blocks that comprise a text (typically laid out in a grid-like



Writing: Maya Writing. Fig. 1 Main signs with *T*-numbers.



Writing: Maya Writing. Fig. 2 Affixes with *T*-numbers.

arrangement of columns and rows) (Fig. 4) and the internal elements of the glyph-blocks themselves proceed from upper-left to lower-right (Fig. 5).

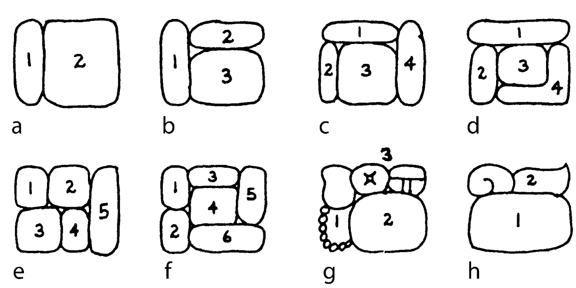
Texts composed of more than one column and one row are usually read from the upper-left corner, two glyphs from each row, descending two columns at a time to the bottom. The next two columns are read in the same manner, and so forth, to the end of the text. The reading order of uneven or exceptionally disposed texts necessarily depart from the ideal form just described (Fig. 4). Departure from the general principle of upper-left to lower-right is probably more common in the reading order of glyphic elements within the glyph-blocks than in the organization of the latter in the texts. This is, no doubt, due in some part to what were apparently culturally prescribed arrangements of certain hackneyed terms such as the **AHPO** superfix on emblem-glyph titles that identify lords of specific Maya cities (Fig. 5g) or the -**NAL** superfix on certain Maya place-names (Fig. 5h), in greater part to the flexibility of the glyphic elements in both size and shape, and in large part to the creativity of individual scribes.

Though an argument over whether the hieroglyphic signs were of ideographic, morphemic, or phonetic value raged for decades in the world of Maya scholarship, today there is general agreement that there are glyphs of both morphemic and phonetic kinds, and that there is at least one glyph that always functions as a semantic determinitive. About 180 distinct glyphic elements have so far been demonstrated to carry the phonetic values of some 77 consonant–vowel (cv) syllables, leaving undetected but 23 of the 100 probable sounds employed in the ancient script. At the same time, in addition to the signs for the 20-day names, about 90 glyphic elements have been demonstrated to represent consonant–vowel–consonant (cvc), or even more complex, morphemes. Thus, words can be recorded by using a single morphemic sign (should there exist one that signifies the desired word), by assembling a phonetic construction from cv-signs that sound it out, in which case the final vowel sound is dropped, or by combining the two, perhaps using a cv-sign as a (silent) phonetic complement to reinforce the pronunciation of the intended word.

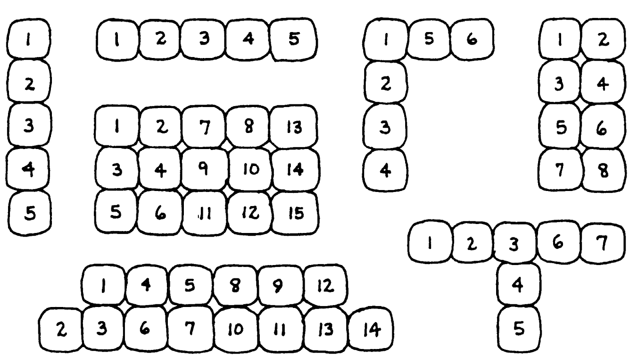
In addition to the aforementioned options available to the Maya scribe, there were four further features of the writing system:

1. Allographs are multiple signs that were used interchangeably to express the same phoneme. The sound *u*, for example, could be expressed by any one of at least a dozen different allographs (Fig. 6a).
2. Puns are single signs used to express homophonous words of multiple semantic value. As an example, the Mayan word *chan* means "snake", "sky", and "four". The glyphs for these three meanings could be used interchangeably to convey the sound *chan*, with

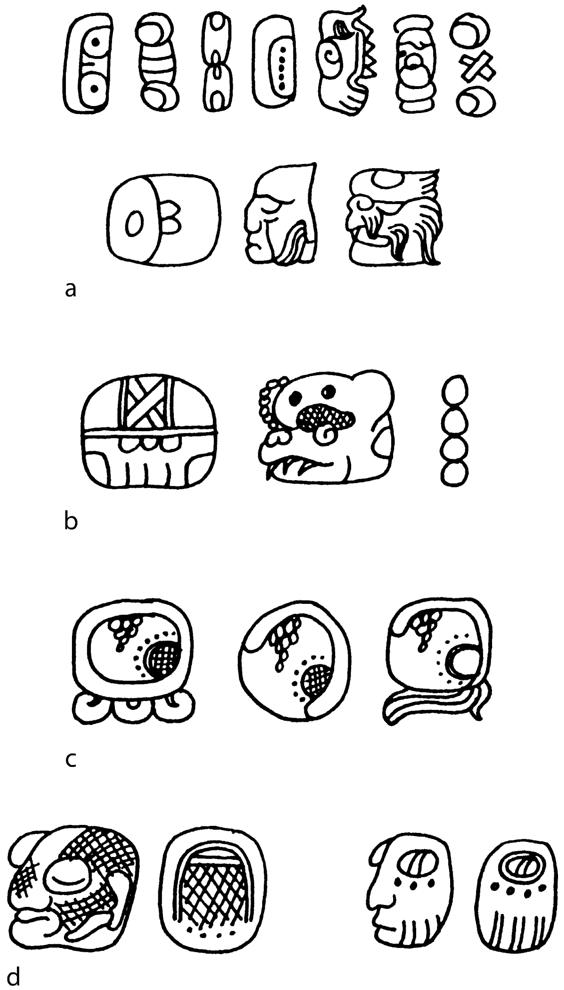
Writing: Maya Writing. Fig. 3 Three spellings of the title *bakab*. All are constructed *ba-ka-ba*. Note the variation in size of the elements, substitutions and the use of head variants.



Writing: Maya Writing. Fig. 5 Reading order for the elements within a glyph-block.



Writing: Maya Writing. Fig. 4 Reading order for the texts.



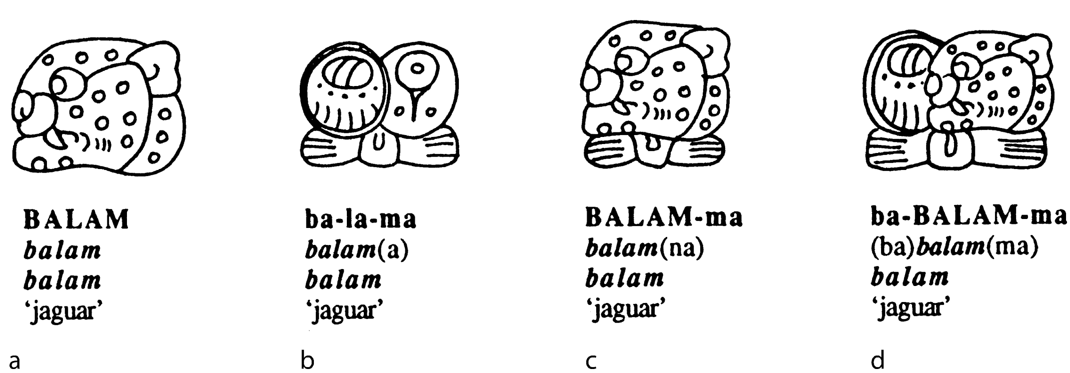
Writing: Maya Writing. Fig. 6 (a) Ten allographs for the phoneme *u*. (b) Three signs for chan: “sky”, “snake”, and “four”. (c) Polyvalency of T528, as the day-name *Kawak*, the phoneme *ku*, and with phonetic complement **ni** to spell **TUN**-(ni). (d) Head variants for the phonemes **pa** and **ba**.

the intended semantic value, which was sometimes multiple, to be inferred from the context (Fig. 6b).

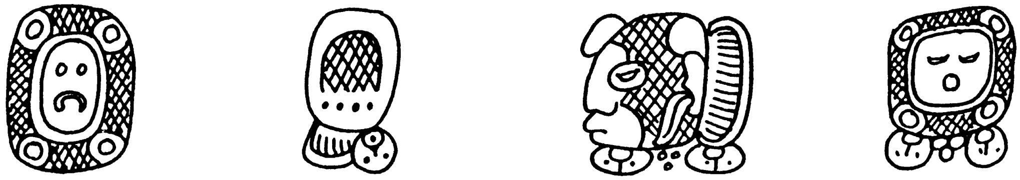
3. Polyvalent signs are single signs of multiple phonetic and/or semantic value which, again, are best understood from their context. Thus when the sign T528 appears framed by the day-name cartouche (serving as a semantic determinant), it is understood to represent the name of the day *Kawak*; when it appears suffixed with T116, the sign for **ni** (serving as a phonetic complement), it is understood to represent the term **tun** (“stone” or “year”); and when it appears with no affixes, it *usually* represents the syllable *ku* (Fig. 6c).
4. Head variants are main signs modified from their generally rounded forms into the profile heads of persons or monsters that retain their diagnostic markings (Fig. 6d).

The range of possible sizes of the various glyphic elements, their substitutability and variety of appearance (anthropomorphic, zoomorphic, and abstract), their use as cv syllables, cvc morphemes, and phonetic complements, all go toward accounting for the rich variety of visual expression that characterizes the Maya hieroglyphic writing system. Though many words could be written with a single glyph, those same words could also be expressed in other ways. As an example, the word for *balam* (jaguar) was variously expressed by using the sign that represents both the word and the concept (Fig. 7a), by using the signs for the syllables *ba*, *la*, and *ma* (Fig. 7b), by using the sign for **BALAM** with *ma* as a phonetic complement (Fig. 7c), or by using the **BALAM** sign with both **ba** and **ma** complements (Fig. 7d).

Similarly, *pakal* (shield) was expressed by using a sign that portrays a shield (Fig. 8a), by the signs for the three syllables *pa*, *ka*, and *la* (Fig. 8b,c), or by the **PAKAL** sign with a *la* phonetic complement (Fig. 8d). It will be noted that, in spite of their difference in visual effect, both the second and third of these examples are phonetic constructions of the syllables *pa-ka-la* – the second example substituting a head variant of the more usual *pa*-glyph.

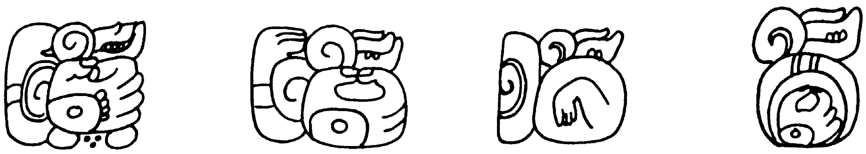


Writing: Maya Writing. Fig. 7 Four ways of spelling **balam** (jaguar).



a	b	c	d
PAKAL	**pa-ka-la**	**pa-ka-la**	**PAKAL-la**
pakal	**pakal**(a)	**pakal**(a)	**pakal**(la)
pakal	***pakal***	***pakal***	***pakal***
'shield'	'shield'	'shield'	'shield'

Writing: Maya Writing. Fig. 8 Four ways of spelling **pakal** (shield).



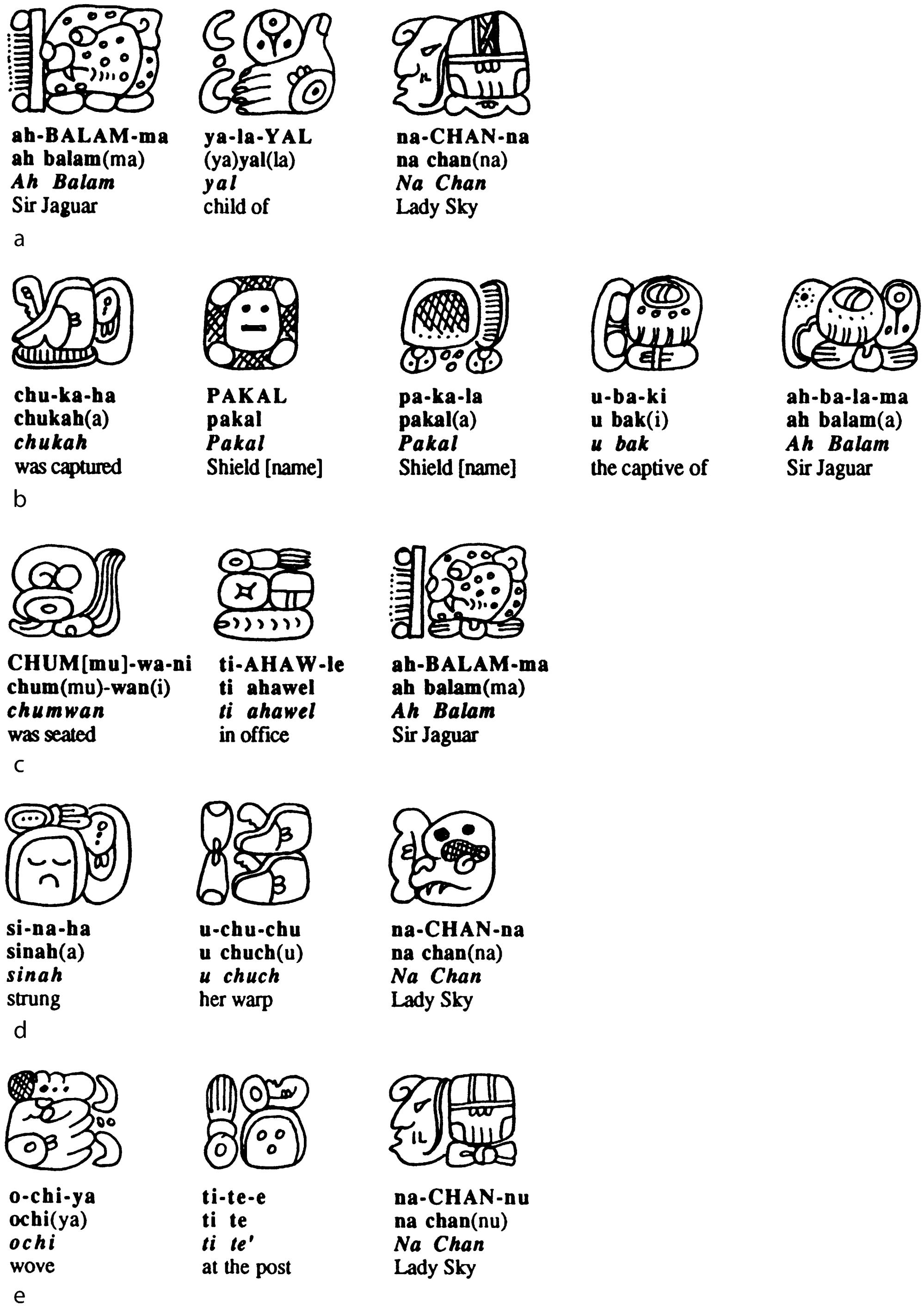
a	b	c	d
yi-NAL-chi-la	**yi-NAL-chi**	**yi-NAL-YICH**	**Nal-yi-chi**
yichnal(la)	**yichnal**	(yi)**yichnal**	(yi)**yichnal**
yichnal	***yichnal***	***yichnal***	***yichnal***
'together with'	'together with'	'together with'	'together with'

e	f	g
NAL-YICH-la	**NAL-YICH**	**NAL-yi-chi-la**
yichnal(la)	**yichnal**	(yi)**yichnal**(la)
yichnal	***yichnal***	***yichnal***
'together with'	'together with'	'together with'

Writing: Maya Writing. Fig. 9 Seven ways of spelling **yichnal** (together with).

Despite these general principles, there were words for which there was no single sign and the organization of which often defied the general upper-left to lower-right reading order. The word **yichnal** (together with) is a particularly interesting example of such a construction, in part because it always includes the previously mentioned -**NAL** ending superfixed to its main sign (Fig. 9). The latter might be either the standard sign for phonetic *chi* or the "torso-and-left-arm" sign that represents the sound **YICH**. The several ways of recording **yichnal**, with the elements read in the usual order, were **yi**-*NAL-chi-la* (Fig. 9a), **yi-NAL**-*chi* (Fig. 9b), **yi-NAL-YICH** (Fig. 9c), *NAL-yi-chi* (Fig. 9d), **NAL-YICH-la** (Fig. 9e), **NAL-YICH** (Fig. 9f), and *NAL-yi-chi-la* (Fig. 9g).

Among the tasks to which a Maya scribe might be called upon to apply his skills was the execution of commissions to inscribe in stone the dynastic history and military achievements of his city's royal family. Commissions of this sort would typically involve the recording of a variety of genealogical relationships such as *Ah Balam yal Na Chan* (Sir Jaguar is the child of Lady Sky), where the two names are separated by a glyph-block that defines their relationship, with the subordinate person named first (Fig. 10a). A military encounter might be expressed with two phrases such as *Chukah Pakal. Pakal u bak Ah Balam* (Pakal was captured. Pakal was the captive of Sir Balam), the first being a typical verb-initial Mayan sentence followed

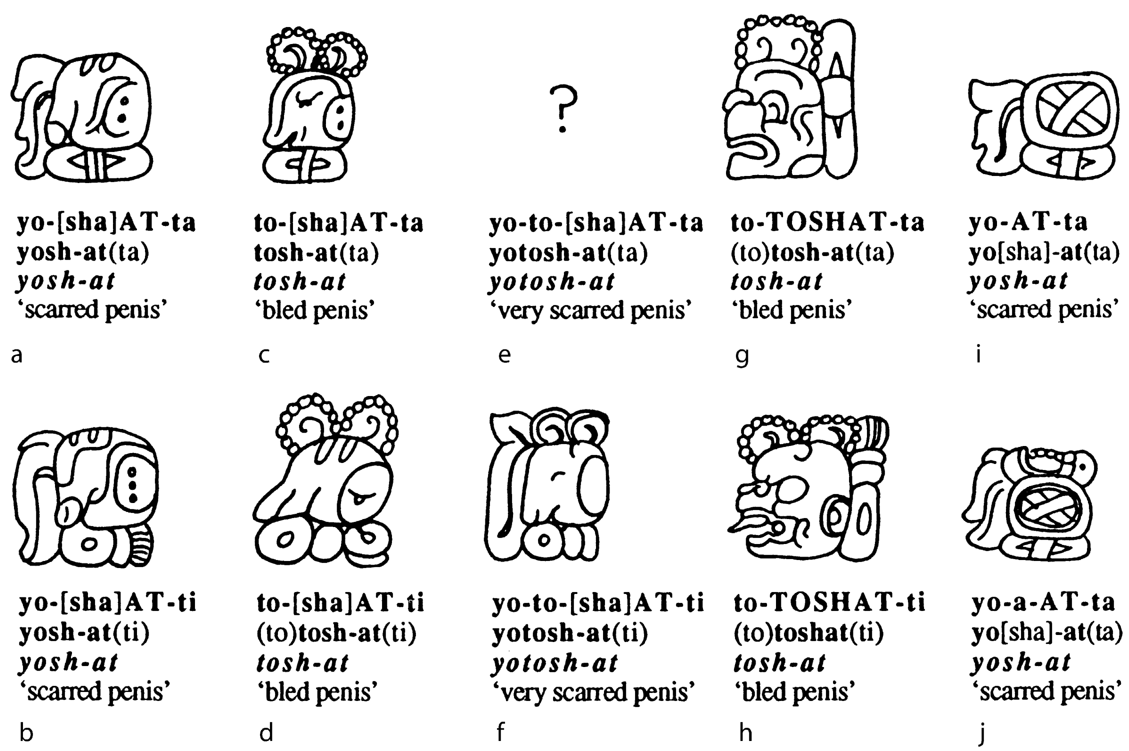


Writing: Maya Writing. Fig. 10 The construction of Maya sentences.

by the subject, the second defining another relationship with the identical syntax as the earlier example (Fig. 10b). Accession to political office might be recorded as *Chumwan ti ahawel Ah Balam* (Sir Jaguar was seated in the Lordship), in another typical verb-initial Mayan sentence where a positional verb is followed by a prepositional phrase with the subject named last (Fig. 10c). Were our scribe to turn from his work on public monuments to the designing of a personal book for and about Lady Sky, he might record such sentences as **Sinah u chuch Na Chan** (Lady Sky strung her warpboard) or **Och-i ti te' Na Chan** (Lady Chan wove at the post), the first a verb-initial sentence with a transitive verb followed by a possessed object and the subject (Fig. 10d), and the second a verb-initial sentence with the verb followed by a prepositional phrase and the subject (Fig. 10e). It should be clear from the preceding examples of inscriptions on public monuments that Maya hieroglyphic writing is indeed a true writing system, fully capable of recording the language it represents.

However, for all of the marvelous achievements of recent Maya epigraphy, much work remains. Many glyphs are undeciphered and problems still linger amongst glyphs for which solutions have been offered. An understanding of the kinds of difficulties encountered by epigraphers in deciphering individual glyphs can be gained from a close look at a fairly common lordly title, the five basic forms of which preclude ready demonstration of their homophony, and suggest instead the presence of both phonetic and semantic substitutions. Known to scholars as the "penis" title, the three most widely distributed forms consist of a main sign that has the appearance of a profile representation of male genitalia infixed with the sign for **sha** and suffixed alternatively with **-ti** or **-ta** affixes (Fig. 11a–f). Desirable as it might be to have a homophonous reading for the three forms – and their interchangeability in the texts is beyond doubt – the conflicting sounds of their initiating prefixes would appear to preclude any such solution. One form is prefixed with the sign for **yo-** (Fig. 11a,b), and second with **to-** (Fig. 11c,d), and a third with both **yo-** and **to-** (Fig. 11e,f). Because these substituting sounds are prefixed, the words that they signify must begin with the sounds **yo**, **to**, and **yoto**, respectively. The likelihood that the male genitalia-main sign is intended to convey the sound **AT** (the pan-Mayan word for penis) is confirmed by the interchangeable **-ti** and **-ta** suffixes that invariably accompany it, apparently serving as phonetic complements. If, then, the **sha** infix is read before the presumed sound of the main sign, the sound sequence should be **sha-AT** (ti/ta), or the not too promising **shat**. However, if the previously mentioned **yo-** prefix is added to this, the result is **yoshat**, or **yosh-at** (scarred penis); if **to-** is added, the result is **toshat**, or **tosh-at** (bled penis); and if **yo-to** is added, the result is **yotoshat**, or **yotosh-at** (very scarred penis). Though any such title might strike those of us with a background in Western European culture as bizarre, nevertheless given the wealth of evidence for the presence of penis-perforation ceremonies in which Maya lords engaged and the occasional portrayal of a scarred penis on figures in Maya art, the existence of a hieroglyphic form of a title that testified to a lord's personal sacrifice perhaps ought not to surprise anyone.

Understanding of the remaining two of the five forms which this title assumes is less certain. The first of these is a head variant that is always superfixed with **to-** and postfixed with **-ti** or **-ta** (Fig. 11g,h), suggesting the possibility that the head represents the full term



Writing: Maya Writing. Fig. 11 Semantic substitutions in the "penis title."

TOSHAT, or **TOSH-AT**, with both affixes serving as phonetic complements. The second (of which there are but two examples) is a phonetic construction that is in clear contradiction to the previously discussed **yosh-at** renderings: one reads **yo-ta-ta**, the other **yo-a-ta-ta** (Fig. 11i,j). Not only is the **ta** sound doubled in each, but there is also nothing present that could be construed to represent **sha**, the necessary middle consonant of **yosh-at**. Nor is there an easy resolution of this difficulty; either the previously proposed **yosh-at**, **tosh-at**, and **yotosh-at** readings are in error and the arguments in support of them faulty, or the Maya scribe that recorded the two purely phonetic constructions (they are both at Copan) failed to include all the sounds of the word he intended to record, or – and this is a solution that preserves both the earlier **yosh-at**, **tosh-at**, and **yotosh-at** readings and the literary reputation of the Copan scribe – the scribe deliberately omitted the middle (**sh**) consonant, as is thought to have been done with other two-syllable words. One can only hope that further research and further field discoveries will someday throw stronger light on this and similar difficulties. Nor has there ever been a time when Maya scholars were more optimistic about the possibilities of their ultimate decipherment of this poetically conceived, strikingly beautiful, and wonderfully complex ancient writing system.

Postscript. Since the preceding was written and submitted to the publisher, an alternative to the reading of the penis title presented above has been proposed by Linda Schele based upon a recently recognized example that appears to include a sign for the sound **ho**. Schele proposes a **yoh-at** reading for the **yo**-prefixed form and phonetic construction, a **toh-at** reading for the **to**-prefixed form (and its head-form), but is silent regarding the **yo-to**-prefixed form. This should convey some idea of the difficulties raised in the closing paragraphs above.

See also: ►Cuneiform

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Writing in the Middle East

Alan Millard

Writing and the alphabet were two of the major inventions of the human mind. They were conceived and developed in the Middle East between about 3500 and 1000 BCE. Other writing systems appeared in China about 1200 BCE and in Central America during the first millennium BCE, probably independently, although the Chinese may have been indirectly influenced from Babylonia.

Cuneiform Writing

Writing began over 5,000 years ago in the developing urban culture of southern Mesopotamia known as the Uruk IV period. At first simple pictures were scratched on stone or clay tablets held in the hand. Some showed a complete object, such as a fish, others part of an object, such as the head of a cow, while others cannot be identified. More than 1,200 signs were used in the oldest known texts, which deal with the income and expenditure in kind of temples. The number of signs soon shrank to about 600 and as well as serving as word-signs (logograms), many also came to be used phonetically (phonograms) on the rebus principle. Thus in English the picture of a thin man beside a king read as ideograms could mean "The thin man is king" or "The king is a thin man," but taking their values phonetically could yield the two syllables of "thinking," a concept harder to express pictorially. The rebus principle enabled the script to express any words, including foreign terms and names. The syllabic signs are vowels (*a*, *e*, *i*, *u*), "open" (e.g. *ba*, *gi*, *du*, *am*, *ir*, *uz*) and "closed" (e.g. *bab*, *gim*, *dur*) and some longer ones (e.g. *alad*, *gibil*) (Fig. 1). Additionally, a small number of signs were placed before or after word-signs to indicate their class. These determinative signs mark categories such as "man," "woman," "wooden object," "fish," "pot," and plurality. By 3000 BCE the language of the texts is evidently Sumerian, a language unrelated to any other now known, and it is likely the script was invented by Sumerians. The Sumerian language appears to have many homophonous words, which suggests it may have been tonal, and so several signs can have the same phonetic value when transcribed into roman letters, which scholars distinguish by accents and subscript numbers (thus *sá* "to be equal," sa_4 "to name," sa_{10} "to buy"). Simplification for speed and impressing a reed stylus on clay produced angular strokes and resulted in the signs rapidly losing their pictorial form, so becoming the wedge-shaped or cuneiform script. The range of texts expanded over the centuries from the

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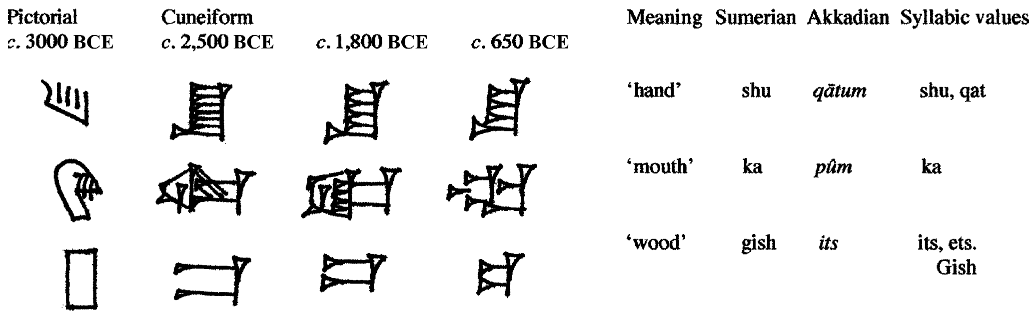


Writing in the Middle East. Fig. 1 Cuneiform signs: their meanings and their development. Column 1 pictorial, ca. 3000 BCE, Column 2 cuneiform ca. 2500 BCE, Column 3 ca. 1800 BCE, Column 4 ca. 650 BCE. Line 1, Meaning "hand," Sumerian *shu*, Akkadian *qåtum*, syllabic values *shu*, *qat*. Line 2, Meaning "mouth," Sumerian *ka*, Akkadian *pûm*, syllabic value *ka*. Line 3, Meaning "wood," Sumerian *gish*, Akkadian *its*, syllabic values *gish, its, ets*.

accounts and lists of words by category of the earliest period to embrace almost every type of written composition. By ca. 2500 BCE archives of clay tablets include hymns and prayers, proverbs and wise advice, riddles, legends and myths and brief historical records. At that time the script was adapted for writing the East Semitic Akkadian language (ancestral to Babylonian and Assyrian). Word signs could now be read in Akkadian and a much wider use of phonetic values of signs became common as words were written syllabically (e.g. the word-sign "bull's head," read in Sumerian as *gud*, in Akkadian as *alpum*, could be written *al-pu-um*). While some texts were written almost wholly with syllabic signs, especially in the early second millennium BCE (the Old Babylonian period), scribes usually wrote with a mixture of syllabic and word signs, preceded or followed by the determinative signs. This system continued until the beginning of the Christian era, spread across the Near East, especially in the second millennium BCE, and was adopted for writing unrelated languages such as Elamite in Iran and Indo-European "Hittite" languages in Anatolia. The tens of thousands of clay tablets in modern museums attest the activity of scribes in writing down almost every aspect of life, but the script never lost its complexity and so writing remained a specialized craft, usually the monopoly of the trained scribe.

Egyptian Writing

Egyptian hieroglyphic writing began almost simultaneously with the ancestor of the cuneiform script in Babylonia and was possibly influenced by it. (There are clear signs of other influences from Mesopotamia in Egyptian culture at the end of the fourth millennium BCE, e.g. the distinctive cylindrical seal.) The hieroglyphs are pictures and from the first were closely associated with narrative art, as is evident in predynastic carvings (e.g. the Narmer Palette) and thousands of later sculptures and objects of all kinds. They were employed both as word-signs (ideograms) and, through the rebus principle, as sound-signs (phonograms). In the early stages over 1,000 signs occur, a number soon diminishing to 600 or 700 which were in regular use until Hellenistic and Roman times when the number multiplied enormously. In their day-to-day activities, clerks, writing rapidly on papyrus, reduced the hieroglyphic script to a cursive form, known as hieratic, examples occurring from the earliest dynasties onwards. A highly cursive and abbreviated script, demotic, developed in the first millennium BCE and continued beside the hieroglyphs well into the Christian era. Both hieratic and demotic were written from right to left; the hieroglyphs could run in any direction. The hieroglyphs are, to modern eyes, purely consonantal; the ancient readers supplied the appropriate vowels, facilitated by the structure of the language, as in the West Semitic "alphabet" (see below). There are three classes of hieroglyphs giving phonetic, apart from their ideographic, values. The 26 with a single consonant are often called the Hieroglyphic Alphabet, but it is important to recognize that the Egyptians did not separate them from the other signs. Each of these seems to denote the dominant sound of the word represented (e.g. *n* from *nt*, "water," *dz* from *w'dzyt*, "cobra"). About eighty signs are biliteral and seventy triliteral. These phonograms often followed an ideogram, in effect "spelling out" its value, thus accompanying the sign for "pyramid," *mr*, could be the two consonant sign *mr* and the "alphabetic" signs *m* and *r* (Fig. 2). In addition, a range of determinative signs marked categories of terms, the best known being the oval cartouche enclosing

Writing in the Middle East. Fig. 2 Egyptian hieroglyphs: *mr* + *m* + *r* + pyramid = "pyramid".

pharaohs' names. Problems in representing foreign names in the early second millennium BCE led to a special combination of signs to produce syllabic spellings, called "group writing" or "syllabic orthography." Egyptian scribes normally wrote on papyrus which decays rapidly when buried except in very dry situations, so most of their work is lost. Enough survives to show that, although appearing needlessly complex, the Egyptian writing system could express as wide a range of ideas as the Babylonian. Its complexity meant that it remained a specialist skill, practised by, it is estimated, less than 1% of the population.

Other Ancient Scripts

The second millennium BCE – the Middle and Late Bronze Ages in archaeological terms – saw a proliferation of writing systems. In Anatolia, the Indo-European speaking Hittites invented a hieroglyphic script for writing the Luwian language, about 1600 BCE. It is known from stone monuments, seals and a few documents engraved on lead strips, but it is likely it was written more extensively on wooden panels, now perished. It has a basic syllabary of 70 consonant + vowel signs, a few more complex syllabic signs and 78 logograms for commonly occurring terms (e.g. king, country) and so is similar in concept to the Cretan scripts (see below). The values of the syllabic signs appear to derived acrophonically from the initial syllable of the word each picture depicted. After the Hittite empire ended ca. 1200 BCE, smaller kingdoms in Turkey and north Syria continued to write with the hieroglyphs until the seventh century BCE.

Similar to the Hittite hieroglyphs are the scripts found in Crete, the Cretan hieroglyphs and, perhaps descended from them, Linear A and Linear B. Only the last has been convincingly deciphered, revealing a simple syllabary of 54 consonant + vowel signs and five vowel signs, with numerous logograms which sometimes have their names written syllabically beside them, all recording an early form of Greek. Linear B was scratched awkwardly on clay tablets and was probably also written on wax tablets and other perishable materials. Apparently an offshoot of Cretan writing is the Cypro-Minoan system current in Cyprus in the Late Bronze Age, with rare examples found in the Levant. Like Linear B, surviving examples are on clay, but impressed with a stylus rather than scratched. They seem to record notes of ownership or delivery and longer compositions, but the script remains unread. Later in the first millennium the Cypriot syllabary of 50 consonant + vowel signs and five vowel signs survives on stone, pottery and coins. It is clearly a continuation of the Cypro-Minoan signs, probably applied to a different language, and can be read, thanks to texts with parallel versions in Greek.

A clay disk found at Phaistos in Crete is a unique representative of a pictographic script impressed on the surface by 45 separate dies in various arrangements, a precursor of printing. It may have been brought to Crete from Turkey, but without other examples, there is little likelihood that it can be understood.

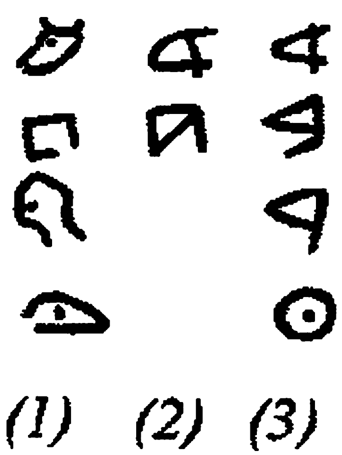
At Byblos, north of Beirut, a dozen documents were unearthed inscribed with signs evidently forming a large syllabary of 114 signs, fairly clearly based upon the Egyptian hieratic script. These "pseudo-hieroglyphs" of the mid second millennium BCE await convincing decipherment. There are other, isolated, specimens of writing systems which cannot yet be read. Short texts scratched on clay tablets about 1200 BCE at Tell Deir 'Alla in the Jordan Valley are reminiscent of Cretan Linear B, but clearly not the same script.

The Alphabet

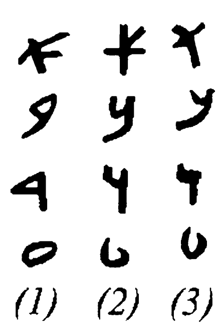
Out of this medley of scripts, one arose early in the second millennium BCE which would ultimately have the greatest impact since the invention of writing. A scribe working in the Levant, perhaps in Byblos, found none of the scripts available to him, Egyptian and cuneiform, suitable for registering his West Semitic language, so he created a system in which each sign stood for a major consonantal sound (phoneme). It seems that he drew a series of simple pictures, and used each to stand for the initial sound of its name, thus "door" = d (the acrophonic principle), yielding between 20 and 30 signs. In the West Semitic languages (e.g. Canaanite, Aramaic, Hebrew, Phoenician) no word began with a vowel and it proved possible to represent the languages adequately without signs for vowels, so at first they were not marked at all. That continues to be basically true for Arabic and Hebrew today. The system was not, therefore, a true alphabet, which should have a sign for each major sound in the language, whether consonants or vowels, but the term can be applied to it and its descendants for convenience. The scribe was accustomed to the Egyptian practice of writing with ink on papyrus and followed the Egyptian direction, writing from right to left, as Arabic and Hebrew are still written. The use of perishable papyrus sheets and wooden tablets coated with wax means that most examples of this Canaanite Linear Alphabet are lost. A few specimens scratched on metal, stone and pottery have been found at Middle Bronze Age sites in Canaan and two were discovered on a rock at Wadi el-Hol on the desert road across the bend of the Nile north of Thebes. The date of these two is debatable, but they certainly belong to a very early stage in the history of the script. More extensive examples come from the area of turquoise mines at Serabit el-Khadem in western Sinai. They were apparently written in the middle of the second millennium by workmen imported from Canaan who revered the mother-goddess, Egyptian Hathor, whom the Egyptians entitled “lady.” Although brief or badly damaged, so far as these inscriptions can be read, they refer to “lady” also (West Semitic *ba‘alat*). The signs in these “Proto-Sinaitic” inscriptions appear in more developed forms scratched or painted on various objects from Late Bronze Age Canaan, and by about 1000 BCE they are almost standardized across the Levant, their number reduced to twenty-two, as examples from Byblos and other sites show (Fig. 3).

Two or three centuries earlier, scribes at Ugarit (now Ras Shamra) on the coast of Syria, trained in Babylonian tradition, realised the Canaanite Linear Alphabet was better suited to their West Semitic language than Babylonian cuneiform and imitated it by creating a cuneiform “alphabet” of twenty-seven signs, then adding three to mark sounds necessary for recording the completely different Hurrian language. Scribes at Ugarit used their script to write every type of text, letters and administrative documents, rituals, legends and myths, on clay tablets. Their survival in the ruins of the city illustrates the sort of documents which it can be surmised were written also in Canaan, but they have perished. A very few pieces of Ugaritic writing from other sites in the Levant, as far south as Beth Shemesh west of Jerusalem, demonstrate its spread, but the script disappeared with the collapse of the Late Bronze Age city states.

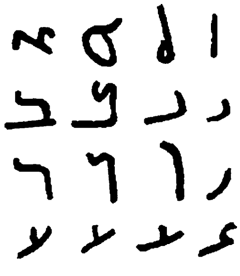
It was the Canaanite alphabet that survived the chaos at the end of the Late Bronze Age to be adopted widely. One form spread into Arabia where it became the North and South Arabic scripts, the former being known mainly from graffiti which shepherds and travellers left on rocks from the sixth century BCE to the Islamic period, the latter being attested in thousands of inscriptions on stone in the Yemen and Hadhramaut from the ninth century BCE until the seventh century AD. An offshoot of the South Arabic script survives in the Ethiopic alphabet which has augmented the letters to mark vowels. The other form of the Canaanite alphabet was adopted by the new West Semitic speaking kingdoms and eventually eclipsed all other writing systems in the region. The Israelites occupying Canaan found the script appropriate for Hebrew (except that it did not provide two signs to distinguish the phonemes *s* and *ś*). They used this “Phoenician” or “Old Hebrew” alphabet until the Persian period, continued it for some literature and revived it for nationalistic purposes in the Roman period. Aramean kingdoms wrote their language with the same alphabet, despite the lack of signs to distinguish certain sounds (e.g. *t* and *t*). Already in the ninth century BCE Aramaean scribes gave some characters a double value, noting both consonants and long vowels (e.g. one sign for *w* and *û*, one for *y* and *î*). Under the Persian Empire (539–331 BCE), the Aramaic language and form of script, which had been spreading widely under Assyrian and Babylonian rule, became the common vehicle of administration from the Indus to the Aegean, from the Black Sea to Egypt and the Red Sea (Fig. 4). The Jews used it for writing Hebrew and, slightly developed, it has been the Hebrew alphabet ever since. Aramaic speakers in southern Turkey, in the area around Urfa and Haran, derived from it the forms of cursive script known as Syriac (Estrangelo and Serto) still read among Christian churches of the Middle East. Another form arose in the caravan city of Palmyra (first to third centuries AD.). Most significantly, Nabataean Arab tribes in southern Syria and Jordan began to write with the Aramaic alphabet in the last centuries BCE and their cursive letters, known from a few papyri surviving dehydrated in caves near the Dead Sea and some other examples, are clearly the origin of the Arabic alphabet (Fig. 5). Thus the modern Arabic and modern Hebrew alphabets have the same ancestor. However, in the cursive Nabataean of the early Christian centuries, the



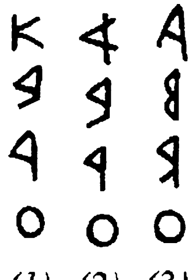
Writing in the Middle East. Fig. 3 Development of the early alphabet. Column 1, Sinai mines, ca. 1500 BCE, Column 2, Canaan, ca. 1400 BCE, Column 3, Canaan, ca. 1200 BCE.



Writing in the Middle East. Fig. 4 Letters used in Hebrew handwriting ca. 600 BCE (1), Aramaic writing on stone, ca. 400 BCE (2) and on papyrus or leather, ca. 400 BCE (3).



Writing in the Middle East. Fig. 5 Letters in forms used in Hebrew handwriting, 1st century (1), Nabataean inscriptions, 1st century (2), Nabataean documents 2nd century (3), early Arabic (4).



Writing in the Middle East. Fig. 6 Semitic Alphabetic script: Column 1, Phoenician, ca. 1000 BCE, Column 2, Moabite, ca. 830 BCE, Column 3, Greek, ca. 700 BCE.

shapes of some letters had become almost indistinguishable (e.g. *r* and *z*) and the Arabic language distinguished more consonantal sounds than the Aramaic alphabet marked, so dots were added above or below certain letters to distinguish some and to create new ones. In Syriac, Arabic and Hebrew, beside some signs for consonants marking long vowels as well, small marks were added in the early Middle Ages above, below and occasionally within the letters to indicate all the vowels necessary for public reading of sacred texts such as the Gospels, the Torah and the Qurʾān. As Islam spread it carried the Arabic script with it and so it came to be applied to non-Semitic languages. For Persian additional diacritical marks were placed on four letters to mark Iranian phonemes and for Ottoman Turkish modifications were needed for six. In 1928, Kemal Atatürk's modernization programme, the Ottoman script was replaced with roman letters, augmented by diacritical marks to 29 characters (Daniels and Bright 1996).

The Aramaic, Hebrew and early Arabic scripts are known today from haphazard collections of inscriptions on stone and other hard surfaces and from rare groups of texts on papyrus, mostly found in Egypt. The reduced number of signs, 22–28, made the tasks of writing and reading simpler than for Babylonians, Egyptians or Hittites, and so more people may have learnt to read and write, but widespread literacy did not result. For most people there was no need for either skill, and if they had the need, they could find a professional scribe. Nevertheless, there is some evidence for a proportionately wider distribution of writing in ancient Israel than in neighbouring lands (Millard 1995).

On the coast of Lebanon scribes in the Phoenician cities (Tyre, Sidon, Beirut, Byblos) continued to write with the Canaanite linear alphabet. Their products are almost entirely lost, only a few texts on stone, metal and potsherds surviving. It was from them that the Greeks learnt it. Greek could not be written intelligibly without marking vowels (otherwise there was no way to write the Greek word for "no," *ou*), so signs for Phoenician, Semitic, phonemes alien to Greek were given new values as vowels, partly in line with the use of some consonants to mark long vowels in Aramaic (e.g. *w* for *û*, *y* for *î*). That yielded the first true alphabet (Fig. 6).

See also: ►Cuneiform

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W

Xiahou Yang

ANG TIAN SE

Much of the life story of Xiahou Yang remains unknown, and so is the date of *Xiahou Yang Suanjing* (Xiahou Yang's Mathematical Classic), a text purported to have been written by him. When Zhang Qiujian wrote his mathematical text some time between AD 468 and 486, he criticized the inaccuracy of the solution of a "rectangular granary" problem from Xiahou Yang's work. This shows that Xiahou Yang was either Zhang's contemporary or his predecessor. The text also mentioned a change of volume standard which took place in AD 425, thus affirming that both Xiahou Yang and Zhang Qiujian were mathematicians of the Northern Wei dynasty (AD 386–535) and that the text of Xiahou Yang was written between AD 425 and 468.

The *Xiahou Yang Suanjing* appeared to be an important text as it was selected by Yu Zhining in AD 656 for use in the National Academy during the Tang dynasty (AD 618–906). In AD 662, the text was annotated by Li Chunfeng along with nine others for use in the imperial examinations. However, when the text was reprinted and included as one of the *Ten Mathematical Classics* in AD 1084 during the succeeding Song dynasty, it appeared to have been rewritten, probably by Han Yan (AD 780–804) in the Tang dynasty. This is evident in the text itself where a number of statutes governing the Tang systems of land, taxation, and official hierarchy were mentioned.

The present version of the text has three chapters consisting of 82 problems. It deals with percentages and roots, as well as the ordinary logistic operations. Xiahou Yang seemed to have understood both the positive and negative properties of powers of 10 such as $10{,}000 = 10^4$ and $1/10{,}000 = 10^{-4}$. He also seemed to have understood the developed conception of decimals. In one problem, he suggested the conversion of the last four metrological units to simply writing down the numbers in four successive places as they would be expressed in modern decimal notation. Though Xiahou Yang provided some modified forms for multiplication and division in some problems, he also repeated some inaccurate solutions found in the *Wu Cao Suanjing* (Mathematical Classics of the Five Government Departments) of the fourth century, the most glaring of which was the rule for determining the area of a figure consisting of two congruent trapezoids and a quadrilateral.

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Xu Yue

ANG TIAN SE

Xu Yue, whose literary name is Gonghe, was a native of Donglai (in present Ye District, Shandong Province). Very little is known of his background except that he was a follower of Liu Hong, an eminent mathematician and calendar expert of the second century. He studied mathematics and astronomy under Liu Hong and had frequent discussions with him and the Astronomer-Royal of the Astronomical Bureau on matters pertaining to calendrical astronomy. He was said to have written a commentary on the *Jiuzhang Suanshu* (Nine Chapters on Mathematical Art) and a mathematical text known as *Shu Shu Ji Yi* (Memoir on Some Traditions of Mathematical Art) around AD 190. The commentary had long been lost while the *Shu Shu Ji Yi* was handed down with a commentary written by Zhen Luan (fl. AD 570). There are a number of Buddhist references in Zhen Luan's commentary.

Xu Yue. Table 1 The three classes of large numbers following Xu Yue

	wan	*yi*	*zhao*	*jing*	*gai*	*zi*	*rang*	*gou*	*jian*	*zheng*	*zai*
Upper	10^4	10^8	10^{16}	10^{32}	–	–	–	–	–	–	–
Middle	10^4	10^8	10^{12}	10^{16}	10^{20}	10^{24}	10^{28}	10^{32}	10^{36}	10^{40}	10^{44}
Lower	10^4	10^5	10^6	10^7	10^8	10^9	–	–	–	–	–

The *Shu Shu Ji Yi* was written in a terse and obscure style, tinged with Daoism and divination. Xu Yue mentioned that the mathematics he learnt from Liu Hong was that transmitted directly by a Daoist adept called Tian-Mu Xiansheng (Mr Eye-of-Heaven). The text mentions 14 old methods of calculation, many of them bearing the names taken from the *Yijing* (*I Ching*, Book of Changes). Of special interest is one called "ball-arithmetic," a trough-and-ball instrument similar to an abacus. Three other methods also involved the use of "balls". The first involved the use of one ball per column moving up and down a board or a trough. The second used two balls of two different colors, one relating to a *y*-axis on the left and the other to a *y*-axis on the right. Both these methods seem to have utilized a map-like grid of lines, similar to that of Cartesian coordinates. The third utilized balls of three different colors for use on three horizontal positions only. Joseph Needham has commented that this system of calculation "shows an interesting appreciation of coordinate relationships."

Another interesting aspect of *Shu Shu Ji Yi* is its reference to large numbers and to their representation in three forms of arithmetical series. Xu Yue called them the "upper, middle, and lower" classes of numbers, all beginning with *wan* (10^4). The three classes of large numbers may be summarized in Table 1.

The *Shu Shu Ji Yi* also gives a description of the "calculations of the nine balls", which according to the commentary provided by Zhen Luan was a simple magic square of order 3.

Though brief, obscure, and couched in religious nuances, Xu Yue's *Shu Shu Ji Yi* was selected as a prescribed mathematical text for imperial examinations during the Tang dynasty (AD 618–906). It was a difficult text, and candidates had to learn it by heart in order to pass the examinations.

See also: ►Liu Hong, ►*Jiuzhang Suanshu*, ►Magic Squares

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Yaᶜqūb ibn Ṭāriq

Jan P. Hogendijk

Yaᶜqūb ibn Ṭāriq was one of the earliest astronomers in the Islamic tradition. Very little is known about his life. He worked in the last quarter of the eighth century, when Arabic astronomy was not yet influenced by Ptolemy's *Almagest*. The works of Yaᶜqūb are lost, but some fragments have come down to us in later astronomical treatises and handbooks. The following information is based on such fragments. Yaᶜqūb authored three works:

1. A *zīj* (Astronomical Handbook with Tables), which was influenced by Indian and pre-Islamic Persian astronomy. For example, he took the zero meridian and the mean motion of the planets from India, and he seems to have adopted the planetary equations from a Persian source. In the lunar visibility theory, Yaᶜqūb used an Indian method to measure the width of the lunar crescent in "digits." His lunar visibility table is extant.
2. The *Tarkīb al-Aflāk* (Composition of the Heavenly Spheres) is summarized in some detail in al-Bīrūnī's *India*. In this work Yaᶜqūb discussed the size of the earth and the distances of the planets.
3. In the *Kitāb al-ᶜllal* (Book of Reasons), Yaᶜqūb explained trigonometrical rules, which he probably used in his *zīj*. A few citations of this work are given by al-Bīrūnī. Yaᶜqūb based his trigonometrical calculations on a sine table with base 3,438.

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Yaḥyā ibn Abī Manṣūr

Emilia Calvo

Yaḥyā ibn Abī Manṣūr was an astronomer from an important family of Persian scientists (his father was an astrologer). Yaḥyā spent his life casting horoscopes and trying to determine the positions of the stars with precision. He began working for al-Faḍl ibn Sahl, the vizier of the Caliph al-Maᵓmūn and, after his death, for the Caliph himself. He taught the Banū Mūsā and died near Aleppo, Syria in AD 832.

Yaḥyā was the director of a group of astronomers working under the Caliph al-Maᵓmūn, in the observatories of Shamāsiyya in Baghdad and Dayr Murrān in Damascus. The scholars included in the group were al-Marwarrūdhī, al-Khwārizmī, Sanad ibn ᶜAlī, the Banū Mūsā and al-Jawharī. They measured 1° of meridian by using two different procedures. The results of the observations were recorded in various *zīj*es (Astronomical Handbooks with Tables), one of which is the *Zīj al-mumtaḥan* (The Tested Tables) that was written by Yaḥyā himself. The observations ended when Yaḥyā and the Caliph died almost simultaneously.

Yaḥyā's *zīj* is preserved in one manuscript (Escorial 927) which is badly bound and comprises many folios that are not from Yaḥyā's work. It contains an explanation of calendars and chronological eras. The elements to calculate planetary longitudes are the result of the combination of Hindu–Iranian and Ptolemaic methods.

Yaḥyā's tables exerted a great influence on later astronomers: Thābit ibn Qurra wrote an introduction to them, Ibn Yūnus adapted them to Egypt, and Ibn al-Zarqāllu derived from them certain values such as the inclination of the ecliptic.

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Yang Hui

Ho Peng Yoke

Yang Hui (fl. 1261–1275), a native of Qiantang (in modern Hangzhou), ranks with Qin Jiushao (ca. 1202–ca. 1261), Li Zhi (1192–1279), and Zhu Shijie (fl. 1280–1303) as one of the four great mathematicians during the golden age of mathematics in thirteenth-century China. Of the four we know the least about Yang Hui's life, yet he has left behind a much larger number of writings than the others, showing that his mathematical interest also covered a wider field than any of his contemporaries known to us.

In the year 1261 he wrote the *Xiangjie jiuzhang suanfa* (Detailed Analysis in the Mathematical Rules in the Nine Chapters and Their Reclassifications). The original work comprised 12 chapters and an Appendix, which included an arrangement of numbers which he attributed to the eleventh-century mathematician Jia Xian and which in 1654 came to be known as Pascal's Triangle. Although the original work is no longer extant in its entirety, sections of it are quoted in the early fifteenth-century Imperial Compendium, the *Yongle dadian*.

Yang Hui also wrote the *Xiangjie suanfa* (Mathematical Methods with Detailed Explanations) on the processes of multiplication and division. Then in 1262 he produced an elementary text for beginners called the *Riyong suanfa* (Everyday Mathematics). In 1274 he wrote the *Chengqu tongbian suanbao* (Precious Reckoner for Variations in Multiplications and Divisions). In 1275 he wrote the *Tianmou bilei chengqu jiefa* (Practical Rules of Arithmetic for Surveying). The same year he assembled some old and forgotten materials and published the *Xugu zheqi suanfa* (Continuation of Ancient Mathematical Methods for Elucidating the Strange Properties of Numbers). This is the earliest Chinese monograph that we have on magic squares. The last three works mentioned above were published together in 1378 under a single title *Yang hui suanfa* (Yang Hui's Mathematical Methods). A full study of this book was undertaken by Lam Lay Yong in 1977.

Like his contemporaries Yang Hui used numerical equations of higher degree. His *sanchengfang* (quartic root) method is very similar to that rediscovered by Horner and Ruffini in the early nineteenth century. He employed freely the concepts of "dummies" and substitution in his algebra. At the same time his attention was on the practical side, always trying to provide the quickest working method. It seems that Chinese mathematicians were quite active during the eleventh and twelfth centuries, but none of their writings remains. At least we have come to know something about them through Yang Hui's writings.

See also: ►Magic Squares, ►Qin Jiushao, ►Li Zhi, ►Zhu Shijie

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Yavaneśvara

K. V. Sarma

The name Yavaneśvara, meaning Lord of Greeks, referring to one of Greek descent, is said to be the author of a number of Indian astrological works. He is mentioned for the first time by Sphujidhvaja who wrote his *Yavanajātaka* in AD 269–270. Towards the close of his book, Sphujidhvaja states that his work was based on that of Yavaneśvara. Yavaneśvara, who had been blessed by the Sungod, is stated to have rendered a Greek work on genethlialogy (divination by the influence: The Stars at birth) into Sanskrit in AD 150, at the instance of the ruler of the land. This work shows the position and influence of the stars at one's birth. The date mentioned by Sphujidhvaja is a little after the Kṣatrapa dynasty of Greek descent had established itself in the region of Saurashtra and Gujarat and ruled with its capital at Ujjain. The patron of Yavaneśvara has been identified, on the basis of coins and inscriptions, as Rudradāman I. Sphujidhvaja states that he (Rudradāman I) was quite conversant with the said Greek work.

Though the original work of Yavaneśvara is apparently lost, it is possible to get an idea of its extent and contents from *Yavanajātaka* which is its redaction. The *Yavanajātaka*, as it is available now, is an extensive work in 79 chapters, and takes under its purview a large variety of topics on horoscopy and natural astrology, including the delineation of the planets, their lords, their characteristics, the major and minor influences they exert on human beings at different periods, predictions relating to professions, experience of happiness and sorrow on account of planetary combinations, and predictions of the future on the basis of questions, omens, and military astrology. Most of these would have been depicted by Yavaneśvara as well. This is borne out also by several later texts, which are ascribed to Yavaneśvara. Among such works might be mentioned: The *Candrābharaṇahorā*, an extensive work in 101 chapters, prevalent in South India, and a shorter work with the same title prevalent in North India; two texts with the title *Yavanasaṃhitā*; a work called *Bhāvadīpikā* or *Bhāvādhyāya*, making predictions on the basis of the placement of the planets in the horoscope; *Nakṣatracūḍāmaṇi*, being predictions on the basis of the 27 constellations; and, a *Yavanapārijāta* depicting the results of good and evil deeds in life. It is clear from this that a regular school of the Yavana tradition of astrology had developed in India.

What is significant is that in all these texts which ostensibly go under the authorship of "Yavana," Hellenistic practices have been Indianized, both in the matter of content and presentation. Hindu caste distinctions and social orders are duly taken note of in making predictions; Hindu deities and their descriptions are duly invoked, and suitable modifications are made to their Greek counterparts. In effect, these texts seem to be wholly indigenous but for the ascription of their authorship to Yavana (Greek).

See also: ►Astrology in India

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Yinyang

WEIHANG CHEN

Yinyang is a Chinese term composed of two words. *Yin* means the shade and *yang* the sunshine. It is the most important concept in the traditional Chinese way of thinking, the basic concept for classification and explanation in Chinese science, medicine, and philosophy.

The word *yinyang* designates a special method for looking at things as well as for describing the phenomena of the world, including the human body. *Yin* and *yang* make a pair which exist together. In their coexistence, these two oppose each other in their different functions and at the same time help each other. They both contribute and are necessary to the other's existence. All phenomena can be looked at and described using the *yinyang* paradigm. This is the typical methodology of Chinese science.

The concept of *yinyang* can be compared with the Western dialectic method. However, in Chinese science this way of thinking has developed into a very complicated system of knowledge, in which *yin* and *yang* are represented in every real object. Therefore, *yinyang* is more than a way of thinking; it is also a theory that provides guidelines for human action.

The use of the concept of *yinyang* can be best illustrated by examples. The earliest example which can be found in extant Chinese ancient texts is from the Confucian classic *Yijing* (*I Ching*, The Book of Changes). It is not to be found in the *Yijing* proper, but in the commentaries (so-called *Yizhuan*, *I Chuan*, or the Ten Wings). It is generally accepted that *Yizhuan* was complied during the Warring States period (the fifth to the third century BCE), so that is the earliest date we can attribute to the origin of the concept of *yinyang*. *Yizhuan* uses *yinyang* to explain the *Yijing* proper in such a way that the binary notation for every possible movement (change) in the real world is explained as representing the actual acting of the two opposing factors (or forces in the Western sense of the word) that substantiate the situation under consideration. Thus in the relation of men and women, *yang* represents man and *yin* represents woman. Likewise in the relation of heaven and earth, of sun and moon, of day and night, etc., *yang* represents the former and *yin* the latter. Furthermore, *yang* and *yin* are used to represent opposite qualities including natural attributes like hot and cold, hard and soft, bright and dark, odd and even, as well as human dispositions like aggressiveness and submissiveness, or activeness and inactiveness.

Two points need to be emphasized here. The first is that the designation of *yang* or *yin* to an object is only effective in certain relationships. Relative to the woman, the man is *yang*. But there are other traditionally important relations that man comes into, such as that of heaven and man, of man and gods, of man and his fate, or of individual man and his family or society. In any of these, "man is *yang*" does not apply. Therefore, the traditional designation of *yang* and *yin* forms the hard core of a knowledge about the world. The second is that the use of the concept of *yinyang* is a pragmatic one. To say something or some quality is *yang* and the opposite is *yin* will be meaningful only if this designation classifies these two objects or qualities into two existing categories into which many other things or qualities are already classified. A wrong designation will make a real difference in human action when using this knowledge of classification to make a decision according to a certain theory.

According to Chinese historical records, especially the authoritative *Shi Ji* (Records of Historians) by Si Maqian (b. 145 or 135 BCE), during the Warring States period one of the six most important schools of ideas was called the *yinyang* school. It is generally accepted that, beside its political and philosophical relevance, this school brought about two important developments, which somewhat related to each other throughout the 2,000 years afterward. One is the Daoist practice of alchemy and physical immortality; the other is Chinese traditional medicine, or more accurately, Chinese body science.

From both the Chinese traditional viewpoint and from the modern Western point of view, the most important use of the *yinyang* concept can be found in the theory and practice of Chinese traditional medicine. The earliest extant medical literature was unearthed in 1973 from the Han Tomb No. 3 at Mawangtui, Changsha, Hunan Province, China. There are records which show that these texts were buried in the tomb with the dead Marquis in the year 168 BCE. In these texts the *yinyang* concept is used as the most basic classifying concept. It is the same with the *Huangdi Neijing* (Yellow Emperor's Classic of Internal Medicine), which contains medical essays edited in the first centuries AD. From these texts we know that the *yinyang* concept was used in Chinese medical theory much earlier than the second century BCE.

In Chinese medical theory, *yin* and *yang* are two different kinds of *qi* (literally "breath" but occasionally translated as meaning "vital force"), which function within the human body contradictorily and complementarily, and thus make the body alive. Human health is attained by keeping these two *qi* in a good, natural balance. All health problems are caused by the lost of this balance. All medical theories, diagnoses, and therapies can be understood as practical knowledge of how to classify the imbalance into a certain system of categories and how to use different means, which are classified into corresponding categories, to retrieve the natural balance. For a simplified example, two common health problems are diagnosed as *yang*-deficiency–*yin*-excess and *yin*-deficiency–*yang*-excess, which correspond to cold and heat syndromes. In diagnosis these two syndromes are related to two categories of symptoms which include every possible change in the pulse, the complexion, the tongue, the breath, the excrement and urine, etc., of the patient. In therapy, herbal medicine, or the method and location of acupuncture points are correspondingly classified.

There are two other concepts which are closely connected with the *yinyang* concept. They are the *wuxing* (five phases), which is extremely important in Chinese science, and the *taiji* (the ultimate beginning), which is more important in Chinese philosophy. The *yinyang* concept is also the basic concept used in Chinese fortune telling such as astrology (*suanming*, literally "calculating the fate") and geomancy (*fengshui*, literally "wind and waters").

See also: ►Five Phases, ►Astrology, ►Geomancy, ►Medicine in China, ►Divination in China, ►*Huangdi Neijing*, ►*Qi*, ►Fengushui

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Yoga

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Yoga is one of the six principal systems of Indian thinking known as *darśanas*. The word *darśana* is derived from the Sanskrit root *drs*, meaning "to see." Fundamentally, *darśana* means "view" or "a particular way of viewing." Yoga, as one of the six *darśanas*, has its source in the Vedas. In the traditional Indian view these are called *vaidika*, or Vedic *darśanas*. These are *nyāya*, *vaiśeṣika*, *saṅkhyā*, *yoga*, *mīmāṃsā*, and *vedānta* (there are other *darśanas* that do *not* accept the supremacy of the Vedas, such as Buddhism and Jainism). While the source of Yoga was the Vedas, Yoga was formalized by Patañjali, one of the great Indian sages. His classic text is *Yoga Sūtra* (Aphorisms on Yoga). Although there are many other major treatises on Yoga that postdate Patañjali's, his work is the most authoritative.

All the *darśanas* proclaim that it is their aim to help human beings achieve clarity and balance of perception and action. Yoga is unique in as much as it offers practical suggestions and guidelines to achieve this end. According to the tenets of Yoga, human beings are under the influence of *avidyā*, which is what prevents correct perceptive analysis. Sage Patañjali suggests practical ways to reduce and remove *avidyā*. In his *Yoga Sūtra*, three things are suggested to help us explore the meaning of Yoga and therefore feel *avidyā*. These are *tāpas*, *svādhyāya*, and *īśvara-pranidhāna*. *Tāpas* is a means by which we keep ourselves fit and clean. Often *tāpas* is defined as penance, mortification, and dietary austerity, but what is meant is the practice of *āsana* (postures), *prāṇāyama* (control of the breath), and other disciplines. These practices aid in the removal of impurities from our systems. In so doing we gain control of our whole system. It is the same principle as heating gold to purify it.

The next part of Yoga is *svādhyāya*, the study of the self. Where are we? What are we? What is our relationship to the world? It is not enough to keep ourselves fit; we should know who we are and how we relate to others. This is not easy because we do not have an actual mirror for our minds as we do for our bodies. We must use reading, study, discussion, and reflection as a mirror to the mind.

The third means of exploration is *īśvara-pranidhāna*. It is usually defined as "love of God" but it also means "quality of action." We must carry out our jobs, and all our actions must be done with quality. Since we can never be certain of the fruits of our labors, it is better to remain slightly detached from them and pay more attention to the actions themselves.

Together, these three cover the whole of human action: fitness, inquiry, and quality of action. Taken together, these practices are known as *Kriyā Yoga*, the Yoga of action. Yoga is not passive. We must be involved in life, and preparation is necessary for this involvement.

Patañjali's Yoga is sometimes called *Aṣṭāṅga* Yoga, which literally means Eightfold Yoga. These eight are *yama*, *niyama*, *āsana*, *prāṇāyāma*, *pratyāhāra*, *dhārāṇa*, *dhyāna*, and *samādhi*.

Patañjali considers five different attitudes (*yamas*) or relationships between an individual and "the outside." The first is *ahimsā*. While the word *himsā* means injury or cruelty, *ahimsā* means more than merely the absence of *himsā*. It means kindness, consideration, or thoughtful consideration of people or things. The next *yama* is called *satya*, "to speak the truth." The third *yama* is *asteya*. *Steya* means "to steal"; *asteya*, the opposite, means if we are in a situation where people trust us, we will not take advantage of them. The next yama is *brahmacarya*. The word is composed of the root *car* (to move) and *brahma* (the truth). If we move toward the understanding of truth, and sensual pleasures get in the way, we must keep our direction and not become lost. The last *yama* is *aparigraha*, "hands off." *Parigraha* is the opposite of the word *dana*, which means "to give." *Aparigraha* means "to receive exactly what is appropriate."

Niyamas, like *yamas*, are attitudes and are not to be taken as actions or practices. The five *niyamas* are more intimate in the sense that they are the attitudes we have toward ourselves. The first *niyama* is *śauca*, or cleanliness. There are two parts to this, external and internal. External *śauca* has to do with simply keeping ourselves clean. Internal *śauca* has to do with cleanliness of the internal organs and mind. The practice of *āsanas* or *prāṇāyāma* could be an internal *śauca*. The second *niyama* is *santosa*, a feeling of contentment. The next is *tāpas*, a word we have already discussed. With *tāpas* the idea is to bring out *asuddhi*, "dirt" inside the body. *Svādhyāya* is the fourth *niyama*. As we defined it earlier, *sva* means self; *adhyaya* means study or inquiry. Actually, *adhyaya* means to go near. *Svādhyāya* means to go near yourself, i.e., to study yourself. Any study, reflection, or contact that helps us understand more about ourselves is *svādhyāya*. The last *niyama* has also been mentioned before. *Īśvarapraṇidhāna* means "to leave all our actions at the feet of the Lord." Since our actions often come from *avidyā* it is possible that they might go wrong. That is why contentment is so important. This attitude suggests that we have done our best, and can leave the fruits of our actions in the hands of something higher than ourselves.

The third *aṅga* is *āsana*. In the theory of *āsana* practice, there are two aspects, *sukha* and *sthira*. We must be comfortable and at ease (*sukta*) and we must be steady and alert (*sthira*). We must be involved and at the same time attentive. Yoga suggests ways to achieve these qualities in *āsana*. The fourth *aṅga* is *prānāyama* which is conscious regulated breathing. *Pratyāhāra*, the fifth *aṅga*, involves the senses. The word *āhāra* means "food." *Pratyāhāra* means "withdrawing from that on which we are feeding." This refers to the senses: when the senses refrain from "feeding" on their objects, i.e., *pratyāhāra*.

Dhāraṇā comes from the root *dhr*, "to hold." *Dhāraṇā* occurs when we create a condition so that the mind, normally going in a hundred different directions, is directed toward one point. *Dhāraṇā* is a step leading toward *dhyāna*. In *dhāraṇā* the mind is moving in one direction; nothing else has happened. In *dhyāṇa*, when we become involved with a particular thing and we begin to investigate it, there is a link between ourselves and this object; i.e., there is a perceptual and continuous communication between the object and our mind. This communication is called *dhyāṇa*. Further, when we become so involved with an object that our mind completely merges with it, that is called *samādhi*. In *samādhi* we are almost absent; we become one with that object.

There are many varieties of Yoga. Some people say that *dhyāna* is the means to *Jñāna Yoga*. In this context, this means inquiry about the truth, the real understanding that we attain in a state of *samādhi*. Inquiry in which we hear, then reflect, and then gradually see the truth, is *Jñāna Yoga*. In the *Yoga Sūtra* it is said that in the state of mind where there is no *avidyā*, automatically there is *Jñāna*.

Bhakti Yoga comes from the root *bhak* which means "to serve that which is higher than ourselves." This means an attitude of devotion. In *Mantra Yoga*, a teacher who knows us very well might give us a *mantra* which has a particular connotation because of the way it has been arranged. If that *mantra* is repeated in a certain way, if we are aware of its meaning, and perhaps if we want to use a particular image, *Mantra Yoga* brings about the same effect as *Jñāna* or *Bhakti Yoga*. In *Rāja Yoga*, the word *Rāja* means "the king who is always in a state of bliss, who is always smiling." Any process through which we achieve greater understanding of the mysterious and the obscure is *Rāja Yoga*. In the Vedas there are many references to the word *Rāja* in relation to *īśvara*.

It is best to explain *Laya Yoga* in a context of *samādhi*. When the meditator completely merges with the object of meditation, that is *Laya*. We merge with the object and nothing else exists.

In recent times, much has been written about Hinduism, and a lot of it pertains to and derives from the viewpoint of *Vedānta*. It is important to see that the viewpoint of Yoga differs in some crucial respects from the viewpoint of *Vedānta*. Brahman is considered the "*Pāramārthika Satya*" or ultimate truth, and the world we live in and experience through our senses is granted the status of truth at an operational level, i.e., "*Vyāvahārika Satya.*" In a sense, this carries the implication that the world is false and illusory. According to Yoga, everything we see, experience, and feel is not an illusion but is true and real. This concept is called *satvāda*.

Everything, including *avidyā*, dreams, and even fancy and imagination, is real. However, all these are constantly in a state of flux. This concept of change is called *pariṇāmavāda*. In Yoga, although everything we see and experience is true and real, changes do occur either in character or in content.

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Yuktibhāṣā of Jyeṣṭhadeva

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Jyeṣṭhadeva (fl. 1500–1610) was a Nambūthiri Brahmin from the Ālattūr village, an important Brahmin settlement near Cochin. He was probably a student of Dāmodara, the son of Parameśvara, who also taught Nīlakaṇṭha Somayāji. His fame rests on the authorship of one of the most important texts of the Kerala school of mathematics and astronomy, the *Yuktibhāṣā* (An Exposition of the Rationale [of mathematics and astronomy]) also called *Gaṇita-nyāya-saṇgraha* (Compendium of Mathematical Rationale). It is a unique work on the rationale of Hindu mathematics and astronomy as it was understood in medieval India. It is unique in the sense that it is neither a textbook nor a commentary, but a work which is wholly devoted to a systematic exposition of mathematical rationale, written in Malayalam, the local language of Kerala.

Born about 1500, Jyeṣṭhadeva probably composed the *Yuktibhāṣā* about 1530, since it is known that a little after 1534, Śaṅkara Vāriyar, another contemporary astronomer, used it in his commentaries. Another work of Jyeṣṭhadeva, the *Dṛkkaraṇam*, also in Malayalam, was composed in AD 1608.

At the outset of the work, the author states that he is attempting "to set out in full the rationale useful for understanding the planetary motion according to the *Tantrasaṅgraha* of Nīlakaṇṭha Somayāji" (b. 1444). But he actually goes much beyond that and subjects to rationalistic analysis the entire gamut of mathematics and astronomy. In fact, he takes up the treatment from the very fundamentals, the concept of numeration and the theory of numbers. The work is made up of two divisions, each one divisible into several sequential chapters.

The first deals with the following subjects (1) the eight fundamental operations, from simple addition to the roots of sums and differences of squares, wherein several methods, including diagrammatic solutions are offered; (2) algebraic problems; and (3) operations on fractions. The other chapters deal with: (4) the general nature of the Rule of Three (direct proportion) and (5) application of the Rule of Three in the computation of mean planets; (6) elaborate rationalizations of the circumference of the circle; and the last chapter: (7) the rationales of the derivation of the R sines, R versed sines, and their addition, properties of cyclic quadrilaterals, and the surface area and volume of a sphere. Many of the rationales are demonstrated both algebraically and geometrically.

Part Two is devoted to the exposition of rationales in astronomy, including (1) the computation of mean and true planets by means of two types of epicycles, supplemented by corrections; (2) the celestial sphere, the related great circles and secondaries, the precession of the equinoxes, and the armillary sphere; (3) declination, right ascension, and related matters; (4) problems related to spherical triangles; (5) problems connected with direction and shadow; (6) computation of the rising and setting points of the ecliptic, the ecliptic having constant variation. A direct method, enunciated in Indian astronomy for the first time, is used; (7) eclipses and the attendant parallax corrections; (8) the *Vyatipāta*, which is the moment when the sun and the moon have equal declinations, but in different quadrants; and (9) reduction of computed results to observation and with the phases of the moon.

Some points are of special interest in the *Yuktibhāṣā*. One is the rationale for three or four steps for true planets, although the result can also be obtained in two steps; the derivation of inverse declination and inverse right ascension; novel solutions for some of the problems on spherical triangles and on shadows; refinements for parallax corrections; and an alternate method with a novel correction for the computation of the moment of *Vyatipāta*. A noteworthy characteristic is its elucidating rationale from the fundamentals, first setting out the axioms and postulates involved, then developing the arguments and methodologies step by step.

It might also be noted here that Śaṅkara Vāriyar provided a valuable service by incorporating rationales from the *Yuktibhāṣā* into Sanskrit, the language of scholars. This he did in two elaborate commentaries called *Kriyākramakarī* on the *Līlāvatī* by Bhāskarācārya, and *Yuktidīpikā* on the *Tantrasaṅgraha*, a work on astronomy by Nīlakaṇṭha Somayāji. There is also a highly corrupt rendering of *Yuktibhāṣā* into Sanskrit.

See also: ►Nīlakaṇṭha Somayāji, ►Parameśvara, ►Rationale in Indian Mathematics, ►Śaṇkara Vāriyar

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Zacut, Abraham

José Chabás

Abraham bar Samuel bar Abraham Zacut was the most prominent astronomer of the late Middle Ages in the Iberian peninsula. He was born in 1452 in Salamanca (Spain), a Castilian town whose university had established a renowned chair of astrology (including astronomy) in the mid-fifteenth century.

Although he is chiefly known for his astronomical activity, Zacut wrote on other subjects such as lexicography (*Hosafot lasefer ha-'arukh*) and history (*Sefer Yuḥasin*).

Zacut's most outstanding work is *Ha-ḥibbur ha-gadol* (The Great Composition), a text in Hebrew consisting of more than fifty astronomical tables and lengthy canons explaining their use. The tables have 1473 as radix, they are arranged for the Christian calendar, and their entries are computed for the meridian of Salamanca. The tables give the positions of the Sun, the Moon, and the five planets presented in the form of an almanac. Of special interest are the tables listing the daily positions of the Sun (for 4 years from 1473) and the Moon (for 31 years from 1473). All the entries are computed according to the Alfonsine Tables, well known in Salamanca since the arrival of Nicholaus Polonius, the incumbent of the chair of astrology at the University of Salamanca ca. 1460. Another table lists all true syzygies (new and full moons) for 31 years; it is based on the cycle of 767 syzygies discovered by the Catalan astronomer, Jacob ben David Bonjorn, author of astronomical tables for Perpignan (1361), and a follower of Levi ben Gerson (1288–1344). Among others, both these Jewish astronomers are mentioned in Zacut's *Ḥibbur*. In fact, the only Christian scholar mentioned in the *Ḥibbur* is king Alfonso of Castile. The work was finished around 1478, and 3 years later it was translated from Hebrew to Castilian, with the help of Zacut himself, by Juan de Salaya, who held the chair of astrology after Nicholaus Polonius.

At the request of his new patron, Juan de Zúñiga, Master of the Order of Alcántara, in 1486 Zacut wrote a book on medical astrology: *Tratado de las influencias del cielo* (*Treatise on the Influence of the Heavens*), followed by a short text on eclipses: *Juicio de los eclipses* (Judgment on Eclipses). Two other works on astrology have been attributed to Zacut: *'Oṣar ḥayyim* (Treasure of Life) and *Mishpeteị ha-'iṣṭagnin* (Judgment of the Astrologer).

Because of the expulsion of the Jews decreed by the rulers of Spain (1492), Zacut moved to Portugal and entered the service of King João II as an astronomer and chronicler.

A version of Zacut's *Ḥibbur* was published in Leiria, Portugal, under the title *Tabulae tabularum coelestium motuum sive Almanach Perpetuum* (1496). The Portuguese scholar, José Vizinho, was responsible for this version, which contains a summary of the canons of *Ha-ḥibbur* and most of its tables. Actually, two editions came out of the Portuguese printing house that year: one with the canons in Castilian, the translation of which was made by Vizinho, the other in Latin. The *Almanach Perpetuum* is said to have played a significant role in the navigation projects of the kingdom of Portugal, and especially the tables giving the daily positions and declinations if the Sun. For a facsimile of the tables, see ►http://www.fondoantiguo.us.es/obras/200/index.html.

After the practice of Judaism was declared illegal in Portugal in 1496, Zacut traveled to Northern Africa and settled in Tunis. He adapted his tables for the year 1501 and he compiled another set of tables, beginning with year 1513, arranged for the Jewish calendar and the meridian of Jerusalem where he then lived. Both sets of tables only survive in fragmentary texts. Zacut died in 1515, probably in Damascus.

Zacut's work had a considerable impact on the astronomical community. All, or some of, the tables in the *Almanach Perpetuum* were reprinted several times in astronomical texts published in 1498, 1502, 1525, and 1528. All four editions were printed in Venice, in three different printing houses. Further evidence for the fame of Zacut and his tables is found in many authors in the late fifteenth and sixteenth centuries, and even later, among Jewish, Muslim, and Christian scholars.

See also: ►Levi ben Gerson, ►Alfonso X

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Zero

R. N. MUKHERJEE

Mathematics today owes its existence in part to the discovery of zero. For the purpose of calculation it needed a short symbol, which is at present denoted by a small circle in nearly every part of the world. In India in the early period the form of short symbol which represented zero (*śūnya*) was both a dot and a small circle.

In the Vedic literature, in the *Amarakosa*, zero (*śūnyam bindau*) was represented by a dot. The form was also suggested by the word *kṣudra* (very small) in the *Atharvaveda*. The word *randhra*, used in the Hindu *Gaṇita Sastraka*, indicated a small hole. There are many examples of zero being represented as a dot in the Kashmirian *Atharvaveda*, both in the marginal notes and in the text itself.

In the marginal notes, the numbers are as follows:

Symbol	Number	Folio	Page
◊●●	100	100b	192
◊●◊	101	101b	194
◊2●	170	170b	310

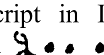
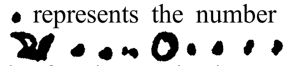
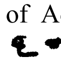
The symbols in the marginal notes represented the Folio numbers. In most of the pages of the book there are examples of the above type. In the text itself the following numbers are found:

1
2
3
4
5
6
7
8
9
10

Small circles in pairs have been used to denote blank spaces in the text. In Folio No. 178a, page 323 in the last line, pairs of small circles are found as follows:

○○ ○○ ○○ ○○ ○○

The numbers in the marginal notes may be taken from a later period, but the symbols in the text itself must be from the time of the *Atharvaveda* (500 BCE).

In the Bakhshālī Manuscript, the oldest extant manuscript in Indian mathematics (AD 200), the symbol  represents the number 4000, while the symbol  represents 500,000,000. The fourth zero in the manuscript is a small circle; the others are dots. In the Shahpur Stone image Inscription of Aditya Sena Bihar, India (AD 672), the symbol  stands for 60, and zero is represented as a dot. In the Malay Inscription at Katakapur (AD 686), symbol  represents the number 608 (Śāka), and zero is represented as a circle with a deep circumference.

In the above examples it is found that zero has been exhibited either as a dot or as a small circle to fit in numbers in the place value scale, or to represent absence. In the inscriptions at Sambor, Palembang, and Kotakapur, which were Indian colonies of the Far East, the numbers have been written to represent the Śāka era. Hence undoubtedly they also represent an Indian origin.

Now the question arises as to why zero has been represented as dot or a small circle and not as a square or rectangle or anything else. Two reasons can be assigned: one is spiritual or metaphysical, the other is physical or atomic.

`In the spiritual sphere, *śūnya*, or zero or nothing, the symbol of absence of everything, identifies itself with *Nirguṇa* Brahma, the absence of all qualities. The no-quality (*Nirguṇa*) in Brahma represents the fact that He is not guided by any of the qualities or constituents of nature. But at the same time Brahma is the source of all qualities, energy, power, and strength. Similarly *śūnya* or zero itself signifies absence when placed independently, but it represents fullness when it is placed in the decimal system of numeration. (Placing zeros on the right side of a number increases the value to an infinite step.)

Since the conception of *śūnya* identifies with the conception of Brahma both in absence and fullness, the symbol of *śūnya* (zero) must be guided by the symbol of Brahma. The conception of Brahma lies in meditation on a particular point or small circle in the space between the two eyebrows.

Swami Sivananda has given concentration the name "one-pointedness". Concentration can also start by fixing one's gaze on a black dot on the wall and later on a bright light first of the size of a pinpoint and later of the size of a sun coming out from the space in between the two eyebrows. Hence the symbol of Brahma can be taken to be a dot or a small circle, and therefore the symbol of mathematical zero is either a point or a small circle.

There are also physical reasons for the symbol for zero. Planets seen from the earth look just like dots. From Vedic times Indians excelled in astronomical observations as we can see in the *Vedāṅga Jyotiṣa* (1200 BCE). So the physical reason for zeros being represented as a dot or a small circle lies in the fact that the sun, moon, and planets were seen as dots or small circles to an observer on the earth.

Now why should a planet be chosen to represent zero? It is because of the other interpretation of mathematical zero, the absence of atoms. The idea of the atom was mentioned in ancient times in the Buddhist work *Lalita Vistara* (500 BCE). The nucleus of the atom is so small that it is a *kṣudra* (minute), a synonym for zero in the *Athravaveda*. Thus the absence in mathematical zero is guided by the absence inherent in the smallness of an atom or its nucleus. The concept of the fullness of mathematical zero is also present in the infinite motion of the planets and of the electrons around the nucleus of an atom.

The electron has no mass in the material sense, and the mass which it has developed from electrical energy is negligible. This guides the concept of mathematical zero. The movement of electrons around the nucleus with a very high velocity and in an infinite motion is identical with the concept of fullness of mathematical zero which guides the numbers to move in an infinite journey like 10, 100, 100, 10,000 to 10^n.

Thus the double interpretations, absence and fullness, of mathematical zero are identical with the double interpretations in a planet, and the symbol of zero is guided by the symbol of a planet which is observed either as a dot or a small circle and whose path is almost circular.

Zero has a double meaning in Vedic literature. Etymologically the word *śūnya* comes from the word *śūna* (*śūna* + *yat*). The word *śūna* has two meanings. One is the killing of animals or the slaughter house, which represents absence; the other is increase, which leads to the conception of fullness.

The synonyms of zero, *randhra*, *tuccha*, *kṣudra*, and *ritka* project a concept of nothingness, while the synonyms *vyoma*, *diba*, *akasa*, *antariksa*, and *jaladhra patha* mean infinite expanse of sky. *Purna* means full, and *ananta* means infinite. *Drabinam* and *balam* mean strength, vigor, and force.

Zero, though it signifies nothing, has a full voltage battery charge when used in the decimal place value system.

The German mathematician Van der Waerden (1961) opines that the symbol of zero as a small circle came from the first letter "o" of the Greek word *ouden* meaning nothing. This claim can be compared with a parallel claim (apparently convincing but far from the truth) that 4 in Brahmi Numerals written as 𑁕 comes from the first letter 𑁕 of the word 𑁕 (our four in English). Similarly in India one may say that the symbol ५ (5) in Deonagri script comes from the first letter of the word पांच (five), ६ (6) in Deonagri comes from the first letter of the word छः (six). But these are not so. Every number symbol has a heritage and a path through which it has come down to its present form. That "o" is the first letter of the word is just a coincidence. Rather the symbol of a small circle (o) was used for the numbers 10, 70, and 100 in Greece.

See also: ►Bakhshālī Manuscript

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Zhang Heng

JIANG XINOYUAN

Zhang Heng was a Chinese astronomer, writer, and machinist (AD 78–139). As a man of noble descent, he assumed many official positions, and from

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AD 115, twice was the head of the imperial astronomical organization for a total of 15 years. He was a versatile man who contributed greatly to Chinese astronomy.

The title of one of his works is *Ling Xian* (Mystical Laws); it is very possibly an outline of astronomy–astrology, but only part of the beginning has been handed down. He made an astronomical instrument like a planetarium to demonstrate the motion of the sun, moon, and planets with stars in the background, and to give the correct time. According to historical records he provided this instrument with an automatic mechanical installation, but the detailed information has not been preserved.

Zhang Heng made a wonderful invention for earthquake measurement. In AD 132 he invented a seismoscope called *Hou Feng Di Dong Yi* (Instrument for Earthquake), and at Luoyang (the capital of the empire) he successfully determined that an earthquake had occurred at a place in the northwest of China more than a thousand kilometers from the capital. We have the following information about this seismograph.

This instrument was cast in copper. Its main body is a standing egg-shaped shell with an erect pendulum in the center. It links eight dragons each of whom, with some dexterous mechanical installations, keeps a small copper ball in its mouth. When an earthquake happens somewhere, the dragon in that direction spits out its ball, so that people know where the earthquake has occurred.

This famous seismoscope was not preserved, so scholars have tried to reproduce it since the nineteenth century. Many reconstructive schemes on the basis of modern seismological principles have been published. Up to now, the most successful was by Wang Zhenduo (1963) of which a model has been made.

Zhang Heng is also an important writer. His *Si Chou Shi* (Four Chapters of Distressed Poems) and *Gui Tian Fu* (To Live in Seclusion) are literary masterpieces and his *Tong Shen G* (Song of Love) is one of the most important early documents for the history of Chinese sexual culture.

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Zhang Ji (Zhang Zhongjing)

Fabrizio Pregadio

The Chinese physician and medical author Zhang Ji (ca. 150–220), also known as Zhang Zhongjing, was born in the Nanyang commandery (in modern Henan). As stated in the preface to his main work, he was prompted to study medicine and collect prescriptions by the spread of epidemic diseases which caused the death of several members of his own clan. The preface adds that he was Governor (*taishou*) of Changsha (modern Hunan), but this detail is not independently confirmed by other sources.

Zhang Ji's main work, completed in the first or second decade of the second century, was originally entitled *Shanghan zabīng lun* (Treatise on Cold Damage and Miscellaneous Disorders) and included 16 chapters. The rather intricate bibliographic history of the text cast doubts on its authenticity. About one century after its compilation, Wang Shuhe (ca. 265–317) produced a revised, expanded version. The final six chapters, lost by the Song period, were replaced on the basis of an abridged version, and published as a separate work. The two main parts in which the text is extant today are entitled *Shanghan lun* (Treatise on Cold Damage) and *Jingui yaolüe* (Essentials from the Golden Casket), respectively. The latter is based on the "Miscellaneous Disorders" section of the original text.

The *Shanghan lun* is the first Chinese medical text devoted to a specific etiology. It is concerned with a class of diseases symptomatized by acute fevers, and named "Cold Damage" after one of their factors. Their diagnosis is based on the identification of symptoms (*zheng* or "evidence") that indicate the stage reached by the disease in its progression toward the vital centers of the body. These stages of development are defined according the Six Warps (*liujing*) system, one of the frameworks used to describe the cyclical flow of energy within the body (others are *qi* and *wuxing*, Five Agents or Phases). The text emphasizes the practical rather than the theoretical aspects of healing. Therapy is based on the administration of medicines (the whole work includes more than 300 prescriptions for specific diseases), and to a lesser extent on acupuncture, moxibustion, and other methods such as baths and massages.

Zhang Ji's work gave rise to the second most important tradition within Chinese classical medicine after the one represented by the texts of the "Inner Canon of the Yellow Emperor" corpus (*Huangdi neijing*). Although Zhang refers to this corpus in the preface, even the most basic notions of the Inner Canon – e.g., the

Five Agents or Phases, the visceral systems (*zangfu*), and the circulation tracts (*jing*) of acupuncture – are absent from his work. As has been pointed out, this is not necessarily a sign of alternative or competing traditions. An extended commentatorial tradition, in fact, has tried to bring together the respective basic notions. Only recent research has shown the ways and extent to which the general framework of the two works differs.

See also: ►*Shanghan lun*, ►Five Phases, ►*Qi*, ►Acupuncture, ►Moxibustion, ►Medicine in China, ►*Huangdi neijing*

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Zhang Qiujian Suanjing

Lam Lay Yong

Zhang Qiujian suanjing (The Mathematical Classic of Zhang Qiujian) is the only known work of the fifth century mathematician, Zhang Qiujian. It is one of ten mathematical books known collectively as *Suanjing shishu* (Ten Mathematical Classics). In AD 656, when mathematics was included in the official examinations, these ten outstanding works, which covered a period of over a thousand years, were specially selected as textbooks.

Jiuzhang suanshu (Nine Chapters on the Mathematical Art) and *Sun Zi suanjing* (The Mathematical Classic of Sun Zi) are two of these texts that precede *Zhang Qiujian suanjing*. All three works share a large number of common topics. Though *Sun Zi suanjing* was intended as a primer, it now provides significant documentation of the rod numerals and their use in multiplication, division, and other mathematical methods. *Jiuzhang suanshu* is undoubtedly the most important and influential of the early mathematical texts. Both works occupy prominent places in the history of Chinese mathematics with one showing the initial learning stage and the other manifesting an evolutional culmination. *Zhang Qiujian suanjing* demonstrates the continuation of the development of mathematics from here, and provides an important bridge of knowledge on the evolution of traditional mathematics to its apogee in the thirteenth century. It is all the more important as such surviving works are few and far between.

Zhang Qiujian regarded fractions of primary importance; he mentioned the difficulty of the subject in his preface and provided more complicated problems than those in *Jiuzhang suanshu*. There are only very brief general descriptions of finding the square root and the cube root of a number in *Jiuzhang suanshu* and these are written with the use of technical phrases. It is a relief to scholars to find that examples are employed in *Zhang Qiujian suanjing* to illustrate the step by step procedures of both methods and also to show how the solution of a nonintegral approximation is obtained.

Zhang Qiujian continued with the tradition of the development of arithmetic by supplying problems involved with what is known in the west as the Rule of Three and extending to problems concerned with proportions, compound proportions, and proportional parts. Other problems are involved with relative speed, different shaped frustums and granaries, the Rule of False Position, the arithmetical progression, the computation of interests and taxes, similar right-angled triangles, and the quadratic equation. There are a number of problems concerned with the well-known *fang cheng* method, which is the Chinese way of solving a set of simultaneous linear equations. The last problem of the book is the famous problem of a hundred fowls. In this problem, somebody is to buy 100 fowls for 100 monetary units, given that a rooster costs five units, a hen 3, and chicks are sold three for one unit. Even though the answers given in the book are correct, it is not clear how the answers were obtained.

Zhang Qiujian's lucid style has been a great help to the scholar's understanding of how the ancient mathematicians manipulated the rod numerals to arrive at the answer. The existing edition of the book has three chapters with 92 problems; the last portion of the second chapter and the beginning of the third chapter are incomplete. The book has been translated into English by Ang Tian Se.

Zhang Qiujian suanjing has an important place in the world history of mathematics: it is one of those rare books before AD 500 that manifests the upward development of mathematics fundamentally due to the notations of the numeral system and the common fraction. The numeral system has a place value notation with ten as base, and the concise notation of the common fraction is the one we still use today.

See also: ►Computation: Chinese Counting Rods, ►Liu Hui and the *Jiuzhang Suanshu*

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Zheng He

Sally Church

Zheng He was originally from Kunyang in Yunnan province, in Southwest China. Born around 1371 to a Muslim family, he was surnamed Ma, a common Muslim surname derived from the Chinese transliteration of the name Muhammed. During the 1380s, the Ming government sent troops to Yunnan on an expedition to pacify the region, expel any remaining Mongol influences, and incorporate it solidly into the newly founded regime. At the age of about 10, Zheng He (then Ma He) was captured by Chinese troops, taken prisoner, and selected to become a eunuch. We know that by 1382, when an inscription was written for his father who had passed away, he was taken into the service of Prince Zhu Di, fourth son of the Ming founder, Emperor Hongwu (Zhu Yuanzhang, r. 1368–1398). There Ma He served Zhu Di in his principality of Yanjing (the region of present-day Beijing). Zhu Di was later to become the third Ming emperor, Yongle (r. 1403–1424).

In his early career, Ma He accompanied Zhu Di on military campaigns against Mongol forces in the Yanjing region. He distinguished himself as a military commander in a campaign against the Mongols outside the Great Wall (1393–1397), and then in the civil war (1399–1402) launched by Zhu Di against Hongwu's successor, Jianwen. This war ended in victory for Zhu Di, who usurped the throne from Jianwen in 1402. For loyal service to him during the civil war, and as a reward for suppressing a rebellion in Yunnan, Zhu Di, then Emperor Yongle, conferred the Chinese surname Zheng on his trusted eunuch. This occurred on New Year's Day in 1404. From then on he was known as Zheng He.

Soon after ascending the throne, Yongle began planning the maritime expeditions which have made Zheng He famous. In some respects they were a continuation of the regular conduct of foreign relations – the sending and receiving of envoys to and from foreign countries, particularly in Southeast Asia – which had occurred during Hongwu's reign (1368–1398) and in previous dynasties. As early as the ninth month of 1402, only three months after proclaiming himself Emperor, Yongle sent ambassadors to these countries to announce his accession. We are told that envoys came to China from Calicut and Chola (the Coromandel coast) for the first time in 1403. In the eighth month of that year, Yongle reopened the three maritime supervisorates in Zhejiang, Fujian, and Guangdong that had operated under Hongwu. Ambassadors came and went, and regular tributary and diplomatic relations proceeded as normal.

In the meantime, there were signs that the emperor had a larger-scale of activity in mind. As early as 1402 he had ordered the construction of ocean-going ships in substantial quantities – first 137 ships, and then 200 in that year alone. A further 188 vessels were to be converted (presumably from ocean-going grain transports) the following year, and 55 more new ships were ordered at the beginning of 1404. Emperor Yongle appointed Zheng He commander of the fleet and on 11 July 1405 issued the order for the first expedition to the "Western Oceans" (Xiyang).

The ultimate purpose of these expeditions is not entirely clear, though there were probably diplomatic, military, and economic motivations. The main reason given in the Ming History (*Ming shi*) – that of finding the deposed emperor Jianwen – was probably not the true purpose. It would not have been necessary to send out a fleet of over a hundred ships and 27,000–28,000 men to search for a single person in the vast oceans of Southeast Asia and beyond, nor does this explain the expeditions' political, military and diplomatic activities in the regions they visited.

In all there were seven major expeditions, each one taking approximately 2 years from departure to return.

The dates of the seven were (1) 1405–1407; (2) 1407–1409; (3) 1409–1411; (4) 1413–1415; (5) 1417–1419; (6) 1421–1422; and (7) 1431–1433. The first three departed quickly in succession, with one leaving in the same year as the previous one returned. After the third, there was a 2-year gap between each. Between the sixth and seventh expeditions a space of 9 years intervened because of the death of Emperor Yongle in 1424. He was succeeded by Emperor Hongxi (r. 1424–1425), who saw the expeditions as unnecessary extravagances and called a halt to them. The final expedition was not launched until the reign of Hongxi's successor, Emperor Xuande (r. 1425–1435). In addition to the seven major expeditions, there were also branch or side expeditions to such countries as Bengal and Thailand.

Because of the monsoon, which Chinese sailors seem to have understood quite early on, the expeditions followed a regular seasonal pattern in their departure and return. They left the port of Taicang (near present-day Shanghai) in the autumn, and sailed down the coast to the port of Changle in Fujian province. There they waited for the monsoon until December or January, before sailing on to Champa (Xinzhou, present-day Qui Nhon), Java, Palembang, Melaka (Malacca), and various places on the island of Sumatra, including Samudra-Pasai. After crossing the Bay of Bengal, they reached Ceylon (present-day Sri Lanka), and then proceeded to Quilon, Cochin, and finally Calicut, a major emporium of the Indian Ocean trade network at the time. The first three expeditions did not go beyond this point. The fourth went further, to Hormuz, and the fifth, sixth, and seventh expeditions traveled to the Arabian Peninsula and East Africa. The journeys beyond Calicut were probably undertaken by portions of the fleet.

The main scientific and scholarly issues involved are the dates of the various expeditions and their implications for such issues as speed of travel, the numbers and types of ships that sailed on the voyages, the logistics of carrying out such a major operation, the routes the expeditions followed, and the techniques and instruments that were used for navigation. The equipment used for military purposes is also of interest, although details are scarce. With regard to the dates, there is some disagreement in the sources, but the discovery of two stone inscriptions in the 1930s in two separate locations on the Chinese coast, each corroborating the other on the years of departure and return for the seven major voyages, has settled the matter for the most part, thanks to the careful elucidation of the issue by Duyvendak (1938). The numbers and types of ships on the voyages cannot be known exactly, but it is highly unlikely that they were the size given in the *Ming shi* of 44 *zhang* long and 18 *zhang* wide, equivalent to 447 × 183 ft. Moreover, there are serious practical reasons for thinking that the ships could not have been of that size. They would have been proportionally much too wide. Moreover the available timber would not have allowed a longitudinal strengthening member to have been made in one continuous length, nor could masts of the height required have been made of a single tree trunk. It has also been estimated that as many as 8,000 men would have been needed for the crew, and there is no evidence for ships carrying more than 500 men on them; more likely there were 200–300 crew members. The "Mao Kun map" (see below) shows conventional ships with only three or four masts, although it has been estimated that a ship of 44 *zhang* in length would need nine masts. There are references to 48, 62, or 63, and 100 ships used on individual voyages, and the initial order for ships to be built in 1403 was for 250. Thus it is difficult to be precise as to the size of the fleet, though there were probably over 100 ships on each expedition. The ships must have been of various sizes for different purposes, including ships for military uses, the transport of supplies, and the transport of personnel. More research needs to be done on the question of logistics, to understand how so many sailors and other specialists (including doctors) were recruited, and how supplies were requisitioned and managed on the voyages. Further study of local histories and gazetteers of the coastal regions around ports such as Taicang and Changle may perhaps shed some further light on this question.

The routes and navigation techniques are perhaps the most rewarding issues for scientific investigation. For this, the most important source is the Mao Kun map, called thus by Mills because it appears in a collection of military preparedness materials (*Wu bei zhi*) compiled by Mao Yuanyi (1597–1661), a grandson of Mao Kun (1512–1601). In Chinese, the map is usually called *Zheng He hanghai tu* (Zheng He's navigation map). It probably came from Mao Kun's library of military materials, which he collected because of his interest in naval matters deriving from involvement in the coastal defense of Fujian. Significant work on this map has been done in the West, particularly by Mills (1970) in his book on Ma Huan, who accompanied three of Zheng He's expeditions and wrote an account, entitled *Yingyai shenglan*, of the places they visited. It is a strip map in 40 folios arranged from right to left, beginning in Nanjing and ending in Hormuz, also showing the east coast of Africa. It depicts not only the places roughly in their geographical locations along the contours of the coast, but also the routes from place to place, marked by dotted lines, and accompanied by sailing directions along the route markings. The sailing directions are expressed in terms of compass points and distances, with occasional references to navigation techniques, such as the need to take soundings in certain areas to avoid shallow waters. Distances are expressed in lengths of time according to the Chinese system of counting watches, or 2-h periods.

The use of astronomy in navigation is evident in some of the sailing directions, particularly those for the north–south route along the coast of Africa, where latitude is indicated by the height of constellations measured in number of fingers at arms' length above the horizon. The Arabs also used this technique in seafaring. The work concludes with four "stellar diagrams" giving precise instructions for positioning a ship in relation to certain stars and constellations on two key segments of the route – between Sumatra and Ceylon and between Hormuz and Calicut. This was in order to ensure arrival at the correct destination over long expanses of ocean.

The expeditions provided regular contact and involvement with distant countries over the course of almost 30 years. Through the accounts not only of Ma Huan but also of Fei Xin and Gong Zhen, certain circles in China were exposed to foreign ideas, practices, and customs. Needham (1971) suggested that one of the aims of the expeditions was the "search for rarities of all kinds… gems, minerals, plants, animals, drugs and the like" for the court, and that knowledge of foreign science, particularly medicine, was transmitted to and from China during this time. This contact seems to have led to some exchange of information and technology between China and other cultures and civilizations – the Arabs and Indians for example – and could have led to more if it had not been for the suppression of information about the voyages in China due to internal politics. Fearing an increase in eunuch power, and citing the extravagant expense of the expeditions, the official Liu Daxia, who later became president of the Ministry of War, discredited the first-hand accounts, calling them "deceitful exaggerations of bizarre things far removed from the testimony of people's ears and eyes." He destroyed all the documents in the official archives that concerned the voyages.

A question much discussed by scholars is why these expeditions, which showed such a high level of scientific and technological expertise, as well as energy, curiosity, and interest in other countries, stopped abruptly after 1433. Did China simply turn inward, cast aside her quest for knowledge of "the other," reject science, technology, and progress, and willingly forfeit a prominent role in international relations, thus sealing her fate in the nineteenth and twentieth centuries? Such a view not only relies too much on hindsight but also seriously underestimates the intelligence of the Chinese people. There was also no amorphous "China" that made such a conscious decision. A handful of people with political power took certain steps for their own short-term reasons. To conclude that China at any point in her history rejected technology and progress simply ignores reality. There were engineers, mathematicians, astronomers, and scientists in many fields during all periods of Chinese history who for practical reasons as well as theoretical interest pursued scientific investigation and activities, sometimes in conjunction with, but more often independently of government policy. Instead, a more likely explanation for the cessation of the maritime expeditions is financial – the expeditions were expensive and there were other demands on the imperial coffers at the time, including not only defense against invaders in the north, but also domestic concerns such as famine relief and dyke repair.

Zheng He's precise time and place of death is not known for certain. It is now accepted in scholarly circles that he did not die abroad, but returned to China and passed away in Nanjing in approximately 1435. A tomb in Nanjing is now conventionally accepted as his.

Despite the destruction of the documents in the official archives, many sources of information about these voyages still survive. Of prime importance are the three first-hand accounts by Ma Huan, Fei Xin, and Gong Zhen, which are remarkable for their attention to the political, economic, social, and religious conditions of the lands they visited, as well as for their frank observations and open attitudes toward the unfamiliar customs and practices they found. In addition to the Mao Kun Map and the various inscriptions on stone steles, including three in China (the Liujiajiang, Changle, and Jinghai temple inscriptions) and others in the countries they visited, an itinerary for the seventh voyage also survives, preserved in a work by Zhu Yunming, giving the dates of arrival and departure from each place visited by the main portion of the fleet. From this itinerary it is possible to calculate the length of the various legs of the journey and the speed of travel. In addition there are numerous references in the *Ming Shilu*, or "Veritable Records" of the Ming dynasty, particularly to the exchange of ambassadors to and from China. References occur in many other Chinese historical documents as well. In the 1980s Zheng Hesheng and Zheng Yijun collected voluminous references to the voyages in Chinese historical and other documents and included them in their monumental multi-volume work entitled *Zheng He xia Xiyang ziliao huibian* (A Collection of Resource Material on Zheng He's Voyages to the Western Oceans), a convenient resource for anyone interested in pursuing research on the expeditions.

In 2002 the British submarine commander (retired) Gavin Menzies, in a popular book entitled *1421*, claimed that the expeditions sailed beyond East Africa to "discover" America and circumnavigate the globe. This theory, though presented as historical fact, remains entirely undocumented. Serious scholars continue to pursue the truth about Zheng He's voyages, and interest in them is currently at a height because it has now been 600 years since their initial launch.

See also: ►Clocks in China, ►Navigation, ►Mapmaking

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Zhenjiu Dacheng

Richard Bertschinger

The *Zhenjiu Dacheng* (Great Compendium of Acupuncture and Moxibustion) is a digest of acupuncture and moxibustion writings from the Han to the Ming dynasties. As such, it forms the greatest comprehensive survey of acupuncture in China ever to be produced during classical times. Much of its greatness is due to its selection of works from the Song and Yuan. It was edited by Yang Jizhou in 1601, as the culmination of his life's work. He was then close on 80-years old and obviously still active.

An early title for the work had been "Secrets of the Dark Inner Mechanism of Acupuncture and Moxibustion for the Preservation of Health." In this text Yang Jizhou included mainly the traditions of his own family, but later he enlarged the book to include earlier literature, and so changed the title. Generally he selected the best of the old, and reedited it, adding a certain amount of his own material where it suited.

The Grand Compendium comprises some ten volumes, covering all aspects of acupuncture and moxibustion. It also contains an appendix on massage techniques particularly suited for children, entitled *Biaoying Shenshu* (The Divine Art of Protecting Infants), taken from an earlier book which is now lost. The work includes listings of channels and points; many point-formulae for medical conditions, particular systems for choosing points; refined needling techniques such as those developed during the Song, Yuan, and Ming; detailed formulae for calculating the precise time and exact point for treatment; glossaries of point names; and selections from the classics, especially the *Huangdi Neijing* and its slighter companion the *Nan Jing*. This all constitutes a great wealth of historical material.

Particularly striking are the exquisite verse poems selected for the second volume. These include the "Ode to the Golden Needle," which focuses on needling techniques, the *Liuzhu Zhiwei Fu* (Ode to Intricacies in the Circulating Flow), which outlines the Law of Midday–Midnight in which the choice of points is determined by the particular hour and day of treatment, and the *Biaoyou Fu* (Ode to the Streamer out of the Dark), the longest and most comprehensive of these poems, which contains an extensive commentary by Yang Jizhou.

A gradual increase in prosperity was spawned by better social conditions during the Ming. These in turn created an interest in the old ideas. Undoubtedly influential on Yang's work were the *Zhenjiu Sunan Yaozhi* (Essentials of Acupuncture and Moxibustion, 1536) and the *Zhenjiu Juying* (Gatherings of Outstanding Acupuncturists, 1546), both issued by Gao Wu during the earlier century. Gao Wu's work was particularly commendable as he made a stand against any superstitions in medicine. Where he was uncertain he would simply state it, without comment. From Gao Wu's work Yang took both an uncluttered approach and a grand overview of the acupuncture tradition. In many places Yang Jizhou pays debt to Gao Wu by copying his selection of classical extracts exactly.

Another great influence was the *Shenying Jing* (Classic of Divine Resonance, 1425) by Chen Hui. From this work Yang Jizhou borrowed his simple and practical approach, cutting great swathes through confusing systems of point selection by adhering strictly to the Divine Resonance's printed lists. This compendium is an invaluable treasure for all acupuncturists and has become well-known abroad as well as in China.

See also: ▶Acupuncture, ▶Moxibustion, ▶Medicine in China

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Zhenjiu Jiayijing

Richard Bertschinger

The *Zhenjiu Jiayijing* (The A–Z Canon on Acupuncture and Moxibustion) was written by Huangfu Mi (AD 215–282), during the short-lived Jin Dynasty. Needham dates the book as being finished some time between AD 256 and AD 282.

This is the oldest surviving text devoted exclusively to acupuncture and moxibustion. It was produced after the fall of the Han nation, during a time of violent turmoil and disruption in Chinese society. Huangfu Mi summarized the knowledge of his day concerning acupuncture and moxibustion, and ordered the many texts then current. He drew from both sections of the *Huangdi Neijing* as well as the *Mingtang Kongxue Zhenjiu Zhiyao* (Therapeutic Essentials of the Acupuncture Points Revealed in the Clear-Lit Hall), of unknown authorship, a book now lost. Huangfu Mi took up medicine in middle age because of his own family's illness and his own arthritis.

This book's most impressive character lies in its systematic outline of the subject (as revealed in the title). The many points are grouped under the various channels to which they belong, with number, name, point location, and tips for finding each. Additionally there are listings of the illnesses, or syndromes, for which each can be used, detailing how deep the needle should be inserted and the number of breaths for which it should be retained in position. Tonification or reducing techniques are also described, as well as angling the needle shaft along or against the direction of energy flow down the channel. In addition, Huangfu mentions the use of moxa, the number of cones for each point being duly recorded. All this had never been so accurately or clearly laid out before.

This book, quite justifiably, has had an enormous influence throughout China and abroad. It became *de rigueur* reading for the Japanese imperial colleges from the seventh century, and found its way to Korea even earlier. Its texts have been the foundation of acupuncture teaching and practice for some 70 generations in the East. As yet, there has been no translation into English.

The book's 128 chapters comprise medical theory, the examination and diagnosis; characteristics and pathology of the channels; a complete catalogue of the points; pulse diagnosis; needling technique; outline of pathology and transmission of disease; types of fevers; pains, swelling, coughing, rheumatism, wasting diseases, and dumbness; eye, nose, and throat problems; woman's and children's illness; and appendices.

Huangfu Mi's approach, in particular, stressed the need for a proper adjustment of the patient's emotions. He knew that physical and environmental factors played a part in illness, that treatment should proceed with great care, and that signs and symptoms should be precisely differentiated. All show a clear and intelligent approach to practice.

Very little has changed in the location and identification of acupuncture points since the publication of this text some 1,800 years ago. For instance, it is mentioned in the preface to the *Essentials of Chinese Acupuncture*, the first acupuncture book produced by the Chinese for a Western audience.

See also: ▶Huangfu Mi

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Zhoubi Suanjing

Christopher Cullen

The *Zhoubi suanjing* (frequently also romanized as *Zhoubei suanjing*), is an anonymous Chinese work on astronomy and mathematics. It is a composite work which probably reached its final form in the first century AD under the Western Han dynasty.

The contents deal mainly with calendrical astronomy, and the shape and size of heaven and earth according to the *gaitian* (umbrella [-like] heaven) cosmography. It opens with a brief dialogue between the Duke of Zhou (fl. ca. 1000 BCE) and Shang Gao, an otherwise unknown figure, who explains the use of the try-square *ju* and refers briefly to a round heaven lying above a square earth. In connection with the try-square Shang Gao refers cryptically to the relationship between the sides of a 3–4–5 right triangle. The text then continues with a long and fairly coherent section which may be the original core of the book.

In this section an otherwise unknown Chen Zi discusses the use of a gnomon (a vertical pole) for observing the shadow cast by the noon sun. It is claimed that the shadow of a pole 80 *cun* (inches) long changes by one *cun* for every 1,000 *li* (about 400 miles) moved north or south in relation to the point on the earth where the sun is directly overhead. The use of this rule, which does not correspond to actual observation, enables the dimensions of the heavens to be calculated. Most of the rest of the book contains calculations relating to the operation of lunisolar calendrical systems of the *si fen* (quarter [remainder]) type. The text bears an important commentary by Zhao Shuang, probably written ca. AD 270–280, and has further annotations by Li Chunfeng, who prepared an edition for use in the State College in AD 656. The book was first printed under the Song dynasty in AD 1084.

See also: ►Gaitian

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Zhu Shijie 朱世傑

Karine Chemla

Virtually nothing is known of the life of this Yuan 元 mathematician, except the little we can learn from the prefaces to his two books, *Suanxue qimeng* 算學啟蒙 (*Introduction to Mathematical Studies*, 1299) and *Siyuan yujian* 四元玉鑒 (*The Jade Mirror of the Four Unknowns*, 1303). The first preface was written by Zhao Cheng and the second one by Mo Ruo 莫若 and Zu Yi 祖乙. From those we can surmise that Zhu came from Yanshan 燕山, near modern Beijing, that he traveled around China for more than 20 years in the last decades of the thirteenth century, after China had been unified under the Mongol rule, and that numerous students came to study with him.

His books attest to the fact that he inherited – from the northern milieu of the Hebei 河北 and Shanxi 山西 provinces which developed the "procedure of the celestial unknown (lit.: origin)" (*Tian yuan shu* 天元術) – how to use polynomial algebra to build an equation with which to solve a problem. This achievement seems to have been unknown in South China and benefited from the potentialities of the counting instrument on which it is based: the surface for computing, on which numbers were represented with counting rods which could be moved or changed in their values throughout the computations. The earliest book that has come down to us and attests this procedure, though it is probably not the first to have dealt with it, dates from 1248. It is Li Ye 李治's (or Li Zhi 李治's, according to the name chosen for this scholar) *Ceyuan haijing* (測圓海鏡 Sea Mirror of the Circle Measurements). Yet Zhu Shijie does not mention this author or any other one. On the basis of extensions to polynomials with two and three indeterminates "that the procedure of the celestial unknown had received previously to him", according to Zu Yi's preface, Zhu Shijie developed it to what was to remain an unsurpassed peak in Yuan and Ming China: the use of polynomial algebra with four indeterminates to establish an equation to solve a given problem. As Hoe (1977) has stressed, the language and notations with which Zhu Shijie developed this algebra can, in their conciseness and precision, stand comparison with aspects of modern algebraic symbolism. Still, he notices some ambiguous modes of expression that do not make it entirely independent from the context. This very language might help us to make the historical connections between Zhu Shijie and such previous authors as Li Ye more precise, since as far as topics such as right-angled triangles are concerned, both use the same terminology. On the other hand, as regards the expression of formulas, they present differences even though their languages share the same basic features. For the expression of formulas or algorithms, Li Ye uses a language whose syntax is restricted in such a way that the understanding of a formula is unambiguous, which makes it context-free, in contrast to Zhu Shijie's (Chemla 2006).

Moreover, Zhu's writings demonstrate that he shared bits of knowledge (for instance, finite difference procedures for the summation of series, a topic to whose development he made crucial contributions) with the authors of the calendar *Shoushili* 授時曆 commissioned by the Mongol Court, the foremost being Guo Shoujing 郭守敬.

In addition to this – is it a reflection of his travels in South China? – his books reveal his interest in algorithms for quick, daily-life computations, or for mercantile and bureaucratic mathematics. In the surviving writings from this period, such topics had mainly been treated by mathematicians from South China, such as Yang Hui 楊輝. At the same time other topics which developed in South China, such as research connected with the Chinese remainder theorem, seem not to have found their way into his writings.

Still, Du Shiran 杜石然 (1966) called attention to the fact that Zhu seems to represent a kind of synthesis of traditions that, for at least decades, had been developing in isolation from each other in North and in South China, though they shared a common basis in the same fundamental characteristics and knowledge, including algorithms to find "the root" of any algebraic equation with positive, negative or null coefficients.

Zhu Shijie's books do not seem to have had any impact on the development of mathematics in China; not only we do not find any mention of his name or achievements after their publication, but also the books themselves would eventually be lost, to be found again in China and reprinted only at the beginning of the nineteenth century. This merely reflects the progressive loss of mathematical knowledge from the Song–Yuan period. In contrast to other writings of the same period, his *Introduction to Mathematical Studies* was to influence the development of mathematics in Korea and Japan. It was probably printed in 1433 in Korea, where it became a textbook for studying mathematics, and was eventually recovered thanks to a Korean edition of 1660. Moreover, its introduction to Japan in the second half of the seventeenth century, where it was reprinted and commented upon many times, allowed Japanese mathematicians to reconstruct the procedure of the celestial unknown, by that time forgotten in China, and to improve it until it became a tool in some ways comparable to the algebra developed in Europe during the same period. Horiuchi (1994) studies this aspect of the mathematics developed in Japan with great care and compares it with elements of the contemporary European algebra. Indeed, Japanese mathematicians' use of the surface for computing for their computations was probably instrumental in that respect, whereas in China this instrument had fallen into oblivion and was completely replaced by the abacus.

See also: ►Computation: Chinese Counting Rods, ►Liu Hui and the *Jiuzhang Suanshu*, ►Guo Shoujing, ►Li Zhi (Li Ye), ►Mathematics in Korea, ►Mathematics in Japan, ►Yang Hui

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Zīj

Raymond Mercier

The term *zīj* is used everywhere in the study of Islamic culture to signify an astronomical handbook. These handbooks consist of a collection of astronomical tables together with such textual material as the reader would need in using the tables. The material is often divided into the following sections:

1. Calendrical conversion
2. Mean motions of the sun, moon, and planets
3. Equations of the sun, moon, and planets
4. Positions of fixed stars
5. Trigonometrical tables (sine, tangent)
6. Spherical astronomy
7. Parallax
8. Eclipses of the sun and moon
9. Geographical coordinates
10. Astrological quantities

The underlying theoretical model of planetary equations was almost invariably Ptolemy's, and to a large extent *zījes* represent a continuation of the *Handy Tables* of Ptolemy (ca. AD 140). However the earliest Arabic *zīj is that of al-Khwārizmī* (ca. AD 830), which was based on procedures derived from the Indian treatise *Brāhmasphutasiddhānta* of Brahmagupta (AD 628). A large number of such works survive intact in Arabic and Persian manuscripts, and many others are known by name only. The most notable modern edition (Nallino 1907) is that of the *Zīj* al-ṣābi' of al-Battānī' (fl. AD 880). For the long Islamic period the *zījes* are a vital repository of data, primarily through the constant improvements in the parameters of mean motions reflecting new observations, and also of improvements in mathematical methods.

In most *zījes* the textual material was generally restricted to instructions in the use of the tables. Larger astronomical treatises, such as the *Qānūn al-Masūdī* of al-Bīrūnī (ca. AD 1030), included all the material which would be found in a *zīj*, but went further in its detailed treatment of the whole subject.

A number of *zījes* were translated into Latin and Greek, and initially at least, the term *zīj* was transcribed as *ezich*, *ezeig*, etc. (=*al-zīj*), and ***, respectively. In Latin the term was soon replaced by *tabulae*, while in Greek one finds ***, reminiscent of Ptolemy's *Almagest*.

The term *zīj* is originally Middle Persian, where it means "stretched cord." The sense "astronomical handbook" goes back to the early sixth century when Sanskrit works were introduced into Iran. The name *zīj* may have arisen as a literal translation of the Sanskrit term *tantra* (from *tan* "to stretch") literally "warp, loom," but which is used in the sense of "system" or "text book." The word is singled out by Varāhamihira (ca. 580) as the name of the branch of astronomy which is concerned with planetary calculations. In a Middle Persian tract of the ninth century, the *Epistles of Manuščihr*, there are references to the *zīg ī hindūg* (Indian Astronomy), and also to a *zīg ī śahriyārān* (Royal Astronomy), a Sasanid compilation probably of the sixth century, referred to later by Arabic authors as the *Zīj al-Shātroyārān*. The former may be one of the works of Āryabhata (ca. AD 5250), which were referred to as Tantras by an early commentator.

See also: ►Astronomy in Islam

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Zodiac in Indian Astronomy

Yano Michio

The signs of the zodiac originated in Mesopotamia. In the first stage of development, 12 constellations along the ecliptic (i.e., the apparent course of the sun in the sky) were roughly marked out and each was named after the animal whose shape it resembled. Later, with the need for a rigid coordinate system for planetary positions, the zodiacal sign assumed a new meaning: the length of 30° along the ecliptic, so that 12 equal signs comprised a complete circuit (360°) of the ecliptic. The change from the older irregular constellations to the signs of regular spacing took place somewhere around 500 BCE.

In the cuneiform texts the ecliptic coordinates were sidereally fixed, and the vernal equinox was several degrees off "the first point of Aries": at the tenth degree of Aries in System A and at the eighth in System B. The Mesopotamian idea of 12 zodiacal signs of equal length was transmitted to Greece about 300 BCE, where the iconography of the signs was modified by their mythology.

With the discovery of the precession of equinoxes by Hipparchus in about 150 BCE, the significance of the zodiacal signs changed drastically. The first point of Aries was equated with the vernal equinox. Since this is in constant retrograde motion relative to the fixed stars (the shift being about 51 min of arc per year), the original relation between the constellations and signs was completely severed and the zodiacal signs became a purely mathematical reference system.

With the development of astrology, which preserved the old association of zoomorphic shape with zodiacal signs (except Libra), the zodiacal signs assumed new meanings. They were classified in various ways: by sex, the ownership of the house of planets, seasons, tastes, four humors, four elements, the governorship over parts of the body, plants, animals, geographical regions, etc.

All these ideas were transmitted to India in the second century of the Christian era. The very Sanskrit names of the zodiacal signs show that they were translated from Greek. In some texts even phonetic translations of Greek words are found. The earliest Sanskrit text which contains a list of these names is the *Yavanajātaka* (ca. AD 269), a Sanskrit version of a Greek book on horoscopic astrology (Table 1).

Three iconographic modifications in the process of transmission are worth mentioning. (1) While Gemini are the twin boys in Western iconography, *mithuna* in Sanskrit is a couple consisting of a male and a female, and this was interpreted as "husband and wife" in

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Zodiac in Indian Astronomy. Table 1 The signs of the zodiac

Degrees	English	Sanskrit
0	Aries	*meṣa*
30	Taurus	*vṛṣan*
60	Gemini	*mithuna*
90	Cancer	*karkaṭa*
120	Leo	*siṃha*
150	Virgo	*kanyā*
180	Libra	*tulā*
210	Scorpio	*vṛścika*
240	Sagittarius	*dhanus* or *dhanvin*
270	Capricorn	*makara* or *mṛga*
300	Aquarius	*kumbha*
330	Pisces	*mīna*

Chinese texts on Buddhist astrology. (2) The Sanskrit word *makara* stands for a kind of sea monster, and *mṛga* for a "forest animal" such as a deer. Thus Capricorn was divided into two separate animals. (3) The word *dhanvin* (one who has a bow) is a better translation of Sagittarius (archer), but the simpler *dhanus* (bow) without a human figure is more frequently used in Sanskrit texts.

In spite of the similarity of the names, the astronomical meaning of Indian zodiacal signs is different from that of the Western ones, because the precession of the equinoxes was not taken into account in India, and the first point (*meṣādi*) of the ecliptic coordinates was sidereally fixed sometime in the third or fourth century AD. The difference (*ayanāṃśa*) between the vernal equinox and the *meṣādi*, which has accumulated in the present day, is about 23°40′; thus the sun's entry into *meṣa* now falls on the 14th of April, and the *makarasaṃkrānti*, originally a winter solstice festival, on the 15th of January.

This seemingly conservative attitude is closely related to the Indian system of naming the lunar month. A year is divided into 12 solar months by the sun's entry (*saṃkrānti*) into a new zodiacal sign. The lunar month is named after the *saṃkrānti* which falls during that month. For example, the lunar month Caitra is defined as the month during which the sun's entry into *meṣa* occurs. The full moon of that month has to be located near the diametrically opposite point on the ecliptic, i.e., at the lunar mansion *citrā*. Thus, in order to keep the relation of the month name and the constellation name, they had to stick to the sidereal (*nirayana*) system even at the sacrifice of the correspondence between the seasons and month names.

The Western system has ignored the original association between constellations and zodiacal signs, and the word *Aries*, for example, has two meanings, one as an actual constellation and the other as the first 30° in the ecliptic longitude. The former is used in astronomy and the latter in astrology. This is not the case in the traditional Indian system.

In South India and Nepal the solar month is still used in the civil calendar. Since a solar month is the time during which the true sun stays in one zodiacal sign, the length of a month varies from 28 to 32 days.

As mentioned above, Indian zodiacal signs were transmitted to China in the eighth century by Buddhist astrology and ultimately to Japan in the ninth century. The iconography of the Indian zodiacal signs was preserved in the star *maṇḍalas* (especially in the temples belonging to the Shingon sect) which were used in the ritual of worshipping the planetary deities.

See also: ►Precession of the Equinoxes, ►Lunar Mansions, ►Astrology in India

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Zodiac in Islam

Paul Kunitzsch

The zodiac, i.e., the band or zone around the sky through which the sun, the moon, and the planets travel in their apparent revolutions, was first established by the Babylonians. They formed the constellations along this zone and instituted its division into 12 equal portions, the "signs." This knowledge was then handed on, in a northern branch of transmission, to the Greeks and through them further on into modern astronomy. In a southern branch of transmission, some of the zodiacal constellations reached the Arabs in the Arabian peninsula. In their folk astronomy they knew some of the zodiacal constellations – though not the complete system of 12 – which, in their astronomical lore, were sometimes located differently. For example the constellation *al-jawzā'* (standing for Gemini) is located in the Greek (and modern) Orion, *al-dalw* (Aquarius) in Pegasus, and *al-ḥūt* (Pisces) in Andromeda.

With the reception of Greek astronomy, through the translation of the most important Greek writings in astronomy and astrology, the system of the 12 zodiacal constellations and the 12 signs was also received and continued to be used by Arabic–Islamic astronomers and astrologers. For some constellations the translators introduced new names (derived from Greek) besides the names inherited from the old Arabs. The names for the 12 constellations of the zodiac in Arabic are:

1. Aries: *al-ḥamal*
2. Taurus: *al-thawr*
3. Gemini: *al-jawzāʾ* (old), *al-tawʾamān* (transl.)
4. Cancer: *al-saraṭān*
5. Leo: *al-asad* (both old and transl.)
6. Virgo: *al-sunbula* (old), *al-ʿadhrāʾ* (transl.)
7. Libra: *al-mīzān*
8. Scorpio: *al-ʿaqrab* (both old and transl.)
9. Sagittarius: *al-qaws* (old), *al-rāmī* (transl.)
10. Capricornus: *al-jady*
11. Aquarius: *al-dalw* (old), *sākib al-māʾ* (transl.)
12. Pisces: *al-ḥūt* (old), *al-samakatān* (transl.)

The zodiac was treated by the Arabic–Islamic astronomers and astrologers according to the teachings of the Greeks. When Arabic astronomical and astrological works were translated into Latin in Europe in the Middle Ages, the Arabic names of the 12 zodiacal constellations were also sometimes borrowed. But they did not gain the same popularity as the Arabic star names and the names of the lunar mansions; most Latin authors used the well-known Latin names for them.

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Zou Yan

Christompher Cullen

Our only source on Zou's life that has any chance of being reliable is the entry in Sima Qian's universal history *Shiji*, completed ca. 90 BCE. According to this, Zou (fl. 250 BCE) was a successful member of the group of wandering scholars who moved from one feudal court to another in China's Warring States period (fifth–third centuries BCE), offering expertise in statecraft and useful arts. He came from the northeastern seaboard state of Qi, where he became a member of the "academy" set up by the ruler of that state to house his more favored scholarly retainers. Although he is said to have written several voluminous books none of them has survived.

According to the *Shiji*, Zou "looked into the rise and fall of the Yin and Yang" and wrote on their "strange transformations." His method of reasoning "started by checking some small thing, and then extrapolated to a large scale." On this basis he is said to have reasoned his way back to the state of affairs "before the origin of heaven and earth" on the basis of his knowledge of more recent times. Similarly, he claimed that China only occupied one-ninth of a large continent, which was itself only one out of nine giant land masses surrounded by a vast ocean.

One source of the seventh century AD (Li Shan's commentary on the Wen Xuan anthology) quotes a work said to be by Zou Yan, in which it is stated that he taught that the successive dynasties ruling in China had each come to power by virtue of the cyclical dominance in the cosmos of one of the *wude* (Five Powers) of earth, wood, metal, fire, and water. (These are more commonly called the *wuxing*, Five Phases.) While such a view is not inconsistent with Zou Yan's thought as known from the *Shiji*, it is by no means certain that he originated it. Whatever its origins, this theory of the cosmological determination of political dominance was adopted by the first emperor of the Qin dynasty when he came to the throne in 221 BCE, and remained important for several centuries thereafter.

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Zu Chongzhi

Ang Tian Se

Zu Chongzhi, whose literary name was Wenyuan, was born in Jiankang (present Nanjing of Jiangsu Province) in AD 429 into a family of bureaucrats. His great grandfather, a native of Hebei Province, was an official during the Eastern Jin dynasty (AD 317–420), and his grandfather and father were officials of the Northern and Southern dynasties (AD 479–581). Interestingly enough, the Zu family had, for successive generations, been involved in studies of astronomy and calendrical science. Subsequently, they moved south and settled in Jiankang, the political and economic center of the fifth and sixth centuries. From a very young age, Zu Chongzhi received instruction in a variety of subjects. He was particularly interested in mathematical astronomy. While examining many past and existing astronomical systems, he found many errors and discrepancies. This prompted him to compile a calendrical system known as the Daming calendar (Calendar of Great Brightness). However, when he presented this calendar to the throne for promulgation in AD 462, he met with vehement opposition from the emperor's minister Dai Faxin. Zu Chongzhi's innovation and improvement in the astronomical system was branded as "distorting the truth about heaven and violating the teaching of the classics." The Daming calendar was shelved for about half a century before it was finally promulgated for official use in AD 510 when Zu Chongzhi had been dead for 10 years.

The Daming calendar was the epitome of Zu Chongzhi's mathematical and astronomical skills. He was the first person to take into account the fact of precession of the equinoxes discovered by Yu Xi, an astronomer in the fourth century AD. By applying the precession of equinoxes, Zu Chongzhi differentiated the tropical year from the sidereal year (the time at which the sun's center, departing eastward from the ecliptic meridian of a given star, returns to that meridian). As a matter of fact, he determined several astronomical constants with remarkable accuracy. For example, he gave a value of 365.24281481 days for the tropical year, only about 50 s off the modern value. He also gave a value of 27.21233 days for the length of a nodal month, the modern value being 27.21222 days. For planetary motion, he found that the planet Jupiter completes seven and one-twelfth circuits of the heavens in every 7 cycles of 12 years. This gives Jupiter a sidereal period of 11.859 years, which differs from the modern value by only 1 part in 4,000.

In order to make the lunar year tally with the solar year, ancient Chinese calendar makers inserted 7 intercalary months in every 19 years. This rule of intercalation had been in use for more than a thousand years until AD 412 when Zhao Fei changed it to 221 intercalary months in every 600 years. Zu Chongzhi did not find the rule satisfactory and improved it by introducing 144 intercalations in every 391 years.

The most significant contribution by Zu Chongzhi is in the evaluation of π. He gave two approximating ratios for π: a coarse one of 22/7 and a fine one of 355/113. The true ratio, according to him, lies between 3.1415926 and 3.1415927.

Zu Chongzhi also wrote a mathematical text known by the title *Zhui Shu*. This text, prescribed as a textbook for advanced students of mathematics in the official examinations of the Tang dynasty, was unfortunately lost in the wars of the early twelfth century. Only fragments of the text still exist in the Calendrical and Astronomical Chapters of the Sui and Tang dynasties. Zu Chongzhi was said to have worked out an evaluation of the volume of a sphere. He considered a sphere as a pile of circles of varying sizes and arrived at a formula, which in modern mathematical language, could be expressed as $V = 4/3\pi r^3$.

Zu Chongzhi was a versatile person. Apart from being a celebrated astronomer and mathematician, he was well versed in engineering. He produced a "south-pointing vehicle" worked by a set of five differential cog wheels, a "thousand-mile boat" propelled by paddle wheels, a hydraulic mortar-mill, worked by a combination of separate water-driven mortars and mills, and a brass ruler for measuring the pitch of musical instruments.

Zu Chongzhi's remarkable achievements are acknowledged internationally. A crater on the reverse side of the moon, just south of the Sea of Moscow, is named after him.

See also: ►Precession of the Equinoxes, ►*Pi* in Chinese Mathematics

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